



Water retention and flow characteristics of six calcareous soils of Montana
by Michael Frank Browne

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

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Abstract:

A soil water retention model developed by Dr. Otto Baumer (Baumer and Ricer 1986) from the Soil Conservation Services' National Soil Survey Laboratory was tested on six different Montana soils. Results obtained using Baumer's model were similar to the results obtained in the laboratory. Baumer's model can compute the soil water retention gravimetrically or volumetrically at any pressure. This model can save time and money by eliminating expensive laboratory and field studies.

A new hydraulic conductivity model has been proposed and warrants further study as a result of the hydraulic conductivity determinations from the flooded-plot experiment used in this field research. This new hydraulic conductivity model, should it prove to be valid with more thorough testing, determines maximum field hydraulic conductivity if the soil bulk density and 1/3 bar volumetric water content are known. Determination of the maximum field hydraulic conductivity is important because this value gives a good estimate of the rate at which soluble chemicals (fertilizers, herbicides, pesticides, etc.) can be transported by water through a soil system.

The effect of high amounts of CaCO_3 on hydraulic conductivity was also investigated. Results from this research indicate no significant correlation between hydraulic conductivity and the total CaCO_3 content of the soil.

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LIST OF SYMBOLS

Symbol	Meaning
K	Hydraulic conductivity (cm^3/cm^3)
ψ_m	Matric soil water potential (cm)
θ	Soil water content (cm^3/cm^3)
V	Soil water flux, or flow velocity (cm/sec)
ψ_h	Hydraulic soil water potential (cm)
z	Vertical distance, or a given depth (cm)
$K(\theta)$	Unsaturated hydraulic conductivity
$K(\theta/\psi_h)$	Unsaturated hydraulic conductivity - dependent on soil water content and potential conditions (cm/min)
$K(\theta')$	Unsaturated hydraulic conductivity - dependent on the average soil water content (cm/min)
ψ_g	Gravitational soil water potential (cm)
$d\psi_h/dz$	Hydraulic gradient - saturated soil conditions (dimensionless)
$d(\psi_m + \psi_g)/dz$	Hydraulic gradient - unsaturated soil conditions (dimensionless)
q	Quantity of flow (cm^3)
t	Time
q/t	Flow rate
ρ	Fluid density (g/cm^3)
g	Acceleration of gravity (cm/sec^2)
k	Intrinsic permeability (cm^2)
f	Fluidity of a liquid or gas ($1/(\text{cm sec})$)

LIST OF SYMBOLS-Continued

Symbol	Meaning
η	Fluid viscosity (g/cm min)
Q	Cumulative infiltration (Eq. [8]) (cm ³ /t)
a	The value of Q at $t=1$ (Eq. [8])
b	Slope of the infiltration line (Eq. [8])
ψ_t	Total soil water potential (cm)
ψ_p	Pressure potential (cm)
ψ_π	Osmotic potential (cm)
WC	Gravimetric water content for a given water content (Eq. [12])
WCR	Residual water content (Eq. [12])
WCS	Satiated water content (Eq. [12])
h	Matric soil water potential (Eq. [12])
$a, m, \& n$	Dependent parameters used in Baumer's (Baumer and Rice, 1986) water retention model (Eq. [12])
FC	Field Capacity
NSSL	National Soil Survey Laboratory, Lincoln, Nebraska
MSU	Montana State University
K_m	Maximum hydraulic conductivity (cm/min)
θ_m	Maximum soil water content (cm ³ /cm ³)
β	$m/m-1$ where m is the slope of the regression using the Watson Equation (Eq. [16])
m	Slope of the regression using the Watson Equation (Eq. [16])
I	Intercept of the regression using the Watson Equation (Eq. [16])

LIST OF SYMBOLS-Continued

Symbol	Meaning
W	Total water stored above a depth z
θ'	Average soil water content above depth z (Eq. [17])
J	Slope of the regression using the CGA equation (Eq. [17])
A	Intercept of the regression using the CGA equation (Eq. [17])
ELD	Expected low density (Tables 3-8)
EMD	Expected medium density (Tables 3-8)
EHD	Expected high density (Tables 3-8)
VLP	Volume of large pores
$\theta_{-1/3 \text{ bar}}$	Soil water content at -1/3 bar soil water potential

ABSTRACT

A soil water retention model developed by Dr. Otto Baumer (Baumer and Rice, 1986) from the Soil Conservation Services' National Soil Survey Laboratory was tested on six different Montana soils. Results obtained using Baumer's model were similar to the results obtained in the laboratory. Baumer's model can compute the soil water retention gravimetrically or volumetrically at any pressure. This model can save time and money by eliminating expensive laboratory and field studies.

A new hydraulic conductivity model has been proposed and warrants further study as a result of the hydraulic conductivity determinations from the flooded-plot experiment used in this field research. This new hydraulic conductivity model, should it prove to be valid with more thorough testing, determines maximum field hydraulic conductivity if the soil bulk density and 1/3 bar volumetric water content are known. Determination of the maximum field hydraulic conductivity is important because this value gives a good estimate of the rate at which soluble chemicals (fertilizers, herbicides, pesticides, etc.) can be transported by water through a soil system.

The effect of high amounts of CaCO_3 on hydraulic conductivity was also investigated. Results from this research indicate no significant correlation between hydraulic conductivity and the total CaCO_3 content of the soil.

INTRODUCTION

Importance

Water movement through and drainage from soil profiles is an important factor that must be considered when addressing many environmental or agricultural problems. A quantitative analysis of two fundamental soil hydrologic properties must be considered when assessing and information concerned with water problems that result from drainage or irrigation of soils.

The first hydrologic property to be considered is the relationship of hydraulic conductivity to either the soil water suction or the soil water content. Hydraulic conductivity, as Koorevaar et al. (1983) define it, is a measure of the ability of the soil to conduct a flow of water and is very important when considering problems associated with irrigation or soil drainage. Subsurface drainage water can contribute to groundwater pollution as well as pollution of rivers and streams. Drainage from soil profiles is also responsible for the destruction of cropland as the result of saline seep.

A second important hydrologic property that should be considered is the relationship of soil water potential to soil water content. This is commonly referred to as the soil water retention curve (also referred to as the soil-water characteristic curve or the soil-water release curve). Soil water retention curves are used to predict soil moisture changes as well as hydraulic potential gradients in soil-water flow systems. Soil water retention curves are also used as input for some hydraulic

conductivity models (Arya and Paris, 1981).

Soil water content and soil water potential can be measured independently but are most often described by the soil-water characteristic curve because they are functionally related. The soil-water characteristic curve is important because it expresses the influence of structure, porosity, pore-size distribution, and adsorption on the energy status of soil water. This energy status and how it varies in the soil profile determines the direction and influences the rate of soil-water movement and rate of water uptake by plants (Hillel, 1971).

The increasing need to more fully understand soil characteristics relating to movement of water in soil is complicated by the fact that, usually, the evaluation of soil properties for an entire field or drainage system is based on limited data from only a few locations. Extrapolation of results from just a few locations to larger land areas is experimentally convenient and necessary because of the expense and amount of time involved with laboratory measurements or in situ field determinations of either the hydraulic conductivity or the soil water retention curve. Measurements of the hydraulic conductivity and estimations of the soil water retention curve, for these reasons, are important. The six soils examined in this experiment are extensive in Montana and have properties that are similar to other soils in Montana. Therefore, the hydraulic conductivity and moisture retention data from these six soils can enhance the usefulness of soil data from similar soils in other parts of the state.

Extrapolation of this information becomes more important as

governmental agencies such as the United State Department of Agriculture (USDA), Soil Conservation Service, begin using "allowable plant stress" as a method to help agricultural producers schedule irrigations.

California voters, in November 1986, passed Proposition 65 (Gransbery, 1987). This law prohibits any business from knowingly releasing into any source of drinking water, any chemical agent known to cause cancer or reproductive toxicity. It also makes individual farmers liable for drinking water contamination. It is not unreasonable to suggest that other states as well as Montana could pass similar laws in the future. If so, the need to more fully understand soil characteristics as they relate to water movement phenomenon becomes more important.

Objectives

The objectives of this study were as follows:

1. Verify Baumer's (Baumer and Rice, 1986) soil water retention model for six different Montana soils.
2. Calculate the unsaturated hydraulic conductivity for these six different Montana soils.
3. Attempt to characterize, quantify, and evaluate the effects of high amounts of soil carbonates on water movement and infiltration in these six Montana soils.

LITERATURE REVIEW

The relationship between hydraulic conductivity (K), soil-water potential (ψ_m), and soil-water content (θ) is of much interest to many scientists concerned with the soil-water problems that exist in agriculture as well as the environment. A graphical representation of the relationship between soil water content and soil water potential (also referred to as matric potential) is often called the soil water retention curve. It is necessary to understand these soil-water concepts and the relationship that exists between them to interpret the results from models used to compute soil water retention curves or hydraulic conductivity. An understanding of these concepts may also help to interpret the effects of soil carbonates on water movement within the soil profile.

Saturated and Unsaturated Flow

The basic concept of water movement in soil is described by Gardner (1962):

"When a soil is near saturation, the larger the pores the greater the rate of flow per unit of applied force. However, when a soil is not saturated, large pores contribute little to flow. Water moves on particle surfaces and through the finer pores under these conditions. Two forces cause liquid water to move through soil pores: gravity and adhesion. Gravity causes a downward pressure on water. This force is most important in saturated soil. The second force, adhesion, is due to the attraction of soil particle surfaces for water and becomes important in unsaturated soil. Adhesion - together with cohesion, which causes water molecules to hang together - is responsible for water rise in capillary tubes and the absorptive properties of blotting paper and other porous materials. When soil is very wet the gravitational force predominates. But in soil in which most crops grow, the major force causing water to move is due to adhesion. Water moves until these forces are balanced in the soil. Water films on soil particles will be uniform throughout any homogeneous soil, except for some verticle differences that

exist because of gravitation. Any prosity change occurring in soil affects the rate of water flow."

Liquid water flows in response to a hydraulic potential gradient and not necessarily in response to a water content gradient (Hanks and Ashcroft, 1980). The general equation, (Darcy's Law) used to describe liquid flow through a saturated soil is

$$V = K * d\psi_h/dz \quad [11]$$

where V is the soil water flux (cm/s), K is the hydraulic conductivity (cm/s) and $d\psi_h$ is the difference in hydraulic potential (cm) between two points separated by a distance z (cm).

The moving force in a saturated soil is the gradient of a positive pressure potential whereas the moving force in an unsaturated soil is a negative pressure potential gradient (Hillel, 1982). Water flows from where the matric potential is higher to where it is lower (e.g., from -0.3 bar to -3.0 bar).

One of the most important differences between saturated and unsaturated flow is the hydraulic conductivity. In a saturated soil all of the pores are filled with water. Therefore, continuity of water filled pores and conductivity are at a maximum and flow occurs according to Darcy's Law (Eq. [11]). The saturated hydraulic conductivity (K) will be constant for any given soil. As soil water progresses from a saturated state to an unsaturated state, some of the pores become air filled and the conductive portion of the soil's cross sectional area decreases. The first pores to empty will be the largest and most conductive ones. This transition from saturation to unsaturation generally results in a steep drop in hydraulic conductivity with small changes in water content or potential. Therefore, the unsaturated

hydraulic conductivity $[K(\theta/\psi_h)]$ is not a constant for a given soil but varies with the matric potential and the soil water and must be determined experimentally at different matric potentials. The unsaturated form of Darcy's Law is

$$V = K(\theta/\psi_h) * d(\psi_m + \psi_g)/dz \quad [2]$$

The hydraulic conductivity (K) is now dependent on the soil water content and potential conditions (θ/ψ_h) while the hydraulic gradient $d(\psi_m + \psi_g)/dz$ is determined by the matric (ψ_m) and gravitational potentials (ψ_g).

Hydraulic Conductivity

Hillel (1980 and 1982) defines hydraulic conductivity as:

- (1) the ratio of the soil water flux (v) to the hydraulic gradient ($d\psi_h/dz$) or,
- (2) the slope of the flux versus gradient curve.

One of the most important measurements that can be determined from the calculation of hydraulic conductivity as a function of water content $[K(\theta)]$ is the maximum field hydraulic conductivity (K_m). Determination of K_m is important because it describes water movement during the early stages of drainage and, thus, gives a good estimate of the rate at which soluble chemicals (fertilizers, herbicides, pesticides, etc.) can be transported by water through a soil system. It is also a valuable parameter in the design of irrigation systems. The true maximum field hydraulic conductivity will occur when the soil system is saturated. However, saturated soil systems, under field conditions, are very difficult to achieve because there will always be entrapped air in soil

pores. Therefore, the K_m is somewhat less than K_s (saturated hydraulic conductivity). The maximum hydraulic conductivity is usually when the soil water content (θ) or average soil water content (θ') is at a maximum, θ_m , or θ'_m .

Soil Water Flux

The dimensions of soil water flux are quantity per area times time which reduces to length per unit time. Flux has the same dimensions as velocity and is often referred to as flow velocity. The flow velocity in soils is highly variable since the soil pores vary in shape, width, and direction. For example, wider soil pores will conduct water more rapidly than narrow pores (Hillel, 1982). The velocity of flow is also affected by the length of the path the water must travel. This length is actually greater than would be expected in a vertical soil column because the water particle must travel through pore passages that are not straight. This effect is referred to as tortuosity and is defined as the average ratio of the actual roundabout path to the apparent, or straight, flow path (Hillel, 1982). The tortuosity factor for water vapor movement is greater in wet soils than dry soils (Koorevaar et al., 1973) and the tortuosity factor for liquid water movement is less in wet soils than dry soils. Most water flow processes taking place in soils is laminar flow because of the relatively low flow velocities and narrow tube-like pores. Flow rates within individual pores, given laminar flow, are governed by Poiseuille's Law. Equations governing flow through cylindrical and planar voids, respectively, are

$$q/t = \rho g \pi (r^4) / 8n * d \psi_h / dz \quad [3]$$

and

$$q/t = \rho g \pi (w^3) / 12 \eta * d\psi_h / dz \quad [4]$$

where q/t is flow rate, ρ is the fluid density, g is acceleration due to gravity, η is viscosity, r is the radius of a cylinder and w is the width of a planar pore (Hillel, 1971). It is evident from equation [3] and [4] that small changes in pore size can result in large changes in flow rate. The hydraulic conductivity as illustrated above is dependent on the pore geometry of the soil. This takes into account the total porosity, the distribution of pore sizes, and tortuosity but does not account for the fluid properties of the liquid.

It is possible in theory, and sometimes in practice, to separate K into two factors: intrinsic permeability of the soil (k), which is a description of the cross sectional area of pores available for flow, and fluidity of the liquid or gas (f) where

$$K = kf \quad [5]$$

Fluidity is inversely proportional to viscosity:

$$f = \rho g / \eta \quad [6]$$

therefore,

$$k = K \eta / g \quad [7]$$

where η is the viscosity in poise units (dyne sec/cm²), ρ is the fluid density (gm/cm³), and g is acceleration due to gravity (cm/sec²) (Hillel, 1982). The density of most liquids varies somewhat with temperature and solute concentration but for the most part remains nearly constant. Changes in fluidity result primarily from changes in viscosity. Although fluidity does vary with the composition of the fluid and temperature, it is evident that permeability is primarily affected by the pore geometry of the soil.

Infiltration into soils is a special case of soil water flux. The infiltration rate (IR) is defined by Hillel (Hillel, 1982) as the volume flux of water flowing into the profile per unit of soil surface area. The IR is measured in the same units as velocity (distance/time) and decreases with time. The initial IR is generally high, particularly in dry soil, because the matrix potential gradient causing water movement is large. As the soil wets the matrix potential gradient decreases with time and infiltration slows asymptotically, approaching a steady state. At this point the dominant force causing movement is the gravitational gradient. In relatively uniform soils, short-time (from minutes to hours, depending on the soil) infiltration can be described by the equation,

$$Q = at^b \quad [8]$$

where Q is the cumulative infiltration, t is the time, a is the value of Q at time = 1 and b is the slope of the infiltration line when graphed on log - log paper. a and b are parameters that vary with the soil and the water quality. The magnitude of b is an indication of the rate of infiltration; the larger the b value, the greater the infiltration rate. By taking the logarithm of Q and t from Eq. 8 or plotting on log-log paper it can be transformed into a linear form.

Soil Water Content

The amount of water held in a soil system is referred to as the soil water content (θ). The soil water content can be expressed on a volume basis (cm^3/cm^3) or a mass basis (g/g) [often referred to as the gravimetric water content (θ_g)]. As can be seen in equation [2], water content is an important factor influencing unsaturated hydraulic

conductivity, $K(\theta)$. The soil water content is clearly important for the growth of plants and plays an important role in such mechanical properties as consistency, plasticity, strength, compactibility, penetrability, stickiness, and trafficability. Soil water content is also important because it determines the air content and rate of gas exchange within the soil.

Hydraulic Gradient

The hydraulic gradient is the driving force causing water movement in the soil. The hydraulic gradient for a saturated soil, is $\psi \, d\psi_h/dz$ and for an unsaturated soil is $d(\psi_m + \psi_g)/dz$ (from Eq. [1] and [2]). The potential energy of water may differ from place to place and from time to time within the soil. Most water movement under normal conditions in the field occurs while the soil is in an unsaturated condition and the total soil-water potential is negative.

Hanks and Ashcroft (1980) define the total potential (ψ_T) of soil water as the sum of gravitational potential (ψ_g), matric potential (ψ_m), pressure potential (ψ_p), and osmotic potential (ψ_π) as expressed in Eq. [9].

$$\psi_T = \psi_g + \psi_m + \psi_p + \psi_\pi \quad [9]$$

Differences in total potential determine the direction and magnitude of water flow in a soil system. A measurement of total soil water potential is useful because it indicates the potential plants must overcome to remove water from the soil.

The gravitational potential of soil water is determined by the elevation of a given point relative to an arbitrary reference level. It

is always positive or zero if the point of reference is below the point to be determined. The gravitational potential is always negative if the soil surface is chosen as a reference point.

The matric potential of soil water results from the forces of capillarity, as well as those of adsorption (hydration envelopes over the particle surfaces) on to the soil. These forces lower the potential energy below that of pure water and result in negative matric potentials. In unsaturated soils, capillarity results from adhesive and cohesive forces as well as the surface tension forces in the water menisci of the soil pore spaces. The matric potential of a saturated soil is zero. As a slight suction or pressure is applied to a saturated soil no outflow may occur until a certain critical value is exceeded at which time the largest pore begins to empty. This critical value is called the air-entry point and is generally small in coarse-textured soils and larger in fine textured soils (Hillel, 1982). The progressively smaller pores will continue to empty as suction or pressure is gradually increased. Only the very small pores will contain water at high suction or pressure values. Therefore, the amount of water remaining in a soil is a function of the number of soil pores, size of soil pores, and the amount of matric potential.

The pressure potential in a soil system is the pressure that is associated with a static head of water and exists only below a water table. It can be measured with a piezometer. There is no pressure potential in an unsaturated soil system.

The osmotic potential results from the presence of solutes in soil water. These solutes affect the thermodynamic properties of the soil

water and lower its potential energy. This phenomenon does not significantly affect the flow of water in the soil profile unless there is a semipermeable membrane such as a plant root system. The sum of the matric and osmotic potentials is often used to characterize the energy status of soil water with respect to plant water uptake. In order to extract water from the soil, the water potential of a plant must be lower than the matric and osmotic potential of the soil water. In moist soils when the matric potential approaches zero, the osmotic potential may be the predominant component of the total potential. As the soil dries out, the matric potential becomes progressively more predominant in determining the total soil water potential. Matric forces are capable of lowering water potentials more drastically than most naturally occurring osmotic forces (Meidner and Sheriff, 1976).

The hydraulic potential is frequently used when the only concern is with the direction and magnitude of liquid water flow in the soil system. Hydraulic potential can be defined as

$$\psi_h = \psi_g + \psi_m + \psi_p \quad [10]$$

remembering that either ψ_m or ψ_p is zero at any particular time.

Determination of Hydraulic Conductivity

Determination of hydraulic conductivity (K) as it relates to various suction and wetness values is required before any of the mathematical theories of water flow can be applied in practice. Hydraulic conductivity values must be measured experimentally and can be obtained using laboratory techniques or in situ field methods that have been recently developed. Hydraulic conductivity as a function of water content $[K(\theta)]$ is usually determined in preference to hydraulic

conductivity as a function of soil water potential $[K(\psi_h)]$ because $[K(\theta)]$ it is easier to measure and is not affected by hysteresis.

Hysteresis is a phenomenon that accounts for the fact that water contents are greater during desorption than sorption at a given potential. Topp (1969 and 1971) as well as Staple (1970) determined that there was little, if any, effect of hysteresis on unsaturated hydraulic conductivity as a function of soil water content $[K(\theta)]$ but the effects of hysteresis on unsaturated hydraulic conductivity as a function of soil water potential $[K(\psi_h)]$ was substantial.

Hydraulic conductivity $[K(\theta)]$ values can be obtained from either steady-state or transient-state flow systems. In steady-state flow systems the flow characteristics (water content, hydraulic potential or gradient, and water flux) do not change with time but remain constant (Hanks and Ashcroft, 1980). Water is stored (or in some situations it is coming from storage) in the soil with transient or nonsteady state flow. Therefore in transient state flow, the water flux entering a soil would not equal the water flux leaving a soil and the difference between that entering and that exiting is the storage.

Steady-state flow and the determination of hydraulic conductivity can be accomplished in several ways. One method used to evaluate $K(\theta)$ is to establish a steady flow of water to a water table. A second method used to establish steady-state flow involves the evaporation of water from a soil that has a water table at a fixed depth. A third method commonly used to attain steady-state flow conditions is to thoroughly wet a soil profile by flooding. Steady-state flow conditions are then approached during drainage of the soil profile. It takes a

considerable amount of time , in all cases, to establish a steady-state. The change with depth in matric potential (ψ_m) from Eq.[10] is constant and equal to zero, when a steady-state of flow is attained. Consequently, the $d\psi_h = d\psi_g$ and flow will be entirely a result of the gravitational potential difference. The hydraulic gradient $[d(\psi_m + \psi_g)/dz]$ [Eq. [2]] now equals the gravitational gradient ($d\psi_g / dz$) which will be equal to one. This prompted Hanks and Ashcroft (1980) to establish the following general rule

"If steady-state verticle water flow into soil has been established, the value of the hydraulic conductivity in the zone of constant matric potential (also constant water content) is numerically equal to the flux density of water application."

Eq. [2] can now be written as

$$V = -K \quad [11]$$

The assumption of a unit hydraulic gradient such as that found in Eq. [11] was first introduced by Black et al. (1969). With this assumption the rate of change of soil water content in a soil profile can be used to calculate the hydraulic conductivity $[K(\theta)]$, as shown by Nielsen et al. (1973).

In the past, many studies dealing with water movement and behavior in soils have been conducted in the laboratory using columns of artificially packed or disturbed soils. Cassel et al. (1974) questioned the validity of extrapolating experimentally convenient laboratory results to field situations. Hillel (1982) also feels that all too often theories and models have been validated, if at all, only in highly artificial sets of laboratory produced conditions. Hillel states:

"it is unrealistic to try to measure the unsaturated hydraulic conductivity of field soil by making laboratory determinations on discrete and small samples removed from their natural continuum, particularly when such samples are fragmented or otherwise disturbed".

However, Tommer (1986) did find that good saturated hydraulic conductivity data could be obtained from measurements on undisturbed cores in the lab. Klute (1965a,b) reviewed laboratory methods for determining both saturated hydraulic conductivity and unsaturated hydraulic conductivity.

Richards et al. (1956) and Ogata and Richards (1957) were the first to use flood plot methods on a bare field to determine $K(\theta)$ under field conditions. $K(\theta)$ was calculated from Eq. [1] using tensiometers to determine matric potentials and gravimetric methods for determining flux. By measuring the changes in water content due to drainage as a function of time and dividing this by the hydraulic gradient determined with the tensiometers, they were able to calculate $K(\theta)$. The hydraulic conductivity values calculated from field data were found to be in agreement with values they had previously obtained using both laboratory and field methods. Arya et al. (1975) used a similar approach to determine $K(\theta)$ in the presence of a growing crop. Nielsen et al. (1964) did a flood plot study but used a neutron probe to obtain water data and undisturbed cores for determination of water retention curves. A water budget approach for determination of hydraulic conductivities was used by Rose and associates (Rose et al., 1965; Rose and Stern, 1965). Watson (1966) developed the instantaneous profile method (IPM) for determination of $K(\theta)$. This method is designed to include possible dynamic effects of non-steady-state flow in calculation of $K(\theta)$. Cassel

(1974) developed a computer program for calculation of average θ , flow rate, hydraulic gradient and conductivity for all depths and times, given desorption and tensiometer data collected during drainage of a covered flood plot.

Bouma and Dekker (1981) have more recently developed a field method for determination of saturated hydraulic conductivity that measures both the vertical and horizontal conductivity of a cube of soil. This cube of soil, about 25 cm^3 , is carved out in situ and then covered with gypsum. Bouma and Dekker suggest that their method of determining saturated hydraulic conductivity can be used to measure both vertical and horizontal flow.

In recent years several unit gradient based mathematical models; the Lax algorithm (Sisson et al., 1980), the "CGA" (Chong et al., 1981), and the Theta and Flux models (Libardi et al., 1980); that allow calculation of $K(\theta)$ using only water content measurements at known times during drainage have been proposed. Tommer (1986) fit all of these models to drainage data and determined that the magnitude of the $K(\theta)$ estimates followed the order $\text{CGA} > \text{Lax } \theta \text{ methods} > \text{Lax } W \text{ methods}$. Tommer felt that the CGA and W methods had an advantage in that they are based on measurements of profile storage rather than water contents at a single depth. Analysis of field data with both the CGA and Lax W (Watson equation) models allows a range of values of K to be obtained from a single data handling procedure. Tommer's results, with regard to the magnitude of $K(\theta)$ values using these field models, were substantiated by Jones and Wagenet (1984).

Properties That Affect Hydraulic Conductivity

Hydraulic conductivity and permeability can be affected by several chemical and physical properties within the soil. Lutz and Leamer (1939) studied the effect of texture and swelling on the effective pore size as related to permeability. They found that the permeability of the separate soil fractions increased exponentially with the size of particles and, therefore, with the size of the pores. They also determined that the permeability decreased as the amount of swelling colloidal material increased.

Particle-size distribution (mechanical composition) rather than pore-size distribution has been used most frequently, in the past, to describe granular materials (Childs and Collis-George, 1950). Consequently, most formulas relating permeability to constitution do so in terms of particle size. Marshall (1958) attributes the work of Kozeny, Fair and Hatch, and Carman to the wide use of an equation, usually referred to as the Kozeny equation, relating permeability to particle size.

Childs and Collis-George (1950) developed an equation that relates permeability to pore-size distribution. Their equation considers the various sequences of pores of different sizes when pores are randomly arranged in a porous system. Unfortunately, their equation requires an empirical factor and has not been widely tested for consistency in different materials (Marshall, 1958).

Marshall (1958), found it difficult to apply the Kozeny equation to material containing widely different pore sizes. Therefore, he developed an equation that is similar to that of Childs and Collis-

George (1950). This equation is somewhat limited in that the material should be isotropic and should contain no lengthy conducting channels. Swelling materials may also limit the accuracy of the calculations for soils of moderate or high clay content.

Millington and Quirk (1961) continued the development of the pore interaction model proposed by Childs and Collis-George (1950). This equation describes saturated and unsaturated permeability as a function of bed porosity, fluid content, and pore size distribution. They found that applicability of their method for obtaining steady-state permeability depended on factors such as isotropy of the total pore space distribution data and random distribution of the pore-size classes. This method is not satisfactory if the medium has been compressed to produce a laminated effect. Also the material must be inert in terms of swelling and shrinkage response to the liquid used in obtaining pore-size distribution data and permeability measurements.

Ghazy (1982) examined several soil properties in an attempt to determine which factors affected the downward movement of water in calcareous soils under saturated conditions. He examined texture, particle-size and CaCO_3 fineness, structure and soluble salts. The effects of particle-size and CaCO_3 fineness will be discussed later (see section on soil carbonates and their effect on water movement in soils). Ghazy found the values of hydraulic conductivity varied significantly with soil texture. He found a positive and significant correlation between hydraulic conductivity and coarse sand fraction. Hydraulic conductivity decreased with increased clay content. He concluded that the highest direct and indirect effects on hydraulic conductivity were

related to coarse sand content because of an increase of total drainable pores with the increase of coarse fractions. Childs and Collis-George (1950) also found a significant relationship between hydraulic conductivity and coarse sand fractions.

Ghazy (1982) found that the size and stability of the soil structural unit greatly affected the rate of water movement in the soil profiles. Nagmouh (Ghazy, 1982) stated that the effect of aggregate size is similar to those of mechanical fraction. Ghazy concluded that as the percentage of water stable aggregates increases, the hydraulic conductivity increases.

Several investigators have studied the influence of total soluble salts as a factor affecting water movement in soils. Soluble salts can affect aggregate stability, viscosity of soil water, as well as the solid and liquid phases interaction in the soil (Ghazy, 1982). Ghazy found a positive and significant relation between hydraulic conductivity and total soluble salts. He attributed this to better flocculation of colloidal fractions. Martin and Richards (1959) obtained similar results. Martin and Richards showed that increasing exchangeable H^+ and Ca^{++} caused very little increase in hydraulic conductivity, while increasing exchangeable sodium and potassium reduced it markedly. Ghazy concluded that the effect of exchangeable Ca^{++} on hydraulic conductivity was not pronounced.

Soil Water Retention Curves

The graphical representation of the relationship between soil water content on a volumetric or gravimetric basis and soil water potential is called a soil water retention or desorption curve. Soil water potential

is usually represented on the x-axis and water content on the Y-axis.

Determination of Soil Water Retention Curves

Soil water retention curves can be determined by taking an initially saturated sample and removing, stepwise, increments of water by applying increasing suctions or pressures to the sample. Standard laboratory methods used for soil moisture extractions and determination of soil water retention curves are contained in U.S. Department of Agriculture Handbook No. 60 (Richards, 1969) or Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples (Soil Survey Staff, 1967). These methods are based on developmental work by Richards and Fireman (1943), Richards (1947, 1948, 1949, and 1969), and Reginato and Van Bavel (1962). In brief, soil samples are equilibrated, at known water potentials, on semi-permeable membranes made of ceramic or cellulose. The potentials are controlled by applying a gas pressure to a chamber or by hanging a water column of known height on the membrane. After equilibrium is obtained at a particular potential the water content of the soil sample is determined. Since it is very difficult to accurately control low gas pressure, low potentials in the range of 0.1 bar are determined with a hanging water column. Soil water retention curves, determined in the laboratory are obtained in one of two ways. One method is to take the soil from the field, dry it, sieve it, and place a teaspoon-size sample in retainer rings on a porous plate. A second method involves the use of natural clods or soil cores that are placed on a porous plate. Baker et al. (1974) recommended the use of large undisturbed cores (7.6 cm diameter and 5.0 cm in height). Baker and his colleagues determined that the data from these large undisturbed

cores were more comparable with in situ measurements.

Although the importance of pressure plate or membrane impedance in the pressure-plate outflow measurements of hydraulic conductivity was recognized by Miller and Elrick (1958), the characteristics of the plate or membrane are generally assumed to have no effect on equilibrium moisture content versus matric suction relations as long as the air entry value or "bubbling pressure" of the membrane is not exceeded (Hillel and Mottes, 1966). The validity of the standard moisture retention measurements, using pressure-plates or membranes, has not been questioned (Hillel and Mottes, 1966). But, Hillel and Mottes in the course of their work did come across some anomalies in the standard measurement of soil-moisture retention.

Hillel and Mottes (1966), after reviewing the work of several other scientists determined that sample pretreatment, insofar as it affects soil structure, and pore-size distribution, did affect water retention, especially in the low-suction range. Therefore, soil water retention curves obtained from soil samples that have been air dried, crushed, and sieved are likely to be in error because the pore structure has been changed. Hillel and Mottes found that the results obtained with different instruments varied markedly even where sample pre-treatment was apparently the same. They also found that values obtained for different suction ranges on different types of porous plates or membranes often failed to provide smooth and continuous curves. They suggested that it was inadvisable to use plates of relatively high impedance (either owing to the intrinsic properties of the material, or to eventual clogging by clay) in the low-suction range. Some of the

anomalies that they observed were attributed to the process of "self-puddling" or "aging". This aging process is most evident in clayey soils and results from structural changes that are related to the wetting and drying cycles common in disturbed (compacted or crushed) soil samples. Hillel and Mottes determined that soils which exhibit marked aging effects should be pre-wetted for much longer durations. This would produce a stable initial structure that would resist further change during suction equilibration. They also felt the effects of aging would be less in undisturbed field-core samples than in air-dried samples such as were used in their study.

Field methods used to determine water retention curves involve in situ measurements of soil water pressure by tensiometers installed at depths of interest and of water content by gravimetric sampling or neutron or gamma attenuation techniques. Because the sample environment (confinement and overburden) is not represented in laboratory procedures, laboratory data may not always agree with field data (Arya and Paris, 1981).

Hanks and Ashcroft (1980) found that the water retention curves determined in the field on an undisturbed soil and in the laboratory on the same soil that had been dried, crushed, and sieved were significantly different. For a given water content, the matric potential was greater in the undisturbed field soil samples than in the disturbed laboratory samples. Arya et al. (1975) and Nagpal and deVries (1976) found the disagreement between laboratory and field methods appeared more pronounced at higher water contents. Haverkamp and Parlange (1986) also felt laboratory measurements of the retention curve

based on desorption of initially saturated soil samples were often not applicable under field conditions. Therefore, in situ measurements that are based on simultaneous monitoring of soil water content and water pressure would be preferable.

In situ measurements, as well as laboratory studies, can be expensive, tedious, and slow. Consequently, any simplified methods for estimating or predicting water-retention curves from more easily obtainable physical or chemical characteristics of the soil would be welcomed. Recently, methods using models that are based on laboratory data or physical properties of the soil have been developed to calculate soil water retention curves.

Haverkamp and Parlange (1986) developed a model relating the soil water retention curve to the cumulative particle-size distribution. Their model was tested on 10 different sandy soils that were characterized by relatively uniform particle-size distribution and no organic material. Their model does account for the effects of hysteresis and air entrapment in sandy soils but ignores the effects of root activity as well as cracking and swelling.

One of the simplest predictive approaches used to estimate soil water retention curves consists of relating water contents at specified soil water pressures to soil texture, organic matter, and/or bulk density, using multiple regression analysis (Jamison and Kroth, 1958; Salter et al., 1966; Gupta and Larson, 1979). Haverkamp et al. (1984) found that the methods of Salter et al. (1966) and Gupta and Larson (1979) showed standard deviations between predicted and experimental water content values that were twice as large as the errors introduced

normally by experimental field procedures.

Arya and Paris (1981), in their review of existing literature, discuss other approaches used for the estimation of water retention curves. These approaches involve the use of a power curve with constants that must be evaluated empirically. Additionally, a knowledge of part of the soil water retention curve is required for some models. Although both the statistical studies using regression equations and the power curve formulations are being used to predict moisture retention data, Arya and Paris (1981) feel these methods lack the physical basis to account for the effects of texture and packing characteristic of the medium. They also feel that failure to trace a realistic shape of the curve, particularly in the wet range, is a weakness inherent in both approaches. They proposed an approach to derive the water retention curves of a soil by using its particle-size distribution and bulk density in the natural state of packing. However, Haverkamp and Parlange (1982) believe that the approach proposed by Arya and Paris (1981) contains a serious fundamental limitation because it uses a nonunique pore-size/particle-size relation as the basic equation for the model. Petersen et al. (1968) studied the relationships of morphology and other selected soil properties (coarse fragments, organic matter, clay mineralogy, and silt-sized fractions) to moisture retained after equilibration at $-1/3$ and -15 bar tensions. Husz, as reported by Gupta and Larson (1979) also developed equations using particle-size analysis to describe water retention characteristics between $-1/3$ and -15 bar.

A more recent water retention-soil water potential model has been developed by Baumer (Baumer, 1985; Baumer and Rice, 1986) in an attempt

to predict the curve from the vast quantity of chemical and physical data available in the National Soil Survey Laboratory. This model is based on one by Van Genuchten (1979) that describes the relationship of the soil water fraction by weight to soil water suction. The model is based on the following assumptions:

- 1) the relationship of soil water fraction by weight to the soil water suction is the key factor,
- 2) the slope of curves for all soils should be zero when h (matric potential) is zero (this is the point where the water content is equal to the satiated water content), and
- 3) the curves should become asymptotic to a line parallel to the abscissa which defines the residual water content.

Therefore, curves for all soils should take the general form shown in Figure 1. Baumer's model can be described by the equation:

$$WC = WCR + \frac{WCS - WCR}{[1 + (ah)^{2n}]^{1/m}} \quad [12]$$

where WC is the gravimetric water content for a given water content; WCS is the satiated water content; WCR is the residual water content; h is the matric soil water potential; a , m , and n are dependent parameters directly measured or derived from basic soil data. Satiated water content, the actual water content at zero suction, differs from total porosity by the volume fraction of entrapped air and is a calculated value. Residual water content, also a calculated value, is the water content that occurs when water films have thinned to the point that they are no longer continuous. The basic soils data required to calculate WCS , WCR , and the other parameters are 1/3 and 15 bar values of soil clods, clod bulk density, volume percent of rock fragments, weight

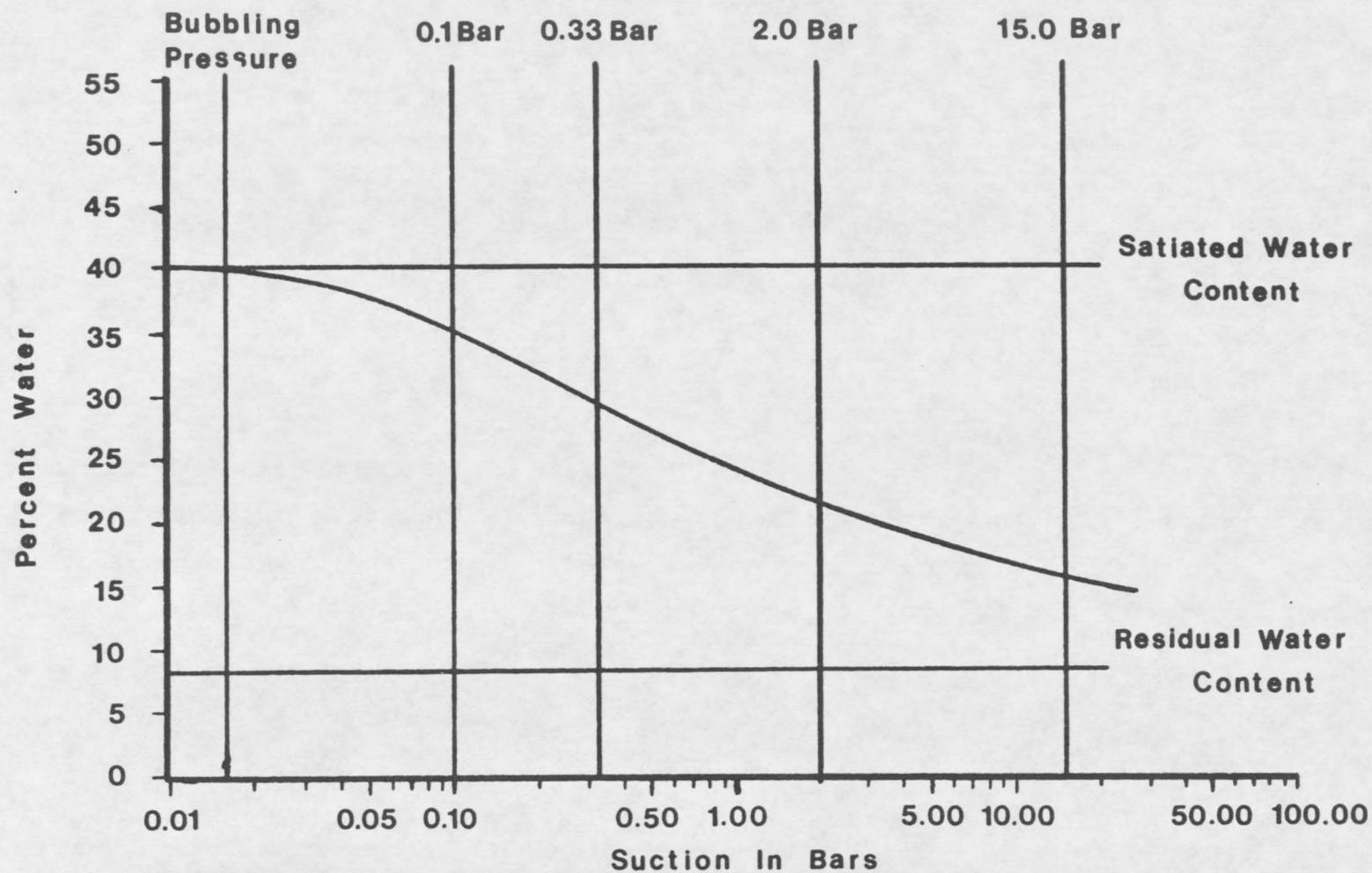


Figure 1. Relationship of saturated and residual water content and bubbling pressure to soil water retention curve (Baumer, 1985).

percent of clay and silt, weight percent of organic matter, and clay activity as expressed by the cation exchange capacity to clay ratio. A brief description of the theory, development, and use of Baumer's model is given in Appendix II.

Properties That Affect Soil Water Retention Curves

The relationship between soil water content and soil water potential is complex and affected by many physical and chemical properties within the soil. Taylor and Ashcroft (1972) illustrated that a small change in water content, for any given texture, usually causes very little change in matric potential when the matric potential is high. However a small change in water content usually results in a larger change in the matric potential when the matric potentials are lower for any given texture. Richards and Marsh (1961) illustrated this same concept in a different way. They showed that a greater percentage of the available water is held at higher matric potentials for a sandy soil than a clayey soil but that the total available water may be considerably greater for a medium textured soil than for sandy soils. The greater the clay content, in general, the greater the water retention for any given suction, and the more gradual the slope of the curve (Hillel, 1971). The relationship between soil water content, soil texture and soil water potential is illustrated in Figure 2 (Baumer, 1985). Soil structure, as well as the total electrolyte concentration, also affects the shape of the soil water retention curve.

Water held at relatively low matric potentials (0 to 1 bar) depends primarily upon the capillary effect and pore size distribution and therefore is strongly affected by the structure of the soil. Water

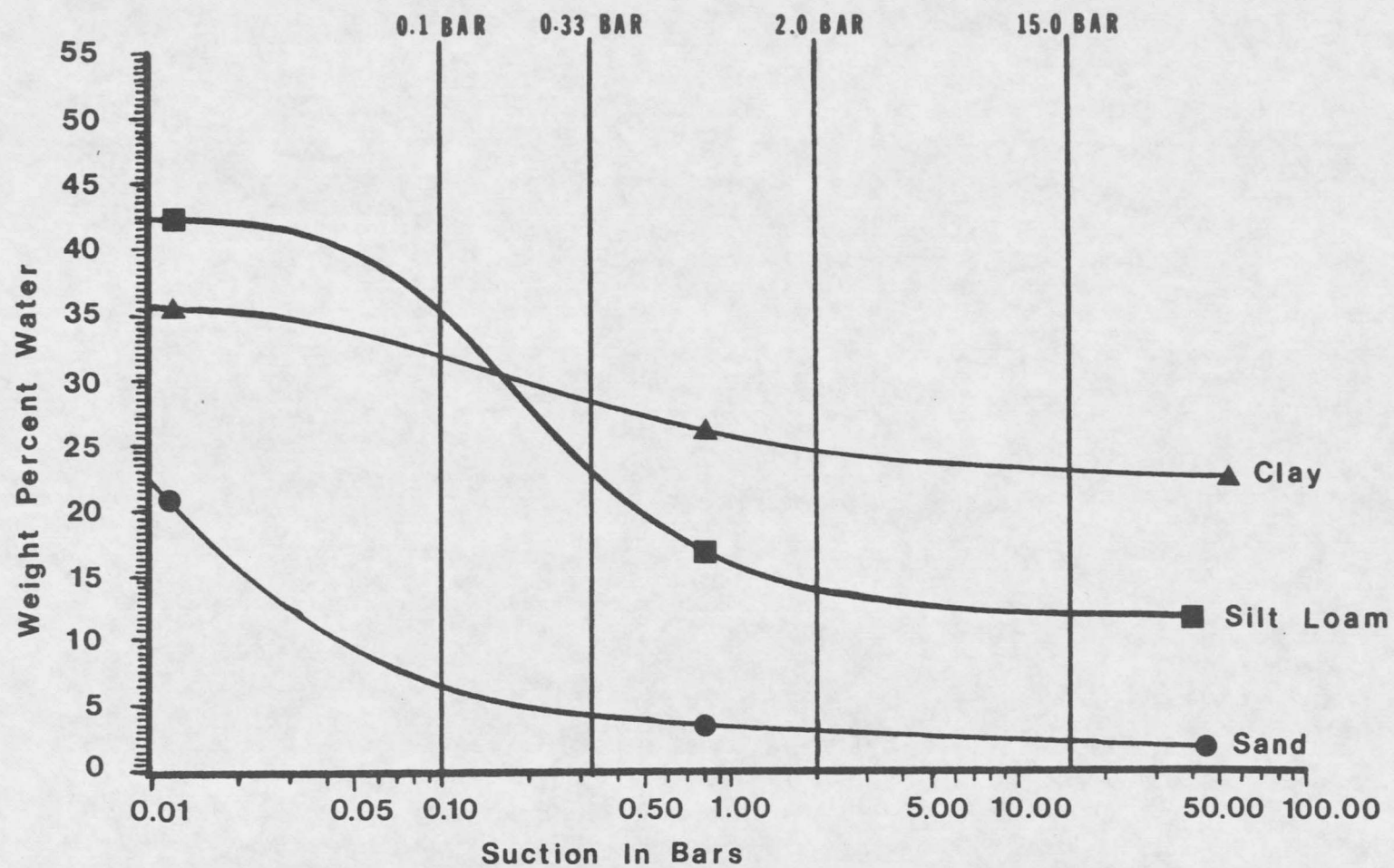


Figure 2. Soil water retention curves for a sand, silt loam, and clay soil (Baumer, 1985).

retention at higher matric potentials is due increasingly to adsorptive rather than capillary forces and is therefore influenced less by structure and more by texture and specific surface of the soil material (Hillel, 1982). Hillel and Mottes (1966) determined that the soil structure of very few soils, if any, is completely stable. Clayey soils with low humus content (such as may occur in arid regions) exhibit structural changes related to wetting-drying cycles (including slaking, swelling, and particle-reorientation). The mechanism of structural change, which begins when a soil is wetted and apparently continues as the moisture is extracted is more noticeable in disturbed (compacted or crushed) soil samples than in undisturbed field-core samples (Hillel and Mottes, 1966). Hillel (1982), after reviewing the work of Dane and Klute (1977), explains the effects of shrinkage and swelling of clay particles on the water retention curve as follow:

"Swelling is generally suppressed when the soil solution is fairly concentrated with electrolytes, particularly in the presence of a preponderance of divalent cations such as calcium. On the other hand, swelling - and hence water retention of any suction value - can be much more pronounced when the soil solution is dilute and with a preponderance of monovalent cations such as sodium."

Entrapment of air bubbles in soil water (Peck, 1969) is also known to affect soil-water interactions and ultimately have an effect on the soil-water retention curve. Air bubbles in soil water affect both the hydraulic conductivity (Christiansen, 1944; Gupta and Swartzendruber, 1964) and the moisture content at a particular matric potential (Poulovassilis, 1962; Cary 1967). Peck (1969) suggests that the slow growth of entrapped bubbles may account for the anomalously slow release of water observed in some outflow experiments. Entrapped air is also

important when considering the effects of hysteresis on soil water retention curves.

Hysteresis, a failure of the soil-water adsorption curve and the soil-water-desorption curve to coincide, has been discussed in detail by many authors (Miller and Miller, 1955a & 1955b; Cary, 1967; Poulouvassilis, 1962; Topp, 1971). The equilibrium soil wetness, as a result of hysteresis, is greater in desorption (drying) than in adsorption (wetting).

Soil Carbonates and Their Effect on Water Movement in Soils

It is a well known fact that soil properties such as texture, bulk density, structure, and the nature and kind of both soluble and exchangeable ions are the important variables affecting water movement in soils. Less well known or understood, is the effect of calcium carbonate on water movement in soils.

Ghazy (1982) found poor correlation between hydraulic conductivity and total calcium carbonate content but did find a significant positive correlation with fine sand, silt and clay sized carbonates. Ghazy's findings were similar to those of Talha et al. (Ghazy, 1982).

Ben-Hur et al. (1984) studied the effect of soil texture and CaCO_3 content on water infiltration in crusted soils. They found that high concentrations of calcium carbonate in calcareous soils (5-16%) had no effect on the infiltration rate. Kazman et al. (1983) obtained similar results with sandy loam and silty loam soils. Ben-Hur et al. (1984) in their review of existing literature, found that calcium carbonate in sodic soils maintained the structure of the soils and prevented the normal decline in hydraulic conductivity that is usually associated with

sodic soils. Shainberg et al. (1981) proposed that when calcareous soils were leached with distilled water, the calcium carbonate released electrolytes at a rate sufficient to maintain the concentration of the soil solution above the flocculation value of the soil clay; thus, clay dispersion and pore clogging were prevented.

Mondal (1979), in laboratory studies, also observed that the hydraulic conductivity of a calcium carbonate system was several times higher than that of a sodium-calcium carbonate system at all stages of leaching with distilled water. He felt this was the result of entry of calcium in the exchange complex and the higher salt concentration around the soil particles. Similar results were also obtained by Shainberg and Gal (1982), Agassi et al. (1981), Martin and Richards (1959) and Kazman et al. (1983).

MATERIALS AND METHODS

Site Selection

The Soil Conservation Service and Montana State University (MSU) in a cooperative effort to test a computer model used to calculate soil water retention curves and evaluate water flow characteristics, sampled eight different soil sites in Montana during July of 1985. Two of these sites were located in Gallatin County and the remaining six in Broadwater County (Figure 3). Detailed site locations, pedon descriptions, and laboratory analyses for six of these sites are given in Appendix 1.

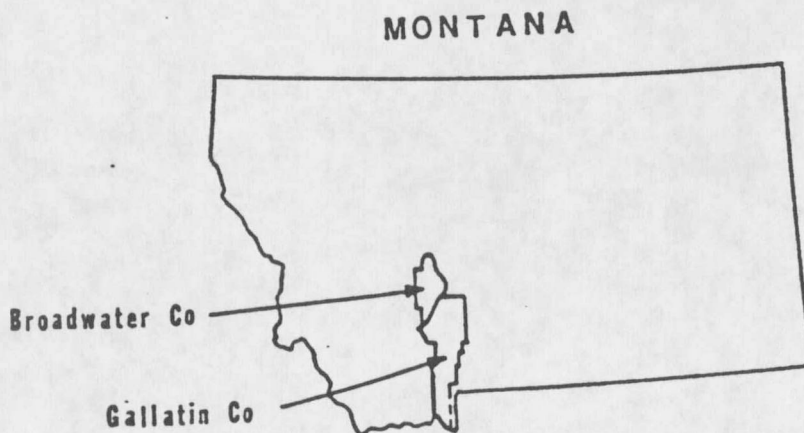


Figure 3. Soil site location map.

Soil Classification and Site Characteristics

The Soil Conservation Service sampled these specific soil sites, not only for the purpose of testing Baumer's soil water retention model (Baumer and Rice, 1986), but also to better understand the effects of

soil carbonates on water movement. These eight soil sites included seven different soil series listed in Table 1. and were considered representative of their respective soil series. A representative soil pedon at each site was described, classified, and sampled according to standards outlined by the Soil Survey Staff (1975 and 1984).

Table 1. Soil sites and classification of soil series.

<u>Site Number</u>	<u>Pedon Classification</u>	<u>Soil Series</u>
1	Fine-silty, mixed Typic Argiboroll	Bozeman Variant
2	Fine-loamy over sandy or sandy-skeletal mixed Typic Argiboroll	Turner
3	Fine-loamy, mixed Borollic Haplargid	Amesha Variant
4	Coarse-loamy, mixed Aridic Haploboroll	Chinook
5	Fine-loamy, mixed (calcareous), frigid Ustic Torriorthent	Mussel
6	Coarse-silty, mixed Borollic Calciorthid	Brocko
7	Fine-loamy, mixed Typic Argiboroll	Martinsdale
8	Coarse-silty, mixed Borollic Calciorthid	Brocko

Only six of the eight sites that were described, sampled, and characterized by the National Soil Survey Laboratory (NSSL) in Lincoln, Nebraska were used in this study. Site 7 and site 8 had to be eliminated from flood plot studies. Site 7 was too far removed from the other sites and site 8 was inaccessible to the 800 gallon water tank used to flood the sites.

Unsaturated Hydraulic Conductivity Study

Flood Plot Layout and Design

Unsaturated hydraulic conductivity of the soils was determined from drainage data as described by Tommer (1986). This required wetting the profile of small plots and measuring water content changes during drainage. These flooded plots were located adjacent (within one to ten meters) to the sampling pits used in characterizing the soils and as sources of the natural-structure clods obtained during the sampling trip by the NSSL in July, 1985.

Plots at sites 1 and 2 consisted of a 3.65 m square area enclosed within a waterproof dike. The waterproof dike consisted of four 3.65 m boards, 2.5 cm thick, and 30.5 cm in width nailed together on each end and placed directly on top of the soil's surface. Cement blocks and a 2.4 m board were placed inside the enclosed dike for access to four aluminum neutron probe access tubes located near the center of each diked area.

The remaining study sites, 3, 4, 5, and 6 were prepared for flooding and subsequent drainage by constructing a rectangular waterproof dike (2.65 m x 2.95 m) from lumber 2.5 cm thick and 30.5 cm wide. A 46 cm wide apron of black plastic was stapled along the inside perimeter of the dike (Fig. 4) to help prevent water from leaking during the flooding stage of this experiment. Soil from outside these sites was backfilled along both the outside and inside perimeters of all sites to add strength to the dikes and assist in preventing leaks during flooding. Cement blocks with a strong plank placed on top of them, above the dike, were used as a platform for access to four aluminum

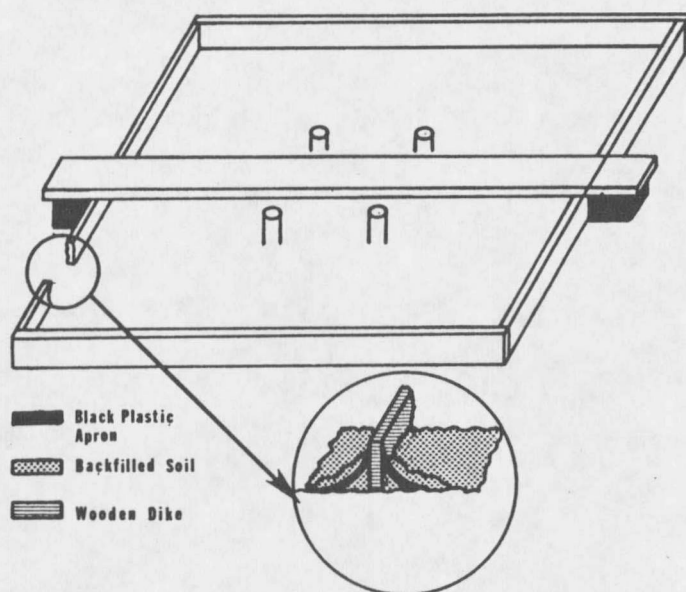


Figure 4. Flood plot design.

neutron probe access tubes located in the center of the dikes.

The entire plot was covered with a canvas frame tent during the first two to three days of the experiment to prevent precipitation from damaging the neutron probe equipment.

Soil water content was measured using a 50 mCi Americium-241/Be source, neutron moisture probe manufactured by Campbell Pacific Nuclear, Corporation. Thin-wall aluminum access tubes, 5 cm outside diameter and 193 cm long, were installed vertically at each site as illustrated in Figure 4. Access tubes were installed to a depth of 152 cm below the soil surface. This allowed approximately 23 cm of water to be ponded within the dike and 18 cm of access tube above the water surface. Rubber stoppers were glued in the bottom of all access tubes prior to installation to prevent water from entering the access tubes and damaging the neutron probe.

Water from the Jefferson or Gallatin Rivers, the source of irrigation water for soils of this area, was used to wet the soils. The plot surface was covered with burlap in order to reduce disturbance of the soil surface when water was applied. The force of the water stream was defused by passing the water through additional burlap.

Neutron probe readings for volumetric water content determinations, as a function of depth and time, were taken at 15 cm increments beginning at a depth of 22.5 cm (15.0 - 30.0 cm midpoint) and ending at a depth of 97.5 cm (90.0 - 105.0 cm midpoint) for site 1. Volumetric water content was determined at a depth of 37.5 cm (30.0 - 45.0 cm midpoint) for site 2. Measurements for soil water content at sites 3-6 were made at 15 cm increments beginning at a depth of 16 cm (8.5 - 23.5 cm midpoint) and ending at a depth of 106.0 cm (98.5 - 113.5 cm midpoint). Readings were taken before flooding began, and at 15 minute intervals during the first two hours of infiltration. Intervals were then increased to one half hour, one hour, and eventually 2-3 hours as infiltration slowed. Flooding was continued until the deepest soil moisture readings with the neutron probe failed to increase significantly. The length of time for flooding varied from 3.5 hours at site 2 (71 cm of silt loam soil over extremely gravelly sand) to 24.5 hours at site 6. At this time the dikes were broken and infiltration stopped shortly thereafter when free water was no longer standing on the soil surface. For the collection of drainage data, this was considered as time zero.

As soon as free water disappeared from the surface, the plots were covered with a plastic tarp to prevent evaporation and the influence of

precipitation after the canvas tent was removed. Soil was placed on top of the plastic tarp to prevent it from blowing away during the 1.0 to 1.5 month period in which drainage readings were taken. Drainage readings with the neutron probe were taken every half hour for the first four or five hours of drainage. Reading intervals were then increased to 1 to 2 hours for the next 10 to 12 hours, then 3 or 4 times daily for 2-5 days, twice daily for several days, and then once daily for several more days. Finally, readings were taken once every three to four days, until the last readings were taken one to two months after drainage began. The length of time in which drainage readings were taken varied from 20 days at site 2 to over 40 days at site 3.

Calibration of Neutron Probe

Taylor and Ashcroft (1972) present a thorough review of the principles behind the operation and calibration of neutron probes. Calibration of the neutron probe for sites 1 and 2 was conducted in access tubes at the Montana State University Post Farm according to the procedures described by Tommer (1985). Calibration of the neutron probe for sites 3-6 was conducted in access tubes near sites 4 and 6. In each case, three access tubes were placed in a fallow field to obtain water contents for moist soil conditions. Three additional access tubes were placed in an adjacent stubble field to obtain calibration data for dry soil conditions. Fifty-five core samples 15 cm in length were collected for determination of gravimetric water content (θ_g) and bulk density (BD). The gravimetric water content is expressed as a weight fraction (g/g) and it is the ratio of the weight of the soil water divided by the oven-dry weight of the soil solids. The volumetric water

content (cm^3/cm^3) was calculated by

$$\theta_g \times BD = \theta \quad [13]$$

Immediately after collection of core samples, aluminum access tubes were placed in the bore holes and neutron counts were taken in the center of the 15 cm depth increment from which the core samples were taken. A linear regression was fit to the data using volumetric water content as the dependent variable and neutron count ratio as the independent variable. The post farm calibration curve used for sites 1 and 2 was

$$\theta = 45.474 * (\text{Rat}) - 5.703 \quad (r^2 = .95) \quad [14]$$

and for sites 3 - 6 was

$$\theta = 21.4350 * (\text{Rat}) - 4.3643 \quad (r^2 = .85) \quad [15]$$

where θ is the volumetric water content and Rat denotes neutron count ratio. Two different neutron probes were used; therefore, two different calibration curves were obtained.

Hydraulic Conductivity Calculations

Tommer (1985) determined that the magnitude of the $K(\theta)$ estimates, as previously discussed (pages 16 - 17), followed the order CGA > Lax θ methods > Lax W methods. Tommer recommended the use of both the CGA and Lax W models for future hydraulic conductivity estimates because estimates from other models fall between these two models.

Water content data used in hydraulic conductivity calculations is based on changes in water content with time during drainage. Hydraulic conductivity can be calculated, using the Watson equation (W method), as follows:

$$K(\theta) = K_m (\theta/\theta_m)^{1/\beta} \quad [16]$$

where $K(\theta)$ is unsaturated hydraulic conductivity,

k_m is maximum hydraulic conductivity,

θ_m is maximum water content,

is $M/(M - 1)$,

M is the slope of the regression of:

$\ln (W/z)$ vs $\ln t$ (min)

K_m is equal to $z (\theta_m) ((\exp I)/(1 - \theta_m))^{1/m}$ and

I is equal to the intercept of the regression of:

$\ln (W/z)$ vs $\ln t$ (min)

where W is the total water stored above depth z and t is time of measurement after the beginning of drainage.

Hydraulic conductivity can be calculated, using the CGA (Chong et al., 1981) equation as follows:

$$K(\theta') = -zJA (J^{**} - 1.0) (\theta' ** (J-1/J)) \quad [17]$$

where $K(\theta')$ is the unsaturated hydraulic conductivity,

θ' is the average water content above any depth z ,

z is the depth of the reading,

J is the slope of the regression of:

$\ln \theta'$ vs $\ln t$ (min) and

A is the intercept of the regression of:

$\ln \theta'$ vs $\ln t$ (min)

Regression variables and constants determined by the regression for the Watson and CGA model are illustrated in Table 2. Note that $W/z = \theta$, so the regression variables for the Watson and CGA methods are identical (see Tables 35 - 40 of Appendix IV). Water content data collected during drainage from sites 1-6 were converted to the dependent variable

using a "water use" program that was originally developed by Sisson (1972) and revised by Tommer (1985). The author revised the original program to make it more "user friendly". The new program (Fig. 17, Appendix III) now prompts the user for the required information needed to run each new set of drainage data. The procedure followed for

Table 2. Regression variables used to determine $K(\theta)$ for the Watson and CGA models as well as the constants determined by regression results.

<u>Regression Variables</u>			
<u>Model</u>	<u>Dependent</u>	<u>Independent</u>	<u>Constants Determined</u>
Watson	$\ln (W/z)$	$\ln t$	km, B
CGA	$\ln (\theta')$	$\ln t$	a, j

conversion of drainage data to the variables used in the linear regression, using the "water use" program, are described in detail by Tommer (1985). The MREGRESS program on MSUSTAT (Lund, 1985) was used to run the regressions. The constants used in calculation of $K(\theta)$ were calculated from the slope and intercept results determined by MREGRESS (See Tables 35-40, Appendix IV).

Soil Water Retention Study

Field Sampling

National Soil Survey Laboratory. In July, 1985, the eight sites chosen by the Soil Conservation Service were sampled by the NSSL. The soil pits at sites 1 and 2, in Gallatin County, and site 3 in Broadwater

County were all dug with a tractor-mounted backhoe. Sites 4, 5, and 6 in Broadwater County were dug by hand. All soil pits were approximately 2 m deep, 1.2 m wide, and 1.8 - 2.4 m in length. One end of the soil pit was slopped downward at a gradual angle for easy access while sampling.

A soil pedon from each pit was described and classified according to standards outlined by the Soil Survey Staff (1975). From each soil horizon, samples were collected for laboratory analysis according to the procedures described by the Soil Survey Staff (1984). Natural clods (three per horizon) approximately 100 to 200 cm³ in volume were collected from each horizon. These clods were placed in disposable hair nets and were suspended in air. The clods were immersed, momentarily, in a container that contained a premixed Saran resin dissolved in methyl ethyl ketone. Saran-solvent ratios of 1:4 or 1:7 can be used depending on the porosity of the soil, as well as the strength of the clods. If the clods were very friable, a 1:4 mixture is preferred. The Saran-coated clods were allowed to dry for 30-45 minutes and then placed in waterproof plastic bags that were each enclosed in individual compartments of a rigid cardboard container. The cardboard container was placed in a heavy-duty aluminum trunk for transport to the NSSL.

Montana State University. Field sampling and encasement of soil cores was accomplished using Tommer's (1985) procedure (with one exception) developed for water flow analysis. This procedure minimizes the handling of core samples and sample disturbance. The soil cores used in this sampling procedure were removed from three sides of each site using a Giddings soil probe. Liquid rubber latex was poured over

samples from sites 1 and 2 and allowed to dry. The PVC pipe containing these individual samples was then completely filled with melted wax (the exception to Tommer's procedures) and allowed to dry. The PVC pipe, containing the samples from sites 3-6, were filled with the same lightweight concrete mixture recommended by Tommer. After the wax, used for sites 1 and 2, and the cement, used for sites 3-6, had dried, the samples were ready for transport to the laboratory.

Laboratory Analysis

National Soil Survey Laboratory. The physical and chemical characterization of field samples was completed by the NSSL in accordance with the procedures described by the Soil Survey Staff (1984). Moisture contents at 1/3 bar were obtained from the natural clods (procedure 4B1C) while 15 bar water content was obtained using a pressure-membrane apparatus, rubber retainer rings, and sieved soil samples (procedure 4B2).

Montana State University. Laboratory analyses for the soil water retention studies were initially attempted at 1/3 bar and 15 bar pressures using soil samples that were encased following Tommer's (1985) procedures and recommendations. The initial size of the soil cores used for this soil water retention study was approximately 7.6 cm in length and 4.2 cm in width. The soil cores were initially left encased inside the PVC pipe. The soil core was cut so that it barely protruded above the surrounding wax (samples from sites 1 and 2) or the concrete filler (samples from sites 3-6). The wax and concrete were used as a filler and for protection between the soil core and the PVC pipe (see Fig. 5). A fine-tooth carbide-tipped saw blade was used to cut samples from sites

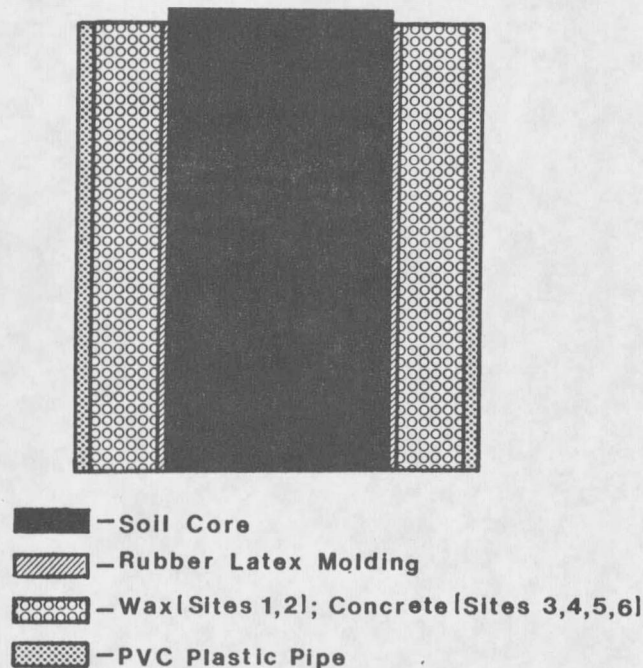


Figure 5. Initial "Undisturbed" core sample using Tommer's (1985) soil sample encasement technique.

1 and 2 on a table saw and a carborundum impregnated wire gauze blade was used to cut the samples from sites 3-6 on the table saw. The soil cores' surface then had to be lightly scrapped to remove any wax that may have become impregnated on the cores' surface during cutting. The soil samples to be used for the extraction of 1/3 bar water were then placed on a ceramic plate, with relatively low impedance, that had been pre-wetted for 4-6 hours. The samples were saturated by flooding over the plate with a one-centimeter depth of free water for 12-14 hours. The samples were then placed inside a pressure cooker (Fig. 6) where they were allowed to equilibrate (usually 2-3 days) at the applied pressure.

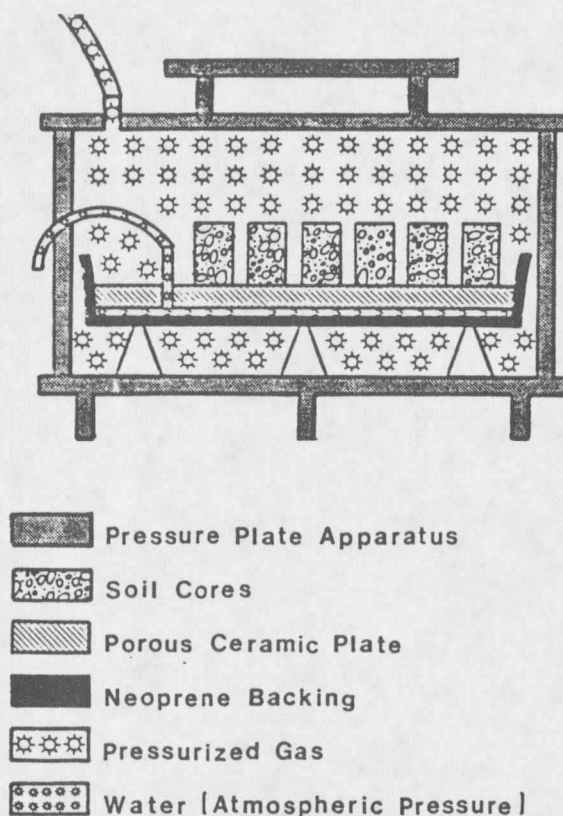


Figure 6. Pressure-membrane apparatus for obtaining 1/3 bar and 15 bar water.

Gravimetric moisture contents of the soil samples at 1/3 bar pressures were then determined by removing the equilibrated samples and oven drying them at 105 degrees C until there was no further water loss. This required about forty-eight hours.

An attempt was made to collect 15 bar water data from the cores using pressure membrane rather than pressure plate equipment. However, because the cores cut the membrane and a very long equilibrium time was required, this was abandoned. Instead, 3 bar water content data were obtained using the pressure plate equipment. This required an equilibrium time of 5 to 7 days. Although water held at 3 bar potential

is considered plant available, in most soils little plant available water remains at this potential.

Determination of 1/3 bar and 15 bar water using the technique described by Tommer (1985) for field encasement of soil cores did not work for water retention analysis. The following problems were encountered:

- (1) It was very difficult and time consuming trying to cut the PVC pipe, the cement (or wax), and then the rubber coating surrounding the core so that the soil core barely protruded above the encasement material.
- (2) It was difficult trimming the soil core's surface flat so a good contact between the soils surface and the ceramic plate could be maintained.
- (3) The encased soil samples were too wide to accommodate very many samples in the pressure membrane apparatus.

For these reasons, soil cores were removed from the surrounding encasement material and re-coated with a layer of melted wax (see Fig. 7). This was necessary to add strength to the soil core and prevent it from slaking during saturation. Prior to determination of 1/3 bar and 3 bar water, the wax-coated soil cores were weighed in air and then immersed and weighed in water. This allowed the calculation of bulk density and volumetric water content.

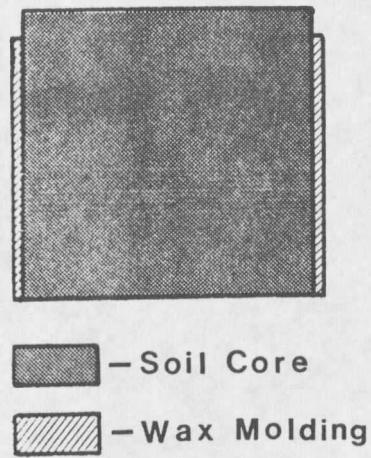


Figure 7. Soil core used for determination of 1/3 bar and 3 bar soil water retentions.

RESULTS AND DISCUSSION

Soil Water Retention StudyNational Soil Survey Laboratory Data

Soil samples collected from the six study sites were analyzed by the NSSL to obtain the actual measured values for the soil water retention at 1/3 and 15 bar water contents. Appendix I contains the profile descriptions and the physical and chemical characterization data from the six study sites. The results from the measured 1/3 and 15 bar water contents obtained from this physical and chemical characterization data were then used in the soil water retention model developed by Baumer (Baumer and Rice, 1986) to obtain the model parameters and equations for the soil water retention curves.

Computer printout results¹ from the soil water retention model for the six study sites were too voluminous to be included in this thesis. Examples of soil water retention curves (Site 1) obtained using the soil water retention model are given in Part 3 of Appendix II. Tables 3-8 (SCS WATER RETENTION MODEL) contain all of the computer printout results for study sites 1-6. The 1/3 bar values at measured field density (MFD) in tables 3-8 are the only values actually obtained from the samples in the laboratory. The 1/3 bar water by weight values (tables 3-8) at expected low density (ELD), expected medium density (EMD), and at expected high -density (EHD) are all computed soil water retention

¹The computer printout results for all soil horizons from all six study sites can be obtained from Dr. Gerald Nielsen, Plant and Soil Science Dept., Montana State University, Bozeman, MT, 59717 or from the State Soils Staff, Soil Conservation Service, Bozeman, MT, 59715

Table 3. Laboratory results for soil water retention study - Site 1, Bozeman soil series.

SCS WATER RETENTION MODEL										MSU WATER RETENTIONS								
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT ---- COMPUTED SWR VALUES ----					1/3 BAR WATER BY WEIGHT				3 BAR WATER BY WEIGHT				
Depth	MFD ¹	ELD ²	EMD ³	END ⁴	MFD ¹	ELD ²	EMD ³	END ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 4	Hole 1	Hole 2	Hole 3	Hole 4	
cm	----- % -----				----- % -----				cm	----- % -----				----- % -----				
AP1	0-10		25.8	24.3	22.9		15.1	14.7	14.6									
AP2	10-23	21.0	25.5	24.1	22.6	15.5	14.9	14.5	14.4	22.5	20.1	21.0	23.3	22.2	17.5	24.9*	22.6*	16.8
Bt1	23-33	23.1	27.6	26.0	24.3	15.9	17.5	17.3	17.5									
Bt2	33-51	20.1	26.7	25.2	23.6	14.1	16.3	14.1	16.2	37.5	19.2	19.8	20.4	23.4	31.1*	30.7*	20.5*	15.8
BtK	51-84	20.0	24.9	23.5	22.0	13.2	15.7	15.7	15.9	52.5	20.1	23.6	20.1	22.4	14.5	16.7	20.8*	15.7
										67.5	19.0	19.5	20.1	23.6	22.7*	24.7*	21.1*	17.2
										82.5	19.8	23.3	23.0	18.8	22.3*	21.6	15.4	10.6
										97.5								
BK1	84-104		23.0	22.0	20.6		13.2	13.1	13.3									
BK2	104-132	18.1	21.7	20.4	19.2	10.8	11.5	11.3	11.4									
BC	132-145		17.7	16.7	15.7		8.9	8.7	8.5									
2C	145-180		6.5	6.1	5.8		2.7	2.6	2.5									

- ¹ AT Measured Field Density
² AT Expected Low Density
³ AT Expected Medium Density
⁴ AT Expected High Density

* These values eliminated in the "comparison of Selected Laboratory Data" section.

Table 4. Laboratory results for soil water retention study - Site 2, Turner soil series.

SCS WATER RETENTION MODEL									MSU WATER RETENTIONS										
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT --- COMPUTED SWR VALUES ---				1/3 BAR WATER BY WEIGHT					3 BAR WATER BY WEIGHT					
Depth	MFD ¹	ELD ²	EMD ³	EHD ⁴	MFD ¹	ELD ²	EMD ³	EHD ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5
cm	----- % -----				----- % -----				cm	----- % -----					----- % -----				
AP1	0-10		22.6	21.3	20.0		13.0	12.7	12.5										
AP2	10-18	21.8	25.4	23.9	22.4	15.0	16.1	15.7	15.7										
Bt1	18-30	21.9	27.7	26.1	24.4	15.7	17.9	17.7	18.5	22.5	21.2	20.7	21.2	19.5	21.0	16.7	21.9*	17.6	16.4
Bt2	30-43	18.5	24.5	23.2	21.8	12.3	14.0	13.6	13.6	37.5	19.7	21.2	20.7			15.9	14.3	16.4	16.7
BK1	43-58	20.5	22.6	21.4	20.1	13.0	13.3	13.0	13.1										
BK2	58-71		14.9	14.0	13.2		9.0	8.3	8.0										
2C	71-152		4.7	4.5	4.2		2.0	1.9	1.8										

- ¹ AT Measured Field Density
² AT Expected Low Density
³ AT Expected Medium Density
⁴ AT Expected High Density

* This value eliminated in the "Comparison of Selected Laboratory Data" section.

Table 5. Laboratory results for soil water retention study - Site 3, Amesha Variant soil series.

SCS WATER RETENTION MODEL										MSU WATER RETENTION							
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT --- COMPUTED SWR VALUES ---					1/3 BAR WATER BY WEIGHT				3 BAR WATER BY WEIGHT			
Depth	MFD ¹	ELD ²	EMD ³	EHD ⁴	MFD ¹	ELD ²	EMD ³	EHD ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 4	Hole 1	Hole 2	Hole 3	Hole 4
cm	----- % -----				----- % -----				cm	----- % -----			----- % -----				
AP	0-15	13.4	15.8	14.9	14.6	8.2	9.7	9.4	9.2								
BK	15-43	20.9	22.5	21.3	20.0	14.8	16.4	16.0	15.5	16	14.0	18.4	20.1		10.0	11.4	19.3
										31	19.8	26.9	28.8		19.4	20.3	15.1
BtK	43-69	22.7	25.2	23.7	22.2	16.8	19.0	18.4	18.9	46	28.5	29.1	35.8		13.7	24.3	27.2
										61	12.5*	28.6	28.6		19.4	23.8	21.5
2BtZ	69-81	22.3	24.2	22.9	21.4	16.2	18.3	17.7	17.8	76	12.6	29.1	20.3		5.1	20.4	8.0
2BZ	81-119	19.8	25.1	23.7	22.1	15.6	18.9	18.4	18.5	91	20.5	21.4	24.6		17.2	15.4	20.5
										106	29.9	19.6	29.1		23.5	19.6	22.5
2BC	119-152	31.2	33.4	31.4	27.6	24.8	26.6	26.3	25.1								
2C	152-211		10.6	10.5	9.7		6.6	6.2	5.9								

- ¹ AT Measured Field Density
- ² AT Expected Low Density
- ³ AT Expected Medium Density
- ⁴ AT Expected High Density

* These values eliminated in the "Comparison of Selected Laboratory Data" section.

Table 6. Laboratory results for soil water retention study - Site 4, Chinook soil series.

SCS WATER RETENTION MODEL									MSU WATER RETENTIONS										
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT ---- COMPUTED SWR VALUES ----				1/3 BAR WATER BY WEIGHT					3 BAR WATER BY WEIGHT					
Depth	MFD ¹	ELD ²	EMD ³	EHD ⁴	MFD ¹	ELD ²	EMD ³	EHD ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5
CM	----- % -----				----- % -----				CM	----- % -----					----- % -----				
AP1	0-10		12.6	12.1	11.4		7.2	6.9	6.5										
AP2	10-25	9.6	12.4	11.8	11.2	4.9	6.9	6.5	6.2	16	8.0	9.2	9.6		6.8	7.9	8.0		
BW	25-38	7.1	11.1	10.5	10.4	3.4	5.8	5.6	5.2	31	7.0	13.3	7.6	19.6	20.0	6.2	15.1	6.7	10.4
BK1	38-48	13.3	14.0	13.3	12.6	7.7	7.7	7.5	7.1	46	13.8	12.0	11.3		13.8	7.7	8.7		
BK2	48-76	8.3	11.0	10.4	9.8	3.8	4.8	4.7	4.5	61	6.9	10.0	7.5	20.3	18.2	5.4	6.4	6.5	10.3
ZBK	76-84		11.3	10.6	10.0		5.1	4.9	4.8	76	13.2	14.9	11.1		4.6	10.6	6.8		9.1
3BK	84-91		11.9	11.2	10.6		5.5	5.3	5.2										
4BK	91-99		11.1	10.5	9.9		5.3	5.2	5.0	91	19.3	15.5			22.9	23.4			
5C	99-152	6.0	9.7	9.2	8.7	2.5	4.3	4.2	4.1	106	8.7	14.7	20.3	16.7	6.8	10.4	10.1	11.0	

- ¹ AT Measured Field Density
² AT Expected Low Density
³ AT Expected Medium Density
⁴ AT Expected High Density

Table 7. Laboratory results for soil water retention study - Site 5, Mussel soil series.

SCS WATER RETENTION MODEL										MSU WATER RETENTIONS					
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					1/3 BAR WATER BY WEIGHT			3 BAR WATER BY WEIGHT		
Depth	MFD ¹	ELD ²	EMD ³	EHD ⁴	MFD ¹	ELD ²	EMD ³	EHD ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 1	Hole 2	Hole 3
cm	-----	%	-----	-----	-----	%	-----	-----	cm	-----	%	-----	-----	%	-----
AP 0-13		16.4	15.5	14.6		8.3	8.11	7.9							
BK1 13-41	14.4	14.4	13.6	12.8	9.8	8.1	8.0	7.7	16	11.5	12.4	11.1	7.3	9.0	8.4
BK2 41-66	15.3	15.1	14.3	13.4	9.6	9.8	9.5	9.2	31	13.6	15.0	17.2	10.2	10.5	12.0
BK3 66-89	14.5	18.1	17.1	16.1	10.2	11.9	11.6	11.3	46	18.2			10.4		
BKZ 89-130	14.6	18.5	17.5	16.4	10.5	11.3	11.0	10.8	61	18.1	19.0	19.8	12.6	10.3	11.7
BK4 130-145	16.0	15.7	14.8	13.9					76	20.7	24.4	16.5	11.7	13.6	14.1
BC 145-152	12.9	15.5	14.6	13.8					91	18.4	22.3		10.4	15.4	
									106	18.6	19.7			10.2	

- ¹ AT Measured Field Density
² AT Expected Low Dnesity
³ AT Expected Medium Density
⁴ AT Expected High Density

Table 8. Laboratory results for soil water retention model - Site 6, Brocko soil series.

SCS WATER RETENTION MODEL										MSU WATER RETENTIONS						
1/3 BAR WATER BY WEIGHT COMPUTED SWR VALUES					3 BAR WATER BY WEIGHT --- COMPUTED SWR VALUES ---					1/3 BAR WATER BY WEIGHT			3 BAR WATER BY WEIGHT			
Depth	MFT ¹	ELD ²	EMD ³	EHD ⁴	MFD ¹	ELD ²	EMD ³	EHD ⁴	MIDPT DEPTH	Hole 1	Hole 2	Hole 3	Hole 1	Hole 2	Hole 3	
CM	----- % -----				----- % -----				CM	----- % -----			----- % -----			
AP	0-15		22.0	20.7	19.5		11.5	11.2	10.9							
BK1	15-43	17.0	21.5	20.3	19.0	11.5	11.6	11.3	11.2	16	19.0	20.3	18.6	14.2	15.2	14.0
										31	19.3			11.1		
BK2	43-74	16.4	22.4	21.1	19.9	9.6	10.6	10.4	9.6	46	19.8	17.5	17.4	10.7	10.6	10.9
										61	19.5			10.3		
BK3	74-104	15.5	22.0	20.7	19.5	9.0	10.6	10.4	10.2	76	21.2	18.8	19.4	9.9	3.8*	9.8
										91	13.6	16.6		7.9	9.9	
BZ	104-142	19.2	21.9	20.6	19.4	9.2	10.3	10.0	9.9	106	13.0	13.4		10.4	9.6	
BC	142-157	16.0	15.8	14.9	14.1	9.2	9.9	9.9	9.4							

- ¹ AT Measured Field Density
² AT Expected Low Density
³ AT Expected Medium Density
⁴ AT Expected High Density

* This value eliminated in the "Comparison of Selected Laboratory Data" section.

values from the soil water retention model output. All 3 bar water by weight values in tables 3-8 at MFD, ELD, EMD and EHD were calculated using the parameters and equations computed for each horizon from the soil water retention model.

Montana State University Laboratory Data

One third bar and 3 bar water by weight values from tables 3-8 (MSU WATER RETENTIONS) are actual water retention values obtained in the laboratory. Because 15 bar data were not obtained on the core samples, verification of the soil water retention model's ability to work on Montana soils consisted of the following:

1. A comparison of 1/3 bar soil water retention values obtained in the laboratory at MSU with the 1/3 bar soil water retention values obtained by the NSSL and,
2. A comparison of 3 bar soil water retention values obtained in the laboratory at MSU with computed 3 bar soil water retention values using the soil water retention model.

Comparison Of All Laboratory Data

Tables 9-14 are summaries of the laboratory results (for percent water by weight) using all of the data from tables 3-8. The 1/3 and 3 bar water retention values from tables 9-14 for the MSU laboratory measurements were obtained by averaging all of the readings for every hole at each depth.

A comparison of 1/3 bar soil water retention values obtained in the laboratory at MSU with the 1/3 bar soil water retention values obtained by the NSSL was shown as percent difference between the MSU results and the NSSL results (tables 9-14). The percent difference between the two

Table 9. Summary of laboratory results (% water by weight) for soil water retention study - Site 1, Bozeman soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED 1/3 BAR FD ¹	COMPUTED 3 BAR FD ¹	MEASURED 1/3 BAR FD ¹	MEASURED 3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-10	SIL				
10-23	SIL	21.0	15.5	21.7	20.5
23-33	SICL	23.1	15.9		
33-51	SICL	20.1	14.1	20.7	24.5
51-84	SIL	20.0	13.2	21.1	18.6
84-104	SIL				
104-132	SIL	18.1	10.8		
132-145	GR-L				
145-180	GRX-S				

Table 10. Summary of laboratory results (% water by weight) for soil water retention study - Site 2, Turner soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED 1/3 BAR FD ¹	COMPUTED 3 BAR FD ¹	MEASURED 1/3 BAR FD ¹	MEASURED 3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-10	SIL				
10-18	SICL	21.8	15.0		
18-30	SICL	21.9	23.7	20.7	17.9
30-43	SICL	18.5	12.3	20.5	15.5
43-58	SIL	20.5	13.0		
58-71	GRV-L				
71-152	GRX-S				

¹Field Density

Table 11. Summary of laboratory results (% water by weight) for soil water retention study - Site 3, Amesha Variant soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED	COMPUTED	MEASURED	MEASURED
		1/3 BAR FD ¹	3 BAR FD ¹	1/3 BAR FD ¹	3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-15	SL	13.4	8.2		
15-43	L	20.9	14.8	21.4	16.0
43-69	SCL	22.7	16.8	27.2	22.0
69-81	SCL	22.3	16.2	20.7	11.2
81-119	SCL	19.8	15.6	24.2	19.8
119-152	SCL	31.2	24.8		
152-211	SL				

Table 12. Summary of laboratory results (% water by weight) for soil water retention study - Site 4, Chinook soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED	COMPUTED	MEASURED	MEASURED
		1/3 BAR FD ¹	3 BAR FD ¹	1/3 BAR FD ¹	3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-10	SL				
10-25	SL	9.6	4.9	8.9	7.6
25-38	SL	7.1	3.4	13.5	9.8
38-48	SL	13.3	7.7	12.4	10.1
48-76	SL	8.3	3.8	12.6	7.5
76-84	SL			13.1	7.3
84-91	SL				
91-99	SL			17.4	23.2
99-152	SL	6.0	2.5	15.1	9.6

¹Field Density

Table 13. Summary of laboratory results (% water by weight) for soil water retention study - Site 5, Mussel soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED 1/3 BAR FD ¹	COMPUTED 3 BAR FD ¹	MEASURED 1/3 BAR FD ¹	MEASURED 3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-13	FSL				
13-41	SL	14.4	9.8	13.5	9.6
41-66	SCL	15.3	9.6	18.6	11.0
66-89	SCL	14.5	10.2	20.5	13.1
89-130	L	14.6	10.5	19.8	11.6
130-145	GR-SCL	16.0	10.9		
145-152	SL	12.9	8.9		

Table 14. Summary of laboratory results (% water by weight) for soil water retention study - Site 6, Brocko soil series.

DEPTH	TEXTURE	WATER RETENTION			
		SCS		MSU	
		MEASURED 1/3 BAR FD ¹	COMPUTED 3 BAR FD ¹	MEASURED 1/3 BAR FD ¹	MEASURED 3 BAR FD ¹
cm		-----	% -----	-----	% -----
0-15	SIL				
15-43	SIL	17.0	11.5	19.3	12.8
43-74	SIL	16.4	9.6	18.9	10.5
74-104	SIL	15.5	9.0	17.5	8.4
104-142	L	19.2	9.2	13.2	10.0
142-157	SCL	16.0	9.2		

¹Field Density

results was calculated as follows:

$$\text{Percent Difference} = \frac{\text{larger value} - \text{smaller value}}{\text{smaller value}} \times 100 \quad [18]$$

Seventy-three percent of the 1/3 bar water retention measurements obtained in the laboratory at MSU were greater than the values from the NSSL. The mean of the measured 1/3 bar water retention values from the MSU laboratory was 18.3 percent water by weight while the mean from the NSSL was 16.3 percent water by weight.

The same procedure was used for comparing 3 bar soil water retention values obtained in the laboratory at MSU with computed 3 bar soil water retention values using the soil water retention model. Eighty-two percent of the measured 3 bar water retention measurements obtained in the laboratory at MSU were greater than the computed 3 bar water retention values using the soil water retention model. The mean of the measured 3 bar water retention values from the MSU laboratory was 13.5 percent water by weight while the computed mean from the NSSL was 10.6 percent water by weight.

These comparisons of actual 1/3 bar soil water retentions and actual measured 3 bar soil water retentions with computed 3 bar soil water retentions were obtained using all of the values for each site in tables 3-8. However these results are misleading in that some of the differences, obtained in the MSU laboratory, between 1/3 bar soil water retention and 3 bar soil water retention are physically not possible. For instance, while the 1/3 bar water by weight value must always be greater than the 3 bar water by weight value for the same samples from the same holes, this was not always the case. A more reasonable comparison between actual measured 1/3 bar water by weight values and

actual 3 bar water by weight values were obtained by discarding the percent water by weight values that are physically impossible or not reasonable. These values are indicated by an asterisk in Tables 3-8.

A comparison of soil water retentions, discarding the data that are obviously wrong and using the same procedures or methods of calculation for 1/3 and 3 bar water by weight described in the previous section, resulted in the following:

1. The mean of the measured 1/3 bar water retention values from the MSU laboratory was 18.4 percent water by weight while the mean of the NSSL was 16.3 percent.
2. The mean of the measured 3 bar water retention values from the MSU laboratory was 12.9 percent water by weight while the computed mean from the NSSL was 11.1 percent water by weight.
3. Again, 73 percent of the 1/3 bar water retention measurements obtained in the laboratory at MSU were greater than the values from the NSSL and 82 percent of the measured 3 bar water retention measurements from MSU were greater than the computed 3 bar water retention values using the soil water retention model.

The majority of the water retention measurements (73% for the 1/3 bar and 82 percent for the 3 bar) obtained by MSU were greater than those of the NSSL. The mean of the computed 1/3 bar water retention values from MSU was 12.9 percent larger, using the selected laboratory data, than the mean from the NSSL. The mean for the measured 3 bar water retention values from MSU was 16.2 percent larger, using the selected laboratory data, than the computed mean using the soil water

retention model.

The pressure membrane equipment is simple and easy to use but is subject to errors and, as noted in the literature review, different values are often obtained with the same soil on different pieces of equipment. Valid data depend on maintaining the soil in close contact with the ceramic plate during the equilibration at each pressure. Shrinking of the soil away from the ceramic plate can result in the sample retaining more water than at true equilibrium. This is almost certainly what happened in the several cases where the 3 bar sample contained more water than the 1/3 bar sample. In a few cases the water retained in a particular sample was much less than expected. Since the samples could not be re-used, valid data could not be obtained on these samples. Data that was clearly in error was not used. Using what appeared to be valid data, the MSU values were about 13 percent and 16 percent higher than the NSSL data at 1/3 (measured) and 3 bar (calculated), respectively. This difference, as discussed in the literature review, may be due to differences in sample pre-treatment or in the equipment. It might be partly related to the fact that the MSU laboratory used soil cores, containing fracture planes between clods, and the NSSL used soil clods. In our experience (unpublished data) the bulk density of cores is lower than that of clods and, therefore, contains more pore space. This may result in soil cores retaining more water at low water potentials than clods but would probably not explain the difference at 3 bar. Our data are close enough to the calculated values from Baumer's model to generally confirm the model. But, we did not obtain enough good data to thoroughly check the model, one of our

major objectives.

Hydraulic Conductivity Study

The second objective of this research was to calculate the unsaturated hydraulic conductivity as a function of water content $[K(\theta)]$. The maximum field hydraulic conductivity (K_m) can then be determined from these results. The results of the K_m determinations are illustrated in tables 15 through 20. Values of θ_m and θ'_m (from drainage data) were chosen and used in the appropriate equations (Eq. 16 and 17) to calculate K_m by the two models. There are exceptions, but, in general, the K_m values calculated by the CGA model are greater than by the Watson model. Considering that $K(\theta)$ may change by several orders of magnitude with relatively small changes in water content, the differences between the two models are not excessive.

The average K_m (mean of the CGA and Watson values) was determined at each given depth for all six soils. The average K_m values were then compared to the laboratory data presented in Tables 21-26 to determine if there was a relationship between the soil properties and K_m . The selected data from tables 21-26 was determined by the NSSL.

Table 15. Unsaturated hydraulic conductivity at maximum field moisture content - Site 1, Bozeman soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	K_m	θ'_m	K_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-10	23.2	1.60				
10-23	22.5	1.59	.392	.0030	.392	.008
23-33	27.7	1.35				
33-51	24.7	1.36	.390	.0040	.391	.012
51-84	27.2	1.43	.400	.0150	.396	.022
84-104	20.2	1.50	.376	.0003	.392	.013

Table 16. Unsaturated hydraulic conductivity at maximum field moisture content - Site 2, Turner soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	K_m	θ'_m	K_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-10	19.7	1.40				
10-18	25.7	1.50				
18-30	28.4	1.40	.382	.001	.382	.003
30-43	19.7	1.31	.414	.215	.398	.026

Table 17. Unsaturated hydraulic conductivity at maximum field moisture content - Site 3, Amesha Variant soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	K_m	θ'_m	K_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-15	14.6	1.48				
15-43	31.8	1.35	.463	.0064	.463	.0183
43-69	35.2	1.39	.430	.0037	.450	.0275
69-81	33.9	1.39	.386	.0005	.434	.0278
81-119	33.2	1.47	.373	.0005	.420	.0304

Table 18. Unsaturated hydraulic conductivity at maximum field moisture content - Site 4, Chinook soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	K_m	θ'_m	K_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-10	8.9	1.50	.381	.008	.381	.021
10-25	8.1	1.58	.391	.016	.386	.037
25-38	6.4	1.64	.410	.037	.394	.052
38-48	9.0	1.49	.360	.006	.386	.056
48-76	4.6	1.52	.370	.012	.382	.059
76-84	5.1	1.50				
84-91	5.5	1.50	.368	.015	.380	.072
91-99	5.5	1.50	.336	.006	.374	.094

Table 19. Unsaturated hydraulic conductivity at maximum field moisture content - Site 5, Mussel soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	k_m	θ'_m	k_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-13	9.0	1.40				
13-41	11.6	1.40	.454	.013	.457	.040
41-66	16.6	1.48	.428	.012	.444	.058
66-89	20.5	1.48	.415	.010	.436	.065
89-130	18.0	1.37	.389	.005	.426	.063

Table 20. Unsaturated hydraulic conductivity at maximum field moisture content- Site 6, Brocko soil series.

DEPTH	LAB DATA		HYDRAULIC CONDUCTIVITY			
	CLAY	B.D. 1/3 BAR	WATSON		CGA	
			θ_m	k_m	θ'_m	k_m
cm	%	g/cc	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min
0-15	13.5	1.20				
15-43	16.7	1.22	.464	.016	.466	.050
43-74	12.3	1.33	.456	.023	.461	.076
74-104	12.7	1.31	.429	.011	.453	.079
104-142	12.1	1.41	.388	.004	.441	.090
142-157	16.1	1.45				

Table 21. Summary of selected laboratory data and soil properties - Site 1, Bozeman soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density 1/3 Bar	Oven Dry	Water Content By Weight		CAC03
	cm			%			%			g/cc		1/3 Bar	15 Bar	
AP1	0-10	SIL	1 f & m gr	26	6.0/--	23.2	64.4	12.4		1.60			10.7	
AP2	10-23	SIL	1 c pl	26	5.8/--	22.5	64.0	13.5		1.59	1.71	21.2	11.6	
Bt1	23-33	SICL	1 cpr to 2 msbk	32	6.2/--	27.7	62.0	10.3		1.35	1.51	23.1	12.7	
Bt2	33-51	SICL	1 cpr to 2 msbk	32	7.4/--	24.7	64.5	10.8		1.36	1.48	19.5	11.8	TR
BtK	51-84	SIL	1 cpr to 2 csbk	24	8.0/ev	27.2	60.5	12.3	10	1.43	1.56	20.0	10.2	23
BK1	84-104	SIL	1 cpr	24	8.6/ev	20.2	67.3	12.5	3	1.50			9.1	14
BK2	104-132	SIL	1 cpr	24	8.8/es	16.5	55.4	18.1		1.56	1.65	18.1	7.8	11
BC	132-145	GR-L	m		8.2/es	12.2	52.5	35.3		1.60			5.9	10
2C	145-180	GRX-S	sg		8.2/e	2.3	4.2	93.5		1.70			1.6	10

Table 22. Summary of selected laboratory data and soil properties - Site 2, Turner soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density		Water Content By Weight		CaCO3
	cm			%			%			1/3 Bar	Oven Dry	1/3 Bar	15 Bar	
										g/cc			%	
AP1	0-10	SIL	2 fgr		6.0/--	19.7	57.3	23.0		1.40			9.0	
AP2	10-18	SICL	1mpl	30	6.0/--	25.7	55.3	19.0		1.50	1.71	21.8	11.6	
Bt1	18-30	SICL	2mpr	33	6.2/--	28.4	59.2	12.4		1.40	1.57	21.9	12.9	
Bt2	30-43	SICL	1 mpr to 1 csbk	30	6.6/--	19.7	63.9	16.4		1.31	1.41	18.3	9.9	2
BK1	43-58	SIL	1mpr	25	8.6/ev	21.4	60.0	18.6	4	1.34	1.41	20.5	9.3	21
BK2	58-71	GRV-L	m	22	8.6/ev	13.4	34.9	51.7	4	1.40			6.2	18
2C	71-152	GRX-S	sg		8.4/e	1.6	4.5	93.9	1	1.50			1.2	11

Table 23. Summary of selected laboratory data and soil properties - Site 3, Amesha Variant soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density 1/3 Bar	Oven Dry	Water Content By Weight		CAC03
	cm			%			%			g/cc		1/3 Bar	15 Bar	%
AP	0-15	SL	2	18	7.8/es	14.6	25.1	60.3	2	1.48	1.58	12.3	7.9	5.0
BK	15-43	L	1 mpr	25	8.2/ev	31.8	28.6	39.6	15	1.35	1.43	20.9	11.9	28.0
BtK	43-69	SCL	1 mpr to 1 co sbk	33	8.4/es	35.2	29.4	35.4	9	1.39	1.60	22.7	14.0	17.0
2BtZ	69-81	SCL	1 mpr	30	8.6/es	33.9	27.8	38.3	3	1.39	1.60	22.3	13.4	15.0
2BZ	81-119	SCL	2 co pr	25	7.8/es	33.2	28.1	38.7		1.47	1.58	18.6	14.6	9.0
2BC	119-152	SCL	1 co pr	21	7.8/e	47.6	31.6	20.8		1.13	1.39	31.2	21.5	8.0
2C	152-211	SL	m	15	8.2/ev	9.9	11.5	78.6		1.60			4.6	5.0

Table 24. Summary of selected laboratory data and soil properties - Site 4, Chinook soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density 1/3 Bar	Oven Dry	Water Content By Weight		CAC03
	cm			%			%			g/cc		1/3 Bar	15 Bar	%
AP1	0-10	SL	1 Vfgr	11	7.6/e	8.9	14.7	76.4		1.50		5.2		1
AP2	10-25	SL	1 m & c sbk	11	7.6/e	8.1	13.6	78.3		1.58	1.65	8.9	5.2	1
BW	25-38	SL	1 cpr	11	8.0/es	6.4	11.0	82.6		1.64	1.69	6.3	4.7	3
BK1	38-48	SL	1 cpr to 1 m & C sbk	17	8.4/ev	9.0	21.0	70.0	4	1.49	1.55	11.7	7.2	10
BK2	48-76	SL	1 cpr	15	8.4/es	4.6	18.1	77.3		1.52	1.55	7.4	4.9	6
2BK	76-84	SL	1 mpl	19	8.6/ev	5.1	18.4	76.5	2	1.50		4.6		7
3BK	84-91	SL	m	7	8.6/es	5.5	21.0	73.5		1.50		5.2		5
4BK	91-99	SL	m	19	8.6/ev	5.5	15.6	78.9		1.50		4.9		4
5C	99-152	SL	m	7	8.6/es	4.1	11.5	84.4		1.56		5.2	4.1	TR

Table 25. Summary of selected laboratory data and soil properties - Site 5, Mussel soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density 1/3 Bar	Oven Dry	Water Content By Weight		CAC03
	cm			%						g/cc		1/3 Bar	15 Bar	
AP	0-13	FSL	1 fgr	13	8.2/e	9.0	31.6	59.4		1.40			6.2	TR
BK1	13-41	SL	1 m&c pr	17	8.4/ev	11.6	29.0	59.4	6	1.40	1.46	14.4	7.7	14
BK2	41-66	SCL	2 mpr	21	8.4/ev	16.6	25.0	58.4	7	1.48	1.54	15.3	7.2	18
BK3	66-89	SCL	1 mpr	25	8.6/ev	20.5	33.3	46.2	7	1.48	1.58	14.5	8.3	15
BKZ	89-130	L	1 c pr to 1 f pl	20	8.4/ev	18.0	40.6	41.4	5	1.37	1.44	14.6	8.5	14
BK4	130-145	GR-SCL	m	21	8.4/ev	18.2	26.0	55.8	6	1.53	1.58	16.0	8.5	21
BC	145-152	SL	m	15	8.4/ev	15.1	29.8	55.1	5	1.43	1.48	12.8	7.1	12

Table 26. Summary of selected laboratory data and soil properties - Site 6, Brocko soil series.

Soil Horizon	FIELD DESCRIPTION					LAB DATA								
	Depth	Texture	Structure	Estimated Clay	Reaction Efferves	Clay	Silt	Sand	Carbonate Clay	Bulk Density 1/3 Bar	Oven Dry	Water Content By Weight		CAC03
	cm			%						g/cc		1/3 Bar	15 Bar	
AP	0-15	SIL	1 vf & fgr	15	8.2/es	13.5	53.5	33.0	3	1.20			9.5	7.0
BK1	15-43	SIL	1 mpr	20	8.4/ev	16.7	60.0	23.3	4	1.22	1.28	16.9	9.1	17.0
BK2	43-74	SIL	1 mpr	20	8.6/ev	12.3	70.6	17.1	3	1.33	1.38	16.4	7.0	14.0
BK3	74-104	SIL	1 mpr	23	9.0/ev	12.7	68.7	18.6		1.31	1.35	15.5	6.6	10.0
BZ	104-142	L	1 mpr to 1 mpl	24	8.4/ev	12.1	70.2	17.7		1.41	1.45	19.3	6.1	10.0
BC	142-157	SCL	m	23	8.4/ev	16.1	29.5	54.4	6	1.45	1.50	16.0	6.7	13.0

Hydraulic Conductivity Versus Soil Properties

Small changes in pores size can result in large changes in the hydraulic conductivity (see equations 3 and 4). Any or all of the soil properties listed in Tables 21-26 might effect pore size. Therefore, the effect of these soil properties on K_m was determined by regressing the average K_m at each depth for sites 1, 3, 4, 5, and 6 with specific soil properties listed in the tables. Site 2 was not used in the analysis because it was relatively shallow over sand and gravel and because of this abrupt discontinuity does not meet the criteria of the unit gradient model used to determine K_m . There was essentially no correlation between soil property values given in Tables 21-26 and mean K_m values. This indicates that none of these properties consistently influenced pore size in such a way as to consistently change K_m .

However, regression of K_m with sand content (Figure 8) did reveal an interesting relationship between K_m and a soil property. A discussion of the K_m values in Figure 8 is in order before discussing the sand content- K_m relationship. At first glance the scatter of the K_m values at a site appear to be excessive. In fact, with the possible exception of site 4, the K_m values are not excessively scattered. The hydraulic conductivity data are estimates of a highly dynamic process and dynamic processes in porous media tend to be highly variable, even in very uniform material, and log-normally rather than normally distributed. These soils are not, from the stand point of a flow process, uniform. Each soil horizon or depth increment at a given site has, for instance, a slightly different bulk density or sand content or pore organization and a different K_m . Static parameters such as sand

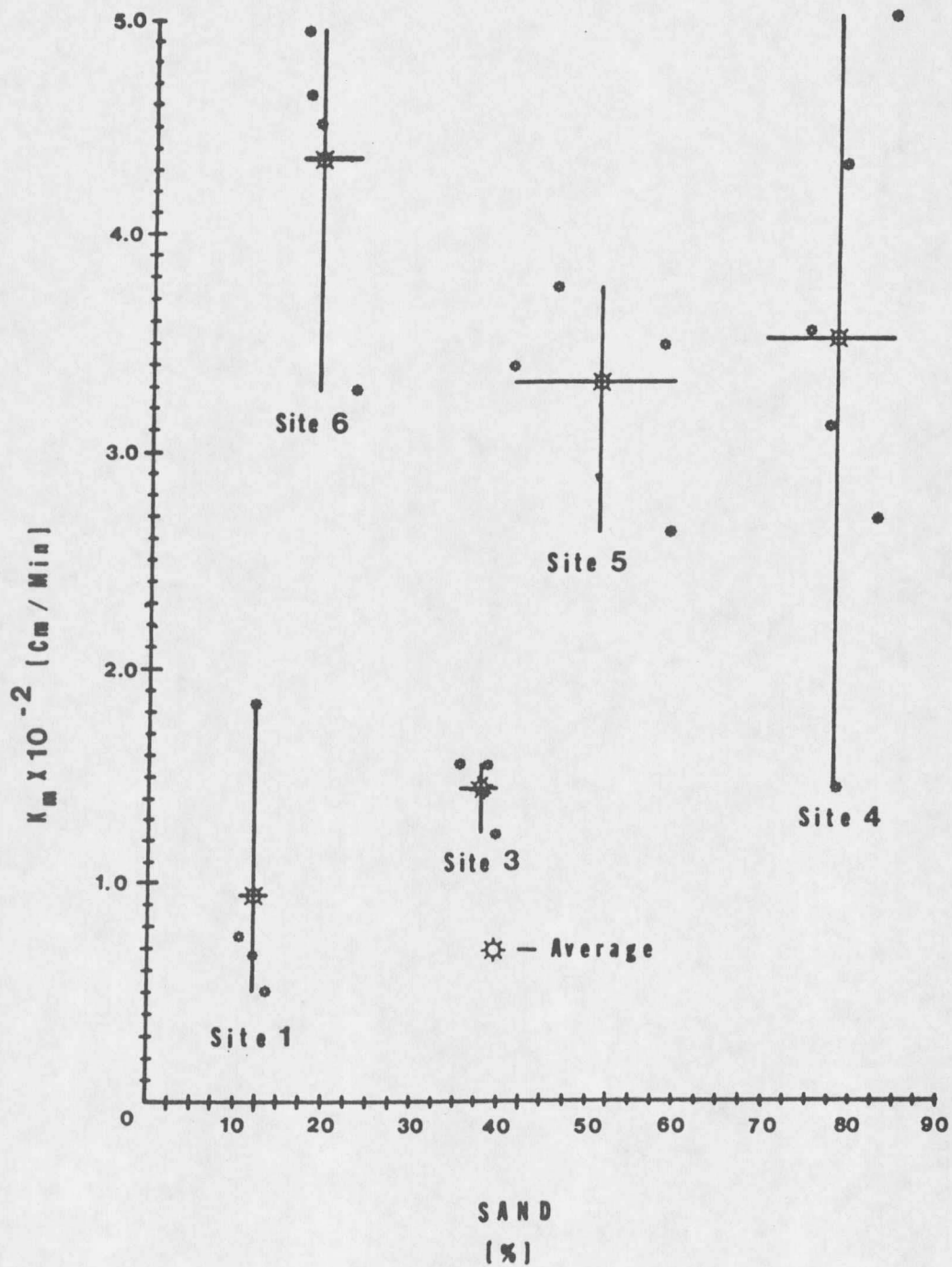


Figure 8. Maximum hydraulic conductivity (K_m) versus percent sand.

content tend to be normally distributed and are much less variable.

Clearly, as illustrated in Figure 8, there is little correlation between the sand content of sites 1, 3, 4, 5, and 6 and K_m ; this is further emphasized in Table 27 which gives the linear regression fit, $r^2=0.13$, of the data. However, a linear regression between sand content and K_m for sites 1, 3, 4, and 5 results in an r^2 of 0.82 as is shown in Table 28. Examination of Tables 21-25 shows that sites 1, 3, 4, and 5 had similar bulk densities whereas the bulk density of site 6 was considerably lower. It is reasonable to assume that in soils of approximately the same bulk density, the number of large pores should be related to the sand content, other factors being equal. By definition, K_m must be described by that flow that occurs when a wet soil is draining down to "field capacity", a point beyond which drainage is very slow, because it is calculated from water content changes that occur during that process. Basically, water movement that occurs when hydraulic conductivity is at a maximum is from the large pores; under these conditions, a high correlation between sand content and K_m should be expected. Site 6 is an anomaly in that it has the highest mean K_m but a low sand content. However, it does have significantly lower bulk density than the other four sites (Tables 21-26) and this translates into a higher porosity than the other sites assuming similar particle densities. Higher porosity does not necessarily indicate large pores that would empty during drainage but that is, never the less, a reasonable assumption.

The above data and reasoning lead to the hypothesis that K_m might be more highly correlated with the quantity of "large pores" than with

Table 27. Regression coefficients and coefficient of determination (r^2) for the relationship between maximum hydraulic conductivity and percent sand - sites 1, 3, 4, 5 and 6.

Regression Coefficients ¹	Site	K_m ($\times 10^2$)	Sand
		cm/min	%
	1	0.95	12.21
	3	1.44	38.00
	4	3.51	78.07
	5	3.31	51.35
	6	4.35	19.18
a			0.0196
b			1.9336
r^2			0.13

¹Regression coefficients resulting from the linear regression of K_m vs percent sand according to the equation: $y = ax + b$.

Table 28. Regression coefficients and coefficient of determination (r^2) for the relationship between maximum hydraulic conductivity and percent sand - sites 1, 3, 4 and 5.

Regression Coefficients ¹	Site	K_m ($\times 10^2$)	Sand
		cm/min	%
	1	0.95	12.21
	3	1.44	38.00
	4	3.51	78.07
	5	3.31	51.35
a			0.0428
b			0.3791
r^2			0.82

¹Regression coefficients resulting from the linear regression of K_m vs percent sand according to the equation: $y = ax + b$.

any of the direct measurements given in Tables 21-26. Total pore space can be calculated, assuming the same particle density at each site, from

the equation

$$\text{Percent Pore Space} = (1 - \frac{\text{Bulk Density}}{2.65}) \times 100 \quad [19]$$

The 1/3 bar water content is often considered an estimate of field capacity, the point where drainage essentially stops. Water held at this potential is in "small" pores. The volume of large pores (VLP), then, can be calculated by subtracting the volumetric water content at -1/3 bar from the total porosity of the soil. Mean values of bulk density, porosity, volumetric water content at -1/3 bar, and VLP are given in Table 29. Three different values of VLP were obtained by subtracting the MSU data, the SCS data, and the mean of the two for the -1/3 bar water content from the percent porosity. Regression of K_m with these three values of VLP are given in Table 30.

Calculation of K_m using the volumetric water content of the large pores assumes that all pores holding water with a potential greater than -1/3 bar were filled during flooding and therefore contributed in the calculation of K_m . In fact, this was probably not true. It is unlikely that all of the large pores were filled during flooding. Any soil pores that were not filled did not contribute to drainage and would introduce an undetermined source of error in the calculation of K_m .

Data from this research indicate, as illustrated by the high r^2 values from Table 30, that an excellent relationship (r^2 of 0.93 or better) exists between the mean maximum hydraulic conductivity and the mean volumetric water content of the large pores.

This is an exciting result. It provides hope that the very useful parameter, K_m , may be reasonably estimated for any soil or any horizon of a soil by knowing only the bulk density and the -1/3 bar water

Table 29. Summary of soil properties used to determine the relationship between maximum hydraulic conductivity and volumetric water content of large pores.

Site	Sand	Bulk Density	Porosity	Saturated Water Content	1/3 Bar Water Content by Volume			Volume of large pores ²		
					MSU	SCS	AVG. ¹	MSU	SCS	AVG.
	%	g/cc	%	cm ³ /cm ³	-----cm ³ /cm ³ -----			-----cm ³ /cm ³ -----		
1	12.21	1.46	44.91	44.91	30.91	30.46	30.69	14.00	14.45	14.22
3	38.00	1.40	47.17	47.17	32.76	29.97	31.37	14.41	17.20	15.80
4	78.07	1.54	41.89	41.89	20.45	13.72	17.09	21.44	28.17	24.80
5	51.35	1.43	46.04	46.04	25.97	21.07	23.52	20.07	24.97	22.52
6	19.18	1.32	50.19	50.19	22.56	22.48	22.52	27.63	27.71	27.67

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¹Avg. 1/3 Bar water content was calculated using the average 1/3 Bar water content obtained by MSU and by SCS.

²Volume of large pores was calculated by taking the difference between the % porosity and the 1/3 bar water content by volume.

Table 30. Regression coefficients and coefficient of determination (r^2) for the relationship between maximum hydraulic conductivity and volumetric water content of large pores (θ_{VLP}).

Regression	Site	K_m	VLP	K_m	VLP	K_m	VLP
Coefficients ¹		($\times 10^2$)	MSU	($\times 10^2$)	SCS	($\times 10^2$)	AVG
		cm/min	cm ³ /cm ³	cm/min	cm ³ /cm ³	cm/min	cm ³ /cm ³
	1	0.95	13.61	0.95	14.06	0.95	14.22
	3	1.44	14.41	1.44	17.20	1.44	15.80
	4	3.51	21.44	3.51	28.17	3.51	24.80
	5	3.31	20.07	3.31	24.97	3.31	22.52
	6	4.35	27.63	4.35	27.71	4.35	27.67
a =		0.25		0.22		0.25	
b =		-2.05		-2.21		-2.52	
r^2 =		0.94		0.94		1.0	

¹Regression coefficients resulting from the linear regression of K_m vs VLP according to the equation: $y = ax + b$.

content, parameters that are readily available for most soils in SCS soil survey data. The author can find no similar approach in the literature although several complex, and generally unsatisfactory, approaches have been proposed. This indication must be tempered by the fact that the author has based his conclusion on data from only five soils from a small geographical area. But, unless there is a significant change in the soil matrix when going from θ_m to $\theta_{-1/3}$ bar or a very unusual pore size distribution, the author can see no major reasons that it will not work. Considering the well known variability in K_m that occurs in every soil, it will provide only an estimate. But, a reasonable estimate of that parameter based on easily obtained independent variables would amount to a significant improvement for many purposes.

Infiltration Study

The third objective of this research was to attempt to characterize, quantify and evaluate the effects of high amounts of soil carbonates on water movement and infiltration in six Montana soils. The original thought prior to initiation of this research was that the CaCO_3 content did effect water movement or availability. This assumption was justified by the fact that almost all soils on the sedimentary plains of Montana have distinctly lower crop yields when a high amount of lime is present.

Increases in water content of the soil profiles as a function of time during infiltration (flooding) are given in Tables 31 - 33. The equation describing infiltration (Eq. [8]) is a power function.

Table 31. Infiltration Data, site 1 and site 2.

Site 1			Site 2		
Reading	θ	Elapsed Time	Reading	θ	Elapsed Time
	cm^3/cm^3	min		cm^3/cm^3	min
1	0	0	1	0	0
2	1.51	25	2	1.67	15
3	2.79	55	3	2.99	27
4	3.78	75	4	4.29	43
5	5.32	105	5 ^{1,2}	5.22	58
6	6.60	160	6	5.51	73
7	7.81	205	7	5.51	90
8	8.61	255	8	5.85	105
9	9.31	320	9	5.93	120
10	10.43	380	10	6.24	145
11	11.96	460	11	6.21	170
12	12.93	515	12	6.11	200
13	14.58	605	13 ³	6.29	215
14	17.10	705			
15 ¹	18.55	795			
16	18.39	830			
17 ^{3,4}	18.95	850			

¹ Inflection point.

² Wetting front has reached the depth of the lowest measurement.

³ Flooding stopped-drainage begun.

⁴ Wetting front has not reached the depth of the lowest measurement.

Table 32. Infiltration Data, site 3 and site 4.

Site 3			Site 4		
Reading	θ	Elapsed Time	Reading	θ	Elapsed Time
	cm^3/cm^3	min		cm^3/cm^3	min
1	0	0	1	0	0
2	1.54	20	2	1.88	15
3	2.92	43	3	8.90	26
4	4.99	64	4 ¹	10.43	39
5	8.36	88	5	11.71	52
6	10.43	108	6	12.46	64
7	12.05	128	7	13.53	90
8	13.95	152	8	15.15	130
9 ¹	17.78	192	9 ²	16.20	154
10	19.59	231	10	16.40	179
11	21.55	260	11	16.82	218
12	23.76	328	12	17.24	259
13 ²	24.54	378	13	17.03	300
14	24.75	430	14	17.21	340
15	24.71	488	15	17.03	377
16	24.42	561	16 ³	17.20	411
17	24.85	623			
18	24.80	679			
19 ³	24.95	740			

¹ Inflection point.

² Wetting front has reached the depth of the lowest measurement.

³ Flooding stopped—drainage begun.

Table 33. Infiltration Data, site 5 and site 6.

Site 5			Site 6		
Reading	θ	Elapsed Time	Reading	θ	Elapsed Time
	cm^3/cm^3	min		cm^3/cm^3	min
1	0	0	1	0	0
2	0.49	25	2	0.39	20
3	3.51	35	3	0.49	32
4	10.23	45	4	1.19	44
5 ¹	14.54	55	5	1.54	57
6	17.10	65	6	2.77	82
7	19.13	80	7	3.64	112
8	21.01	95	8	4.71	143
9	22.95	110	9	5.77	172
10	24.50	125	10	6.93	204
11	25.98	140	11	8.13	234
12	26.79	155	12	9.24	264
13 ²	28.10	170	13	11.50	324
14	28.48	187	14	13.58	384
15	28.90	212	15	15.75	441
16	29.26	245	16	19.80	501
17	28.42	275	17	19.81	564
18	29.21	305	18	21.64	624
19 ³	29.38	331	19	24.48	684
			20 ¹	26.00	798
			21	26.69	864
			22	26.91	924
			23	27.06	984
			24	26.95	1074
			25	27.40	1134
			26	27.12	1209
			27	27.44	1284
			28	27.02	1344
			29 ^{3,4}	27.29	1464

¹ Inflection point.

² Wetting front has reached the depth of the lowest measurement.

³ Flooding stopped—drainage begun.

⁴ Wetting front has not reached the depth of the lowest measurement.

Therefore, infiltration data fitting the model will plot as a linear equation on log - log paper (Figures 9-14).

A significant deviation from a linear form in Figures 9-14 indicates that water has either encountered a restricting layer or has penetrated below the depth of the access tube. In either case, the infiltration equation is invalid for times beyond this inflection point (signified by the superscript 1 in Tables 31, 32, and 33) because it assumes a measurement of all of the water movement into an infinitely deep medium. This inflection point indicates a change from true infiltration to a slow accumulation of water in the profile and is indicated by the superscript 2 in Tables 31 - 33. Increases in soil water content beyond this time are associated with increased stored water in the profile and not with true infiltration. Therefore, the infiltration equation was fit only to those time data points occurring prior to the inflection point. At Sites 1 and 6 (Figures 9 & 14) the wetted front did not pass beyond the deepest depth of measurement. The parameters calculated from the infiltration equation; a/b , and r^2 (indicating goodness of fit); are given in Table 34.

Infiltration for all sites slowed down significantly prior to the end of flooding and the beginning of drainage. The point where infiltration reached steady state is signified by the superscript 1 in Tables 31 - 33. Figures 9, 10, 11, and 14 are the type of plots that might be expected for infiltration into "medium textured" soils.

Figures 12 and 13 are the type of plots that might be expected in soils having very high infiltration rates such as sandy soils. Site 4 (Figure 12) does have a high sand (about 75%) and low silt and clay

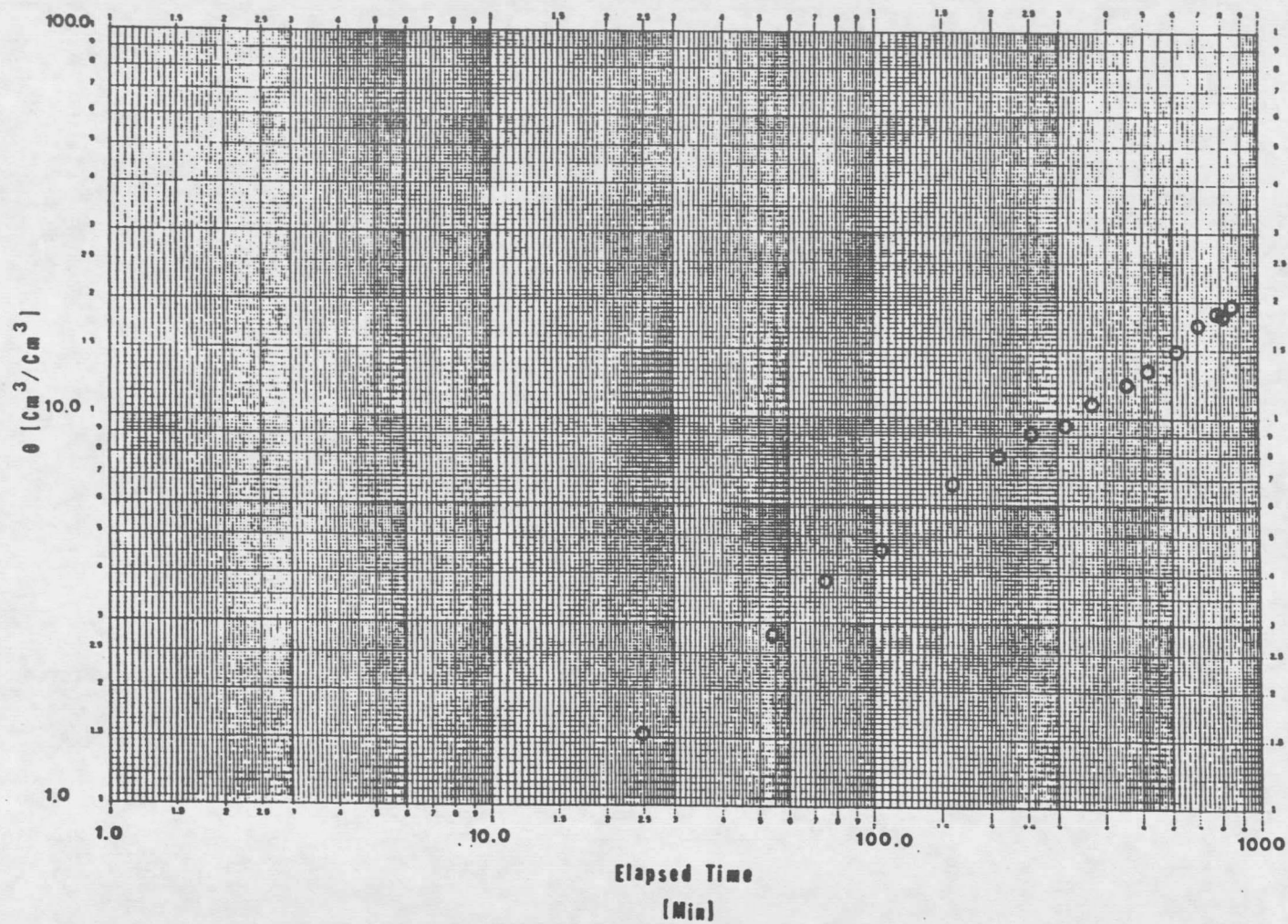


Figure 9. Infiltration - Site 1.

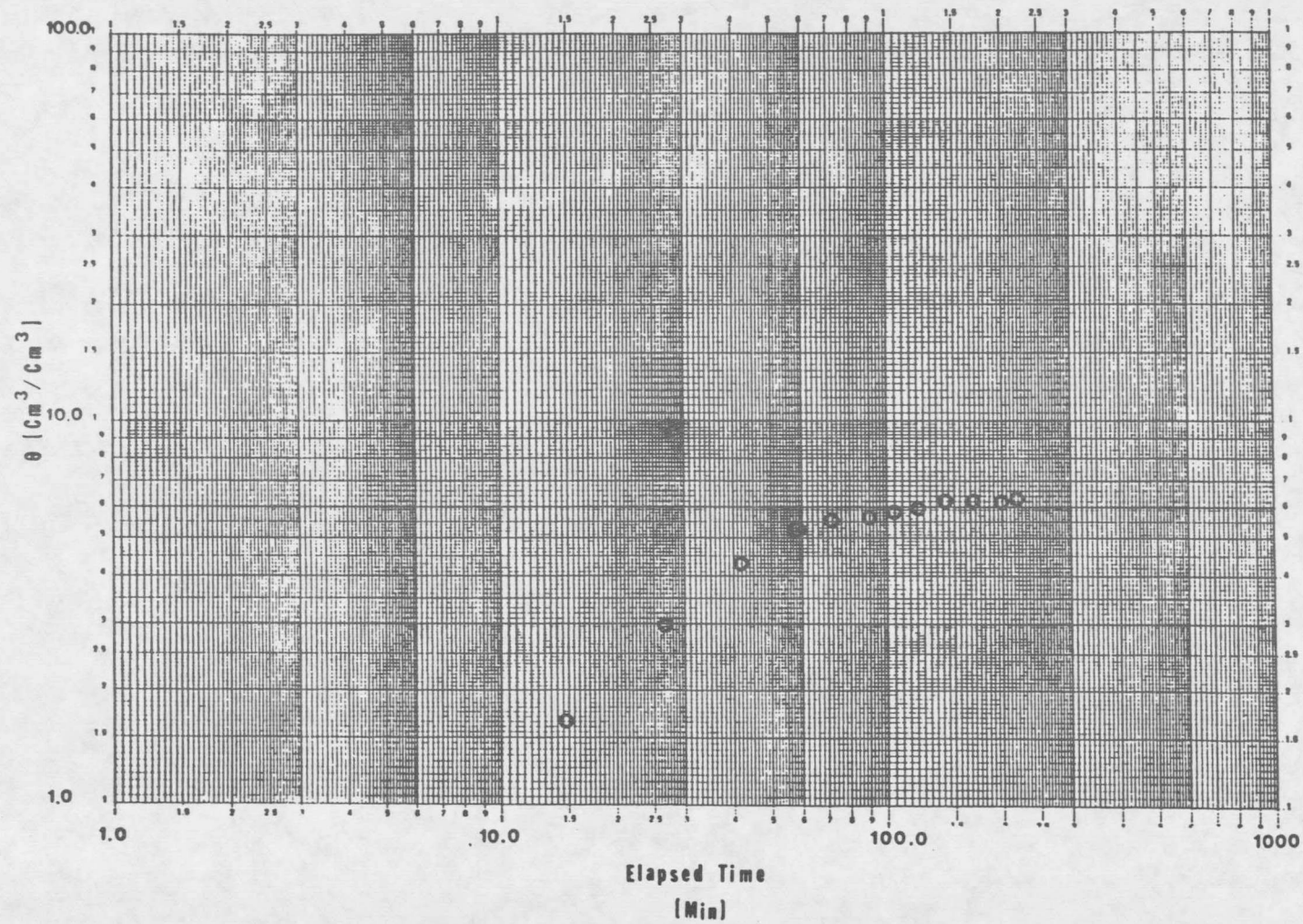


Figure 10. Infiltration - Site 2.

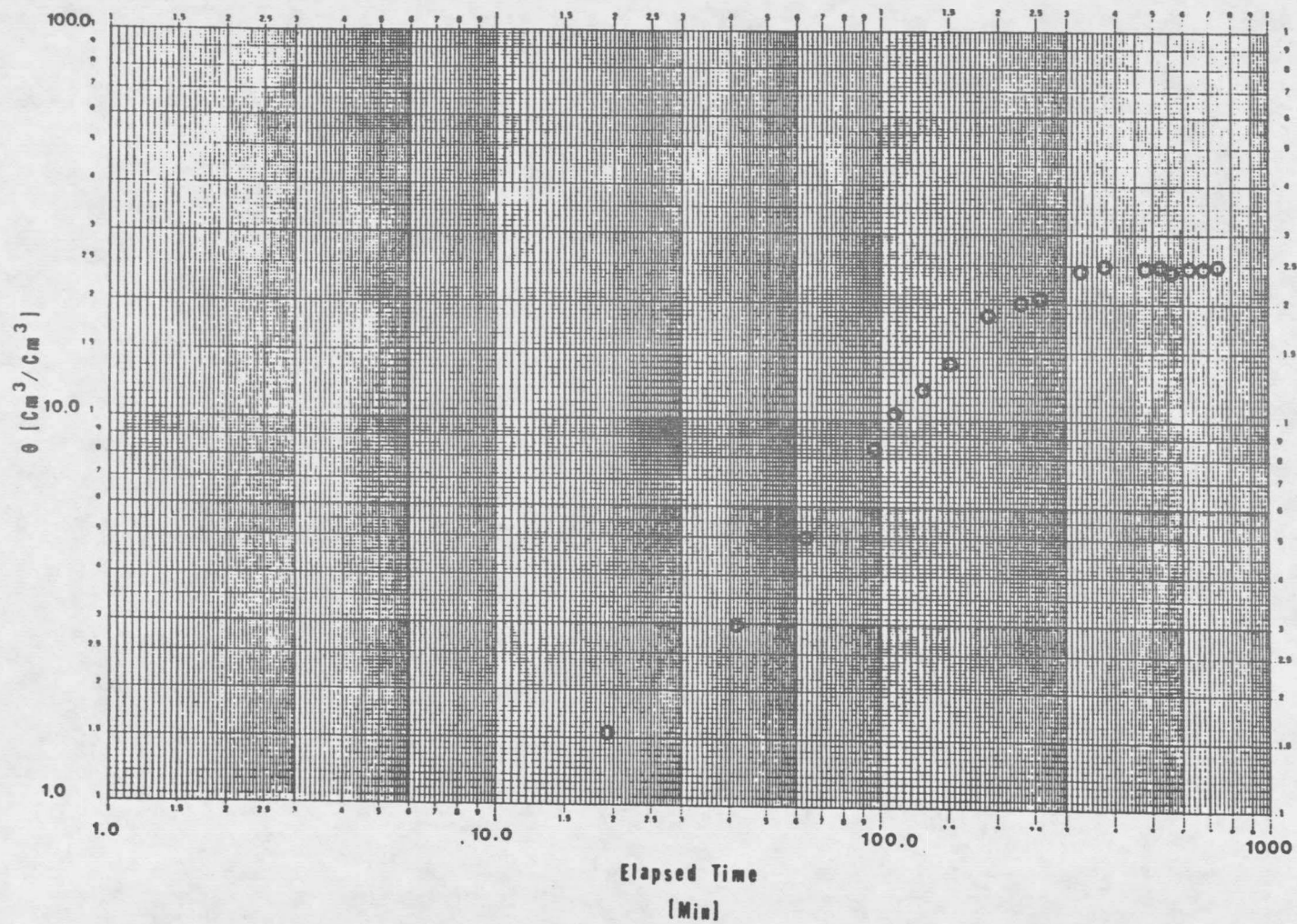


Figure 11. Infiltration - Site 3.

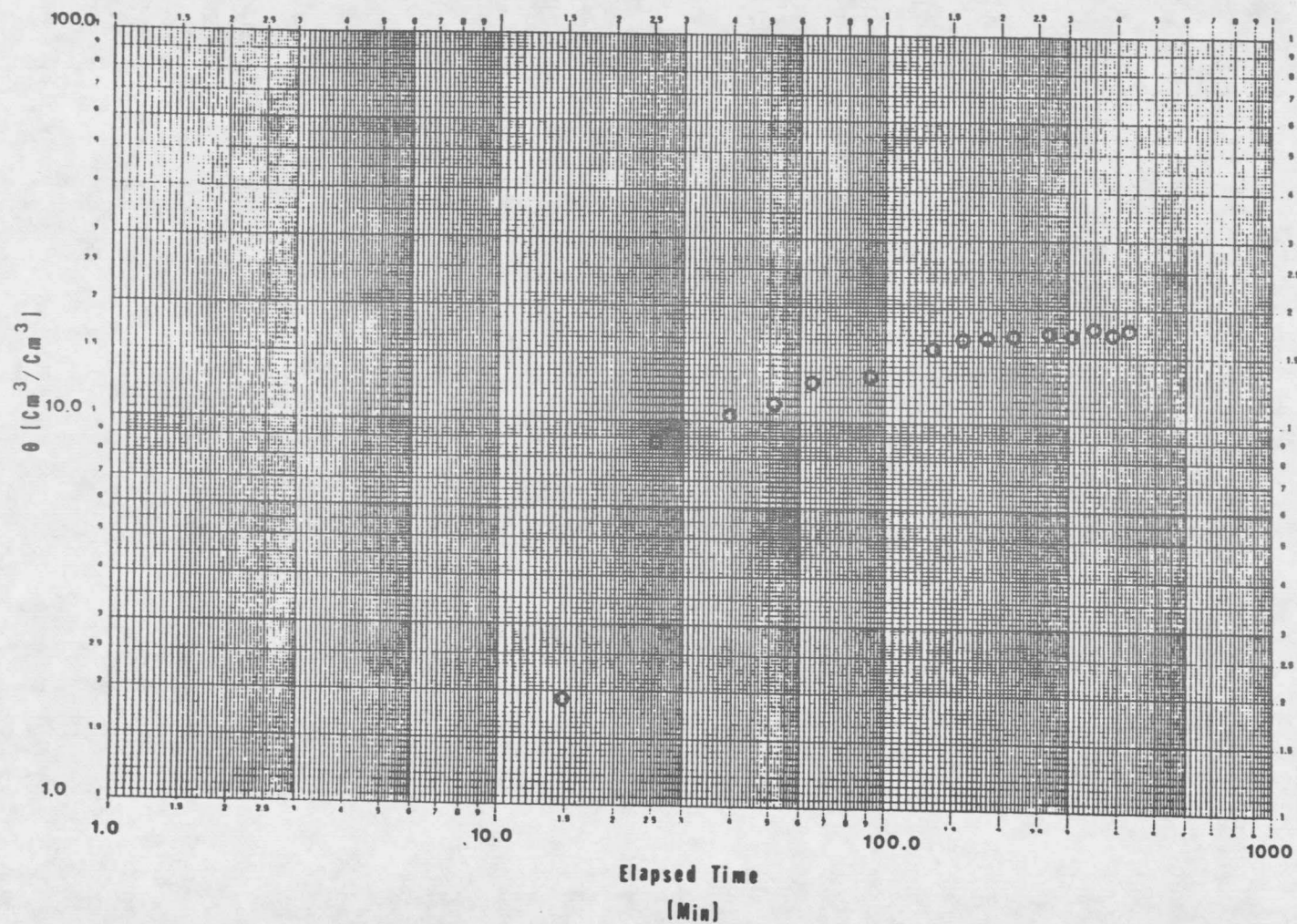


Figure 12. Infiltration - Site 4.

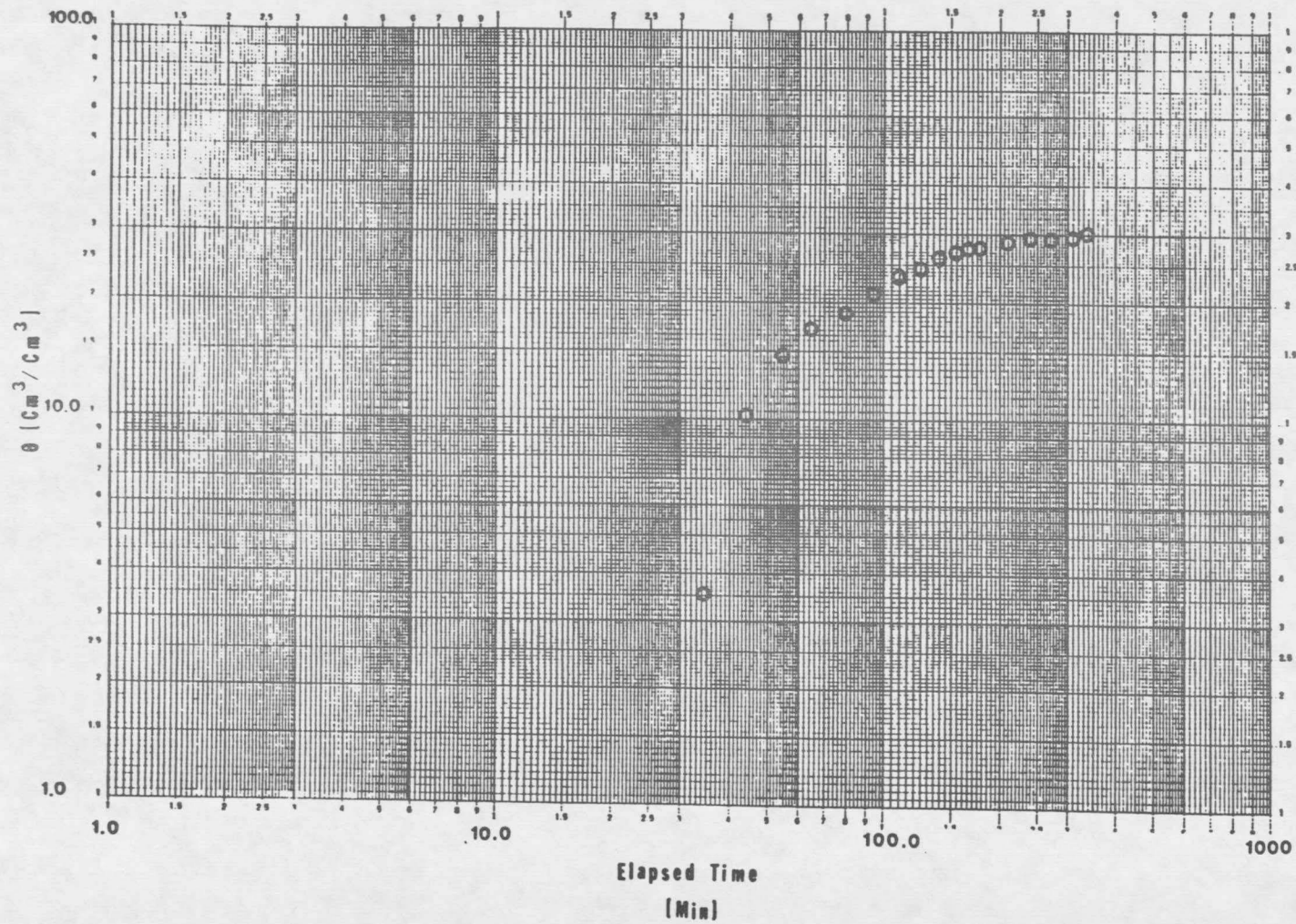


Figure 13. Infiltration - Site 5.

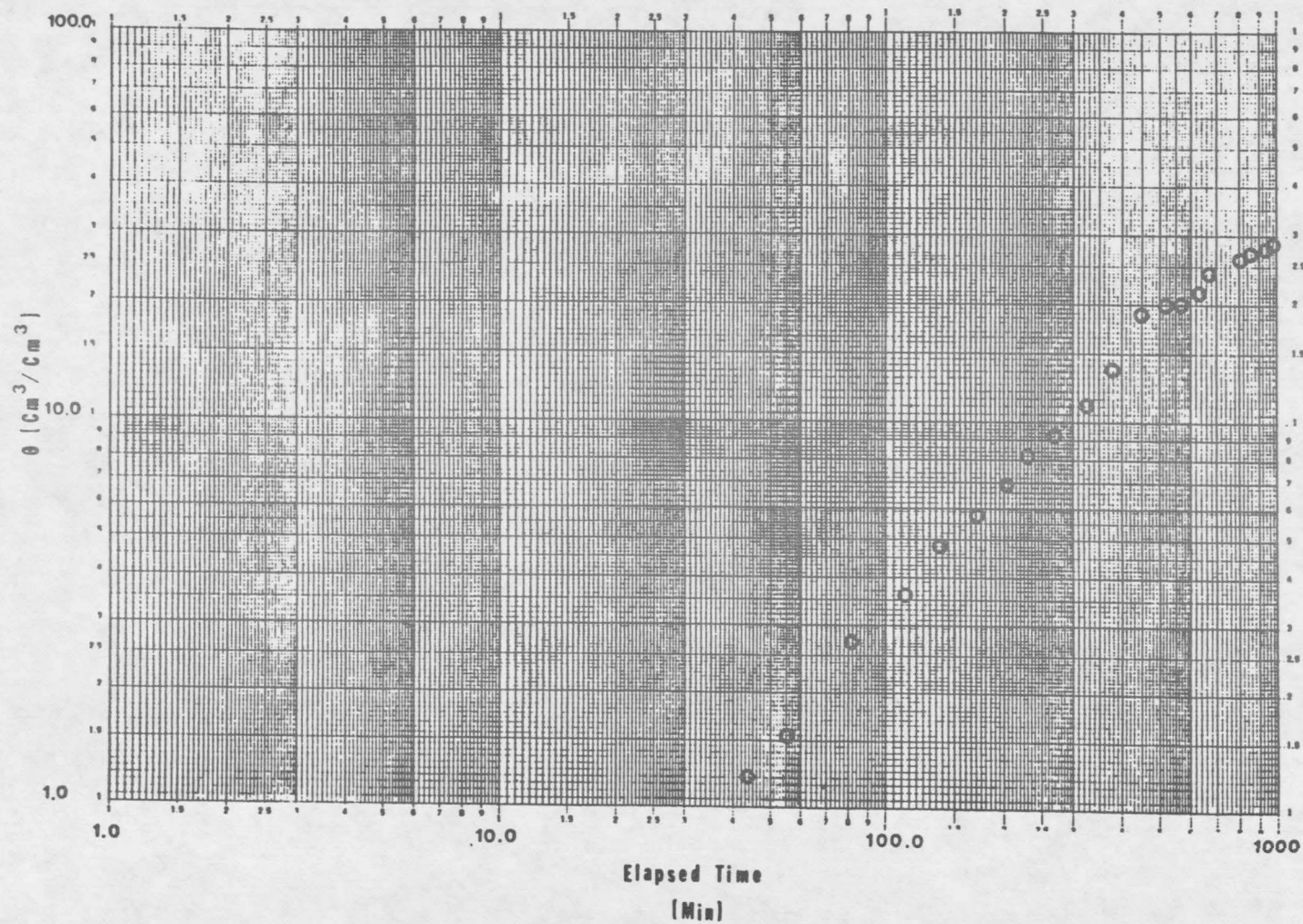


Figure 14. Infiltration - Site 6.

Table 34. Regression coefficients and coefficient of determination, r^2 , for the relationships between θ and time (infiltration)¹.

Site	Reading	a	b	r^2
1	1-15	0.1865	0.6868	0.99
2	1-5	0.1749	0.8457	0.99
3	1-9	0.0478	1.1337	0.99
4	1-4	0.0146	1.8527	0.88
5	1-5	4.3408×10^7	4.3970	0.96
6	1-20	0.0129	1.1685	0.99

¹The equation used to describe infiltration is $Q(\text{cm}^3) = at^b$ ($a > 0$) where Q is the quantity of water infiltrated and t is elapsed time in minutes.

content. The shape of the plot for site 4 indicates water infiltrated very rapidly to the bottom of the access tube. While only a few of the time points for site 4 can be validly fit to the equation, the model parameters in Table 34 are likely valid. Site 5 (Figure 13) has a relatively high sand content (about 60 percent) and the steepness of the initial linear portion of the line appears unreasonably high; but, there were very many large continuous tubular pores throughout the profile (see Appendix I, Soil Profile Description - Site 5) that would contribute to this high infiltration rate. Another possible source of error contributing to a higher than expected infiltration rate is the leaking of water down and around the access tubes. This is unlikely because Bentonite was packed around the top of all the access tubes prior to flooding. If there was any leaking around the access tubes it was usually quite evident when the measurements were being taken and the drainage data were considered invalid and discarded.

Site 2 (Figure 10) is a relatively shallow soil over a sand and

gravel layer starting at about 58 cm. This is indicated in Figure 10 by the large inflection point after about 60 minutes of infiltration. The infiltration rate for sites 1, 3, and 6 are what would be expected in deeper medium - textured soils.

The magnitude of the "a" parameter (Eq.[8], as a first approximation, is an indication of initial water entry into the soil and "b" is an indication of a more long term infiltration rate. Excluding site 5, there is a general correlation between the sand content and the b parameter. Site 1 has the lowest percent sand and the lowest b value. Site 2 has slightly more sand and a slightly higher b value. Site 4 had the highest sand content and the highest b value; the other two sites were intermediate between these 3 sites relative to both sand content and b values.

Site 4 had the highest sand content and, discounting site 5, the highest infiltration rate. It was followed by sites 3 and 6. Site 3 had relatively high sand content; site 6 had relatively low sand content but low bulk density, indicating high porosity. Site 1 contained the least sand and had the lowest infiltration rate. In those sites with similar bulk density (sites 1, 3, & 4) there was a reasonable correlation between sand content and infiltration as might be expected. The reader must be careful in extrapolating these results too far; these soils are high in calcium and are therefore flocculated. Even small amounts of clay might block the pores and destroy any correlation between infiltration and sand content in soils that tend to disperse when wet. Site 6 had a relatively low sand content but an intermediate infiltration rate. The low bulk density and associated high degree of

porosity caused higher infiltration than would have been expected. But, the relative increase in infiltration because of the high porosity was not nearly as great as the relative increase in K_m (Figures 8 and 14). Infiltration is largely a function of the pore size and number at the immediate soil surface whereas drainage (K_m) is a function of the pore size below the surface. Dynamic processes at the surface, including adding water in this study, apparently changed the surface pore size in the soil at site 6 more so than at the more sandy sites.

Correlation analysis indicated that CaCO_3 had no significant influence on infiltration. There was no significant changes in the slopes of the infiltration curves that would indicate a cause and effect relationship between the hydraulic conductivity and the CaCO_3 content. These results are consistent with the findings of Ghazy (1982) and Martin and Richards (1959). Further confirmation of this conclusion can be obtained from examination of Figures 9 - 14. Had the calcium carbonate had a significant influence on infiltration, it would have shown up as a discontinuity in the infiltration curves as water moved into the lime layers; such was not the case.

Results from this experiment indicate that the lower crop yields obtained from soils high in lime do not result from the effect lime has on water movement or availability, but in fact, result from some other affect the lime has on these soils. These same results were obtained by Ghazy (1982) and Martin and Richards (1959). Neither of these researchers found any correlation between hydraulic conductivity and total calcium carbonate content. However, Ghazy felt that CaCO_3 fineness did play a decisive role in this concern.

SUMMARY AND CONCLUSIONS

Soil Water Retention Study

The 1/3 bar soil water retention measurements from the laboratory at Montana State University (MSU) were 12.3 percent greater (18.4 percent water by weight for the MSU laboratory versus 16.3 percent water by weight for the NSSL) than the 1/3 bar soil water retention measurements from the NSSL.

The 3 bar soil water retention measurements from the MSU laboratory were 16.2 percent greater (12.9 percent water by weight for the MSU laboratory versus 11.1 percent water by weight using the soil water retention model) than the 3 bar soil water retention values computed from the soil water retention model developed by Baumer (Baumer and Rice, 1986).

The 1/3 bar soil water retention measurements from the two laboratories were not exactly the same nor were the 3 bar soil water retention measurements using the soil water retention model the same as those measured in the laboratory at MSU. This is not surprising. These results substantiate the findings of Hillel and Mottes (1966). Some of the possible explanations that could account for the difference between 1/3 bar measurements from the MSU laboratory and the NSSL are:

1. sample pretreatment,
2. use of different laboratory equipment,
3. use of different porous plates or membranes,
4. unequal sample height,
5. poor contact between soil sample and porous plates or membranes,

6. shrinkage of soil sample away from the porous plate or membrane, and
7. comparison of soil - clod potential (NSSL) versus potential of soil core (MSU).

The variation between the 3 bar soil water retention measurements in the laboratory at MSU and the 3 bar soil water retention measurements using the soil water retention model is comparable to the differences found between the actual measurements for 1/3 bar soil water retentions in the two laboratories. This research as well as the findings of Hillel and Mottes (1966) indicates that a difference in the results of soil water retention measurements between laboratories can be expected. Because the difference between the 3 bar measured soil water retention (MSU laboratory) and the 3 bar computed soil water retention (soil water retention model) is comparable to the differences between the measurements from the two laboratories for 1/3 bar soil water retention, it is reasonable to suggest that the soil water retention model gives a good estimate of soil water retention values for similar Montana soils.

Hydraulic Conductivity Study

This study found an excellent relationship exists between the maximum hydraulic conductivity (K_m) and the volumetric water content of the large pores (VLP). Results indicate the coefficient of determination (r^2) values for this relationship were as follows:

1. Using laboratory results for 1/3 bar water content measurements from the MSU laboratory; $r^2 = 0.93$.
2. Using laboratory results for 1/3 bar water content measurements from the NSSL: $r^2; = 0.95$.

3. Using the average 1/3 bar water content measurements from both laboratories for determination of θ_{VLP} ; $r^2 = 1.0$.

Infiltration Study

Results from this research indicate that the effect of CaCO_3 on hydraulic conductivity are probably negligible since there was no significant correlation between the hydraulic conductivity and the calcium carbonate (CaCO_3) content of the soil. These results are consistent with the findings of Ghazy (1982) and Martin and Richards (1959). If anything, an increase in hydraulic conductivity should result in soils that are high in Ca^{++} as a result of an increase in the flocculation of colloidal fractions. This researcher feels that the decreased yields in soils that are high in CaCO_3 result from one of two things:

1. A soil fertility response - the CaCO_3 content decreases the availability of phosphorous, or
2. The high lime content causes a physical impedance or barrier for root - movement through the soil as the soil dries out. Soils that are high in lime are characteristically hard or very hard when dry.

Although results from the soil water retention study as well as the hydraulic conductivity study are fairly conclusive and reasonable, further study or verification of the water retention model or the proposed hydraulic conductivity model to substantiate these findings are needed. Any further research to verify the validity of the soil water retention model should include a larger range of soil water retention measurements in the laboratory. This would result in more values that

could be compared with the computed values obtained using Baumer's (Baumer and Rice, 1986) soil water retention model.

Recommendations

1. Baumer's (Baumer and Rice, 1986) model is useful for soils similar to those in this study. The model needs further testing for soils not similar to those in this study, especially those with high clay and high shrink-swell. This would require work at about four more sites.
2. The strong relationship between large pore volume and maximum field hydraulic conductivity is promising and warrants further study.

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APPENDICES

APPENDIX I

SOIL PROFILE DESCRIPTIONS AND LAB

CHARACTERIZATION DATA

Print date: 09-25-1986

Pedon: Bozeman Variant
Soil Survey # S85-MT-031-001

NSSL ID #: 85P0775

Location: 280' E and 400' S of the NW corner of Sec. 26, T.1N., R.5E.
Latitude: ---

Longitude: ---

Classification: Fine-silty, mixed Typic Argiboroll

Physiography:

Geomorphic Position:

Microrelief:

Slope Characteristics: 1%, southwest facing

Elevation: 1391 m MSL

Precipitation: Aridic moisture regime

MLRA: 44

Water Table Depth:

Permeability: Moderately slow

Air Temp. (Centigrade): Ann: Sum: Win:

Soil Temp. (Centigrade): Ann: Sum: Win:

Drainage: Well drained

Land Use:

Stoniness:

Erosion or Deposition: Slight

Particle Size Control Section:

Parent Material: alluvium

Vegetation Codes:

Weather Station:

Diagnostic Horizons:

Date: 07/85

Described by: R. Richardson, J. Rogers and W. Braker

Ap1--0 to 10 cm; brown (10YR 5/3) silt loam; very dark grayish brown (10YR 3/2) moist; weak fine and medium granular structure; friable, sticky, plastic; many fine roots; medium acid; abrupt smooth boundary.
85P4103

Ap2--10 to 23 cm; silt loam; very dark grayish brown (10YR 3/2) moist; weak coarse platy structure; friable, sticky, plastic; many fine roots; medium acid; abrupt smooth boundary.
85P4104

Bt1--23 to 33 cm; silty clay loam; very dark grayish brown (10YR 3/2) and dark brown (10YR 3/3) crushed moist; weak coarse prismatic structure parting to moderate medium subangular blocky; friable, sticky, plastic; many fine roots; continuous distinct clay films on faces of peds and in pores; slightly acid; clear smooth boundary.
85P4105

Bt2--33 to 51 cm; silty clay loam; dark brown (10YR 3/3) and brown to dark brown (10YR 4/3) crushed moist; weak coarse prismatic structure parting to moderate medium subangular blocky; friable, sticky, plastic; many fine roots; continuous distinct clay films on faces of peds and in pores; mildly alkaline; clear smooth boundary.
85P4106

Btk--51 to 84 cm; silt loam; pale brown (10YR 6/3) moist; weak coarse prismatic structure parting to moderate coarse subangular blocky; friable, slightly sticky, slightly plastic; many fine roots; few faint clay films on faces of peds and in pores; many fine soft masses of lime; violently effervescent; moderately alkaline; clear smooth boundary.
85P4107

Bk1--84 to 104 cm; silt loam; brown (10YR 5/3) moist; weak coarse prismatic structure; friable, slightly sticky; many fine roots; common fine threaded soft masses of lime; violently effervescent; strongly alkaline; clear smooth boundary.
85P4108

Bk2--104 to 132 cm; silt loam; yellowish brown (10YR 5/4) moist; weak coarse prismatic structure; friable, slightly sticky, slightly plastic; many fine roots; few fine soft masses of lime; strongly effervescent; strongly alkaline; gradual smooth boundary.
85P4109

BC--132 to 145 cm; gravelly loam; light yellowish brown (10YR 6/4) moist; massive; friable, slightly sticky, slightly plastic; many fine roots; strongly effervescent; moderately alkaline; abrupt wavy boundary.
85P4110

2C--145 to 180 cm; extremely gravelly sand; yellowish brown (10YR 5/4) moist; massive; friable, slightly sticky, slightly plastic; slightly effervescent; moderately alkaline.
85P4111

Print date: 09-25-1986

Pedon: Turner

NSSL ID #: 85P0776

Soil Survey # S85-MT-031-002

Location: 3270' E and 1600' S of the NE corner of Sec. 27, T.1N., R.5E.

Latitude: ---

Longitude: ---

Classification: Fine-loamy over sandy or sandy-skeletal, mixed Typic Argiboroll

Physiography:

Geomorphic Position:

Microrelief:

Slope Characteristics: 1.5%, southwest facing

Elevation: 1366 m MSL

Precipitation: Aridic moisture regime

MLRA: 44

Water Table Depth:

Permeability: Moderate

Air Temp. (Centigrade): Ann: Sum: Win:

Soil Temp. (Centigrade): Ann: Sum: Win:

Drainage: Well drained

Land Use:

Stoniness:

Erosion or Deposition: Slight

Particle Size Control Section:

Parent Material: alluvium

Vegetation Codes:

Weather Station:

Diagnostic Horizons:

Date: 07/85

Described by: R. Richardson, J. Rogers and W. Braker

Ap1--0 to 10 cm; grayish brown (10YR 5/2) silt loam; very dark grayish brown (10YR 3/2) moist; moderate fine granular structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; medium acid; abrupt smooth boundary.
85P4112

Ap2--10 to 18 cm; silty clay loam; very dark grayish brown (10YR 3/2) moist; weak medium platy structure; friable, sticky, plastic; many very fine and fine roots; medium acid; abrupt smooth boundary.
85P4113

Bt1--18 to 30 cm; silty clay loam; very dark grayish brown (10YR 3/2) and dark brown (10YR 3/3) crushed moist; moderate medium prismatic structure parting to moderate fine and medium subangular blocky; friable, sticky, plastic; many very fine and fine roots; continuous distinct clay films on faces of peds and in pores; slightly acid; clear smooth boundary.
85P4114

Bt2--30 to 43 cm; silty clay loam; dark brown (10YR 3/3) and brown to dark brown (10YR 4/3) moist; weak medium prismatic structure parting to weak coarse subangular blocky; friable, sticky, plastic; many very fine and fine roots; continuous faint clay films on faces of peds and in pores; neutral; clear smooth boundary.
85P4115

Bk1--43 to 58 cm; silt loam; brown (10YR 5/3) moist; weak medium prismatic structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; violently effervescent; strongly alkaline; clear wavy boundary.
85P4116

Bk2--58 to 71 cm; very gravelly loam; yellowish brown (10YR 5/4) moist; massive; friable, slightly sticky, nonplastic; many very fine and fine roots; violently effervescent; strongly alkaline; clear wavy boundary.
85P4117

2C--71 to 152 cm; extremely gravelly sand; brown to dark brown (10YR 4/3) moist; single grain; loose, loose; slightly effervescent; moderately alkaline.
Lime pendants on undersides of gravels. 65% gravel.
85P4118

Print date: 09-25-1986

Pedon: Amesha Variant
 Soil Survey # S85-MT-007-003
 Location: 350' N and 110' E of center of Sec. 22, T.22N., R.1E.
 Latitude: ---
 Classification: Fine-loamy, mixed Borollic Haplargid
 Physiography:
 Geomorphie Position:
 Microrelief:
 Slope Characteristics: 2%, east facing
 Precipitation: Aridic moisture regime
 Water Table Depth:
 Air Temp. (Centigrade): Ann: Sum: Win:
 Soil Temp. (Centigrade): Ann: Sum: Win:
 Drainage: Well drained
 pasture
 Stoniness:
 Particle Size Control Section:
 Parent Material: alluvium
 Vegetation Codes:

NSSL ID #: 85P0777

Longitude: ---

Elevation: 1260 m MSL
 MLRA: 44
 Permeability: Moderately slow

Land Use: Pasture land and native

Erosion or Deposition: Slight

Weather Station:

Date: 07/85

Diagnostic Horizons:

Described by: R. Richardson and W. Braker

Ap--0 to 15 cm; brown (10YR 5/3) sandy loam; dark brown (10YR 3/3) and brown to dark brown (10YR 4/3) moist; slightly hard, very friable, slightly sticky, slightly plastic; many medium and coarse roots; many tubular pores; strongly effervescent; mildly alkaline; abrupt smooth boundary.
 85P4119

Bk--15 to 43 cm; very pale brown (10YR 7/3) loam; pale brown (10YR 6/3) moist; weak medium prismatic structure; slightly hard, friable, sticky, plastic; many medium and coarse roots; many tubular pores; violently effervescent; moderately alkaline; clear wavy boundary.
 85P4120

Btk--43 to 69 cm; light yellowish brown (10YR 6/4) sandy clay loam; light yellowish brown (10YR 6/4) moist; weak medium prismatic structure parting to weak coarse subangular blocky; hard, firm, sticky, plastic; many medium and coarse roots; many tubular pores; many distinct clay films on vertical faces of peds; strongly effervescent; moderately alkaline; clear wavy boundary.
 85P4121

2Btz--69 to 81 cm; sandy clay loam; yellowish brown (10YR 5/4) moist; weak medium prismatic structure; hard, friable, sticky, plastic; common medium and coarse roots; many tubular pores; common faint clay films on vertical faces of peds; strongly effervescent; strongly alkaline; clear wavy boundary.
 85P4122

2Bz--81 to 119 cm; sandy clay loam; yellowish brown (10YR 5/4) moist; moderate coarse prismatic structure; slightly hard, friable, sticky, plastic; common medium and coarse roots; many tubular pores; few faint clay films on vertical faces of peds; strongly effervescent; mildly alkaline; gradual wavy boundary.
 85P4123

2BC--119 to 152 cm; sandy clay loam; dark yellowish brown (10YR 4/4) moist; weak coarse prismatic structure; slightly hard, friable, sticky, plastic; few fine and medium roots; many tubular pores; slightly effervescent; mildly alkaline; gradual wavy boundary.
 85P4124

2C--152 to 211 cm; sandy loam; yellowish brown (10YR 5/4) moist; massive; slightly hard, slightly sticky, slightly plastic; many tubular pores; violently effervescent; moderately alkaline.
 85P4125

Pedon: Chinook
 Soil Survey # S85-MT-007-005
 Location: 3200' S and 1100' W of the NE corner of Sec. 33, T.5N., R.2E.
 Latitude: ---
 Classification: Coarse-loamy, mixed Aridic Haploboroll
 Physiography:
 Geomorphologic Position:
 Microrelief:
 Slope Characteristics: 1%, northwest facing
 Precipitation: Udic moisture regime
 Water Table Depth:
 Air Temp. (Centigrade): Ann: Sum: Win:
 Soil Temp. (Centigrade): Ann: Sum: Win:
 Drainage: Well drained
 Stoniness:
 Particle Size Control Section:
 Parent Material: alluvium
 Vegetation Codes:
 Diagnostic Horizons:
 Described by: R. Richardson and W. Braker

NSSL ID #: 85P0779
 Longitude: ---
 Elevation: 1223 m MSL
 MLRA: 44
 Permeability: Moderate
 Land Use:
 Erosion or Deposition: Slight
 Weather Station:
 Date: 07/85

Ap1--0 to 10 cm; very dark grayish brown (10YR 3/2) sandy loam; grayish brown (10YR 5/2) and brown (10YR 5/3) dry; weak very fine and fine granular structure; very friable, slightly sticky, nonplastic; common very fine and fine roots; slightly effervescent; mildly alkaline; abrupt smooth boundary.
 85P4133

Ap2--10 to 25 cm; very dark grayish brown (10YR 3/2) sandy loam; brown (10YR 5/3) dry; weak medium and coarse subangular blocky structure; very friable, slightly sticky, nonplastic; common very fine and fine roots; slightly effervescent; mildly alkaline; abrupt smooth boundary.
 85P4134

Bw--25 to 38 cm; brown to dark brown (10YR 4/3) and dark grayish brown (10YR 4/2) sandy loam; light brownish gray (10YR 6/2) dry; weak coarse prismatic structure; very friable, slightly sticky, nonplastic; common very fine and fine roots; strongly effervescent; moderately alkaline; clear wavy boundary.
 85P4135

Bk1--38 to 48 cm; brown (10YR 5/3) sandy loam; light gray (10YR 7/2) dry; weak coarse prismatic structure parting to weak medium and coarse subangular blocky; very friable, slightly sticky, slightly plastic; common very fine and fine roots; many fine threaded soft masses of lime; violently effervescent; moderately alkaline; clear wavy boundary.
 85P4136

Bk2--48 to 76 cm; brown to dark brown (10YR 4/3) and brown (10YR 5/3) sandy loam; pale brown (10YR 6/3) dry; weak coarse prismatic structure; very friable, slightly sticky, slightly plastic; common very fine and fine roots; strongly effervescent; moderately alkaline; clear wavy boundary.
 85P4137

2Bk--76 to 84 cm; brown (10YR 5/3) sandy loam; pale brown (10YR 6/3) dry; weak medium platy structure; very friable, slightly sticky, slightly plastic; few very fine and fine roots; common to many threaded soft masses of lime; violently effervescent; strongly alkaline; clear wavy boundary.
 85P4138

3Bk--84 to 91 cm; brown (10YR 5/3) sandy loam; pale brown (10YR 6/3) dry; massive; very friable, nonsticky, nonplastic; few very fine and fine roots; strongly effervescent; strongly alkaline; clear wavy boundary.
 85P4139

4Bk--91 to 99 cm; brown to dark brown (10YR 4/3) sandy loam; pale brown (10YR 6/3) dry; massive; very friable, slightly sticky, slightly plastic; few very fine and fine roots; few to common threaded soft masses of lime; violently effervescent; strongly alkaline; clear wavy boundary.
 85P4140

5C--99 to 152 cm; brown to dark brown (10YR 4/3) and brown (10YR 5/3) sandy loam; pale brown (10YR 6/3) dry; massive; very friable, nonsticky, nonplastic; few very fine and fine roots; strongly effervescent; strongly alkaline.
 85P4141

Print date: 09-25-1986

Pedon: Mussel NSSL ID #: 85P0780

Soil Survey # S85-MT-007-006

Location: 1000' S and 250' E of the NW corner of Sec. 17, T.4N., R.2E.

Latitude: --- Longitude: ---

Classification: Fine-loamy, mixed (calcareous), frigid Ustic Torriorthent

Physiography:

Geomorphic Position:

Microrelief:

Slope Characteristics: 1.5%, north facing

Precipitation: Aridic moisture regime

Water Table Depth:

Air Temp. (Centigrade): Ann: Sum: Win:

Soil Temp. (Centigrade): Ann: Sum: Win:

Drainage: Well drained

Stoniness:

Particle Size Control Section:

Parent Material: alluvium

Vegetation Codes:

Elevation: 1254 m MSL

MLRA: 44

Permeability: Moderate

Land Use: Rangeland grazed

Erosion or Deposition: Slight

Diagnostic Horizons:

Described by: R. Richardson and W. Braker

Weather Station:

Date: 07/85

Ap--0 to 13 cm; brown (10YR 5/3) fine sandy loam; very dark grayish brown (10YR 3/2) moist; weak fine granular structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; slightly effervescent; moderately alkaline; abrupt smooth boundary.
85P4142

Bk1--13 to 41 cm; light gray (10YR 7/2) sandy loam; brown (10YR 5/3) moist; weak medium and coarse prismatic structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; common fine threaded soft masses of lime; violently effervescent; moderately alkaline; clear wavy boundary.
85P4143

Bk2--41 to 66 cm; very pale brown (10YR 7/3) sandy clay loam; brown (10YR 5/3) moist; moderate medium prismatic structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; many coarse irregular soft masses of lime; violently effervescent; moderately alkaline; clear wavy boundary.
Lime (10YR 8/2) masses.
85P4144

Bk3--66 to 89 cm; light yellowish brown (10YR 6/4) sandy clay loam; yellowish brown (10YR 5/4) moist; weak medium prismatic structure; friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; common fine soft masses of lime; violently effervescent; strongly alkaline; gradual wavy boundary.
85P4145

Bkz--89 to 130 cm; loam; yellowish brown (10YR 5/4) moist; weak coarse prismatic structure parting to weak fine platy; friable, slightly sticky, slightly plastic; few very fine roots; many tubular pores; common fine masses of gypsum; violently effervescent; moderately alkaline; clear wavy boundary.
Gypsum on vertical faces.
85P4146

Bk4--130 to 145 cm; very pale brown (10YR 7/4) gravelly sandy clay loam; light yellowish brown (10YR 6/4) moist; massive; friable, slightly sticky, slightly plastic; few very fine roots; many tubular pores; few fine masses of gypsum; violently effervescent; moderately alkaline; clear wavy boundary.
85P4147

BC--145 to 152 cm; sandy loam; yellowish brown (10YR 5/4) moist; massive; very friable, nonsticky, nonplastic; few very fine roots; many tubular pores; few fine masses of gypsum; violently effervescent; moderately alkaline.
85P4148

Print date: 09-25-1986

Pedon: Brocko

NSSL ID #: 85P0781

Soil Survey # S85-MT-007-007

Location: 3100' W and 35' N of the SE corner of Sec. 16, T.4N., R.1E.

Latitude: ---

Longitude: ---

Classification: Coarse-silty, mixed Borollic Calciorthid

Physiography:

Geomorphic Position:

Microrelief:

Slope Characteristics: 2%, southwest facing

Elevation: 1293 m MSL

Precipitation: Aridic moisture regime

MLRA: 44

Water Table Depth:

Permeability: Moderate

Air Temp. (Centigrade): Ann: Sum: Win:

Soil Temp. (Centigrade): Ann: Sum: Win:

Drainage: Well drained

Land Use:

Stoniness:

Erosion or Deposition: Moderate

Particle Size Control Section:

Parent Material: alluvium over eolian sand

Vegetation Codes:

Weather Station:

Diagnostic Horizons:

Date: 07/85

Described by: R. Richardson, W. Braker and J. Rogers

Ap--0 to 15 cm; pale brown (10YR 6/3) silt loam; brown to dark brown (10YR 4/3) moist; weak very fine and fine granular structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; strongly effervescent; moderately alkaline; abrupt smooth boundary.
85P4149

Bk1--15 to 43 cm; very pale brown (10YR 7/3) silt loam; brown (10YR 5/3) moist; weak medium prismatic structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; many very fine and fine soft masses of lime; violently effervescent; moderately alkaline; clear wavy boundary.
85P4150

Bk2--43 to 74 cm; very pale brown (10YR 7/3) silt loam; yellowish brown (10YR 5/4) moist; weak medium prismatic structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; common very fine and fine soft masses of lime; violently effervescent; strongly alkaline; clear wavy boundary.
85P4151

Bk3--74 to 104 cm; pale brown (10YR 6/3) silt loam; brown to dark brown (10YR 4/3) moist; weak medium prismatic structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; many tubular pores; violently effervescent; strongly alkaline; clear wavy boundary.
85P4152

Bz--104 to 142 cm; pale brown (10YR 6/3) loam; brown to dark brown (10YR 4/3) moist; weak medium prismatic structure parting to weak medium platy; very friable, slightly sticky, slightly plastic; common very fine roots; many tubular pores; common threaded masses of gypsum; violently effervescent; moderately alkaline; clear wavy boundary.
85P4153

BC--142 to 157 cm; light yellowish brown (10YR 6/4) sandy clay loam; dark yellowish brown (10YR 4/4) moist; massive; very friable; common very fine roots; many tubular pores; common masses of gypsum; violently effervescent; moderately alkaline.
85P4154

PRIMARY CHARACTERIZATION DATA

BOZEMAN (VARIANT) GALLATIN COUNTY, MONTANA

DATE PRINTED 07/25/86

PAGE 1 OF 2 PAGES

SAMPLED AS: FINE-SILTY, MIXED TYPE ARGINDROLL

S E 57T-031 -001

SAMPLE NO. 85D4103-4111

U. S. DEPARTMENT OF AGRICULTURE

P=0.74 (N). 850 775

SOIL CONSERVATION SERVICE

PROJECT: SOUTHWEST AREA

PROJECT NO. 95P 152

NATIONAL SOIL SURVEY LABORATORY

GENERAL METHODS 161A, 2A1, 2A

LINCOLN, NEBRASKA 68504-3966

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	HZN %	DEPTH (CM)	HORIZON	(- - - TOTAL - - -) (- - CLAY - -) (- - SILT - -) (- F - - - SAND - - -) (- CLASSE FRACTIONS (MM) -) (>2mm)																	
				CLAY		SILT	SAND		FINE	FINE		COURSE	V.F	F	M	C	VC	WEIGHT		WT	
				LT	.002	.05	LT	LT	.002	.02	.05	.10	.25	.5	1	2	5	20	.1	PCT OF	
				.002	.05	-	.002	.002	.02	.05	.10	.25	.5	1	2	5	20	.75	40%		
				PCT OF CLAY (3A1) - - - ->																	
				PCT OF CLAY (3A1) - - - ->																	
954103	15	0- 10	AP1	23.2	54.4	12.4			25.7	33.7	9.4	1.4	1.0	0.4	0.2	TR	1	--	4	1	
954104	25	10- 23	AP2	22.5	54.0	13.5			25.5	37.4	10.5	1.5	0.3	0.5	0.2	TR	T4	--	3	TR	
954105	35	23- 34	BT1	27.7	52.0	10.3			24.3	37.7	9.1	0.1	0.2	0.2	--	--	--	--	1	--	
954106	45	34- 50	BT2	24.7	54.5	10.8			23.7	40.6	9.8	0.4	0.2	--	--	--	--	--	1	--	
954107	55	50- 85	BT3	27.2	55.5	12.3		10	21.2	39.3	10.3	1.0	0.3	0.2	--	--	TR	--	1	--	
954108	65	85-105	BK1	20.2	57.3	12.5		3	22.7	44.6	11.1	1.0	0.3	0.1	--	--	--	--	1	--	
954109	75	105-137	BK2	16.5	55.4	14.1			21.1	44.3	13.5	2.5	1.2	0.6	0.3	TR	2	1	7	3	
954110	95	133-144	BC	12.2	52.5	35.3			16.8	35.7	11.7	6.4	3.7	5.4	2.9	3	12	SW	41	23	
954111	95	145-152	2C	2.3	4.2	93.5			1.2	3.0	3.7	15.7	27.5	23.9	22.4	12	28	24Y	20	64	

SAMPLE NO.	HZN NO.	ORIG. TOTAL C		EXTR. TOTAL P		(- - -) WITH-CIT (- - -) EXTRACTABLE			(- - -) (RATIO/CLAY) (ATTEN/ERG) (- - -) LIMITS -				(- - -) FIELD 1/3		(- - -) SOIL MOIST		(- - -) WATER CONTENT - (- - -)		RD			
		1	2	1	2	FE	AL	MN	CFC	BAR	LL	PI	MOIST	BAR	MOIST	BAR	1/10	1/3		15	WHOLE	
		5410	5434			5434	5024	6074	6024	501	801	451	451	4434	4210	4310	401	444	4910	4810	400	401
		- PCT OF <2MM -		- PCT OF <2MM -		- PCT OF <2MM -		- PCT OF <2MM -				PCT <0.4MM			G/GC			CM/CM		- PCT OF <2MM -		CM/CM
P54103	1	1.67	0.155							0.83	0.46	33	13		1.60						10.7	
P54104	2	1.49	0.113							0.84	0.52			1.59	1.71	0.025			21.2	11.6	0.15	
P54105	3	0.77	0.113							0.84	0.45			1.35	1.51	0.035			23.1	12.7	0.14	
P54106	4	0.54								0.91	0.43	39	21	1.35	1.49	0.029			19.8	11.9	0.11	
P54107	5	0.52								0.47	0.23			1.43	1.56	0.018			20.0	10.2	0.15	
P54108	6	0.30								0.59	0.45			1.53						7.1		
P54109	7	0.25								0.79	0.47			1.56	1.65	0.019			18.1	7.3	0.16	
P54110	8	0.17								0.80	0.48			1.50						5.9		
P54111	9	0.11								1.17	0.70			1.70						1.6		

*** CONTINUATION OF NEXT PAGE ***

DATE PRINTED 07/25/86																					PAGE 2 OF 2 PAGES									
BOZEMAN		(VARIANT)		S 85MT-031 -201																	PEOIN NO. 858 775 NATIONAL SOIL SURVEY LABORATORY									
		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--									
		(- NH4OAC EXTRACTABLE BASES -) ACIDITY										(- DEC-) EXCH		SAR	BASE SATURATION		CO3 AS RES.	CASO4 AS	(- - - -PH - - -)											
SAMPLE NO.	HZN NO.	CA	MG	NA	K	SUM	ITY	SUM	NH4-	EXCH	NA	SAR	SUM	NH4OAC	CAC03	OHMS	GYPSUM	SAT	CACL2	H2O										
		6N7E	6J2D	6P2B	6L2B	6H5A		6H5A	6A3A	6P5D		5E	5C3	5C1	5C1G	AE1	6F1A	6F4	6C1A	6C1F	6C1F									
		< - - - - - MEQ / 100 G - - - - -										< - - - - - PCT - - - - -			< - - - - - PCT - - - - -			< - - - - - PCT - - - - -		< - - - - - PCT - - - - -										
854103	1	11.7	5.5	0.1	1.1	18.4	5.1	23.5	19.2	1	1	79	94						5.7	5.3	5.1									
854104	2	11.7	5.5	TR	0.7	19.5	4.9	23.5	19.7	TR	1	79	94						5.2	5.7	5.1									
854105	3	14.3	8.0	0.2	0.7	23.2	3.0	26.2	23.4	1		89	99						5.1	5.1	5.4									
854106	4	15.5	8.4	0.2	0.5	25.2	2.2	27.4	22.4	1	1	92	103		TR				7.2	6.7	7.2									
854107	5		10.7	0.5	0.3				13.2	2	2					23			3.0	1.1	4.1									
854108	6		15.9	2.4	0.3				13.1	14	10					14	1800		3.5	3.7	3.7									
854109	7		15.0	3.5	0.3				12.7	17	12					11		--	4.3	4.6	4.6									
854110	8		12.1	2.7	0.2				9.8	13	9					10			3.0	3.3	3.3									
854111	9		3.2	1.0	TR				2.7	17	8					10			3.2	3.4	3.4									
		(- - - - - WATER EXTRACTED FROM SATURATED PASTE - - - - -) (- - - - - MINERALOGY - - - - -)																												
SAMPLE NO.	HZN NO.	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	H2O	SALTS	TOTAL ELEC. CONC.		(- - - - - X-RAY - - - - -)		(- - - - - CLAY - - - - -)		(- - - - - DTG - - - - -)		TOTAL 20M									
		6N1A	6J1A	6P1B	6L1B	6I1B	6J1A	6K1C	6L1C	6M1C	8A	805	44475	7A2I	7A2I	7A2I	7A2I	7A3	7A3	7A3	7A3									
		< - - - - - MEQ / LITER - - - - -										< - - - - - PCT - - - - -		< - - - - - PCT - - - - -		< - - - - - PCT - - - - -		< - - - - - PCT - - - - -		< - - - - - PCT - - - - -										
854103	1	4.4	3.1	1.2	0.6	--	1.3	0.4	0.9	5.2	51.0	TR	0.97	MT 4	MI 3	VP 2	KK 2	KK13												
854104	2	3.1	2.5	1.0	0.4	--	0.7	0.3	0.7	5.1	52.6	TR	0.93																	
854105	3												0.19																	
854106	4	3.3	2.7	1.6	0.2	--	4.6	0.4	0.4	0.6	55.1	TR	0.74	MT 4	MI 3	KK 3	QZ 1	KK 2												
854107	5	1.9	2.4	3.1	1.1	--	4.3	0.5	0.5	0.4	50.2	TR	0.72																	
854108	6	0.7	1.3	9.3	0.1	--	6.1	2.4	2.1	0.6	48.9	TR	1.14																	
854109	7	1.7	7.4	26.5	0.2	--	4.2	13.0	20.1	--	49.3	0.1	3.43																	
854110	8	6.5	31.7	38.7	0.3	--	3.2	24.6	46.7	--	37.5	0.2	6.31																	
854111	9	2.4	2.2	20.5	0.2	--	3.1	13.1	18.7	--	25.1	0.1	3.11																	

AVERAGES: DEPTH 34- 84: PCT CLAY 20 PCT .1-75MM 1

ESTIMATED BULK DENSITY FOR LAYER 1, 5, 8, 9,

MMHOS/CM OF 1:2 WATER EXTRACT (31) 5 EXCH NA AS EXTRACTABLE NA FOR LAYERS 3,

ANALYSES: 5E ALL ON SIEVED <2MM BASIS VE 75-20MM FROM VOLUME ESTIMATES

MINERALOGY: KIND OF MINERAL: MT MONTMORILL MI MICA VR VERMICULITE KK KAOLINITE QZ QUARTZ

RELATIVE AMOUNTS: 5 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

CPH5MT238

		MINERALOGY																			(TOT ANAL)			
		OPTICAL										X-RAY			DTA									
		SAND/SILT										CLAY												
SAMPLE NO.	HZN NO.	FA	RE	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7A2I	7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE				
		7B1A	7B1A																		7B1A	7B1A	7B1A	7B1A
		PCT																			PCT			
		RELATIVE AMOUNTS																			RELATIVE AMOUNTS			
85P4103	1											MT 4	MI 3	VR 2	KK 2	OZ 1	KK13		1.3	6.0				
85P4104	2																							
85P4105	3																							
85P4106	4											MT 4	MI 3	KK 3	OZ 1		KK 2		2.0	6.0				
85P4107	5																							
85P4108	6																							
85P4109	7																							
85P4110	8																							
85P4111	9																							

ANALYSES: S=ALL ON SIEVED < 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: QZ = QUARTZ MI = MICA MT = MONTMORILLONITE VR = VERMICULITE KK = KAOLINITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

PRIMARY CHARACTERIZATION DATA

TURNER

GALLATIN COUNTY, MONTANA

FINAL

DATE PRINTED 09/25/86

PAGE 1 OF 2 PAGES

SAMPLED AS: FINE-LOAMY OVER SANDY OR SANDY SKELETAL TYPIC ARGIDRILL

S 05PT-031-002

SAMPLE NO. 95P4112-4113

U. S. DEPARTMENT OF AGRICULTURE

PEJON NO. RFP 776

SOIL CONSERVATION SERVICE

PROJECT: SOUTHWEST AREA

PROJECT NO. 35P 152

NATIONAL SOIL SURVEY LABORATORY

LINCOLN, NEBRASKA 68504-3866

GENERAL METHODS 1B1A, 2A1, 2B

		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	(- - - TOTAL - - -) (- - CLAY - -) (- - SILT - -) (- - - SAND - - -) (- - COARSE FRACTIONS (MM) - -) (>2MM) CLAY SILT SAND FINE CO3 FINE COARSE VF F C VC - - - - WEIGHT - - - - WT .002 .002 .05 LT LT .002 .02 .05 .10 .25 .5 1 2 5 20 .1- PCT OF .002 .05 .2 .002 .002 .02 .05 .10 .25 .50 .1 -2 -5 -20 -75 75 400L < - - - - - PCT OF <2MM (JAI) - - - - - > < - PCT OF <75MM (JBI) - - - - - SOIL																	

954112	15	0-10	A1	19.7	57.3	23.0				24.0	33.3	9.0	4.1	4.7	3.0	1.3	1	TR	--	15	1
954113	25	10-17	A2	25.7	55.3	19.0				24.0	31.3	8.7	3.3	3.7	2.7	0.6	TR	TR	--	10	TR
954114	35	17-30	A1	24.4	59.2	12.4				24.6	34.6	3.5	1.5	1.3	0.9	0.1	TR	--	--	4	--
954115	45	30-43	B1	19.7	53.9	15.4				22.0	41.9	11.5	2.1	1.0	1.0	0.2	TR	TR	--	5	--
954116	55	43-53	B1	21.4	50.0	13.6			4	21.7	38.3	11.6	2.6	2.2	1.4	0.9	1	1	--	2	2
954117	65	53-70	B2	13.4	14.9	51.7			4	12.3	22.5	8.3	4.2	10.9	4.7	14.1	11	33	14V	76	59
954118	75	70-152	2C	1.6	4.5	93.9			1	2.2	2.3	4.2	18.0	34.3	24.6	12.8	9	35	25V	97	69

SAMPLE NO.	HZN NO.	IRON TOTAL		EXTRA TOTAL (- - WITH-CIT - -)				(PATIO/CLAY)		(ATTEBURG)		(- BULK DENSITY -)				(- - WATER CONTENT - -)				WFO								
		C	N	P	S	EXTRACTABLE				15	BAR	- LIMITS -		FIELD	1/3	OVER WHOLE	FIELD	1/10	1/3		15	WHOLE						
						FE	AL	MN	CFC			LL	PT										MOIST	BAR	SOIL	MOIST	BAR	SOIL
954112	1	0.99	0.120					0.91	0.46	23	8	1.40										9.0						
954113	2	0.87	0.107					0.81	0.45			1.50	1.71	0.044					21.8	11.5		0.15						
954114	3	0.78	0.084					0.97	0.45	40	18	1.40	1.57	0.039					21.9	12.9		0.13						
954115	4	0.81						1.00	0.50			1.21	1.41	0.025					18.3	9.9		0.11						
954116	5	0.65						0.61	0.46			1.35	1.41	0.017					20.5	9.1		0.14						
954117	6	0.50						0.56	0.45			1.40										6.2						
954118	7	0.09						0.75	0.75			1.50										1.2						

*** CONTINUATION ON NEXT PAGE ***

TIPIN:

DATE PRINTED 09/25/86

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TURNER

S H5MT-031 -002

PELON NO. BSP 774

NATIONAL SOIL SURVEY LABORATORY

		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--

		(- NH4OAC EXTRACTABLE BASES -) ACIDITY						(- -CFC- -) EXCH			SAR	BASE SATURATION		CO3 AS RES.		CASO4 AS		(- - - PH - - -)			
SAMPLE NO.	HZN NO.	CA	MG	NA	K	SUM	ITY	SUM	NH4	UAC	NA	SE	SUM NH4OAC	C2M4	CO3	OHMS	C2M4	C2M4	SAT	CACL2	H2O
		503A	503A	503A	503A	503A	503A	503A	503A	503A	503A		503A	503A	503A	503A	503A	503A	503A	503A	503A

		/ 100						PCT				PCT		PCT		PCT		1:2		1:1	
854112	1	11.4	3.4	0.9	0.9	16.7	4.0	20.7	15.9		6		91	100					6.1	6.5	
854113	2	14.4	4.5	TR	0.5	19.8	3.9	23.7	20.7	TR			84	95					8.0	6.4	
854114	3	18.1	6.1	TR	0.8	25.0	3.3	28.3	24.6	TR			78	100					6.4	6.9	
854115	4	32.9	5.3	TR	0.5	39.7	--	39.7	19.6	TR	TR	TR	100	100	2				7.7	7.4	7.9
854116	5		4.5	TR	0.3				13.0	TR	TR	TR			21				7.9	7.9	8.2
854117	6		3.5	TR	0.2				7.5	TP	TP	TP			19				8.0	7.7	8.2
854118	7		1.2	TR	TR				1.2	1	TR				11	13000			8.4	8.4	8.7

(- - - - - WATER EXTRACTED FROM SATURATED PASTE - - - - -)													(- - - - - MINERALOGY - - - - -)														
SAMPLE NO.	HZN NO.	CA	MG	NA	*	CO3	HCO3	CL	SO4	NO3	H2O	TOTAL	ELEC.	(- - - - - CLAY - - - - -)				(- - - - - X-PAY - - - - -)				(- - - - - DT4 - - - - -)				TOTAL DM	
		6011	6018	6014	6016	611E	6119	6K1C	6L1C	6M1C	6A	6D5	EST.	PA3A	(- - - - - <2U - - - - -)				(- - - - - <2U - - - - -)				2FS WEATH				
		/ LITER										< - - - - - PCT - - - - -		< - - - - - RELATIVE AMOUNTS - - - - -										< - - - - - PCT - - - - -			
854112	1												0.07	MI 3	MT 3	KK 2	OZ 1	KKTR									
854113	2												0.09														
854114	3												0.09	MT 4	MI 3	KK 2	OZ 1	KK 4									
854115	4	3.0	1.1	0.3	0.1	--	3.7	0.2	0.3	--	54.1	TR	0.40														
854116	5	2.4	1.0	0.3	0.2	--	3.1	0.2	0.5	--	47.3	TR	0.38														
854117	6	3.3	1.3	0.3	0.2	--	3.6	0.2	0.5	--	34.7	TR	0.44														
854118	7	2.1	1.0	0.5	0.2	--	2.5	0.2	0.7	--	25.0	TR	0.35														

AVERAGES: DEPTH 17-43: PCT CLAY 24 PCT <1-75MM 5

ESTIMATED BULK DENSITY FOR LAYER 1: 8.7

MMPCS/CM OF 1:2 WATER EXTRACT (91) & EXCH NA AS EXTRACTABLE NA FOR LAYERS 1: 2: 3:

ANALYSES: S= ALL ON SIEVED <2MM BASIS

V= 75-20MM FROM VOLUME ESTIMATES

MINERALOGY: K14 OF MINERAL: MI MICA

MT MONTMORILL

KK KAOLINITE

OZ QUARTZ

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

CPR5MT238

		MINERALOGY																					
		OPTICAL										X-RAY				DTA		TOT ANAL					
		SAND/SILT										CLAY											
SAMPLE NO.	HZN NO.	FA	RE										7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE			
		7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	RELATIVE AMOUNTS				PCT		6Q3A	6C7A			
		PCT																					
B5P4112	1												MI 3	MT 3	KK 2	QZ 1		KK 1	2.1	5.7			
B5P4113	2																						
B5P4114	3												MT 4	MI 3	KK 2	QZ 1		KK 4	1.8	5.5			
B5P4115	4																						
B5P4116	5																						
B5P4117	6																						
B5P4118	7																						

ANALYSES: S=ALL ON SIEVED : 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: QZ = QUARTZ MI = MICA MT = MONTMORILLONITE KK = KAOLINITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

PRIMARY CHARACTERIZATION DATA

AMFSHA (VARIANT) BROADWATER COUNTY, MONTANA

DATE PRINTED 09/25/86

PAGE 1 OF 2 PAGES

SAMPLES AS: FINE-LOAMY, MIXED BUDOLIC HAPLARGID

FINAL

S BENT-007 -003

SAMPLE NO. 854119-4125

U. S. DEPARTMENT OF AGRICULTURE

PEODN NO. 854 777

SOIL CONSERVATION SERVICE

PROJECT: SOUTHWEST AREA

PROJECT NO. 459 152

NATIONAL SOIL SURVEY LABORATORY

GENERAL METHODOS 1814, 2A1, 23

LINCOLN, NEBRASKA 68504-3966

		-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--			
		(- - - TOTAL - - -) (- - CLAY - -) (- - SILT - -) (- - SAND - -) (- - COARSE FRACTIONS (MM) - -) (>2MM)																						
SAMPLE NO.	HZN NO.	DEPTH (C1)	HORIZON	CLAY	SILT	SAND	FINE	C13	FINE	COARSE	VF	F	M	C	VC	WEIGHT				PCT				
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF	
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	1	2	5	20	1-	WT OF		
				LT	LT	LT	LT	LT																

CP85MT238

		MINERALOGY																						
		-----OPTICAL-----												-----X-RAY-----				-----DTA-----		(TOT ANAL)				
		-----SAND/SILT-----																-----CLAY-----						
SAMPLE NO.	HZN NO.	FA	RE																					
		7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7A2I	7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE			
		<-----PCT-----												<-----RELATIVE AMOUNTS-----				<-----PCT-----						
B5P4119	1												MT 3	MI 2	CA 2	KK 2		KK<1		1.5	3.6			
B5P4120	2																							
B5P4121	3												MT 4	CA 2	KK 2	MI 1		KK 1		0.8	3.9			
B5P4122	4																							
B5P4123	5																							
B5P4124	6																							
B5P4125	7																							

ANALYSES: S=ALL ON SIEVED < 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: CA = CALCITE MI = MICA MT = MONTMORILLONITE KK = KAOLINITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

PRIMARY CHARACTERIZATION DATA

CHINOOK

BROADWATER COUNTY, MONTANA

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SAMPLED AS: COARSE-LIMONY, MIXED ARIDIC HAPLOCHROLL

S 85MT-007 -005

SAMPLE NO. 85P4133-4141

U. S. DEPARTMENT OF AGRICULTURE

REGION NO. 85P 779

SOIL CONSERVATION SERVICE

PROJECT: SOUTHWEST AREA

PROJECT NO. 85P 152

NATIONAL SOIL SURVEY LABORATORY

GENERAL METHODS 141A, 2A1, 2B

LINCOLN, NEBRASKA 68503-3866

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-															
				(- - - TOTAL - - -) (- - CLAY - -) (- - SILT - -) (- - SAND - -) (- - COARSE FRACTIONS (MM) - -) (>2MM)															
				CLAY	SILT	SAND	FINE	CO3	FINE	COARSE	VF	F	M	C	VC	1	2	5	20
				LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
854133	15	0- 10	AP1	8.9	14.7	76.4			4.4	10.3	22.9	38.4	13.4	1.5	0.2	TR	--	--	53
854134	25	10- 25	AP2	8.1	13.6	74.3			4.3	9.3	24.9	38.6	12.3	1.7	0.3	TR	--	--	53
854135	35	25- 35	BA	6.4	11.0	82.6			2.7	8.1	28.3	41.1	11.7	1.3	0.2	TR	--	--	54
854136	45	35- 45	BK1	9.0	21.0	70.0		4	8.3	12.7	25.8	31.9	9.2	1.9	1.2	J	3	PV	52
854137	55	45- 75	BK2	4.6	18.1	77.3			5.3	12.0	29.6	35.4	10.3	1.4	0.6	TR	TR	--	41
854138	65	75- 84	2BK	5.1	18.4	76.5		2	7.3	11.2	19.6	34.0	19.3	2.9	1.0	TR	TR	--	57
854139	75	84- 92	3BK	5.5	21.0	73.5			7.0	14.0	23.4	30.9	16.3	2.2	0.2	TR	--	--	42
854140	85	92- 99	4BK	5.5	15.6	73.9			6.1	9.5	21.9	41.3	14.2	1.0	--	TR	TR	--	57
854141	75	99-152	5C	4.1	11.5	84.4			4.8	6.7	26.1	43.3	9.3	0.3	0.4	TR	TR	--	59

SAMPLE NO.	HZN NO.	ORGN TOTAL		EXTR TOTAL		(- - - WITH-CIT - -) (RATIO/CLAY)				(- - - BULK DENSITY - -)		COLE (- - - WATER CONTENT - -)		WHOLE SOIL						
		C	N	P	S	EXTRACTABLE				15	- LIMITS -	FIELD 1/3	OVEN WHOLE	FIELD 1/10	1/3	15				
		6A1C	6B3A			FF	AL	MN	CEC	BAR	LL	PI	MOIST	DRY	SOIL	MOIST	BAR	BAR	BAR	
		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		PCT OF <2MM		
854133	1	0.62							1.21	0.59			1.53						5.2	
854134	2	0.51							1.28	0.64			1.53	1.65	0.015			8.2	5.2	0.06
854135	3	0.31							1.34	0.73			1.64	1.59	0.010			6.3	4.7	0.03
854136	4	0.33							1.41	0.90			1.49	1.55	0.012			11.7	7.2	0.06
854137	5	0.19							2.04	1.07			1.52	1.55	0.007			7.4	4.9	0.04
854138	6	0.13							1.76	0.90			1.50							4.0
854139	7	0.14							2.00	0.95			1.53							5.2
854140	8	0.14							1.96	0.89			1.50							4.3
854141	9	0.15							2.15	1.00			1.55	1.59	0.004			5.2	4.1	0.02

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CHINDOCK

S 85MT-007 -005

PEDON NO. 75P 779

NATIONAL SOIL SURVEY LABORATORY

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--

	(- NH4OAC EXTRACTABLE BASES -) ACID-					(- -CEC- -) EXCH		SAR	BASE		CARBONATE		CASO4 AS		(- - -PH - - -)					
SAMPLE	CA	MG	NA	K	SUM	ITY	SUM	NH4-	NA	SAT	AS	CACO3	GYPSUM	SAT	CACL2	H2O				
NO.	595A	595A	595A	595A	595A	595A	CATS	OAC	5053	SE	SUM NH4OAC	<2MM	<20MM	<2MM	<20MM	PASTE	7014			
	NO. 592E	602D	602D	602D	602D	602D	5A3A	5A83	5053	SE	5C3	5C1	4916	6E4	6F1A	6F4	9C1B	9C1C	9C1D	9C1E
	< - - - - - MEQ / 100 C - - - - -					< - - - - -		< - - - - -		PCT	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >	1:2		1:1			
854133	1		2.5	0.1	0.4			10.4	1	TR		1				9.0	7.5	9.2		
854134	2		2.2	0.1	0.5			10.4	1	TR		1				7.7	7.7	9.2		
854135	3		2.3	0.1	0.5			8.5	2			3				7.4	7.4	9.3		
854136	4		3.2	0.2	0.6			12.7	1			10				7.4	7.4	9.4		
854137	5		2.4	0.1	0.5			7.4	1			6				7.4	7.4	9.4		
854138	6		2.4	0.2	0.5			9.0	2			7				8.1	8.1	9.5		
854139	7		2.9	0.2	0.7			11.3	2			5				8.7	8.7	9.5		
854140	8		2.7	0.2	0.7			10.4	2			4				7.7	7.7	9.5		
854141	9	20.1	2.8	0.2	0.5	23.6		8.9	2			100	TR			7.4	7.4	9.5		

	(- - - - - WATER EXTRACTED FROM SATURATED PASTE - - - - -)										(- - - - - MINERALOGY - - - - -)									
	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	H2O	TOTAL ELEC.		(- - - - - CLAY - - - - -)		(- - - - - X-RAY - - - - -)		(- - - - - DATA - - - - -)		TOTAL DM	
SAMPLE	NO.	5913	6013	6013	6013	6013	6013	6013	6013	6013	9A	905	MMHOS	7A21	7A21	7A21	7A21	7A3	7A3	7A3
NO.	5913	6013	6013	6013	6013	6013	6013	6013	6013	6013	9A	905	MMHOS	7A21	7A21	7A21	7A21	7A3	7A3	7A3
	< - - - - - MEQ / LITER - - - - -										< - - PCT - >	/CM	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >	< - - PCT - >
854133	1	5.7	1.4	0.7	0.6	--	5.2	0.5	0.8	--	32.4	TR	0.67	MT 3	MI 3	KK 2		KKTR		
854134	2	3.5	0.4	0.7	0.3	--	4.0	0.2	0.5	--	32.5	TR	0.48							
854135	3												0.20							
854136	4												0.20	MT 3	MI 2	KK 1	CA 1	KK 3		
854137	5												0.17							
854138	6												0.17							
854139	7												0.17							
854140	8												0.17							
854141	9												0.17							

AVERAGES: DEPTH 25-100: PCT CLAY 5 PCT 0.1-75MM 52

ESTIMATED BULK DENSITY FOR LAYER 1, 6, 7, 8,

MMHOS/CM OF 1:2 WATER EXTRACT (UI) & EXCH NA AS EXTRACTABLE NA FOR LAYERS 3, 4, 5, 6, 7, 8, 9,

ANALYSIS: S= ALL CN SIEVED <2MM BASIS V= 75-20MM FROM VOLUME ESTIMATES

MINERALOGY: KIND OF MINERAL: MT MONTMORILL MI MICA KK KAOLINITE CA CALCITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

CP85MT138

		MINERALOGY																			X-RAY				DTA		TOT ANAL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
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		SAND/SILT											CLAY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
SAMPLE NO.	HZN NO.	FA	RE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																

ANALYSES: S=ALL ON SIEVED < 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: MI = MICA MT = MONTMORILLONITE KK = KAOLINITE CA = CALCITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

PRIMARY CHARACTERIZATION DATA

MUSSTL

BROADWATER COUNTY, MONTANA

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SAMPLED AS: FINE-LOAMY, MIXED (CALCAREOUS), FRIGID USTIC TORRIFORMENT

S 85MT-007 -006

SAMPLE NO. 85P4142-4149

U. S. DEPARTMENT OF AGRICULTURE

PEODN NO. 85P 730

SOIL CONSERVATION SERVICE

PROJECT: SOUTHWEST AREA

PROJECT NO. 85P 152

NATIONAL SOIL SURVEY LABORATORY

LINCOLN, NEBRASKA 68509-3156

GENERAL METHODS 181A, 2A1, 2B

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--		

	(- - - TOTAL - - -)				(- - - CLAY - - -)				(- - - SILT - - -)				(- - - SAND - - -)				(- - - COARSE FRACTIONS (MM) - - -)					
SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	CLAY	SILT	SAND	FINE	CO3	FINE	COARSE	VF	F	M	C	VC	W	WT	WT	WT	WT		
				LT	.002	.05	LT	LT	.002	.02	.05	.10	.25	.5	1	2	5	20	75	100	100	
				.002	.05	.2	.0002	.002	.002	.05	.10	.25	.5	1	2	5	20	75	100	100		

				PCT OF <2MM (3A1)																		

				PCT OF <75MM (3A1)																		
854142	15	0-13	A0	9.0	31.6	59.4			8.5	23.1	25.3	18.5	9.5	3.4	2.6	1	1	--	35	2		
854143	25	13-40	BK1	11.6	29.0	59.4		6	10.5	18.5	19.3	21.9	11.3	3.1	3.3	3	4	1	45	8		
854144	35	40-66	BK2	15.6	25.0	58.4		7	8.8	16.2	22.3	20.9	10.3	2.8	2.2	2	2	TR	29	4		
854145	45	66-89	BK3	20.5	33.3	46.2		7	11.4	21.9	26.6	9.8	4.9	2.5	2.4	3	2	TR	24	5		
854146	55	89-130	BK2	18.0	40.6	41.4		5	14.3	26.3	25.5	6.7	3.9	2.2	3.1	3	4	--	22	7		
854147	65	130-145	BK4	13.2	26.0	55.8		6	10.3	15.7	22.7	12.0	9.0	6.1	6.0	7	13	15V	57	35		
854148	75	145-152	BC	15.1	29.8	55.1		5	10.4	19.4	32.2	11.0	6.1	3.1	2.7	3	3	--	29	6		

SAMPLE NO.	HZN NO.	C	N	P	S	(- - - DITH-CIT - - -)				(- - - RATIO/CLAY - - -)		(- - - ATTERBERG - - -)		(- - - PULK DENSITY - - -)		(- - - COLE - - -)		(- - - WATER CONTENT - - -)				(- - - WRD - - -)	
						FF	AL	MN	CFC	BAR	LL	PI	MOIST	DRY	DRY	SOIL	MOIST	BAR	BAR	BAR	SOIL	WHOLE	WHOLE
						6A1C	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A	6A13A

						PCT OF <2MM																	
854142	1	1.20	0.101						1.52	0.69				1.43								5.2	
854143	2	0.70	0.069						0.91	0.66				1.43	1.46	0.014					14.4	7.7	0.09
854144	3	0.38							0.60	0.43	24	7		1.43	1.54	0.018					15.3	7.2	0.12
854145	4	0.23							0.60	0.40				1.43	1.58	0.021					14.5	3.3	0.09
854146	5	0.19							0.71	0.47				1.37	1.44	0.016					14.6	3.5	0.08
854147	6	0.18							0.53	0.47				1.53	1.53	0.008					15.0	8.5	0.09
854148	7	0.13							0.72	0.47				1.43	1.46	0.011					12.8	7.1	0.08

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MUSSEL

S 85MT-007 -006

PEDON NO. 850 780

NATIONAL SOIL SURVEY LABORATORY

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--									
	(- NH4OAC EXTRACTABLE BASES -) ACID- (- -CSC- -) EXCH SAR JASE C3 AS RES. CASO4 AS (- - -PH - - -)																												
SAMPLE	H2O	CA	MG	NA	K	SUM	ITY	SUM	NH4-	NA	SE	SATURATION	CAC03	CMH4S	GYP SUM	SAT	CAC03	H2O											
NO.	6N25	6N25	6N25	6P23	6I23	6H5A	6H5A	5A3A	5A8A	5B5B	5E	SC3	FC1	6F1G	HE1	6F1A	6F4	6C1A	6C1F	6C1F									
	< - - - - -					< - - - - -					< - - - - -					< - - - - -					< - - - - -								
	MEV / 100 G										PCT					PCT					PCT								
854142	1	21.0	2.0	0.1	1.0	24.1	0.5	24.6	13.7	1	TR	93	100	TR				7.8	7.4	7.3									
854143	2		3.5	0.1	0.4				10.5	1	TR			14				8.0	7.7	8.2									
854144	3		7.7	0.1	0.4				9.9	3	2			18				8.3	8.1	8.7									
854145	4		12.4	2.7	0.6				12.2	13	8			15		--		8.3	8.3	8.5									
854146	5		12.0	4.7	0.6				12.0	16	9			14	580	2		8.0	8.1	8.1									
854147	6		9.5	3.2	0.4				9.6	17	10			21		TR		8.1	8.3	8.3									
854148	7		3.1	3.5	0.4				10.3	16	12			12		--		8.1	8.2	8.4									
(- - - - - WATER EXTRACTED FROM SATURATED PASTE - - - - -) (- - - - - MINERALOGY - - - - -)																													
SAMPLE	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	H2O	TOTAL ELEC.	(- - - - - CLAY - - - - -)																	
NO.	6N13	6N13	6P13	6N13	6I13	6J13	6K13	6L13	6M13	6A	EST. BASE	(- - - - - X-RAY - - - - -) (- - - - - DTA - - - - -)																	
	< - - - - -										< - - - - -																		
	MEV / LITER										PCT																		
854142	1	9.0	1.5	0.1	0.3	--	3.3	0.5	0.4	--	39.3	TR	1.00	MT 3	MI 3	VR 2	KK 2	KK 2											
854143	2	3.4	1.4	0.2	0.2	--	4.0	0.2	0.4	--	37.3	TR	0.46																
854144	3	1.4	2.0	2.1	0.2	--	4.0	0.5	0.7	--	35.3	TR	0.53	CA 3	MT 2	MI 2	KK 1	KK 1											
854145	4	0.4	22.0	31.4	0.0	--	2.1	18.6	34.9	--	35.1	0.1	5.33																
854146	5	31.3	60.5	63.7	0.3	--	2.1	33.1	103.8	--	34.1	0.3	11.23																
854147	6	24.7	45.6	58.5	0.5	--	1.3	40.3	75.6	--	35.7	0.3	10.16																
854148	7	9.1	20.7	45.3	0.3	--	1.7	32.0	39.6	--	33.3	0.2	6.24																

AVERAGES: DEPTH 25-100: PCT CLAY 10 PCT .1-75MM 33

ESTIMATED BULK DENSITY FOR LAYER 1:

ANALYSIS: S= ALL ON SIEVED <2MM BASIS

V= 75-20MM FROM VOLUME ESTIMATES

MINERALOGY: KIND OF MINERAL: MT MONTMORILL MI MICA VR VERMICULITE KK KAGLINITE CA CALCITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

CPR5MT23B

		MINERALOGY																			
		OPTICAL										X-RAY				DTA		TOT ANAL			
		SAND/SILT										CLAY									
SAMPLE NO.	HZN NO.	FA	RF	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7A2I	7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE	
		7B1A																		6Q3A	6C7A
		PCT										RELATIVE AMOUNTS						PCT			
85P4142	1											MT 3	MI 3	VR 2	KK 2		KK 2		1.8	3.6	
85P4143	2											CA 3	MT 2	MI 2	KK 1		KK 1		1.0	2.6	
85P4144	3																				
85P4145	4																				
85P4146	5																				
85P4147	6																				
85P4148	7																				

ANALYSES: S=ALL ON SIEVED < 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: MI = MICA MT = MONTMORILLONITE VR = VERMICULITE KK = KAOLINITE CA = CALCITE

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

PRIMARY CHARACTERIZATION DATA

ARJCKU

BROADWATER COUNTY, MONTANA

595

DATE PRINTED 09/25/86

PAGE 1 OF 2 PAGES

SAMPLED AS: COARSE-SILTY, MIXED BOROLIC CALCITHEID

S 854T-1227 -007

SAMPLE NO. 15P4149-4154

PE034 40. 95P 731

PROJECT NO. ASP 152

U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

NATIONAL SOIL SURVEY LABORATORY

LINCOLN, NEBRASKA 68506-3860

GENERAL METHODS 121A, 2A1, 2B

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	H2N NO.	DEPTH (CM)	HORIZON	(- - - TOTAL - - -) (- - CLAY - -) (- - SILT - -) (- - SAND - -) (- - COARSE FRACTIONS (M) - -) (>2MM)												WT	PCT OF WHOLE SOIL				
				CLAY		SILT		FINE		COARSE		VF		C				VC		WEIGHT	
				LT	.002	.05	LT	CO	.002	.02	.05	.10	.25	.5	1			2	5	20	75
				.002	.05	.2	.0002	.002	.02	.05	.10	.25	.5	1	2	5	20	75			
				PCT OF <2MM (3A1)																	
				PCT OF <75MM (3A1)																	
854149	15	0-15	AP	13.5	53.5	33.0		3	19.7	34.6	21.6	6.3	3.4	1.0	0.5	TR	--	--	11	--	
854150	25	15-43	9K1	10.7	50.0	23.3		4	19.4	40.6	19.3	2.3	1.3	0.2	--	--	--	--	4	--	
854151	35	43-73	9K2	12.3	70.6	17.1		3	24.3	46.3	15.0	1.6	0.5	--	--	--	--	--	2	--	
854152	45	73-104	9K3	12.7	54.7	14.6			23.2	45.5	16.1	1.3	0.7	--	--	--	--	--	2	--	
854153	55	104-142	9K4	12.1	70.2	17.7			25.4	44.8	15.7	1.4	0.5	0.1	--	--	TR	--	2	--	
854154	65	142-157	9K5	13.1	29.5	54.4		6	12.2	17.3	15.7	16.7	13.5	5.5	2.7	3	2	9V	47	14	

SAMPLE NO.	HZM NO.	DRUM TOTAL		EXTR TOTAL		(- - WITH-CIT - -) (RAT1)/CLAY) (ATTERBERG) (- - BULK DENSITY - -) COLE (- - WATER CONTENT - -) WRC																	
		C	M	P	S	EXTRACTABLE																	
		6A10	6A3A	6A2A	6A2B	6A7A	6A2A	901	901	4F1	4F	4A3A	4A11	4A1H	401	4A4	4A1C	4A1C	4A2	4A2	4A2	4A2	
		< - - - -	< - - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	
954149	1	1.44	0.143							1.33	0.70												
954150	2	0.75	0.074							0.99	0.55			30	8		1.22	1.28	0.016		16.9	9.1	0.10
954151	3	0.38								1.15	0.57			29	6		1.33	1.38	0.012		15.4	7.7	0.12
954152	4	0.30								1.09	0.52						1.31	1.35	0.010		15.5	5.5	0.12
954153	5	0.22								1.11	0.50						1.41	1.45	0.007		17.3	5.1	0.19
954154	6	0.10								0.71	0.42						1.45	1.50	0.011		15.0	6.7	0.11

*** CONTINUATION ON NEXT PAGE ***

FORM 51

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PROJECT

S 85MT-007 -007

PEIDON NO. 450 781

NATIONAL SOIL SURVEY LABORATORY

	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10--	-11--	-12--	-13--	-14--	-15--	-16--	-17--	-18--	-19--	-20--

(- NH4CAC EXTRACTABLE BASES -) ACID- (- -CEC- -) EXCH SAR BASE C03 AS RES. CAS04 AS (- - -PH - - -)																				
SAMPLE	HZN	CA	MG	NA	K	SUM	ITY	SUM	NH4-	NA	SAR	SAT	03	AS	RES.	CAS04	AS	(- - -PH - - -)		
NO.	NO.	505A	505A	505A	505A	BASES	6H5A	CATS	0AC		SE	SU4	NH40AC	CAC03	0HMS	GYP04	0HMS	SAT	CAC02	H2O
		6020	6020	6020	6020			5A3A	5A3B	5A54		5C3	5C1	6510	0E1	6F1A	6F4	0C10	0C1F	0C1F

854149	1		3.5	TR	1.0			10.6	TR	TR				7				7.8	7.7	6.1
854150	2		6.3	0.1	0.4			14.2	1	TR				17				8.0	7.9	8.3
854151	3		11.7	0.6	0.5			14.2	3	2				14				8.4	8.1	8.7
854152	4		11.3	2.3	0.6			13.9	12	8				10	1100			8.3	8.2	8.7
854153	5		7.4	3.4	0.5			13.4	12	8				10		TR		7.9	7.9	7.9
854154	6		7.4	2.9	0.3			11.4	13	9				13		--		7.8	8.0	8.1

(- - - - -WATER EXTRACTED FROM SATURATED PASTE- - - - -) (- - - - -MINERALOGY - - - - -)																				
CA MG NA K C03 HC03 CL SD4 NO3 H2O TOTAL ELEC. (- - - - -CLAY - - - - -)																				
SAMPLE	HZN	CA	MG	NA	K	C03	HC03	CL	SD4	NO3	H2O	SALT5	COND.	(- - - - -X-RAY - - - - -)	(- - - - -DTA - - - - -)	TOTAL	0CM			
NO.	NO.	6010	6010	6010	6010	6010	6010	6010	6010	6010	6010	HA	POS	MMH05	7A21	7A21	7A21	7A3	7A3	7A1A

854149	1	8.4	1.8	0.3	0.5	--	4.3	0.3	1.1	2.3	48.3	TR	1.07	MT 3	MI 2	KK 2		KK 3		
854150	2	3.6	1.8	0.3	0.2	--	3.5	0.2	0.6	0.4	53.1	TR	0.96							
854151	3	1.3	2.1	2.6	0.2	--	3.7	0.3	0.5	0.5	41.7	TR	0.94	MT 3	MI 2	KK 2	OZ 1	----		
854152	4	2.0	5.3	16.2	0.4	--	3.8	4.3	17.2	--	39.6	0.1	2.43							
854153	5	28.9	36.4	42.9	0.7	--	2.6	18.6	82.1	--	40.1	0.2	7.94							
854154	6	29.7	31.5	42.4	0.4	--	3.8	33.0	61.5	--	34.6	0.2	8.01							

AVERAGE, DEPTH 25-100: PCT CLAY 11 PCT 0.1-75MM 3

ESTIMATED BULK DENSITY FOR LAYER 1.

ANALYSES: 5= ALL ON SIEVED <2MM BASIS

V= 75-20MM FROM VOLUME ESTIMATES

MINERALOGY: KIND OF MINERAL: MT MONTMORILL MI MICA KK KAOLINITE OZ QUARTZ

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

CP85MT238

SAMPLE NO.	HZN NO.	MINERALOGY																		X-RAY		DTA		TOT ANAL	
		OPTICAL																							
		SAND/SILT																							
		FA	RE																						
		7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7B1A	7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE					
PCT												RELATIVE AMOUNTS				PCT									
												7A2I	7A2I	7A2I	7A2I	7A3	7A3	K2O	FE						
												<----->		<----->		<----->		<----->							
BSP4149	1													MT 3	MI 2	KK 2		KK 3		1.4	3.2				
BSP4150	2																								
BSP4151	3																								
BSP4152	4													MT 3	MI 2	KK 2	QZ 1	--		0.8	2.7				
BSP4153	5																								
BSP4154	6																								

ANALYSES: S=ALL ON SIEVED < 2mm BASIS

MINERALOGY: FA = FRACTION ANALYZED RE = RESISTANT

KIND OF MINERAL: MI = MICA MT = MONTMORILLONITE KK = KAOLINITE QZ = QUARTZ

RELATIVE AMOUNT: 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

MINERALOGY BASED ON SAND/SILT:

MINERALOGY BASED ON CLAY:

FAMILY PLACEMENT:

COMMENTS:

APPENDIX II

SOIL WATER RETENTION MODEL

Development of Computer Program

A short, concise explanation of Baumer's (Baumer and Rice, 1986) model was presented by Baumer (1985) during a workshop at the WNTC. The following excerpt from this workshop gives a brief description of Baumer's (Baumer and Rice, 1986) soil water retention model.

THE DATA

"Over several decades some soil water retention measurements have been made on many soils. However in the majority of cases only two or three water contents at respective suctions of 1/10, 1/3 or 15 bar were measured. Differences of methodology between the various institutions that made such measurements makes the organization of all the available data difficult. Therefore, data analyses was in the main restricted to the results of measurements made by the National Soil Survey Laboratory.

Besides consistency of methodology there were two other important points that recommended the use of the NSSL data. Sets of water retention determinations were accompanied by other soil characterizations of physical, chemical and mineralogical properties, and most importantly bulk densities (wet and dry) and soil water retention values at lower suctions were made on undisturbed clod samples.

Before discussing how the data were to be used, mention should be made of both the kind and quantity of the data that is demanded by the model.

The model equation can simply be viewed as a mathematical relationship between water content and suction which depends on five independent variables, namely the satiated and residual water contents, and the parameters a , m , and n . Consequently, it takes at least four pairs of data (suction and water content) to fit the model uniquely to the data. In addition to data for the satiated and residual water contents which are mandatory, measured values of the water content at one third and 15 bar suction, and the suction value of the bubbling pressure (theoretically the water content at the bubbling pressure is identical to the satiated water content) were added, so that the curve model is fitted to five pairs of data.

(1). The water content at satiation is the actual water content at zero suction. It is the difference of the total

porosity of the wet soil minus the volume fraction of the entrapped air. The total porosity is calculated from the measured bulk density and the assumed particle density. Adjustments for particle density were made for measured iron and organic carbon content. The entrapped volume fraction of air was estimated. Such estimates were made from a simple regression equation based on some 80 measurements.

(2). The Bubbling Pressure. The bubbling pressure is equal to the suction needed to initiate drainage of water from the largest pores of the soil. Brakensiek et al (1982) classified some 3200 measurements for a variety of soils according to soil texture; additional measurements were made at the NSSL mainly to verify and refine further the conclusions drawn by Brakensiek. It was found that not only soil texture, but also bulk density, clay mineralogy and organic matter were strongly correlated to bubbling pressure.

(3 & 4). One third and 15 bar measurements were used routinely from the NSSL data files.

(5). The residual water content (theoretically the water content where water film covering the soil solids is no longer continuous) was calculated on the basis of specific surface and charge density properties of the colloidal fraction of the soil solids. The estimates were based on the published work of Reuben Nelson (1982), and personal communication.

ORGANIZATION OF DATA

To calculate a finite number of soil water retention curves, it was desirable to put the data into classes. The system for classification was determined by the soil properties that had the most significant effect on soil water retention. The hierarchical levels of classification coincide approximately with an ascending order of soil property significance on soil water retention. Accordingly, four properties, clay activity, soil texture, organic matter, and bulk density were selected by combining statistical procedures with pedologic considerations. The first split of the data set was made on the basis of four groups of clay activities. Clay activity was expressed by the CEC to clay ratio, where the measured CEC was adjusted for the CEC due to the organic matter contents in the soil. The distribution of the CEC to clay ratio suggested three distinct groups of data that could be confirmed by comparison with the clay mineralogy measurements. These three groups consisted mainly of clays that were either of the kaolinitic (and some oxidic), illitic or montmorillonitic types. Because these three groups would have left out a large

body of data that could be grouped between the illitic and montmorillonitic types a fourth group was added. So the the first split of the data was made by putting a data set in one of the four mineralogy groups. Tentatively these groups are named for their respective clay activities, low, moderately low, moderately high and high, their respective median CEC to clay ratios are 0.15, 0.35, 0.55, and 0.75. Data sets of soils that had CEC to clay ratios higher than 0.95 were excluded.

The second split was made by soil texture; clay ranging from 2.5 to 77.5 percent, and silt from 2.5 to 97.5 percent. The class interval for both clay and silt is five percent. All possible combinations between the 15 clay (2.5, 7.5, 12.5,, 72.5, 77.5) and all possible silt intervals (the sum of the two cannot exceed 100) results in 200 textural classes.

The third soil property used for splitting the data was organic matter. Organic matter was calculated by multiplying measure organic carbon by a factor of 1.7. Statistical considerations (distribution patterns, size of population of subsets, etc,) and practical considerations (use and management, field determination, taxonomy) suggested 8 classes of organic matter, that consisted of soils with organic matter content that was closest to 0.0, 0.25, 0.50, 1.0, 1.5, 2.0, 4.0, and 8.0 percent. Soils with more than 10.0 percent organic matter were excluded. Superficial statistical analysis would perhaps indicate that organic matter should enter this scheme of data classifications at a much less significant level, however, pedogenic reasoning pertaining to soil structure, soil consistency, macro and microbiological activities, compactability and aggregate stability does put a high enough emphasis on organic matter that warrants its level of importance here.

Of all soil properties used to organize the data, bulk density appears to have the most profound influence on soil water retention. This is especially clear if other soil properties are quite similar (see figure 15.)

The argument here is that similar soils (as far as lab analysis is concerned) can have quite different bulk densities. To still use bulk density for this scheme of data organization, a mean bulk density for each class (predetermined by clay activity, texture and organic matter) was calculated and the data was put into one of three bulk densities groups. The three groups were representative of moderately high, medium (expected), and moderately low compacted soils, where the bulk density of the medium compacted soil was the average bulk density of the respective

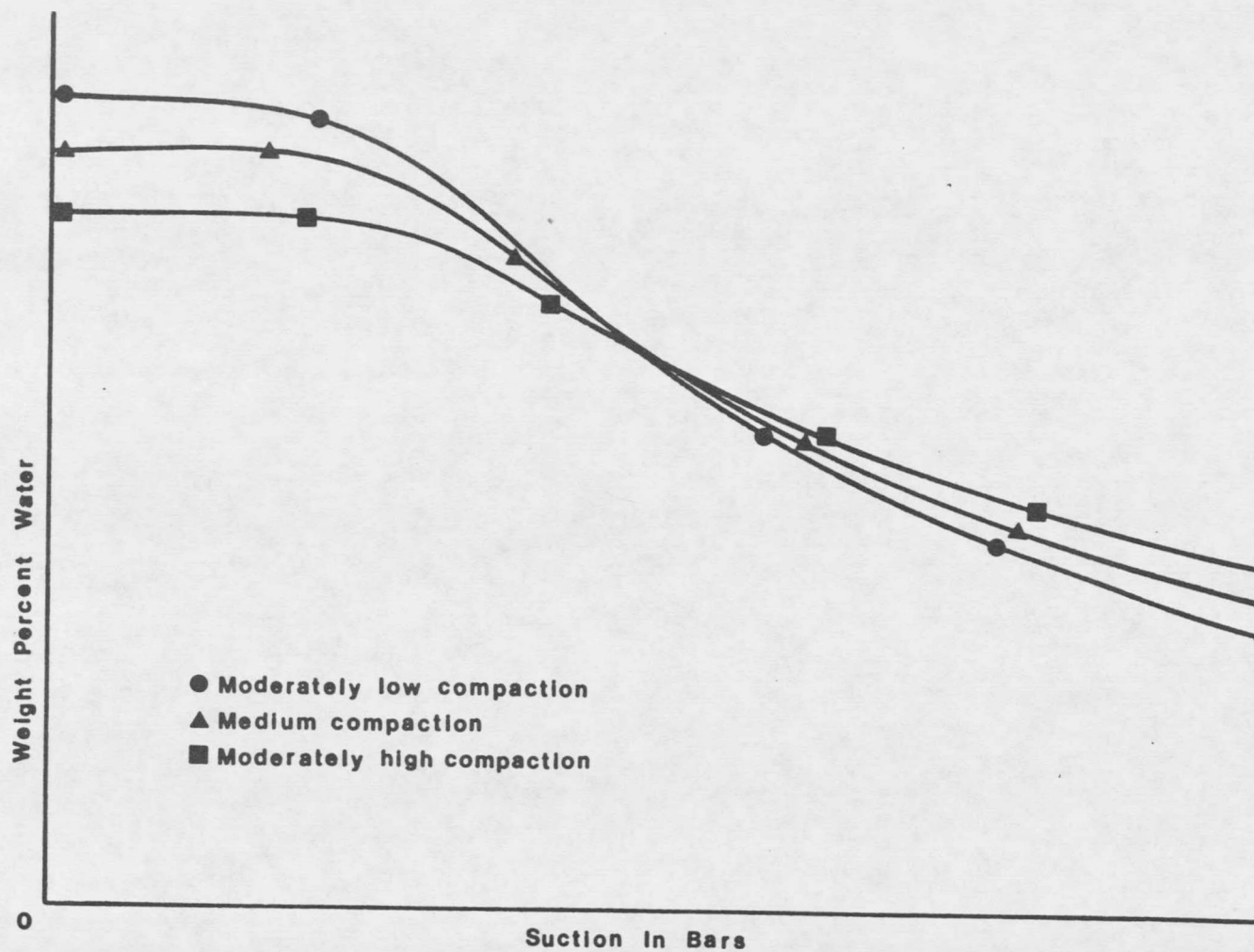


Figure 15. Comparison of high, medium and low compaction soil water retention curves for a clay loam soil (Baumer, 1985).

Notwithstanding its size, the body of data (some 13000 measurements) available was not big enough to make up 19200 different sets of data, and much less 19200 classes of data sets. There were, however, a sufficient number of data groupings that permitted a "fitting" in of the missing data classes mainly by interpolation. Smoothing of the data set classes was done by linear and nonlinear numerical methods. For both, interpolations and smoothing, several models based on physical measurements was employed.

Extrapolation was kept to a minimum, and was only used to derive the extremes of the data set, where needed.

Finally, a set of 19200 data was derived. Each data set corresponds to one of the 19200 classes determined by clay mineralogy, texture, organic matter and relative compaction. The equation parameter for each of the 19200 soil water retention curves was then computed and combined into a new data set. A computer program was written that seeks out the curve parameter nearest to the input data, and then responds with an output that will provide 20 points on the soil water retention curve by weight and volume of the less than 2 mm fraction, and by volume of the whole soil, wet and dry clod bulk densities, the soil water retention curve equation parameters and the parameters of an equation that will allow the computation of the field bulk density (bulk density inclusive of the cracks) at a given water content. This field bulk density is used to compute the soil water retention data on a volumetric bases. An example of the difference between the two curves is shown in figure 16. This output is repeated for each of the three compaction classes.

As the program is now written, input opportunities for identification of soil type or name and horizon designation are provided. This kind of input has no bearing on computations and will only serve as an identification of the soil considered."

The other inputs needed are:

- Volume Percent of Rock Fragments
- Clay Activity
- Weight Percent of Clay
- Weight Percent of Silt
- Weight Percent of Organic Matter

Volume percent of rock fragments was added as an input so that the water contents of the whole soil can be computed."

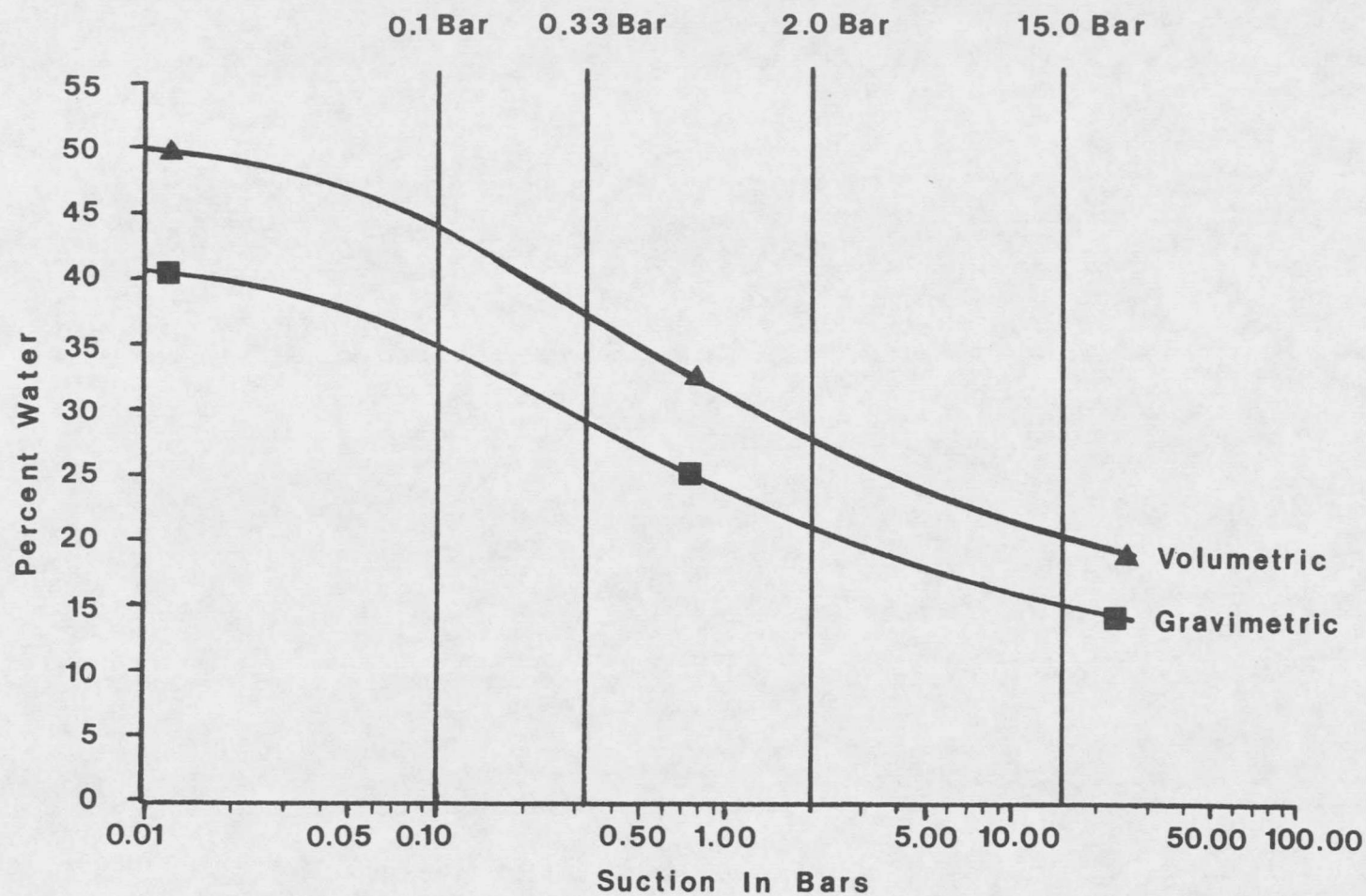


Figure 16. Difference between gravimetric and volumetric soil water retention curves of a clay loam soil (Baumer, 1985).

Baumer (1985) went on to explain that this model was primarily intended to be used in conjunction with the SCS-form 5 and the pedon description. Explicit instructions (see Part 2 of Appendix II) on how to obtain the necessary input data from these documents are described by Baumer and Rice (1986).

Computer Program For Soil Water Retention Curves**SOIL WATER RETENTION DATA PROGRAM**

Description. This program calculates the soil water retention curve for up to nine layers of a soil profile. One of the last prompts allows you to choose an output option of:

- a) composite soil water retention data for the entire profile (see page 13)
- b) soil water retention data for individual horizons (see pages 14-21)
- c) both (a) and (b).

Invocation.

for IBM PCs and compatibles, type: "SWRSYS" <CR>

for AT&T loaded from PC mode, type: "soilwatr" <CR>

for AT&T loaded by sysadm, type: "soilwater" <CR>

Execution. Below is a list of the prompts generated by this program during execution, with explanations regarding their meaning. Be certain to include a decimal point wherever one is requested. If you omit a decimal point where one is required, the program will not detect an error, but the value will be read and stored incorrectly. When you are entering a zero value, no decimal point is necessary. The "%" character should never be entered, even when a percentage is requested.

Enter identification or description of the soil (72 character maximum).

This is an optional prompt, allowing you to enter any soil identification information that you desire. It is carried, unchanged, into the output. You may enter letters, numbers, punctuation and spaces in any combination or you may bypass it entirely by pressing <CR>.

Enter the number of layers (maximum 9) in soil.

This is the number of horizons in the particular soil. If you enter a number greater than nine, the prompt will be redisplayed. If a number less than one is entered, you will be asked if you want to continue the program at all. No decimal point should be entered here, although a trailing point will not cause an error.

SCS-NSSL Method Code: Baumer C986

SOIL WATER RETENTION MODEL

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

<----- SOIL PROPERTIES INPUT BY USER ----->								<----- SOIL SUCTION (bar) ----->					
HORIZON DEPTH (cm)	CLAY ACTIVITY	CLAY <--- weight percent, <2mm --->	SILT	SAND <2mm --->	OM	>2mm vol%	COMPAC- TION	15.0	2.0	1.0	0.33	0.10	0.00
<----- estimated volume percent ----->													
0- 20	high	37.00	37.00	26.00	0.00	0.00	medium	25.93	31.91	34.51	38.91	40.97	41.09
20- 40	high	37.00	37.00	26.00	1.00	0.00	medium	25.42	31.50	34.18	39.07	42.37	42.54
40- 75	high	37.00	37.00	26.00	2.00	0.00	medium	24.78	30.97	33.72	38.87	43.38	43.63
75- 100	high	37.00	37.00	26.00	8.00	0.00	medium	21.00	27.54	30.62	36.59	45.01	49.46
100- 220	low	37.00	37.00	26.00	0.50	0.00	medium	22.16	28.22	30.80	35.52	41.64	42.37
220- 240	mod. low	37.00	37.00	26.00	0.50	0.00	medium	23.30	29.33	31.94	36.80	41.00	41.00
240- 275	mod. high	37.00	37.00	26.00	0.50	0.00	medium	24.50	30.60	33.29	37.99	40.68	40.84
275- 300	high	37.00	37.00	26.00	0.50	0.00	medium	25.68	31.69	34.33	39.00	41.68	41.82

Example 3: Soil Water Retention Program Output (option a)

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #1 (depth= 0- 20 cm.)

required user input: <2mm 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 0.0; clay-activity=high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %
0.00	24.05	37.70	37.70	28.06	41.09	41.09	32.66	44.36	44.36
10.00	24.05	37.70	37.70	28.06	41.09	41.09	32.66	44.36	44.36
20.00	24.05	37.70	37.70	28.06	41.09	41.09	32.66	44.36	44.36
30.00	24.05	37.70	37.70	28.06	41.09	41.09	32.63	44.32	44.32
40.00	24.05	37.70	37.70	28.06	41.09	41.09	32.60	44.28	44.28
60.00	24.05	37.70	37.70	28.04	41.06	41.06	32.50	44.16	44.16
80.00	24.04	37.69	37.69	28.02	41.03	41.03	32.35	43.97	43.97
100.00	24.03	37.67	37.67	27.98	40.98	40.98	32.16	43.74	43.74
150.00	23.99	37.60	37.60	27.80	40.74	40.74	31.55	42.97	42.97
200.00	23.90	37.47	37.47	27.52	40.35	40.35	30.86	42.10	42.10
300.00	23.60	37.03	37.03	26.78	39.33	39.33	29.55	40.44	40.44
340.00	23.45	36.82	36.82	26.47	38.91	38.91	29.09	39.85	39.85
400.00	23.22	36.48	36.48	26.03	38.31	38.31	28.47	39.06	39.06
600.00	22.51	35.42	35.42	24.85	36.67	36.67	26.88	37.02	37.02
1000.00	21.51	33.94	33.94	23.35	34.59	34.59	24.95	34.52	34.52
2000.00	20.22	32.01	32.01	21.49	31.98	31.98	22.60	31.45	31.45
5000.00	18.68	29.70	29.70	19.38	28.97	28.97	19.98	27.96	27.96
10000.00	17.66	28.14	28.14	18.00	27.01	27.01	18.32	25.74	25.74
15300.00	17.08	27.26	27.26	17.25	25.93	25.93	17.42	24.53	24.53
102000.00	14.91	23.94	23.94	14.55	22.01	22.01	14.31	20.30	20.30

clod bulk density for <2mm soil fraction:

oven dry 1.86

wet (1/3 bar) 1.57

1.76

1.47

1.66

1.37

equation parameters:

ALPHA 0.003189
 RM 0.047078
 RN 3.232030
 WCS(WT%) 24.05
 WCR(WT%) 8.44
 BD.INTER 1.67
 BD.SLOPE -0.004094

0.004122
 0.063231
 3.055430
 28.06
 8.44
 1.56
 -0.003589

0.005484
 0.095488
 2.345710
 32.66
 8.44
 1.47
 -0.003266

explanations: ALPHA, RM, RN = independant equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RN)) ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES
 horizon #2 (depth: 20- 40 cm.)
 required user input: <2mm- 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 1.0; clay-activity=high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %
0.00	25.55	38.98	38.98	29.92	42.54	42.54	34.97	45.61	45.61
10.00	25.55	38.98	38.98	29.92	42.54	42.54	34.97	45.61	45.61
20.00	25.55	38.98	38.98	29.92	42.54	42.54	34.97	45.61	45.61
30.00	25.55	38.98	38.98	29.92	42.54	42.54	34.93	45.57	45.57
40.00	25.55	38.98	38.98	29.92	42.54	42.54	34.89	45.51	45.51
60.00	25.55	38.98	38.98	29.90	42.51	42.51	34.74	45.34	45.34
80.00	25.54	38.97	38.97	29.87	42.47	42.47	34.51	45.06	45.06
100.00	25.53	38.95	38.95	29.80	42.38	42.38	34.20	44.69	44.69
150.00	25.44	38.82	38.82	29.46	41.93	41.93	33.24	43.54	43.54
200.00	25.23	38.52	38.52	28.93	41.21	41.21	32.24	42.32	42.32
300.00	24.58	37.59	37.59	27.74	39.63	39.63	30.53	40.24	40.24
340.00	24.32	37.21	37.21	27.32	39.07	39.07	29.97	39.56	39.56
400.00	23.96	36.68	36.68	26.76	38.32	38.32	29.24	38.67	38.67
600.00	23.03	35.34	35.34	25.39	36.46	36.46	27.47	36.48	36.48
1000.00	21.90	33.71	33.71	23.77	34.26	34.26	25.41	33.90	33.90
2000.00	20.51	31.67	31.67	21.81	31.57	31.57	22.93	30.77	30.77
5000.00	18.89	29.28	29.28	19.60	28.50	28.50	20.20	27.28	27.28
10000.00	17.82	27.68	27.68	18.17	26.51	26.51	18.48	25.07	25.07
15300.00	17.21	26.78	26.78	17.39	25.42	25.42	17.56	23.86	23.86
102000.00	14.96	23.40	23.40	14.61	21.48	21.48	14.38	19.68	19.68

clod bulk density for <2mm soil fraction:
 oven dry 1.82
 wet (1/3 bar) 1.53

1.72
 1.43

1.62
 1.32

equation parameters:

ALPHA 0.004573
 RM 0.036589
 RM 4.335960
 WCS(WT%) 25.55
 WCR(WT%) 8.54
 BD.INTER 1.62
 BD.SLOPE -0.003660

0.005500
 0.053871
 3.693770
 29.92
 8.54
 1.52
 -0.003184

0.007074
 0.087286
 2.629330
 34.97
 8.54
 1.41
 -0.003136

explanations: ALPHA, RM, RM = independent equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).
 BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.
 BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RM)) ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #3 (depth: 40- 75 cm.)

required user input: <2mm= 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 2.0; clay-activity=high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %
0.00	27.12	39.94	39.94	31.89	43.63	43.63	37.43	46.80	46.80
10.00	27.12	39.94	39.94	31.89	43.63	43.63	37.43	46.80	46.80
20.00	27.12	39.94	39.94	31.89	43.63	43.63	37.43	46.80	46.80
30.00	27.12	39.94	39.94	31.89	43.63	43.63	37.39	46.75	46.75
40.00	27.12	39.94	39.94	31.89	43.63	43.63	37.33	46.68	46.68
60.00	27.12	39.94	39.94	31.87	43.61	43.61	37.12	46.45	46.45
80.00	27.11	39.93	39.93	31.82	43.54	43.54	36.78	46.05	46.05
100.00	27.09	39.90	39.90	31.70	43.40	43.40	36.32	45.53	45.53
150.00	26.91	39.65	39.65	31.10	42.62	42.62	34.94	43.95	43.95
200.00	26.47	39.04	39.04	30.22	41.51	41.51	33.62	42.42	42.42
300.00	25.46	37.65	37.65	28.67	39.51	39.51	31.57	40.03	40.03
340.00	25.12	37.18	37.18	28.17	38.87	38.87	30.93	39.28	39.28
400.00	24.68	36.57	36.57	27.54	38.05	38.05	30.12	38.32	38.32
600.00	23.63	35.11	35.11	26.02	36.09	36.09	28.18	36.02	36.02
1000.00	22.40	33.38	33.38	24.28	33.80	33.80	25.96	33.36	33.36
2000.00	20.89	31.25	31.25	22.19	31.04	31.04	23.33	30.17	30.17
5000.00	19.15	28.76	28.76	19.85	27.91	27.91	20.46	26.64	26.64
10000.00	17.99	27.11	27.11	18.35	25.89	25.89	18.67	24.40	24.40
15300.00	17.35	26.18	26.18	17.53	24.78	24.78	17.70	23.20	23.20
102000.00	14.98	22.73	22.73	14.64	20.83	20.83	14.42	19.03	19.03

clod bulk density for <2mm soil fraction:

oven dry	1.78	1.67	1.57
wet (1/3 bar)	1.48	1.38	1.27

equation parameters:

ALPHA	0.005799	0.006786	0.008512
RM	0.030141	0.047438	0.081302
RN	5.563780	4.365140	2.919260
WCS(WT%)	27.12	31.89	37.43
WCR(WT%)	8.64	8.64	8.64
BD.INTER	1.57	1.47	1.36
BD.SLOPE	-0.003702	-0.003159	-0.003039

explanations: ALPHA, RM, RN = independant equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RN)) ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #4 (depth= 75- 100 cm.)

required user input: <2mm= 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 8.0; clay-activity=high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %
0.00	38.60	46.03	46.03	46.63	49.46	49.46	56.55	53.37	53.37
10.00	38.60	46.03	46.03	46.63	49.46	49.46	56.55	53.37	53.37
20.00	38.60	46.03	46.03	46.63	49.46	49.46	56.55	53.37	53.37
30.00	38.60	46.03	46.03	46.63	49.46	49.46	56.46	53.30	53.30
40.00	38.60	46.03	46.03	46.63	49.46	49.46	56.19	53.07	53.07
60.00	38.60	46.03	46.03	46.31	49.16	49.16	54.50	51.70	51.70
80.00	38.18	45.58	45.58	43.97	46.98	46.98	51.89	49.56	49.56
100.00	36.78	44.08	44.08	42.05	45.17	45.17	49.47	47.53	47.53
150.00	34.29	41.36	41.36	38.83	42.08	42.08	45.08	43.80	43.80
200.00	32.66	39.57	39.57	36.74	40.04	40.04	42.21	41.30	41.30
300.00	30.55	37.21	37.21	34.04	37.37	37.37	38.53	38.05	38.05
340.00	29.93	36.52	36.52	33.27	36.59	36.59	37.48	37.11	37.11
400.00	29.16	35.65	35.65	32.29	35.61	35.61	36.17	35.93	35.93
600.00	27.36	33.60	33.60	30.03	33.32	33.32	33.17	33.18	33.18
1000.00	25.32	31.26	31.26	27.49	30.71	30.71	29.85	30.11	30.11
2000.00	22.92	28.47	28.47	24.54	27.63	27.63	26.08	26.54	26.54
5000.00	20.28	25.36	25.36	21.36	24.24	24.24	22.13	22.73	22.73
10000.00	18.63	23.40	23.40	19.40	22.13	22.13	19.77	20.42	20.42
15300.00	17.74	22.33	22.33	18.35	21.00	21.00	18.54	19.21	19.21
102000.00	14.70	18.64	18.64	14.86	17.15	17.15	14.59	15.25	15.25

clod bulk density for <2mm soil fraction:

oven dry 1.52

wet (1/3 bar) 1.22

1.41

1.10

1.29

0.99

equation parameters:

ALPHA 0.013145

RM 0.009802

RN 23.838425

WCS(WT%) 38.60

WCR(WT%) 9.24

BD.INTER 1.31

BD.SLOPE -0.003174

0.016705

0.011942

21.322723

46.63

9.24

1.20

-0.002946

0.017238

0.056488

5.165440

56.55

9.24

1.08

-0.002428

explanations: ALPHA, RM, RN = independent equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RM)) ** RM

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #5 (depth: 100- 220 cm.)

required user input: <2mm: 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 0.5; clay-activity=low

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %
0.00	24.62	38.56	38.56	28.71	42.37	42.37	33.39	45.87	45.87
10.00	24.62	38.56	38.56	28.71	42.37	42.37	33.39	45.87	45.87
20.00	24.62	38.56	38.56	28.71	42.37	42.37	33.39	45.87	45.87
30.00	24.62	38.56	38.56	28.71	42.37	42.37	33.39	45.87	45.87
40.00	24.62	38.56	38.56	28.71	42.37	42.37	33.39	45.87	45.87
60.00	24.62	38.56	38.56	28.71	42.37	42.37	33.35	45.81	45.81
80.00	24.61	38.54	38.54	28.66	42.30	42.30	32.62	44.84	44.84
100.00	24.53	38.42	38.42	28.27	41.73	41.73	31.53	43.36	43.36
150.00	23.73	37.18	37.18	26.81	39.61	39.61	29.56	40.71	40.71
200.00	22.99	36.06	36.06	25.78	38.11	38.11	28.26	38.94	38.94
300.00	22.01	34.54	34.54	24.41	36.11	36.11	26.53	36.60	36.60
340.00	21.71	34.08	34.08	24.00	35.52	35.52	26.02	35.91	35.91
400.00	21.33	33.51	33.51	23.49	34.77	34.77	25.38	35.03	35.03
600.00	20.43	32.11	32.11	22.26	32.98	32.98	23.86	32.96	32.96
1000.00	19.36	30.46	30.46	20.82	30.88	30.88	22.09	30.56	30.56
2000.00	18.02	28.39	28.39	19.06	28.29	28.29	19.95	27.64	27.64
5000.00	16.43	25.92	25.92	17.01	25.28	25.28	17.51	24.29	24.29
10000.00	15.35	24.24	24.24	15.65	23.28	23.28	15.92	22.11	22.11
15300.00	14.74	23.28	23.28	14.89	22.16	22.16	15.04	20.89	20.89
102000.00	12.39	19.60	19.60	12.07	17.98	17.98	11.85	16.50	16.50

clod bulk density for <2mm soil fraction:

oven dry 1.65

wet (1/3 bar) 1.57

1.55

1.48

1.45

1.38

equation parameters:

ALPHA 0.009307
 RM 0.011869
 RN 11.267950
 WCS(WT%) 24.62
 WCR(WT%) 4.24
 BD.INTER 1.60
 BD.SLOPE -0.001336

0.010973
 0.012145
 13.369660
 28.71
 4.24
 1.50
 -0.000875

0.014304
 0.013244
 13.913880
 33.39
 4.24
 1.40
 -0.000846

explanations: ALPHA, RM, RN = independent equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RN)) ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #6 (depth: 220- 240 cm.)

required user input: <2mm 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 0.5; clay-activity=mod.low

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	WHOLE SOIL vol. %	WHOLE SOIL vol. %
0.00	23.58	37.65	37.65	27.44	41.00	41.00	31.83	44.23	44.23
10.00	23.58	37.65	37.65	27.44	41.00	41.00	31.83	44.23	44.23
20.00	23.58	37.65	37.65	27.44	41.00	41.00	31.83	44.23	44.23
30.00	23.58	37.65	37.65	27.44	41.00	41.00	31.83	44.23	44.23
40.00	23.58	37.65	37.65	27.44	41.00	41.00	31.83	44.23	44.23
60.00	23.58	37.64	37.64	27.44	41.00	41.00	31.83	44.23	44.23
80.00	23.56	37.63	37.63	27.44	41.00	41.00	31.80	44.19	44.19
100.00	23.54	37.59	37.59	27.44	41.00	41.00	31.65	43.99	43.99
150.00	23.38	37.35	37.35	27.27	40.75	40.75	30.36	42.28	42.28
200.00	23.08	36.88	36.88	26.39	39.48	39.48	29.02	40.49	40.49
300.00	22.34	35.73	35.73	24.95	37.41	37.41	27.19	38.03	38.03
340.00	22.07	35.31	35.31	24.53	36.80	36.80	26.65	37.31	37.31
400.00	21.71	34.75	34.75	23.99	36.02	36.02	25.97	36.40	36.40
600.00	20.81	33.36	33.36	22.73	34.17	34.17	24.38	34.25	34.25
1000.00	19.74	31.68	31.68	21.25	32.02	32.02	22.56	31.77	31.77
2000.00	18.40	29.59	29.59	19.46	29.40	29.40	20.37	28.78	28.78
5000.00	16.84	27.12	27.12	17.42	26.38	26.38	17.92	25.40	25.40
10000.00	15.78	25.47	25.47	16.08	24.40	24.40	16.35	23.22	23.22
15300.00	15.19	24.53	24.53	15.34	23.30	23.30	15.49	22.03	22.03
102000.00	12.95	20.98	20.98	12.65	19.28	19.28	12.46	17.79	17.79

clod bulk density for <2mm soil fraction:
oven dry 1.76
wet (1/3 bar) 1.60

1.66
1.50
1.56
1.40

equation parameters:

ALPHA	0.005296	0.006600	0.008770
RM	0.035227	0.012835	0.024697
RM	4.223560	14.131030	8.330160
WCS(WT%)	23.58	27.44	31.83
WCR(WT%)	6.10	6.10	6.10
BD.INTER	1.65	1.55	1.45
BD.SLOPE	-0.002130	-0.002038	-0.001989

explanations: ALPHA, RM, RM = independant equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + [(WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RM)] ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

Example 9: Soil Water Retention Program Output (option b)

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES
 horizon #7 (depth= 240- 275 cm.)
 required user input: <2mm= 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 0.5; clay-activity=mod.high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %
0.00	23.63	37.51	37.51	27.52	40.84	40.84	31.96	44.07	44.07
10.00	23.63	37.51	37.51	27.52	40.84	40.84	31.96	44.07	44.07
20.00	23.63	37.51	37.51	27.52	40.84	40.84	31.94	44.05	44.05
30.00	23.63	37.51	37.51	27.52	40.84	40.84	31.92	44.01	44.01
40.00	23.63	37.51	37.51	27.52	40.84	40.84	31.88	43.96	43.96
60.00	23.63	37.51	37.51	27.50	40.81	40.81	31.75	43.80	43.80
80.00	23.62	37.49	37.49	27.46	40.77	40.77	31.56	43.55	43.55
100.00	23.61	37.47	37.47	27.41	40.69	40.69	31.32	43.24	43.24
150.00	23.54	37.36	37.36	27.16	40.34	40.34	30.57	42.27	42.27
200.00	23.40	37.15	37.15	26.77	39.79	39.79	29.77	41.22	41.22
300.00	22.95	36.48	36.48	25.85	38.49	38.49	28.33	39.35	39.35
340.00	22.75	36.17	36.17	25.50	37.99	37.99	27.85	38.71	38.71
400.00	22.45	35.72	35.72	25.02	37.31	37.31	27.21	37.87	37.87
600.00	21.62	34.46	34.46	23.77	35.53	35.53	25.61	35.75	35.75
1000.00	20.56	32.83	32.83	22.25	33.36	33.36	23.70	33.21	33.21
2000.00	19.21	30.76	30.76	20.38	30.68	30.68	21.39	30.11	30.11
5000.00	17.63	28.32	28.32	18.27	27.61	27.61	18.82	26.62	26.62
10000.00	16.58	26.69	26.69	16.90	25.61	25.61	17.19	24.40	24.40
15300.00	15.99	25.77	25.77	16.15	24.50	24.50	16.31	23.18	23.18
102000.00	13.78	22.31	22.31	13.46	20.52	20.52	13.25	18.95	18.95

clod bulk density for <2mm soil fraction:
 oven dry 1.82
 wet (1/3 bar) 1.59

1.72
 1.49

1.63
 1.39

equation parameters:

ALPHA 0.003817
 RM 0.044513
 RN 3.517450
 WCS(WT%) 23.63
 WCR(WT%) 7.41
 BD.INTER 1.66
 BD.SLOPE -0.003165

0.004777
 0.060743
 3.196640
 27.52
 7.41
 1.56
 -0.002902

0.006313
 0.092301
 2.405210
 31.96
 7.41
 1.47
 -0.002729

explanations: ALPHA, RM, RN = independent equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RN)) ** RM)
 FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE
 WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)
 WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

CALCULATED SOIL WATER RETENTION CURVE DATA

soil name: SOIL WATER RETENTION DATA SYSTEM EXAMPLES

horizon #8 (depth= 275- 300 cm.)

required user input: <2mm 0.0; clay=37.0; silt=37.0; sand=26.0; OM= 0.5; clay-activity=high

***** WATER CONTENTS *****

SOIL SUCTION (cm) (1 bar = 1020 cm)	MODERATELY HIGH COMPACTION			AVERAGE COMPACTION (expected)			MODERATELY LOW COMPACTION		
	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %	<2mm SOIL FRACTION wt. %	vol. %	WHOLE SOIL vol. %
0.00	24.79	38.34	38.34	28.98	41.82	41.82	33.80	45.19	45.19
10.00	24.79	38.34	38.34	28.98	41.82	41.82	33.80	45.19	45.19
20.00	24.79	38.34	38.34	28.98	41.82	41.82	33.80	45.19	45.19
30.00	24.79	38.34	38.34	28.98	41.82	41.82	33.76	45.15	45.15
40.00	24.79	38.34	38.34	28.98	41.82	41.82	33.73	45.10	45.10
60.00	24.79	38.34	38.34	28.96	41.79	41.79	33.60	44.95	44.95
80.00	24.78	38.33	38.33	28.93	41.75	41.75	33.42	44.72	44.72
100.00	24.77	38.31	38.31	28.88	41.69	41.69	33.17	44.42	44.42
150.00	24.71	38.22	38.22	28.64	41.36	41.36	32.40	43.46	43.46
200.00	24.57	38.02	38.02	28.24	40.82	40.82	31.55	42.40	42.40
300.00	24.11	37.35	37.35	27.27	39.51	39.51	30.03	40.50	40.50
340.00	23.90	37.05	37.05	26.90	39.00	39.00	29.52	39.85	39.85
400.00	23.59	36.60	36.60	26.40	38.32	38.32	28.84	39.00	39.00
600.00	22.75	35.37	35.37	25.10	36.55	36.55	27.16	36.86	36.86
1000.00	21.69	33.81	33.81	23.55	34.41	34.41	25.16	34.30	34.30
2000.00	20.35	31.82	31.82	21.64	31.76	31.76	22.75	31.18	31.18
5000.00	18.78	29.49	29.49	19.48	28.73	28.73	20.08	27.68	27.68
10000.00	17.74	27.91	27.91	18.09	26.76	26.76	18.40	25.46	25.46
15300.00	17.15	27.03	27.03	17.32	25.68	25.68	17.49	24.25	24.25
102000.00	14.95	23.69	23.69	14.58	21.75	21.75	14.35	20.03	20.03

clod bulk density for <2mm soil fraction:

oven dry 1.84

wet (1/3 bar) 1.55

1.74

1.45

1.64

1.35

equation parameters:

ALPHA 0.003913

RM 0.040989

RN 3.770630

WCS(WT%) 24.79

WCR(WT%) 8.49

BD.INTER 1.64

BD.SLOPE -0.003849

0.004832

0.057931

3.376870

28.98

8.49

1.54

-0.003383

0.006305

0.090920

2.488970

33.80

8.49

1.44

-0.003015

explanations: ALPHA, RM, RN = independant equation parameters.

WCS = wt% of water at zero suction (saturation); WCR = residual water content (near air dry).

BD.INTER = bulk density intercept, ie: the field bulk density of the whole soil (including cracks) for dry soil.

BD.SLOPE = the slope with which the field bulk density changes as a function of water content.

model equations: WATER CONTENT (WT%) = WCR + ((WCS - WCR) / (1.0 + (ALPHA * SUCTION) ** RN)) ** RM)

FIELD BULK DENSITY = BD.INTER + WATER(WT%) * BD.SLOPE

WATER CONTENT (VOL%) = WATER(WT%) * (FIELD BULK DENSITY)

WATER CONTENT (WHOLE SOIL - VOL%) = WATER(VOL%) * (1.0 - (ROCK FRAGMENTS(VOL%) / 100.0))

The following prompts are displayed for each of the horizons. Horizon #1 is understood by the program to be the top horizon in the profile, with larger numbers corresponding to horizons at increasing depths.

Enter depth to bottom of layer #x (cm) including decimal point.

The number requested is the depth in centimeters from the top of the soil profile to the bottom of the current horizon (not the thickness of the horizon). The decimal point is required.

Enter percent of rock fragments in soil (with decimal point).

Any value between 0 and 100.0 (inclusive) is acceptable. This prompt is requesting a volume percentage, however all other percent entries are expected to be on a gravimetric basis.

There are four choices of clay activity:

- 1) LOW (kaolinitic or oxidic): 0.15*
- 2) MODERATELY LOW (illitic or mixed with kaolinite): 0.35*
- 3) MODERATELY HIGH (mixed with montmorillonite): 0.55*
- 4) HIGH (montmorillonite dominated): 0.75*

Enter one of these option numbers (1,2,3 or 4)

Any number outside of the range 1-4 will cause the prompt to be redisplayed. No decimal point should be entered, although a trailing point will not cause an error.

Enter percent of clay in soil (less than 80%), including decimal point.

Any value greater than or equal to zero and less than 80.0 is acceptable. Values of 80.0 or greater may be accepted but will cause a run-time error. The decimal point is required.

Enter percent of silt in soil, including decimal point.

Any value from 0 to 100.0 (inclusive) is acceptable. The decimal point is required.

At this point, the program calculates the sand content by subtracting the percentages of clay and silt from 100. If the percentages of clay and silt add up to more than 100, then an error message is displayed, and you are returned to the "percent of clay" prompt.

Enter percent of organic matter (maximum 10%) with decimal point.

Any value between 0 and 10.0 (inclusive) is acceptable. The decimal point is required.

Enter compaction code. 1 - high compaction
 2 - medium compaction
 3 - low compaction

Any value outside the 1-3 range will cause the prompt to be redisplayed. No decimal point should be entered, although a trailing point will not cause an error.

DATA FOR LAYER #x

layer depth = xxxx.x cm
 rock fragments = xxxx.x %
 clay activity = aaaaaaaa
 clay = xxx.xx %
 silt = xxx.xx %
 sand = xxx.xx %
 organic matter = xxx.xx %
 compaction = aaaaa

Are the above values correct? (Y(default)/N)

The x's in the prompt are numeric values and the a's are descriptive words. Review the information displayed here, and if there are any errors, enter an 'n' (upper or lower case). This will return you to the start of the program and you will have to re-enter all the information. If you type 'Y' or just press <CR> without typing anything, the program will continue to the next step which is to look up the equation parameters in the data tables. (If you are using a PC, this is where you will be prompted to insert one of the data disks in the A disk drive.)

After reading the information from the data tables, the program will loop back for the information about the next horizon or, if all horizons have been entered, request the desired program function via the next prompt.

Enter the code number for the desired program function (from the list below).

- 1 - Composite profile information*
- 2 - Both individual and composite*
- 3 - Individual horizon information*
- 4 - Quit*

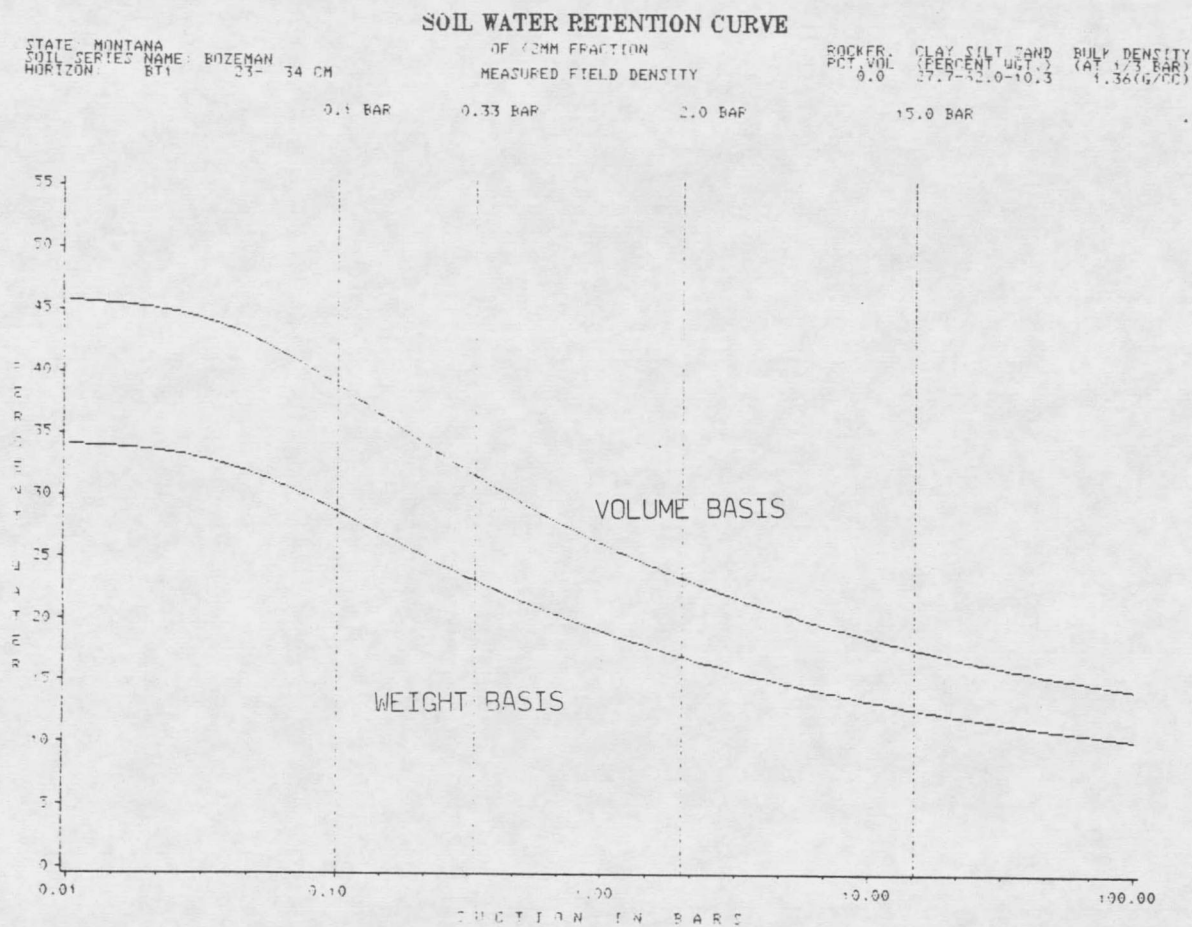
Any value outside the 1-4 range will cause the prompt to be redisplayed. Option 1 will calculate and print out one table of soil and hydraulic parameters for all horizons in the profile. Option 3 will print out an individual table for each horizon. Option 2 causes both outputs to be prepared. No decimal point should be entered, but a trailing point will not cause an error.

Do you want another run? (Y/N(default))

After all calculations for the soil profile have been completed, the above prompt is displayed. If you enter a 'y' (upper or lower case), then you will be returned to the beginning of the program for an entirely new run. Entering an 'n' or pressing <CR> without entering anything will end the program and return you to the operating system.

Measured Field Density

Examples of Soil Water Retention Curves



NOTE: VOLUME GRAPH IS GREATER THAN THE WEIGHT GRAPH

NSSL - 10 854105-0

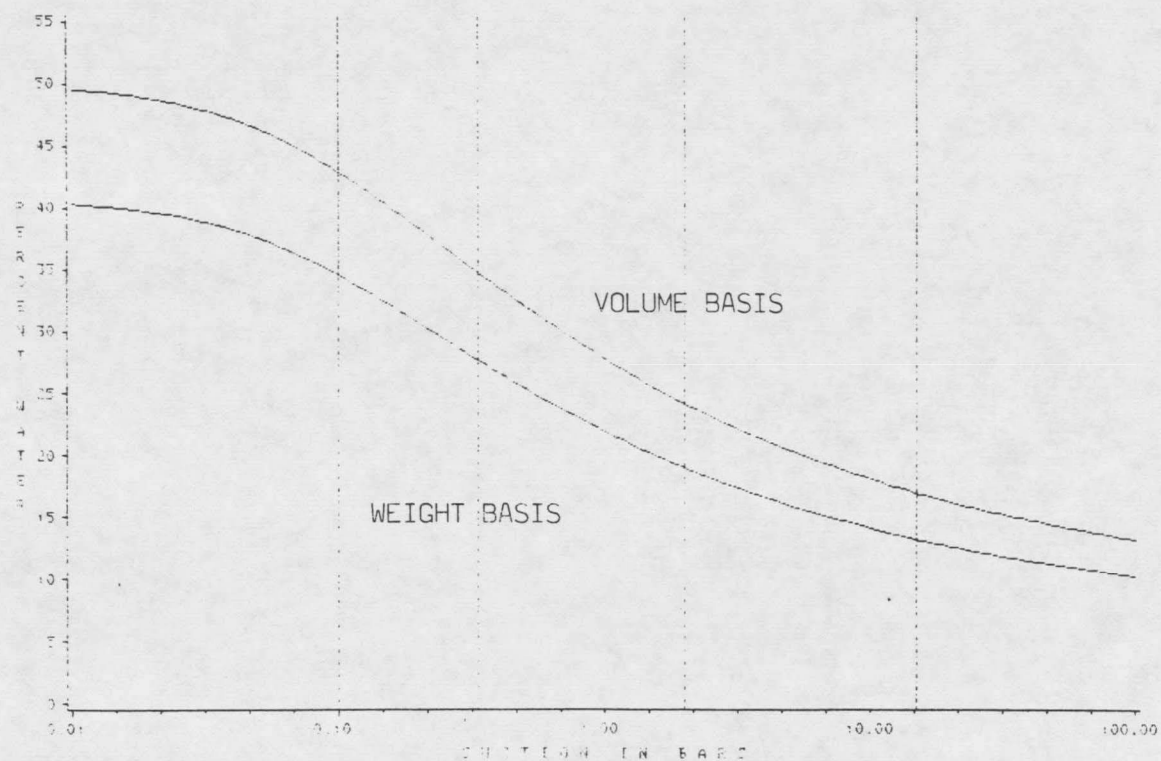
SOIL WATER RETENTION CURVE

STATE: MONTANA
SOIL SERIES NAME: BOZEMAN
HORIZON: B11 34 CM

OF (2MM FRACTION)
EXPECTED LOW DENSITY

ROCKER: CLAY SILT SAND BULK DENSITY
PCT VOL (PERCENT WGT) (AT 1/3 BAR)
0.0 27.7-62.0-10.3 1.25(G/CC)

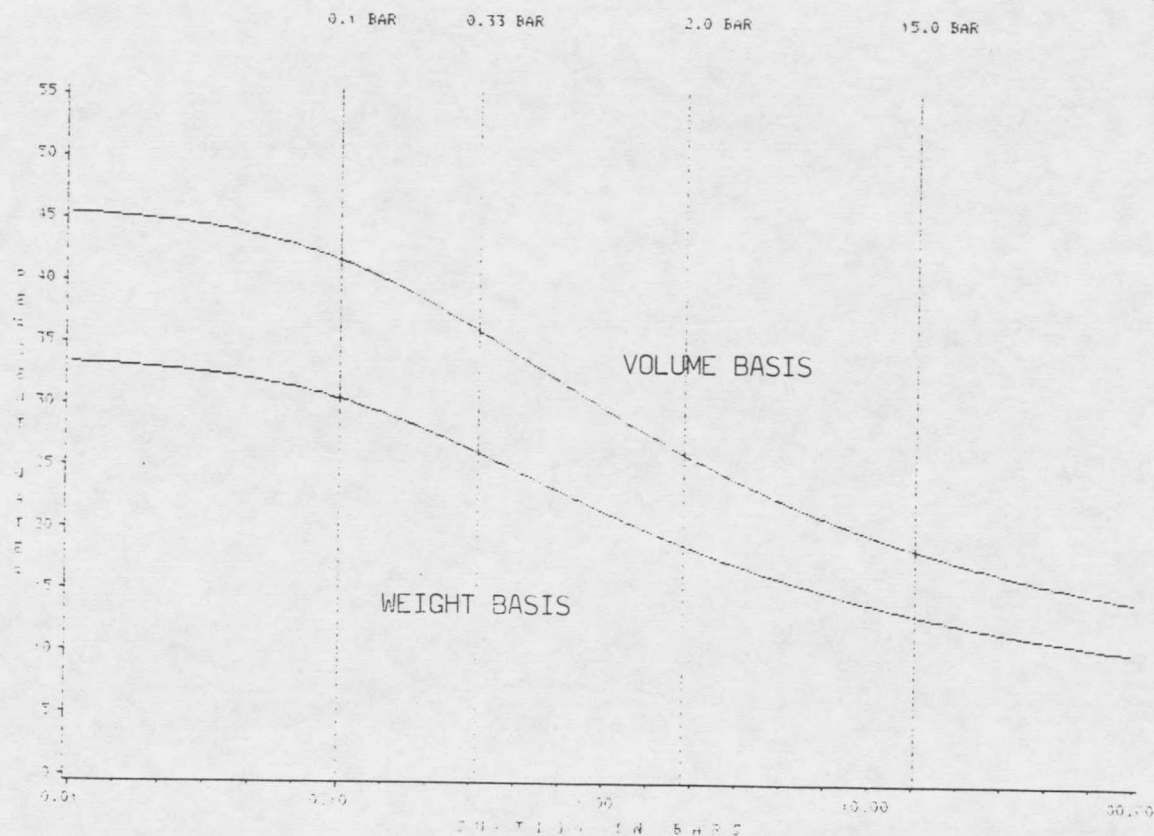
0.1 BAR 0.33 BAR 2.0 BAR 15.0 BAR



NOTE: VOLUME GRAPH IS GREATER THAN THE WEIGHT GRAPH

NSSL - ID 854105-3

STATE: MONTANA
 SOIL SERIES NAME: BOZEMAN 34 CM
 HORIZON: BT1
 SOIL WATER RETENTION CURVE
 OF 2MM FRACTION
 EXPECTED MEDIUM DENSITY
 ROCKS: 0.0
 CLAY: 27.7
 SILT: 62.0
 SAND: 10.3
 BULK DENSITY (AT 1/3 BAR)
 1.37 (G/CC)



NOTE: VOLUME GRAPH IS GREATER THAN THE WEIGHT GRAPH

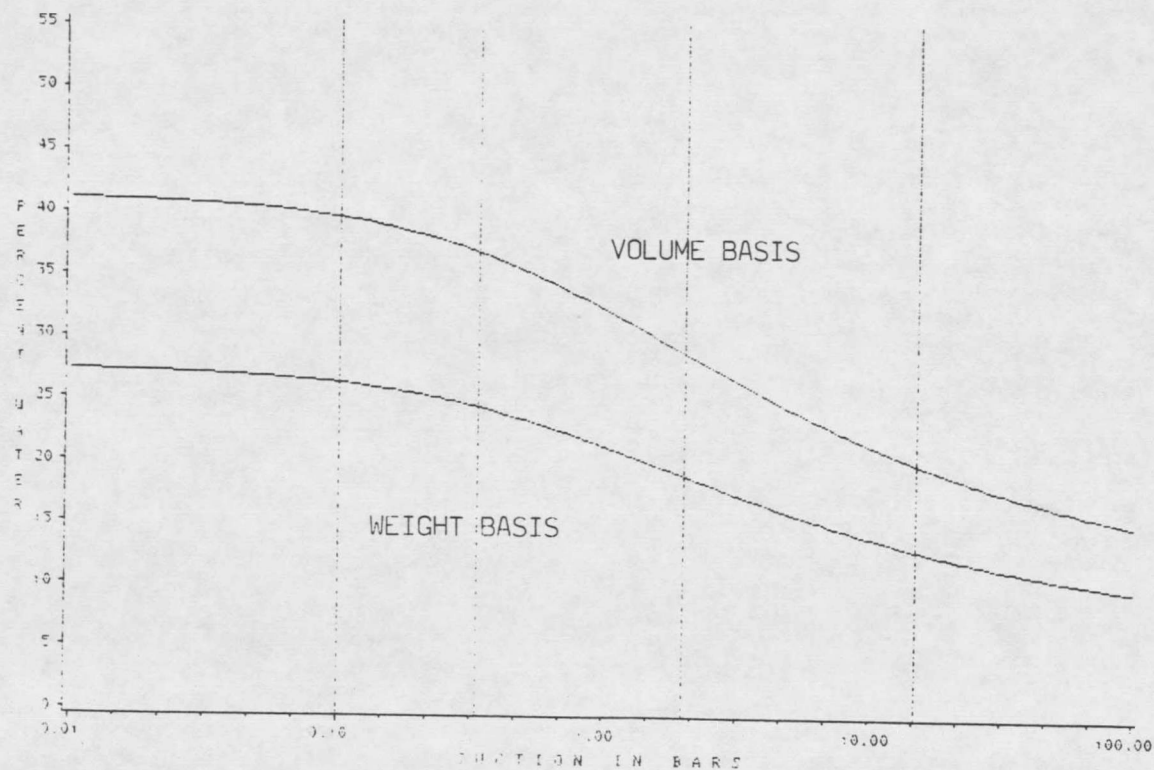
MOCL - 10 854105-2

STATE: MONTANA
SOIL SERIES NAME: BOZEMAN 34 CM
HORIZON: B11 23- 34 CM

SOIL WATER RETENTION CURVE
OF (2MM FRACTION)
EXPECTED HIGH DENSITY

ROCKFR. PCT. VOL. 0.0
CLAY SILT SAND (PERCENT WGT.) 27.7-62.0-10.3
BULK DENSITY (AT 1/3 BAR) 1.50 (G/CC)

0.1 BAR 0.33 BAR 2.0 BAR 15.0 BAR



NOTE: VOLUME GRAPH IS GREATER THAN THE WEIGHT GRAPH

NSSL - FD 854105-1

APPENDIX III

WATER USE COMPUTER PROGRAM

Figure 17. Computer program for conversion of drainage data to regression variables.

```

      INTEGER ND,NT
      PARAMETER(ND=100)
      PARAMETER(NT=100)
      DIMENSION DEPTH(ND),SUMWC(ND)
      DOUBLE PRECISION TIME(NT)
      DOUBLE PRECISION WC(ND,NT),W(ND,NT),S(ND,NT)
      REAL Y1,Y2,Y4,X
      OUTPUT "INPUT DEPTH (FOLLOWED BY DECIMAL POINT): "
      READ(105,100)RDEPTH
100  FORMAT(F5.2)
      OUTPUT "INPUT THETA-M: "
      READ(105,115)THETAM
115  FORMAT(F5.3)
      READ(25,103)NHOLE,NTIME,NDEPTH
      DEPTH(1)=RDEPTH
      DO 20 J=1,NTIME
      READ(25,105)IHOLE,JTIME,TIME(J),(WC(I,J),I=1,NDEPTH)
105  FORMAT(I1,I2,F7,100F5)
      SUMWC(1)=WC(1,J)
      SUMWC(2)=WC(2,J)
      DO 25 I=3,NDEPTH
      SUMWC(I)=SUMWC(I-1)+WC(I,J)
25   CONTINUE
      W(1,J)=SUMWC(1)*RDEPTH
      S(1,J)=W(1,J)/DEPTH(1)
      DO 10 K=2,NDEPTH
      W(K,J)=(SUMWC(K)*15.)+W(1,J)
      DEPTH(K)=DEPTH(K-1)+15.
      S(K,J)=W(K,J)/DEPTH(K)
10   CONTINUE
20   CONTINUE
      DO 40 K=1,NDEPTH
      DO 30 J=1,NTIME
      Y1=DLOG(WC(K,J)/THETAM)
      Y2=THETAM-WC(K,J)
      Y4=S(K,J)
      IF (TIME(J) .NE. 0) GO TO 102
      X=0
      GO TO 101
102  X=DLOG(TIME(J)*60.)
101  WRITE(9,160)K,J,Y1,Y2,Y4,X,TIME(J)
30   CONTINUE
40   CONTINUE
160  FORMAT(2I2,7F10.4)
103  FORMAT(3I3)
      END

```

APPENDIX IV

REGRESSION DATA FOR DETERMINATION OF
HYDRAULIC CONDUCTIVITY

Table 35. Regression data, site 1.

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
101	0.3920	-.9365	0.3920	-.9365	0.0000	0.0000
102	0.3910	-.9390	0.3910	-.9390	3.4012	0.5000
103	0.3860	-.9519	0.3860	-.9519	4.0110	0.9200
104	0.3820	-.9623	0.3820	-.9623	4.4998	1.5000
105	0.3830	-.9597	0.3830	-.9597	5.1059	2.7500
106	0.3790	-.9702	0.3790	-.9702	5.3240	3.4200
107	0.3810	-.9649	0.3810	-.9649	5.6525	4.7500
108	0.3720	-.9888	0.3720	-.9888	5.9140	6.1700
109	0.3760	-.9781	0.3760	-.9781	6.1092	7.5000
110	0.3790	-.9702	0.3790	-.9702	6.3103	9.1700
111	0.3790	-.9702	0.3790	-.9702	6.4457	10.4999
112	0.3790	-.9702	0.3790	-.9702	6.5793	12.0000
113	0.3780	-.9728	0.3780	-.9728	6.6911	13.4200
114	0.3790	-.9702	0.3790	-.9702	6.8352	15.4999
115	0.3790	-.9702	0.3790	-.9702	7.0901	20.0000
116	0.3730	-.9861	0.3730	-.9861	7.1854	22.0000
117	0.3700	-.9942	0.3700	-.9942	7.4845	29.6700
118	0.3780	-.9728	0.3780	-.9728	7.7232	37.6700
119	0.3720	-.9888	0.3720	-.9888	7.8710	43.6700
120	0.3660	-1.0051	0.3660	-1.0051	8.1316	56.6700
121	0.3680	-.9996	0.3680	-.9996	8.2414	63.2500
122	0.3760	-.9781	0.3760	-.9781	8.5011	82.0000
123	0.3690	-.9969	0.3690	-.9969	8.7857	109.0000
124	0.3690	-.9969	0.3690	-.9969	8.9695	130.9999
125	0.3680	-.9996	0.3680	-.9996	9.1226	152.6700
126	0.3640	-1.0106	0.3640	-1.0106	9.2610	175.3299
127	0.3640	-1.0106	0.3640	-1.0106	9.4042	202.3300
128	0.3660	-1.0051	0.3660	-1.0051	9.4287	207.3299
129	0.3580	-1.0272	0.3580	-1.0272	9.5097	224.8300
130	0.3610	-1.0188	0.3610	-1.0188	9.6231	251.8301
131	0.3590	-1.0244	0.3590	-1.0244	9.7892	297.3297
132	0.3590	-1.0244	0.3590	-1.0244	9.9417	346.3296
133	0.3580	-1.0272	0.3580	-1.0272	10.0840	399.3295
134	0.3550	-1.0356	0.3550	-1.0356	10.2392	466.3295
135	0.3570	-1.0300	0.3570	-1.0300	10.3372	514.3295
136	0.3530	-1.0412	0.3530	-1.0412	10.4247	561.3296
201	0.3913	-.9382	0.3913	-.9382	0.0000	0.0000
202	0.3903	-.9408	0.3903	-.9408	3.4012	0.5000
203	0.3867	-.9501	0.3867	-.9501	4.0110	0.9200
204	0.3830	-.9597	0.3830	-.9597	4.4998	1.5000
205	0.3820	-.9623	0.3820	-.9623	5.1059	2.7500

Table 35. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
206	0.3780	-.9728	0.3780	-.9728	5.3240	3.4200
207	0.3780	-.9728	0.3780	-.9728	5.6525	4.7500
208	0.3713	-.9907	0.3713	-.9907	5.9140	6.1700
209	0.3747	-.9816	0.3747	-.9816	6.1092	7.5000
210	0.3763	-.9773	0.3763	-.9773	6.3103	9.1700
211	0.3753	-.9800	0.3753	-.9800	6.4457	10.4999
212	0.3757	-.9789	0.3757	-.9789	6.5793	12.0000
213	0.3740	-.9835	0.3740	-.9835	6.6911	13.4200
214	0.3737	-.9843	0.3737	-.9843	6.8352	15.4999
215	0.3730	-.9861	0.3730	-.9861	7.0901	20.0000
216	0.3693	-.9961	0.3693	-.9961	7.1854	22.0000
217	0.3653	-1.0070	0.3653	-1.0070	7.4845	29.6700
218	0.3733	-.9853	0.3733	-.9853	7.7232	37.6700
219	0.3680	-.9996	0.3680	-.9996	7.8710	43.6700
220	0.3630	-1.0133	0.3630	-1.0133	8.1316	56.6700
221	0.3627	-1.0141	0.3627	-1.0141	8.2414	63.2500
222	0.3697	-.9950	0.3697	-.9950	8.5011	82.0000
223	0.3620	-1.0161	0.3620	-1.0161	8.7857	109.0000
224	0.3630	-1.0133	0.3630	-1.0133	8.9695	130.9999
225	0.3610	-1.0188	0.3610	-1.0188	9.1226	152.6700
226	0.3583	-1.0263	0.3583	-1.0263	9.2610	175.3299
227	0.3563	-1.0319	0.3563	-1.0319	9.4042	202.3300
228	0.3590	-1.0244	0.3590	-1.0244	9.4287	207.3299
229	0.3520	-1.0441	0.3520	-1.0441	9.5097	224.8300
230	0.3540	-1.0384	0.3540	-1.0384	9.6231	251.8301
231	0.3527	-1.0421	0.3527	-1.0421	9.7892	297.3297
232	0.3507	-1.0478	0.3507	-1.0478	9.9417	346.3296
233	0.3500	-1.0498	0.3500	-1.0498	10.0840	399.3295
234	0.3480	-1.0555	0.3480	-1.0555	10.2392	466.3295
235	0.3497	-1.0506	0.3497	-1.0506	10.3372	514.3295
236	0.3473	-1.0575	0.3473	-1.0575	10.4247	561.3296
301	0.3940	-.9314	0.3940	-.9314	0.0000	0.0000
302	0.3925	-.9352	0.3925	-.9352	3.4012	0.5000
303	0.3892	-.9436	0.3892	-.9436	4.0110	0.9200
304	0.3860	-.9519	0.3860	-.9519	4.4998	1.5000
305	0.3835	-.9584	0.3835	-.9584	5.1059	2.7500
306	0.3792	-.9696	0.3792	-.9696	5.3240	3.4200
307	0.3787	-.9710	0.3787	-.9710	5.6525	4.7500
308	0.3738	-.9840	0.3738	-.9840	5.9140	6.1700
309	0.3775	-.9741	0.3775	-.9741	6.1092	7.5000
310	0.3775	-.9741	0.3775	-.9741	6.3103	9.1700
311	0.3757	-.9789	0.3757	-.9789	6.4457	10.4999

Table 35. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
312	0.3765	-.9768	0.3765	-.9768	6.5793	12.0000
313	0.3747	-.9816	0.3747	-.9816	6.6911	13.4200
314	0.3762	-.9776	0.3762	-.9776	6.8352	15.4999
315	0.3743	-.9827	0.3743	-.9827	7.0901	20.0000
316	0.3695	-.9956	0.3695	-.9956	7.1854	22.0000
317	0.3665	-1.0037	0.3665	-1.0037	7.4845	29.6700
318	0.3738	-.9840	0.3738	-.9840	7.7232	37.6700
319	0.3693	-.9961	0.3693	-.9961	7.8710	43.6700
320	0.3640	-1.0106	0.3640	-1.0106	8.1316	56.6700
321	0.3623	-1.0152	0.3623	-1.0152	8.2414	63.2500
322	0.3693	-.9961	0.3693	-.9961	8.5011	82.0000
323	0.3620	-1.0161	0.3620	-1.0161	8.7857	109.0000
324	0.3630	-1.0133	0.3630	-1.0133	8.9695	130.9999
325	0.3607	-1.0197	0.3607	-1.0197	9.1226	152.6700
326	0.3593	-1.0236	0.3593	-1.0236	9.2610	175.3299
327	0.3558	-1.0333	0.3558	-1.0333	9.4042	202.3300
328	0.3575	-1.0286	0.3575	-1.0286	9.4287	207.3299
329	0.3528	-1.0418	0.3528	-1.0418	9.5097	224.8300
330	0.3537	-1.0393	0.3537	-1.0393	9.6231	251.8301
331	0.3523	-1.0432	0.3523	-1.0432	9.7892	297.3297
332	0.3495	-1.0512	0.3495	-1.0512	9.9417	346.3296
333	0.3488	-1.0532	0.3488	-1.0532	10.0840	399.3295
334	0.3482	-1.0549	0.3482	-1.0549	10.2392	466.3295
335	0.3488	-1.0532	0.3488	-1.0532	10.3372	514.3295
336	0.3455	-1.0627	0.3455	-1.0627	10.4247	561.3296
401	0.3956	-.9273	0.3956	-.9273	0.0000	0.0000
402	0.3938	-.9319	0.3938	-.9319	3.4012	0.5000
403	0.3910	-.9390	0.3910	-.9390	4.0110	0.9200
404	0.3884	-.9457	0.3884	-.9457	4.4998	1.5000
405	0.3858	-.9524	0.3858	-.9524	5.1059	2.7500
406	0.3822	-.9618	0.3822	-.9618	5.3240	3.4200
407	0.3812	-.9644	0.3812	-.9644	5.6525	4.7500
408	0.3768	-.9760	0.3768	-.9760	5.9140	6.1700
409	0.3794	-.9691	0.3794	-.9691	6.1092	7.5000
410	0.3802	-.9670	0.3802	-.9670	6.3103	9.1700
411	0.3776	-.9739	0.3776	-.9739	6.4457	10.4999
412	0.3796	-.9686	0.3796	-.9686	6.5793	12.0000
413	0.3772	-.9749	0.3772	-.9749	6.6911	13.4200
414	0.3788	-.9707	0.3788	-.9707	6.8352	15.4999
415	0.3756	-.9792	0.3756	-.9792	7.0901	20.0000
416	0.3722	-.9883	0.3722	-.9883	7.1854	22.0000
417	0.3684	-.9985	0.3684	-.9985	7.4845	29.6700

Table 35. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
418	0.3764	-.9771	0.3764	-.9771	7.7232	37.6700
419	0.3710	-.9915	0.3710	-.9915	7.8710	43.6700
420	0.3664	-1.0040	0.3664	-1.0040	8.1316	56.6700
421	0.3638	-1.0111	0.3638	-1.0111	8.2414	63.2500
422	0.3688	-.9975	0.3688	-.9975	8.5011	82.0000
423	0.3630	-1.0133	0.3630	-1.0133	8.7857	109.0000
424	0.3638	-1.0111	0.3638	-1.0111	8.9695	130.9999
425	0.3614	-1.0177	0.3614	-1.0177	9.1226	152.6700
426	0.3600	-1.0216	0.3600	-1.0216	9.2610	175.3299
427	0.3556	-1.0339	0.3556	-1.0339	9.4042	202.3300
428	0.3574	-1.0289	0.3574	-1.0289	9.4287	207.3299
429	0.3528	-1.0418	0.3528	-1.0418	9.5097	224.8300
430	0.3526	-1.0424	0.3526	-1.0424	9.6231	251.8301
431	0.3518	-1.0446	0.3518	-1.0446	9.7892	297.3297
432	0.3482	-1.0549	0.3482	-1.0549	9.9417	346.3296
433	0.3480	-1.0555	0.3480	-1.0555	10.0840	399.3295
434	0.3458	-1.0619	0.3458	-1.0619	10.2392	466.3295
435	0.3464	-1.0601	0.3464	-1.0601	10.3372	514.3295
436	0.3436	-1.0682	0.3436	-1.0682	10.4247	561.3296
501	0.3955	-.9276	0.3955	-.9276	0.0000	0.0000
502	0.3938	-.9319	0.3938	-.9319	3.4012	0.5000
503	0.3920	-.9365	0.3920	-.9365	4.0110	0.9200
504	0.3893	-.9434	0.3893	-.9434	4.4998	1.5000
505	0.3867	-.9501	0.3867	-.9501	5.1059	2.7500
506	0.3837	-.9579	0.3837	-.9579	5.3240	3.4200
507	0.3833	-.9589	0.3833	-.9589	5.6525	4.7500
508	0.3787	-.9710	0.3787	-.9710	5.9140	6.1700
509	0.3817	-.9631	0.3817	-.9631	6.1092	7.5000
510	0.3820	-.9623	0.3820	-.9623	6.3103	9.1700
511	0.3792	-.9696	0.3792	-.9696	6.4457	10.4999
512	0.3828	-.9602	0.3828	-.9602	6.5793	12.0000
513	0.3793	-.9694	0.3793	-.9694	6.6911	13.4200
514	0.3817	-.9631	0.3817	-.9631	6.8352	15.4999
515	0.3785	-.9715	0.3785	-.9715	7.0901	20.0000
516	0.3747	-.9816	0.3747	-.9816	7.1854	22.0000
517	0.3717	-.9896	0.3717	-.9896	7.4845	29.6700
518	0.3793	-.9694	0.3793	-.9694	7.7232	37.6700
519	0.3742	-.9829	0.3742	-.9829	7.8710	43.6700
520	0.3695	-.9956	0.3695	-.9956	8.1316	56.6700
521	0.3667	-1.0032	0.3667	-1.0032	8.2414	63.2500
522	0.3712	-.9910	0.3712	-.9910	8.5011	82.0000
523	0.3657	-1.0059	0.3657	-1.0059	8.7857	109.0000

Table 35. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
524	0.3660	-1.0051	0.3660	-1.0051	8.9695	130.9999
525	0.3633	-1.0125	0.3633	-1.0125	9.1226	152.6700
526	0.3623	-1.0152	0.3623	-1.0152	9.2610	175.3299
527	0.3577	-1.0280	0.3577	-1.0280	9.4042	202.3300
528	0.3598	-1.0222	0.3598	-1.0222	9.4287	207.3299
529	0.3545	-1.0370	0.3545	-1.0370	9.5097	224.8300
530	0.3550	-1.0356	0.3550	-1.0356	9.6231	251.8301
531	0.3535	-1.0398	0.3535	-1.0398	9.7892	297.3297
532	0.3503	-1.0489	0.3503	-1.0489	9.9417	346.3296
533	0.3493	-1.0518	0.3493	-1.0518	10.0840	399.3295
534	0.3473	-1.0575	0.3473	-1.0575	10.2392	466.3295
535	0.3475	-1.0569	0.3475	-1.0569	10.3372	514.3295
536	0.3453	-1.0633	0.3453	-1.0633	10.4247	561.3296
601	0.3927	-.9347	0.3927	-.9347	0.0000	0.0000
602	0.3911	-.9387	0.3911	-.9387	3.4012	0.5000
603	0.3893	-.9434	0.3893	-.9434	4.0110	0.9200
604	0.3879	-.9470	0.3879	-.9470	4.4998	1.5000
605	0.3859	-.9521	0.3859	-.9521	5.1059	2.7500
606	0.3830	-.9597	0.3830	-.9597	5.3240	3.4200
607	0.3830	-.9597	0.3830	-.9597	5.6525	4.7500
608	0.3780	-.9728	0.3780	-.9728	5.9140	6.1700
609	0.3811	-.9646	0.3811	-.9646	6.1092	7.5000
610	0.3813	-.9641	0.3813	-.9641	6.3103	9.1700
611	0.3803	-.9667	0.3803	-.9667	6.4457	10.4999
612	0.3836	-.9581	0.3836	-.9581	6.5793	12.0000
613	0.3813	-.9641	0.3813	-.9641	6.6911	13.4200
614	0.3846	-.9555	0.3846	-.9555	6.8352	15.4999
615	0.3800	-.9675	0.3800	-.9675	7.0901	20.0000
616	0.3769	-.9757	0.3769	-.9757	7.1854	22.0000
617	0.3724	-.9877	0.3724	-.9877	7.4845	29.6700
618	0.3810	-.9649	0.3810	-.9649	7.7232	37.6700
619	0.3754	-.9797	0.3754	-.9797	7.8710	43.6700
620	0.3711	-.9912	0.3711	-.9912	8.1316	56.6700
621	0.3687	-.9977	0.3687	-.9977	8.2414	63.2500
622	0.3719	-.9891	0.3719	-.9891	8.5011	82.0000
623	0.3666	-1.0034	0.3666	-1.0034	8.7857	109.0000
624	0.3659	-1.0054	0.3659	-1.0054	8.9695	130.9999
625	0.3640	-1.0106	0.3640	-1.0106	9.1226	152.6700
626	0.3631	-1.0130	0.3631	-1.0130	9.2610	175.3299
627	0.3584	-1.0261	0.3584	-1.0261	9.4042	202.3300
628	0.3596	-1.0227	0.3596	-1.0227	9.4287	207.3299
629	0.3541	-1.0381	0.3541	-1.0381	9.5097	224.8300

Table 35. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
630	0.3554	-1.0345	0.3554	-1.0345	9.6231	251.8301
631	0.3541	-1.0381	0.3541	-1.0381	9.7892	297.3297
632	0.3500	-1.0498	0.3500	-1.0498	9.9417	346.3296
633	0.3486	-1.0538	0.3486	-1.0538	10.0840	399.3295
634	0.3464	-1.0601	0.3464	-1.0601	10.2392	466.3295
635	0.3473	-1.0575	0.3473	-1.0575	10.3372	514.3295
636	0.3446	-1.0653	0.3446	-1.0653	10.4247	561.3296

Table 36. Regression data, site 2.

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
101	0.3820	-.9623	0.3820	-.9623	0.0000	0.0000
102	0.3810	-.9649	0.3810	-.9649	2.8904	0.3000
103	0.3820	-.9623	0.3820	-.9623	3.5322	0.5700
104	0.3770	-.9755	0.3770	-.9755	4.2077	1.1200
105	0.3790	-.9702	0.3790	-.9702	4.6540	1.7500
106	0.3740	-.9835	0.3740	-.9835	4.9781	2.4200
107	0.3780	-.9728	0.3780	-.9728	5.3240	3.4200
108	0.3740	-.9835	0.3740	-.9835	5.5805	4.4200
109	0.3740	-.9835	0.3740	-.9835	5.7844	5.4200
110	0.3760	-.9781	0.3760	-.9781	5.9538	6.4200
111	0.3750	-.9808	0.3750	-.9808	6.0985	7.4200
112	0.3780	-.9728	0.3780	-.9728	6.2250	8.4200
113	0.3670	-1.0024	0.3670	-1.0024	6.3372	9.4200
114	0.3710	-.9915	0.3710	-.9915	6.4381	10.4199
115	0.3700	-.9942	0.3700	-.9942	6.4618	10.6699
116	0.3640	-1.0106	0.3640	-1.0106	6.9985	18.2500
117	0.3680	-.9996	0.3680	-.9996	6.9985	18.2500
118	0.3680	-.9996	0.3680	-.9996	7.1740	21.7499
119	0.3620	-1.0161	0.3620	-1.0161	7.1740	21.7499
120	0.3650	-1.0078	0.3650	-1.0078	7.3872	26.9199
121	0.3670	-1.0024	0.3670	-1.0024	7.3872	26.9199
122	0.3680	-.9996	0.3680	-.9996	7.5731	32.4199
123	0.3670	-1.0024	0.3670	-1.0024	7.5731	32.4199
124	0.3620	-1.0161	0.3620	-1.0161	7.8898	44.5000
125	0.3600	-1.0216	0.3600	-1.0216	7.8898	44.5000
126	0.3710	-.9915	0.3710	-.9915	7.9862	48.9999
127	0.3680	-.9996	0.3680	-.9996	7.9862	48.9999
128	0.3620	-1.0161	0.3620	-1.0161	8.0708	53.3299
129	0.3680	-.9996	0.3680	-.9996	8.0708	53.3299
130	0.3620	-1.0161	0.3620	-1.0161	8.3640	71.4999
131	0.3640	-1.0106	0.3640	-1.0106	8.3640	71.4999
132	0.3620	-1.0161	0.3620	-1.0161	8.8537	116.6700
133	0.3600	-1.0216	0.3600	-1.0216	8.8537	116.6700
134	0.3550	-1.0356	0.3550	-1.0356	9.2063	165.9999
135	0.3600	-1.0216	0.3600	-1.0216	9.2063	165.9999
136	0.3580	-1.0272	0.3580	-1.0272	9.4842	219.1699
137	0.3600	-1.0216	0.3600	-1.0216	9.4842	219.1699
138	0.3510	-1.0469	0.3510	-1.0469	9.7503	286.0000
139	0.3550	-1.0356	0.3550	-1.0356	9.7503	286.0000
140	0.3510	-1.0469	0.3510	-1.0469	9.9040	333.5000
141	0.3530	-1.0412	0.3530	-1.0412	9.9040	333.5000

Table 36. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
142	0.3500	-1.0498	0.3500	-1.0498	10.0411	382.5000
143	0.3520	-1.0441	0.3520	-1.0441	10.0411	382.5000
144	0.3440	-1.0671	0.3440	-1.0671	10.2091	452.4999
145	0.3440	-1.0671	0.3440	-1.0671	10.2091	452.4999
146	0.3500	-1.0498	0.3500	-1.0498	10.3119	501.4999
147	0.3470	-1.0584	0.3470	-1.0584	10.3119	501.4999
201	0.3927	-.9347	0.3927	-.9347	0.0000	0.0000
202	0.3897	-.9423	0.3897	-.9423	2.8904	0.3000
203	0.3900	-.9416	0.3900	-.9416	3.5322	0.5700
204	0.3860	-.9519	0.3860	-.9519	4.2077	1.1200
205	0.3860	-.9519	0.3860	-.9519	4.6540	1.7500
206	0.3820	-.9623	0.3820	-.9623	4.9781	2.4200
207	0.3857	-.9527	0.3857	-.9527	5.3240	3.4200
208	0.3807	-.9657	0.3807	-.9657	5.5805	4.4200
209	0.3817	-.9631	0.3817	-.9631	5.7844	5.4200
210	0.3843	-.9563	0.3843	-.9563	5.9538	6.4200
211	0.3813	-.9641	0.3813	-.9641	6.0985	7.4200
212	0.3850	-.9545	0.3850	-.9545	6.2250	8.4200
213	0.3767	-.9763	0.3767	-.9763	6.3372	9.4200
214	0.3773	-.9747	0.3773	-.9747	6.4381	10.4199
215	0.3757	-.9789	0.3757	-.9789	6.4618	10.6699
216	0.3710	-.9915	0.3710	-.9915	6.9985	18.2500
217	0.3740	-.9835	0.3740	-.9835	6.9985	18.2500
218	0.3733	-.9853	0.3733	-.9853	7.1740	21.7499
219	0.3697	-.9950	0.3697	-.9950	7.1740	21.7499
220	0.3727	-.9869	0.3727	-.9869	7.3872	26.9199
221	0.3713	-.9907	0.3713	-.9907	7.3872	26.9199
222	0.3743	-.9827	0.3743	-.9827	7.5731	32.4199
223	0.3733	-.9853	0.3733	-.9853	7.5731	32.4199
224	0.3683	-.9988	0.3683	-.9988	7.8898	44.5000
225	0.3677	-1.0004	0.3677	-1.0004	7.8898	44.5000
226	0.3763	-.9773	0.3763	-.9773	7.9862	48.9999
227	0.3747	-.9816	0.3747	-.9816	7.9862	48.9999
228	0.3683	-.9988	0.3683	-.9988	8.0708	53.3299
229	0.3737	-.9843	0.3737	-.9843	8.0708	53.3299
230	0.3677	-1.0004	0.3677	-1.0004	8.3640	71.4999
231	0.3697	-.9950	0.3697	-.9950	8.3640	71.4999
232	0.3670	-1.0024	0.3670	-1.0024	8.8537	116.6700
233	0.3647	-1.0086	0.3647	-1.0086	8.8537	116.6700
234	0.3617	-1.0169	0.3617	-1.0169	9.2063	165.9999
235	0.3653	-1.0070	0.3653	-1.0070	9.2063	165.9999

Table 36. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
236	0.3630	-1.0133	0.3630	-1.0133	9.4842	219.1699
237	0.3647	-1.0086	0.3647	-1.0086	9.4842	219.1699
238	0.3573	-1.0291	0.3573	-1.0291	9.7503	286.0000
239	0.3597	-1.0224	0.3597	-1.0224	9.7503	286.0000
240	0.3560	-1.0328	0.3560	-1.0328	9.9040	333.5000
241	0.3570	-1.0300	0.3570	-1.0300	9.9040	333.5000
242	0.3543	-1.0376	0.3543	-1.0376	10.0411	382.5000
243	0.3567	-1.0308	0.3567	-1.0308	10.0411	382.5000
244	0.3500	-1.0498	0.3500	-1.0498	10.2091	452.4999
245	0.3497	-1.0506	0.3497	-1.0506	10.2091	452.4999
246	0.3540	-1.0384	0.3540	-1.0384	10.3119	501.4999
247	0.3517	-1.0449	0.3517	-1.0449	10.3119	501.4999

Table 37. Regression data, site 3.

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
101	0.4630	-.7700	0.4630	-.7700	0.0000	0.0000
102	0.4580	-.7808	0.4580	-.7808	3.8836	0.8100
103	0.4500	-.7985	0.4500	-.7985	4.3412	1.2800
104	0.4410	-.8187	0.4410	-.8187	4.7041	1.8400
105	0.4340	-.8347	0.4340	-.8347	4.9445	2.3400
106	0.4280	-.8486	0.4280	-.8486	5.3003	3.3400
107	0.4200	-.8675	0.4200	-.8675	5.5622	4.3400
108	0.4120	-.8867	0.4120	-.8867	5.7696	5.3400
109	0.4110	-.8891	0.4110	-.8891	5.9333	6.2900
110	0.4050	-.9038	0.4050	-.9038	6.0726	7.2300
111	0.4010	-.9137	0.4010	-.9137	6.2815	8.9100
112	0.3940	-.9314	0.3940	-.9314	6.4275	10.3100
113	0.3910	-.9390	0.3910	-.9390	6.5650	11.8300
114	0.3900	-.9416	0.3900	-.9416	6.7212	13.8299
115	0.3800	-.9675	0.3800	-.9675	6.8569	15.8399
116	0.3780	-.9728	0.3780	-.9728	6.9758	17.8400
117	0.3710	-.9915	0.3710	-.9915	7.3794	26.7100
118	0.3660	-1.0051	0.3660	-1.0051	7.4665	29.1400
119	0.3630	-1.0133	0.3630	-1.0133	7.6062	33.5100
120	0.3610	-1.0188	0.3610	-1.0188	7.7797	39.8599
121	0.3450	-1.0642	0.3450	-1.0642	8.0260	50.9899
122	0.3440	-1.0671	0.3440	-1.0671	8.1808	59.5299
123	0.3460	-1.0613	0.3460	-1.0613	8.4242	75.9299
124	0.3400	-1.0788	0.3400	-1.0788	8.5445	85.6400
125	0.3390	-1.0817	0.3390	-1.0817	8.7487	105.0399
126	0.3350	-1.0936	0.3350	-1.0936	8.9230	125.0400
127	0.3320	-1.1026	0.3320	-1.1026	9.0845	146.9600
128	0.3290	-1.1117	0.3290	-1.1117	9.2418	171.9900
129	0.3180	-1.1457	0.3180	-1.1457	9.3729	196.0901
130	0.3230	-1.1301	0.3230	-1.1301	9.4923	220.9600
131	0.3120	-1.1647	0.3120	-1.1647	9.6061	247.5900
132	0.3230	-1.1301	0.3230	-1.1301	9.6847	267.8400
133	0.2970	-1.2140	0.2970	-1.2140	9.7838	295.7403
134	0.3050	-1.1874	0.3050	-1.1874	9.8502	316.0297
135	0.3080	-1.1776	0.3080	-1.1776	9.9911	363.8397
136	0.3090	-1.1744	0.3090	-1.1744	10.1243	415.7098
137	0.3050	-1.1874	0.3050	-1.1874	10.1782	438.7603
138	0.3020	-1.1973	0.3020	-1.1973	10.2778	484.6801
139	0.2940	-1.2241	0.2940	-1.2241	10.3774	535.4297
140	0.2880	-1.2448	0.2880	-1.2448	10.5051	608.4096
141	0.2900	-1.2378	0.2900	-1.2378	10.5832	657.7602

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
142	0.2870	-1.2482	0.2870	-1.2482	10.6451	699.8397
143	0.2830	-1.2623	0.2830	-1.2623	10.7734	795.5898
144	0.2820	-1.2658	0.2820	-1.2658	10.8312	842.9296
145	0.2680	-1.3167	0.2680	-1.3167	10.9652	963.8397
146	0.2600	-1.3470	0.2600	-1.3470	11.1481	0.0000
201	0.4625	-.7711	0.4625	-.7711	0.0000	0.0000
202	0.4580	-.7808	0.4580	-.7808	3.8836	0.8100
203	0.4510	-.7962	0.4510	-.7962	4.3412	1.2800
204	0.4478	-.8034	0.4478	-.8034	4.7041	1.8400
205	0.4422	-.8159	0.4422	-.8159	4.9445	2.3400
206	0.4357	-.8308	0.4357	-.8308	5.3003	3.3400
207	0.4287	-.8470	0.4287	-.8470	5.5622	4.3400
208	0.4212	-.8646	0.4212	-.8646	5.7696	5.3400
209	0.4197	-.8682	0.4197	-.8682	5.9333	6.2900
210	0.4142	-.8814	0.4142	-.8814	6.0726	7.2300
211	0.4073	-.8982	0.4073	-.8982	6.2815	8.9100
212	0.4022	-.9108	0.4022	-.9108	6.4275	10.3100
213	0.4007	-.9145	0.4007	-.9145	6.5650	11.8300
214	0.3987	-.9195	0.3987	-.9195	6.7212	13.8299
215	0.3906	-.9400	0.3906	-.9400	6.8569	15.8399
216	0.3862	-.9514	0.3862	-.9514	6.9758	17.8400
217	0.3812	-.9644	0.3812	-.9644	7.3794	26.7100
218	0.3752	-.9803	0.3752	-.9803	7.4665	29.1400
219	0.3751	-.9805	0.3751	-.9805	7.6062	33.5100
220	0.3731	-.9859	0.3731	-.9859	7.7797	39.8599
221	0.3552	-1.0350	0.3552	-1.0350	8.0260	50.9899
222	0.3566	-1.0311	0.3566	-1.0311	8.1808	59.5299
223	0.3610	-1.0188	0.3610	-1.0188	8.4242	75.9299
224	0.3545	-1.0370	0.3545	-1.0370	8.5445	85.6400
225	0.3496	-1.0509	0.3496	-1.0509	8.7487	105.0399
226	0.3447	-1.0650	0.3447	-1.0650	8.9230	125.0400
227	0.3422	-1.0723	0.3422	-1.0723	9.0845	146.9600
228	0.3382	-1.0841	0.3382	-1.0841	9.2418	171.9900
229	0.3311	-1.1053	0.3311	-1.1053	9.3729	196.0901
230	0.3341	-1.0963	0.3341	-1.0963	9.4923	220.9600
231	0.3251	-1.1236	0.3251	-1.1236	9.6061	247.5900
232	0.3336	-1.0978	0.3336	-1.0978	9.6847	267.8400
233	0.3183	-1.1447	0.3183	-1.1447	9.7838	295.7403
234	0.3181	-1.1453	0.3181	-1.1453	9.8502	316.0297
235	0.3215	-1.1347	0.3215	-1.1347	9.9911	363.8397
236	0.3206	-1.1375	0.3206	-1.1375	10.1243	415.7098

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
237	0.3156	-1.1532	0.3156	-1.1532	10.1782	438.7603
238	0.3165	-1.1504	0.3165	-1.1504	10.2778	484.6801
239	0.3124	-1.1634	0.3124	-1.1634	10.3774	535.4297
240	0.3035	-1.1923	0.3035	-1.1923	10.5051	608.4096
241	0.3079	-1.1779	0.3079	-1.1779	10.5832	657.7602
242	0.3030	-1.1940	0.3030	-1.1940	10.6451	699.8397
243	0.2936	-1.2255	0.2936	-1.2255	10.7734	795.5898
244	0.2985	-1.2089	0.2985	-1.2089	10.8312	842.9296
245	0.2849	-1.2556	0.2849	-1.2556	10.9652	963.8397
246	0.2827	-1.2633	0.2827	-1.2633	11.1481	0.0000
301	0.4542	-.7892	0.4542	-.7892	0.0000	0.0000
302	0.4485	-.8018	0.4485	-.8018	3.8836	0.8100
303	0.4438	-.8123	0.4438	-.8123	4.3412	1.2800
304	0.4410	-.8187	0.4410	-.8187	4.7041	1.8400
305	0.4373	-.8271	0.4373	-.8271	4.9445	2.3400
306	0.4335	-.8358	0.4335	-.8358	5.3003	3.3400
307	0.4275	-.8498	0.4275	-.8498	5.5622	4.3400
308	0.4205	-.8663	0.4205	-.8663	5.7696	5.3400
309	0.4198	-.8679	0.4198	-.8679	5.9333	6.2900
310	0.4132	-.8838	0.4132	-.8838	6.0726	7.2300
311	0.4069	-.8991	0.4069	-.8991	6.2815	8.9100
312	0.4022	-.9108	0.4022	-.9108	6.4275	10.3100
313	0.4001	-.9160	0.4001	-.9160	6.5650	11.8300
314	0.3965	-.9250	0.3965	-.9250	6.7212	13.8299
315	0.3940	-.9314	0.3940	-.9314	6.8569	15.8399
316	0.3881	-.9464	0.3881	-.9464	6.9758	17.8400
317	0.3844	-.9560	0.3844	-.9560	7.3794	26.7100
318	0.3758	-.9787	0.3758	-.9787	7.4665	29.1400
319	0.3760	-.9781	0.3760	-.9781	7.6062	33.5100
320	0.3740	-.9835	0.3740	-.9835	7.7797	39.8599
321	0.3597	-1.0224	0.3597	-1.0224	8.0260	50.9899
322	0.3577	-1.0280	0.3577	-1.0280	8.1808	59.5299
323	0.3633	-1.0125	0.3633	-1.0125	8.4242	75.9299
324	0.3586	-1.0255	0.3586	-1.0255	8.5445	85.6400
325	0.3524	-1.0429	0.3524	-1.0429	8.7487	105.0399
326	0.3480	-1.0555	0.3480	-1.0555	8.9230	125.0400
327	0.3470	-1.0584	0.3470	-1.0584	9.0845	146.9600
328	0.3433	-1.0691	0.3433	-1.0691	9.2418	171.9900
329	0.3372	-1.0870	0.3372	-1.0870	9.3729	196.0901
330	0.3387	-1.0826	0.3387	-1.0826	9.4923	220.9600
331	0.3306	-1.1068	0.3306	-1.1068	9.6061	247.5900

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
332	0.3406	-1.0770	0.3406	-1.0770	9.6847	267.8400
333	0.3283	-1.1138	0.3283	-1.1138	9.7838	295.7403
334	0.3262	-1.1202	0.3262	-1.1202	9.8502	316.0297
335	0.3272	-1.1171	0.3272	-1.1171	9.9911	363.8397
336	0.3279	-1.1150	0.3279	-1.1150	10.1243	415.7098
337	0.3223	-1.1322	0.3223	-1.1322	10.1782	438.7603
338	0.3238	-1.1276	0.3238	-1.1276	10.2778	484.6801
339	0.3201	-1.1391	0.3201	-1.1391	10.3774	535.4297
340	0.3112	-1.1673	0.3112	-1.1673	10.5051	608.4096
341	0.3171	-1.1485	0.3171	-1.1485	10.5832	657.7602
342	0.3111	-1.1676	0.3111	-1.1676	10.6451	699.8397
343	0.3039	-1.1910	0.3039	-1.1910	10.7734	795.5898
344	0.3065	-1.1825	0.3065	-1.1825	10.8312	842.9296
345	0.2934	-1.2262	0.2934	-1.2262	10.9652	963.8397
346	0.2946	-1.2221	0.2946	-1.2221	11.1481	0.0000
401	0.4463	-.8067	0.4463	-.8067	0.0000	0.0000
402	0.4415	-.8175	0.4415	-.8175	3.8836	0.8100
403	0.4380	-.8255	0.4380	-.8255	4.3412	1.2800
404	0.4371	-.8275	0.4371	-.8275	4.7041	1.8400
405	0.4328	-.8374	0.4328	-.8374	4.9445	2.3400
406	0.4307	-.8423	0.4307	-.8423	5.3003	3.3400
407	0.4244	-.8570	0.4244	-.8570	5.5622	4.3400
408	0.4204	-.8665	0.4204	-.8665	5.7696	5.3400
409	0.4194	-.8689	0.4194	-.8689	5.9333	6.2900
410	0.4121	-.8864	0.4121	-.8864	6.0726	7.2300
411	0.4074	-.8979	0.4074	-.8979	6.2815	8.9100
412	0.4056	-.9023	0.4056	-.9023	6.4275	10.3100
413	0.4018	-.9118	0.4018	-.9118	6.5650	11.8300
414	0.3984	-.9203	0.3984	-.9203	6.7212	13.8299
415	0.3962	-.9258	0.3962	-.9258	6.8569	15.8399
416	0.3913	-.9382	0.3913	-.9382	6.9758	17.8400
417	0.3877	-.9475	0.3877	-.9475	7.3794	26.7100
418	0.3812	-.9644	0.3812	-.9644	7.4665	29.1400
419	0.3800	-.9675	0.3800	-.9675	7.6062	33.5100
420	0.3790	-.9702	0.3790	-.9702	7.7797	39.8599
421	0.3657	-1.0059	0.3657	-1.0059	8.0260	50.9899
422	0.3644	-1.0095	0.3644	-1.0095	8.1808	59.5299
423	0.3696	-.9953	0.3696	-.9953	8.4242	75.9299
424	0.3648	-1.0084	0.3648	-1.0084	8.5445	85.6400
425	0.3601	-1.0213	0.3601	-1.0213	8.7487	105.0399
426	0.3520	-1.0441	0.3520	-1.0441	8.9230	125.0400

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
427	0.3514	-1.0458	0.3514	-1.0458	9.0845	146.9600
428	0.3477	-1.0564	0.3477	-1.0564	9.2418	171.9900
429	0.3426	-1.0711	0.3426	-1.0711	9.3729	196.0901
430	0.3434	-1.0688	0.3434	-1.0688	9.4923	220.9600
431	0.3378	-1.0853	0.3378	-1.0853	9.6061	247.5900
432	0.3473	-1.0575	0.3473	-1.0575	9.6847	267.8400
433	0.3226	-1.1313	0.3226	-1.1313	9.7838	295.7403
434	0.3340	-1.0966	0.3340	-1.0966	9.8502	316.0297
435	0.3333	-1.0987	0.3333	-1.0987	9.9911	363.8397
436	0.3336	-1.0978	0.3336	-1.0978	10.1243	415.7098
437	0.3289	-1.1120	0.3289	-1.1120	10.1782	438.7603
438	0.3315	-1.1041	0.3315	-1.1041	10.2778	484.6801
439	0.3262	-1.1202	0.3262	-1.1202	10.3774	535.4297
440	0.3187	-1.1435	0.3187	-1.1435	10.5051	608.4096
441	0.3234	-1.1288	0.3234	-1.1288	10.5832	657.7602
442	0.3182	-1.1450	0.3182	-1.1450	10.6451	699.8397
443	0.3108	-1.1686	0.3108	-1.1686	10.7734	795.5898
444	0.3150	-1.1551	0.3150	-1.1551	10.8312	842.9296
445	0.3037	-1.1917	0.3037	-1.1917	10.9652	963.8397
446	0.3055	-1.1858	0.3055	-1.1858	11.1481	0.0000
501	0.4344	-.8337	0.4344	-.8337	0.0000	0.0000
502	0.4308	-.8421	0.4308	-.8421	3.8836	0.8100
503	0.4277	-.8493	0.4277	-.8493	4.3412	1.2800
504	0.4268	-.8514	0.4268	-.8514	4.7041	1.8400
505	0.4231	-.8601	0.4231	-.8601	4.9445	2.3400
506	0.4227	-.8610	0.4227	-.8610	5.3003	3.3400
507	0.4164	-.8761	0.4164	-.8761	5.5622	4.3400
508	0.4128	-.8847	0.4128	-.8847	5.7696	5.3400
509	0.4116	-.8877	0.4116	-.8877	5.9333	6.2900
510	0.4072	-.8984	0.4072	-.8984	6.0726	7.2300
511	0.4026	-.9098	0.4026	-.9098	6.2815	8.9100
512	0.4009	-.9140	0.4009	-.9140	6.4275	10.3100
513	0.3965	-.9250	0.3965	-.9250	6.5650	11.8300
514	0.3945	-.9301	0.3945	-.9301	6.7212	13.8299
515	0.3930	-.9339	0.3930	-.9339	6.8569	15.8399
516	0.3887	-.9449	0.3887	-.9449	6.9758	17.8400
517	0.3846	-.9555	0.3846	-.9555	7.3794	26.7100
518	0.3786	-.9712	0.3786	-.9712	7.4665	29.1400
519	0.3778	-.9733	0.3778	-.9733	7.6062	33.5100
520	0.3764	-.9771	0.3764	-.9771	7.7797	39.8599
521	0.3634	-1.0122	0.3634	-1.0122	8.0260	50.9899

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
522	0.3631	-1.0130	0.3631	-1.0130	8.1808	59.5299
523	0.3677	-1.0004	0.3677	-1.0004	8.4242	75.9299
524	0.3643	-1.0097	0.3643	-1.0097	8.5445	85.6400
525	0.3581	-1.0269	0.3581	-1.0269	8.7487	105.0399
526	0.3547	-1.0364	0.3547	-1.0364	8.9230	125.0400
527	0.3547	-1.0364	0.3547	-1.0364	9.0845	146.9600
528	0.3501	-1.0495	0.3501	-1.0495	9.2418	171.9900
529	0.3472	-1.0578	0.3472	-1.0578	9.3729	196.0901
530	0.3471	-1.0581	0.3471	-1.0581	9.4923	220.9600
531	0.3410	-1.0758	0.3410	-1.0758	9.6061	247.5900
532	0.3508	-1.0475	0.3508	-1.0475	9.6847	267.8400
533	0.3302	-1.1080	0.3302	-1.1080	9.7838	295.7403
534	0.3387	-1.0826	0.3387	-1.0826	9.8502	316.0297
535	0.3368	-1.0882	0.3368	-1.0882	9.9911	363.8397
536	0.3380	-1.0847	0.3380	-1.0847	10.1243	415.7098
537	0.3328	-1.1002	0.3328	-1.1002	10.1782	438.7603
538	0.3356	-1.0918	0.3356	-1.0918	10.2778	484.6801
539	0.3305	-1.1071	0.3305	-1.1071	10.3774	535.4297
540	0.3233	-1.1291	0.3233	-1.1291	10.5051	608.4096
541	0.3279	-1.1150	0.3279	-1.1150	10.5832	657.7602
542	0.3223	-1.1322	0.3223	-1.1322	10.6451	699.8397
543	0.3167	-1.1498	0.3167	-1.1498	10.7734	795.5898
544	0.3191	-1.1422	0.3191	-1.1422	10.8312	842.9296
545	0.3089	-1.1747	0.3089	-1.1747	10.9652	963.8397
546	0.3084	-1.1763	0.3084	-1.1763	11.1481	0.0000
601	0.4238	-.8584	0.4238	-.8584	0.0000	0.0000
602	0.4201	-.8672	0.4201	-.8672	3.8836	0.8100
603	0.4172	-.8741	0.4172	-.8741	4.3412	1.2800
604	0.4164	-.8761	0.4164	-.8761	4.7041	1.8400
605	0.4137	-.8826	0.4137	-.8826	4.9445	2.3400
606	0.4138	-.8823	0.4138	-.8823	5.3003	3.3400
607	0.4093	-.8933	0.4093	-.8933	5.5622	4.3400
608	0.4047	-.9046	0.4047	-.9046	5.7696	5.3400
609	0.4042	-.9058	0.4042	-.9058	5.9333	6.2900
610	0.4004	-.9152	0.4004	-.9152	6.0726	7.2300
611	0.3959	-.9265	0.3959	-.9265	6.2815	8.9100
612	0.3940	-.9314	0.3940	-.9314	6.4275	10.3100
613	0.3913	-.9382	0.3913	-.9382	6.5650	11.8300
614	0.3885	-.9454	0.3885	-.9454	6.7212	13.8299
615	0.3871	-.9490	0.3871	-.9490	6.8569	15.8399
616	0.3826	-.9607	0.3826	-.9607	6.9758	17.8400

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
617	0.3781	-.9726	0.3781	-.9726	7.3794	26.7100
618	0.3729	-.9864	0.3729	-.9864	7.4665	29.1400
619	0.3716	-.9899	0.3716	-.9899	7.6062	33.5100
620	0.3692	-.9964	0.3692	-.9964	7.7797	39.8599
621	0.3574	-1.0289	0.3574	-1.0289	8.0260	50.9899
622	0.3567	-1.0308	0.3567	-1.0308	8.1808	59.5299
623	0.3613	-1.0180	0.3613	-1.0180	8.4242	75.9299
624	0.3570	-1.0300	0.3570	-1.0300	8.5445	85.6400
625	0.3510	-1.0469	0.3510	-1.0469	8.7487	105.0399
626	0.3515	-1.0455	0.3515	-1.0455	8.9230	125.0400
627	0.3524	-1.0429	0.3524	-1.0429	9.0845	146.9600
628	0.3478	-1.0561	0.3478	-1.0561	9.2418	171.9900
629	0.3447	-1.0650	0.3447	-1.0650	9.3729	196.0901
630	0.3453	-1.0633	0.3453	-1.0633	9.4923	220.9600
631	0.3392	-1.0811	0.3392	-1.0811	9.6061	247.5900
632	0.3489	-1.0529	0.3489	-1.0529	9.6847	267.8400
633	0.3305	-1.1071	0.3305	-1.1071	9.7838	295.7403
634	0.3366	-1.0888	0.3366	-1.0888	9.8502	316.0297
635	0.3350	-1.0936	0.3350	-1.0936	9.9911	363.8397
636	0.3362	-1.0900	0.3362	-1.0900	10.1243	415.7098
637	0.3314	-1.1044	0.3314	-1.1044	10.1782	438.7603
638	0.3332	-1.0990	0.3332	-1.0990	10.2778	484.6801
639	0.3285	-1.1132	0.3285	-1.1132	10.3774	535.4297
640	0.3218	-1.1338	0.3218	-1.1338	10.5051	608.4096
641	0.3261	-1.1205	0.3261	-1.1205	10.5832	657.7602
642	0.3218	-1.1338	0.3218	-1.1338	10.6451	699.8397
643	0.3161	-1.1517	0.3161	-1.1517	10.7734	795.5898
644	0.3173	-1.1479	0.3173	-1.1479	10.8312	842.9296
645	0.3081	-1.1773	0.3081	-1.1773	10.9652	963.8397
646	0.3093	-1.1734	0.3093	-1.1734	11.1481	0.0000
701	0.4169	-.8749	0.4169	-.8749	0.0000	0.0000
702	0.4131	-.8840	0.4131	-.8840	3.8836	0.8100
703	0.4100	-.8916	0.4100	-.8916	4.3412	1.2800
704	0.4096	-.8925	0.4096	-.8925	4.7041	1.8400
705	0.4071	-.8987	0.4071	-.8987	4.9445	2.3400
706	0.4073	-.8982	0.4073	-.8982	5.3003	3.3400
707	0.4029	-.9090	0.4029	-.9090	5.5622	4.3400
708	0.3990	-.9187	0.3990	-.9187	5.7696	5.3400
709	0.3981	-.9210	0.3981	-.9210	5.9333	6.2900
710	0.3950	-.9288	0.3950	-.9288	6.0726	7.2300
711	0.3915	-.9377	0.3915	-.9377	6.2815	8.9100

Table 37. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
712	0.3896	-.9426	0.3896	-.9426	6.4275	10.3100
713	0.3872	-.9488	0.3872	-.9488	6.5650	11.8300
714	0.3845	-.9558	0.3845	-.9558	6.7212	13.8299
715	0.3816	-.9633	0.3816	-.9633	6.8569	15.8399
716	0.3780	-.9728	0.3780	-.9728	6.9758	17.8400
717	0.3721	-.9885	0.3721	-.9885	7.3794	26.7100
718	0.3668	-1.0029	0.3668	-1.0029	7.4665	29.1400
719	0.3655	-1.0064	0.3655	-1.0064	7.6062	33.5100
720	0.3630	-1.0133	0.3630	-1.0133	7.7797	39.8599
721	0.3505	-1.0484	0.3505	-1.0484	8.0260	50.9899
722	0.3494	-1.0515	0.3494	-1.0515	8.1808	59.5299
723	0.3535	-1.0398	0.3535	-1.0398	8.4242	75.9299
724	0.3502	-1.0492	0.3502	-1.0492	8.5445	85.6400
725	0.3431	-1.0697	0.3431	-1.0697	8.7487	105.0399
726	0.3450	-1.0642	0.3450	-1.0642	8.9230	125.0400
727	0.3452	-1.0636	0.3452	-1.0636	9.0845	146.9600
728	0.3403	-1.0779	0.3403	-1.0779	9.2418	171.9900
729	0.3370	-1.0876	0.3370	-1.0876	9.3729	196.0901
730	0.3376	-1.0859	0.3376	-1.0859	9.4923	220.9600
731	0.3318	-1.1032	0.3318	-1.1032	9.6061	247.5900
732	0.3418	-1.0735	0.3418	-1.0735	9.6847	267.8400
733	0.3254	-1.1227	0.3254	-1.1227	9.7838	295.7403
734	0.3300	-1.1086	0.3300	-1.1086	9.8502	316.0297
735	0.3275	-1.1162	0.3275	-1.1162	9.9911	363.8397
736	0.3287	-1.1126	0.3287	-1.1126	10.1243	415.7098
737	0.3237	-1.1279	0.3237	-1.1279	10.1782	438.7603
738	0.3256	-1.1220	0.3256	-1.1220	10.2778	484.6801
739	0.3215	-1.1347	0.3215	-1.1347	10.3774	535.4297
740	0.3146	-1.1564	0.3146	-1.1564	10.5051	608.4096
741	0.3182	-1.1450	0.3182	-1.1450	10.5832	657.7602
742	0.3147	-1.1561	0.3147	-1.1561	10.6451	699.8397
743	0.3088	-1.1750	0.3088	-1.1750	10.7734	795.5898
744	0.3104	-1.1699	0.3104	-1.1699	10.8312	842.9296
745	0.3017	-1.1983	0.3017	-1.1983	10.9652	963.8397
746	0.3030	-1.1940	0.3030	-1.1940	11.1481	0.0000

Table 38. Regression data, site 4.

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
101	0.3810	-.9649	0.3810	-.9649	0.0000	0.0000
102	0.3660	-1.0051	0.3660	-1.0051	3.7796	0.7300
103	0.3510	-1.0469	0.3510	-1.0469	4.2513	1.1700
104	0.3480	-1.0555	0.3480	-1.0555	4.6367	1.7200
105	0.3520	-1.0441	0.3520	-1.0441	4.9402	2.3300
106	0.3400	-1.0788	0.3400	-1.0788	5.3414	3.4800
107	0.3390	-1.0817	0.3390	-1.0817	5.6567	4.7700
108	0.2860	-1.2517	0.2860	-1.2517	5.8894	6.0200
109	0.3210	-1.1363	0.3210	-1.1363	6.0781	7.2700
110	0.3150	-1.1551	0.3150	-1.1551	6.2368	8.5200
111	0.3100	-1.1711	0.3100	-1.1711	6.3477	9.5200
112	0.3080	-1.1776	0.3080	-1.1776	6.4739	10.7999
113	0.3080	-1.1776	0.3080	-1.1776	6.5809	12.0199
114	0.2900	-1.2378	0.2900	-1.2378	6.7774	14.6299
115	0.2860	-1.2517	0.2860	-1.2517	6.9068	16.6499
116	0.2800	-1.2729	0.2800	-1.2729	7.0266	18.7700
117	0.2770	-1.2837	0.2770	-1.2837	7.1749	21.7700
118	0.2690	-1.3130	0.2690	-1.3130	7.3040	24.7700
119	0.2510	-1.3823	0.2510	-1.3823	7.7597	39.0700
120	0.2530	-1.3743	0.2530	-1.3743	7.8666	43.4799
121	0.2440	-1.4105	0.2440	-1.4105	8.2343	62.7999
122	0.2320	-1.4610	0.2320	-1.4610	8.5674	87.6199
123	0.2250	-1.4916	0.2250	-1.4916	8.8329	114.2700
124	0.2290	-1.4740	0.2290	-1.4740	8.9938	134.2199
125	0.2240	-1.4961	0.2240	-1.4961	9.1649	159.2700
126	0.2130	-1.5464	0.2130	-1.5464	9.3059	183.3801
127	0.2110	-1.5559	0.2110	-1.5559	9.5371	231.0699
128	0.2150	-1.5371	0.2150	-1.5371	9.7394	282.8800
129	0.2100	-1.5606	0.2100	-1.5606	9.8164	305.5200
130	0.2110	-1.5559	0.2110	-1.5559	9.9506	349.4297
131	0.2020	-1.5994	0.2020	-1.5994	10.0934	403.1000
132	0.1980	-1.6194	0.1980	-1.6194	10.2507	471.7700
133	0.1970	-1.6245	0.1970	-1.6245	10.3492	520.5999
134	0.1960	-1.6296	0.1960	-1.6296	10.4377	568.7702
135	0.1920	-1.6502	0.1920	-1.6502	10.5913	663.1801
136	0.1930	-1.6450	0.1930	-1.6450	10.6599	710.2701
137	0.1890	-1.6660	0.1890	-1.6660	10.8173	831.3495
138	0.1920	-1.6502	0.1920	-1.6502	11.0009	998.7701
201	0.3858	-.9524	0.3858	-.9524	0.0000	0.0000
202	0.3728	-.9867	0.3728	-.9867	3.7796	0.7300
203	0.3602	-1.0211	0.3602	-1.0211	4.2513	1.1700

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
204	0.3514	-1.0458	0.3514	-1.0458	4.6367	1.7200
205	0.3525	-1.0427	0.3525	-1.0427	4.9402	2.3300
206	0.3448	-1.0647	0.3448	-1.0647	5.3414	3.4800
207	0.3443	-1.0662	0.3443	-1.0662	5.6567	4.7700
208	0.3155	-1.1536	0.3155	-1.1536	5.8894	6.0200
209	0.3341	-1.0963	0.3341	-1.0963	6.0781	7.2700
210	0.3300	-1.1086	0.3300	-1.1086	6.2368	8.5200
211	0.3260	-1.1208	0.3260	-1.1208	6.3477	9.5200
212	0.3225	-1.1316	0.3225	-1.1316	6.4739	10.7999
213	0.3201	-1.1391	0.3201	-1.1391	6.5809	12.0199
214	0.3108	-1.1686	0.3108	-1.1686	6.7774	14.6299
215	0.3078	-1.1783	0.3078	-1.1783	6.9068	16.6499
216	0.3032	-1.1933	0.3032	-1.1933	7.0266	18.7700
217	0.2973	-1.2130	0.2973	-1.2130	7.1749	21.7700
218	0.2937	-1.2252	0.2937	-1.2252	7.3040	24.7700
219	0.2771	-1.2833	0.2771	-1.2833	7.7597	39.0700
220	0.2753	-1.2898	0.2753	-1.2898	7.8666	43.4799
221	0.2682	-1.3160	0.2682	-1.3160	8.2343	62.7999
222	0.2581	-1.3544	0.2581	-1.3544	8.5674	87.6199
223	0.2526	-1.3759	0.2526	-1.3759	8.8329	114.2700
224	0.2580	-1.3548	0.2580	-1.3548	8.9938	134.2199
225	0.2511	-1.3819	0.2511	-1.3819	9.1649	159.2700
226	0.2420	-1.4188	0.2420	-1.4188	9.3059	183.3801
227	0.2381	-1.4350	0.2381	-1.4350	9.5371	231.0699
228	0.2421	-1.4184	0.2421	-1.4184	9.7394	282.8800
229	0.2361	-1.4435	0.2361	-1.4435	9.8164	305.5200
230	0.2376	-1.4371	0.2376	-1.4371	9.9506	349.4297
231	0.2368	-1.4405	0.2368	-1.4405	10.0934	403.1000
232	0.2290	-1.4740	0.2290	-1.4740	10.2507	471.7700
233	0.2328	-1.4575	0.2328	-1.4575	10.3492	520.5999
234	0.2304	-1.4679	0.2304	-1.4679	10.4377	568.7702
235	0.2235	-1.4983	0.2235	-1.4983	10.5913	663.1801
236	0.2254	-1.4898	0.2254	-1.4898	10.6599	710.2701
237	0.2219	-1.5055	0.2219	-1.5055	10.8173	831.3495
238	0.2220	-1.5050	0.2220	-1.5050	11.0009	998.7701
301	0.3937	-.9321	0.3937	-.9321	0.0000	0.0000
302	0.3817	-.9631	0.3817	-.9631	3.7796	0.7300
303	0.3696	-.9953	0.3696	-.9953	4.2513	1.1700
304	0.3610	-1.0188	0.3610	-1.0188	4.6367	1.7200
305	0.3598	-1.0222	0.3598	-1.0222	4.9402	2.3300
306	0.3534	-1.0401	0.3534	-1.0401	5.3414	3.4800

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
307	0.3514	-1.0458	0.3514	-1.0458	5.6567	4.7700
308	0.3320	-1.1026	0.3320	-1.1026	5.8894	6.0200
309	0.3445	-1.0656	0.3445	-1.0656	6.0781	7.2700
310	0.3404	-1.0776	0.3404	-1.0776	6.2368	8.5200
311	0.3361	-1.0903	0.3361	-1.0903	6.3477	9.5200
312	0.3328	-1.1002	0.3328	-1.1002	6.4739	10.7999
313	0.3312	-1.1050	0.3312	-1.1050	6.5809	12.0199
314	0.3233	-1.1291	0.3233	-1.1291	6.7774	14.6299
315	0.3209	-1.1366	0.3209	-1.1366	6.9068	16.6499
316	0.3182	-1.1450	0.3182	-1.1450	7.0266	18.7700
317	0.3112	-1.1673	0.3112	-1.1673	7.1749	21.7700
318	0.3091	-1.1740	0.3091	-1.1740	7.3040	24.7700
319	0.2924	-1.2296	0.2924	-1.2296	7.7597	39.0700
320	0.2902	-1.2371	0.2902	-1.2371	7.8666	43.4799
321	0.2857	-1.2528	0.2857	-1.2528	8.2343	62.7999
322	0.2750	-1.2909	0.2750	-1.2909	8.5674	87.6199
323	0.2690	-1.3130	0.2690	-1.3130	8.8329	114.2700
324	0.2737	-1.2957	0.2737	-1.2957	8.9938	134.2199
325	0.2690	-1.3130	0.2690	-1.3130	9.1649	159.2700
326	0.2596	-1.3486	0.2596	-1.3486	9.3059	183.3801
327	0.2550	-1.3664	0.2550	-1.3664	9.5371	231.0699
328	0.2610	-1.3432	0.2610	-1.3432	9.7394	282.8800
329	0.2530	-1.3743	0.2530	-1.3743	9.8164	305.5200
330	0.2534	-1.3727	0.2534	-1.3727	9.9506	349.4297
331	0.2532	-1.3735	0.2532	-1.3735	10.0934	403.1000
332	0.2469	-1.3987	0.2469	-1.3987	10.2507	471.7700
333	0.2498	-1.3871	0.2498	-1.3871	10.3492	520.5999
334	0.2449	-1.4069	0.2449	-1.4069	10.4377	568.7702
335	0.2412	-1.4221	0.2412	-1.4221	10.5913	663.1801
336	0.2396	-1.4287	0.2396	-1.4287	10.6599	710.2701
337	0.2366	-1.4413	0.2366	-1.4413	10.8173	831.3495
338	0.2357	-1.4452	0.2357	-1.4452	11.0009	998.7701
401	0.3854	-.9534	0.3854	-.9534	0.0000	0.0000
402	0.3758	-.9787	0.3758	-.9787	3.7796	0.7300
403	0.3648	-1.0084	0.3648	-1.0084	4.2513	1.1700
404	0.3576	-1.0283	0.3576	-1.0283	4.6367	1.7200
405	0.3562	-1.0322	0.3562	-1.0322	4.9402	2.3300
406	0.3503	-1.0489	0.3503	-1.0489	5.3414	3.4800
407	0.3486	-1.0538	0.3486	-1.0538	5.6567	4.7700
408	0.3325	-1.1011	0.3325	-1.1011	5.8894	6.0200
409	0.3402	-1.0782	0.3402	-1.0782	6.0781	7.2700

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
410	0.3371	-1.0873	0.3371	-1.0873	6.2368	8.5200
411	0.3329	-1.0999	0.3329	-1.0999	6.3477	9.5200
412	0.3289	-1.1120	0.3289	-1.1120	6.4739	10.7999
413	0.3279	-1.1150	0.3279	-1.1150	6.5809	12.0199
414	0.3202	-1.1388	0.3202	-1.1388	6.7774	14.6299
415	0.3180	-1.1457	0.3180	-1.1457	6.9068	16.6499
416	0.3147	-1.1561	0.3147	-1.1561	7.0266	18.7700
417	0.3082	-1.1770	0.3082	-1.1770	7.1749	21.7700
418	0.3066	-1.1822	0.3066	-1.1822	7.3040	24.7700
419	0.2891	-1.2409	0.2891	-1.2409	7.7597	39.0700
420	0.2869	-1.2486	0.2869	-1.2486	7.8666	43.4799
421	0.2801	-1.2726	0.2801	-1.2726	8.2343	62.7999
422	0.2701	-1.3089	0.2701	-1.3089	8.5674	87.6199
423	0.2646	-1.3295	0.2646	-1.3295	8.8329	114.2700
424	0.2683	-1.3156	0.2683	-1.3156	8.9938	134.2199
425	0.2633	-1.3344	0.2633	-1.3344	9.1649	159.2700
426	0.2546	-1.3680	0.2546	-1.3680	9.3059	183.3801
427	0.2486	-1.3919	0.2486	-1.3919	9.5371	231.0699
428	0.2539	-1.3708	0.2539	-1.3708	9.7394	282.8800
429	0.2459	-1.4028	0.2459	-1.4028	9.8164	305.5200
430	0.2467	-1.3995	0.2467	-1.3995	9.9506	349.4297
431	0.2458	-1.4032	0.2458	-1.4032	10.0934	403.1000
432	0.2396	-1.4287	0.2396	-1.4287	10.2507	471.7700
433	0.2420	-1.4188	0.2420	-1.4188	10.3492	520.5999
434	0.2371	-1.4392	0.2371	-1.4392	10.4377	568.7702
435	0.2333	-1.4554	0.2333	-1.4554	10.5913	663.1801
436	0.2319	-1.4614	0.2319	-1.4614	10.6599	710.2701
437	0.2288	-1.4749	0.2288	-1.4749	10.8173	831.3495
438	0.2254	-1.4898	0.2254	-1.4898	11.0009	998.7701
501	0.3824	-.9612	0.3824	-.9612	0.0000	0.0000
502	0.3751	-.9805	0.3751	-.9805	3.7796	0.7300
503	0.3642	-1.0100	0.3642	-1.0100	4.2513	1.1700
504	0.3573	-1.0291	0.3573	-1.0291	4.6367	1.7200
505	0.3554	-1.0345	0.3554	-1.0345	4.9402	2.3300
506	0.3522	-1.0435	0.3522	-1.0435	5.3414	3.4800
507	0.3493	-1.0518	0.3493	-1.0518	5.6567	4.7700
508	0.3351	-1.0933	0.3351	-1.0933	5.8894	6.0200
509	0.3407	-1.0767	0.3407	-1.0767	6.0781	7.2700
510	0.3379	-1.0850	0.3379	-1.0850	6.2368	8.5200
511	0.3347	-1.0945	0.3347	-1.0945	6.3477	9.5200
512	0.3319	-1.1029	0.3319	-1.1029	6.4739	10.7999

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
513	0.3293	-1.1107	0.3293	-1.1107	6.5809	12.0199
514	0.3245	-1.1254	0.3245	-1.1254	6.7774	14.6299
515	0.3217	-1.1341	0.3217	-1.1341	6.9068	16.6499
516	0.3171	-1.1485	0.3171	-1.1485	7.0266	18.7700
517	0.3117	-1.1657	0.3117	-1.1657	7.1749	21.7700
518	0.3114	-1.1666	0.3114	-1.1666	7.3040	24.7700
519	0.2940	-1.2241	0.2940	-1.2241	7.7597	39.0700
520	0.2919	-1.2313	0.2919	-1.2313	7.8666	43.4799
521	0.2860	-1.2517	0.2860	-1.2517	8.2343	62.7999
522	0.2766	-1.2851	0.2766	-1.2851	8.5674	87.6199
523	0.2712	-1.3049	0.2712	-1.3049	8.8329	114.2700
524	0.2754	-1.2895	0.2754	-1.2895	8.9938	134.2199
525	0.2708	-1.3063	0.2708	-1.3063	9.1649	159.2700
526	0.2608	-1.3440	0.2608	-1.3440	9.3059	183.3801
527	0.2562	-1.3618	0.2562	-1.3618	9.5371	231.0699
528	0.2614	-1.3417	0.2614	-1.3417	9.7394	282.8800
529	0.2534	-1.3727	0.2534	-1.3727	9.8164	305.5200
530	0.2546	-1.3680	0.2546	-1.3680	9.9506	349.4297
531	0.2543	-1.3692	0.2543	-1.3692	10.0934	403.1000
532	0.2481	-1.3939	0.2481	-1.3939	10.2507	471.7700
533	0.2503	-1.3851	0.2503	-1.3851	10.3492	520.5999
534	0.2457	-1.4036	0.2457	-1.4036	10.4377	568.7702
535	0.2421	-1.4184	0.2421	-1.4184	10.5913	663.1801
536	0.2408	-1.4237	0.2408	-1.4237	10.6599	710.2701
537	0.2364	-1.4422	0.2364	-1.4422	10.8173	831.3495
538	0.2321	-1.4605	0.2321	-1.4605	11.0009	998.7701
601	0.3800	-.9675	0.3800	-.9675	0.0000	0.0000
602	0.3737	-.9843	0.3737	-.9843	3.7796	0.7300
603	0.3642	-1.0100	0.3642	-1.0100	4.2513	1.1700
604	0.3572	-1.0294	0.3572	-1.0294	4.6367	1.7200
605	0.3540	-1.0384	0.3540	-1.0384	4.9402	2.3300
606	0.3499	-1.0501	0.3499	-1.0501	5.3414	3.4800
607	0.3461	-1.0610	0.3461	-1.0610	5.6567	4.7700
608	0.3331	-1.0993	0.3331	-1.0993	5.8894	6.0200
609	0.3370	-1.0876	0.3370	-1.0876	6.0781	7.2700
610	0.3348	-1.0942	0.3348	-1.0942	6.2368	8.5200
611	0.3318	-1.1032	0.3318	-1.1032	6.3477	9.5200
612	0.3281	-1.1144	0.3281	-1.1144	6.4739	10.7999
613	0.3261	-1.1205	0.3261	-1.1205	6.5809	12.0199
614	0.3210	-1.1363	0.3210	-1.1363	6.7774	14.6299
615	0.3181	-1.1453	0.3181	-1.1453	6.9068	16.6499

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
616	0.3138	-1.1590	0.3138	-1.1590	7.0266	18.7700
617	0.3093	-1.1734	0.3093	-1.1734	7.1749	21.7700
618	0.3084	-1.1763	0.3084	-1.1763	7.3040	24.7700
619	0.2919	-1.2313	0.2919	-1.2313	7.7597	39.0700
620	0.2896	-1.2392	0.2896	-1.2392	7.8666	43.4799
621	0.2845	-1.2570	0.2845	-1.2570	8.2343	62.7999
622	0.2757	-1.2884	0.2757	-1.2884	8.5674	87.6199
623	0.2702	-1.3085	0.2702	-1.3085	8.8329	114.2700
624	0.2733	-1.2971	0.2733	-1.2971	8.9938	134.2199
625	0.2695	-1.3111	0.2695	-1.3111	9.1649	159.2700
626	0.2608	-1.3440	0.2608	-1.3440	9.3059	183.3801
627	0.2548	-1.3672	0.2548	-1.3672	9.5371	231.0699
628	0.2595	-1.3490	0.2595	-1.3490	9.7394	282.8800
629	0.2519	-1.3787	0.2519	-1.3787	9.8164	305.5200
630	0.2530	-1.3743	0.2530	-1.3743	9.9506	349.4297
631	0.2516	-1.3799	0.2516	-1.3799	10.0934	403.1000
632	0.2460	-1.4024	0.2460	-1.4024	10.2507	471.7700
633	0.2479	-1.3947	0.2479	-1.3947	10.3492	520.5999
634	0.2441	-1.4101	0.2441	-1.4101	10.4377	568.7702
635	0.2406	-1.4246	0.2406	-1.4246	10.5913	663.1801
636	0.2390	-1.4313	0.2390	-1.4313	10.6599	710.2701
637	0.2342	-1.4515	0.2342	-1.4515	10.8173	831.3495
638	0.2301	-1.4692	0.2301	-1.4692	11.0009	998.7701
701	0.3738	-.9840	0.3738	-.9840	0.0000	0.0000
702	0.3683	-.9988	0.3683	-.9988	3.7796	0.7300
703	0.3593	-1.0236	0.3593	-1.0236	4.2513	1.1700
704	0.3537	-1.0393	0.3537	-1.0393	4.6367	1.7200
705	0.3506	-1.0481	0.3506	-1.0481	4.9402	2.3300
706	0.3435	-1.0685	0.3435	-1.0685	5.3414	3.4800
707	0.3376	-1.0859	0.3376	-1.0859	5.6567	4.7700
708	0.3239	-1.1273	0.3239	-1.1273	5.8894	6.0200
709	0.3251	-1.1236	0.3251	-1.1236	6.0781	7.2700
710	0.3215	-1.1347	0.3215	-1.1347	6.2368	8.5200
711	0.3175	-1.1472	0.3175	-1.1472	6.3477	9.5200
712	0.3141	-1.1580	0.3141	-1.1580	6.4739	10.7999
713	0.3115	-1.1663	0.3115	-1.1663	6.5809	12.0199
714	0.3061	-1.1838	0.3061	-1.1838	6.7774	14.6299
715	0.3027	-1.1950	0.3027	-1.1950	6.9068	16.6499
716	0.2984	-1.2093	0.2984	-1.2093	7.0266	18.7700
717	0.2940	-1.2241	0.2940	-1.2241	7.1749	21.7700
718	0.2926	-1.2289	0.2926	-1.2289	7.3040	24.7700

Table 38. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
719	0.2753	-1.2898	0.2753	-1.2898	7.7597	39.0700
720	0.2739	-1.2949	0.2739	-1.2949	7.8666	43.4799
721	0.2681	-1.3164	0.2681	-1.3164	8.2343	62.7999
722	0.2592	-1.3501	0.2592	-1.3501	8.5674	87.6199
723	0.2533	-1.3731	0.2533	-1.3731	8.8329	114.2700
724	0.2557	-1.3637	0.2557	-1.3637	8.9938	134.2199
725	0.2522	-1.3775	0.2522	-1.3775	9.1649	159.2700
726	0.2438	-1.4114	0.2438	-1.4114	9.3059	183.3801
727	0.2383	-1.4342	0.2383	-1.4342	9.5371	231.0699
728	0.2427	-1.4159	0.2427	-1.4159	9.7394	282.8800
729	0.2352	-1.4473	0.2352	-1.4473	9.8164	305.5200
730	0.2358	-1.4447	0.2358	-1.4447	9.9506	349.4297
731	0.2338	-1.4532	0.2338	-1.4532	10.0934	403.1000
732	0.2288	-1.4749	0.2288	-1.4749	10.2507	471.7700
733	0.2311	-1.4649	0.2311	-1.4649	10.3492	520.5999
734	0.2274	-1.4810	0.2274	-1.4810	10.4377	568.7702
735	0.2231	-1.5001	0.2231	-1.5001	10.5913	663.1801
736	0.2222	-1.5041	0.2222	-1.5041	10.6599	710.2701
737	0.2172	-1.5269	0.2172	-1.5269	10.8173	831.3495
738	0.2127	-1.5478	0.2127	-1.5478	11.0009	998.7701

Table 39. Regression data, site 5.

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
101	0.4590	-.7787	0.4590	-.7787	0.0000	0.0000
102	0.4510	-.7962	0.4510	-.7962	2.9549	0.3200
103	0.4340	-.8347	0.4340	-.8347	3.8959	0.8200
104	0.4260	-.8533	0.4260	-.8533	4.3720	1.3200
105	0.4190	-.8698	0.4190	-.8698	4.6932	1.8200
106	0.4030	-.9088	0.4030	-.9088	5.2160	3.0700
107	0.4000	-.9162	0.4000	-.9162	5.4980	4.0700
108	0.3810	-.9649	0.3810	-.9649	5.8977	6.0700
109	0.3760	-.9781	0.3760	-.9781	6.1825	8.0700
110	0.3660	-1.0051	0.3660	-1.0051	6.4039	10.0699
111	0.3610	-1.0188	0.3610	-1.0188	6.5851	12.0700
112	0.3550	-1.0356	0.3550	-1.0356	6.7384	14.0699
113	0.3500	-1.0498	0.3500	-1.0498	6.9462	17.3199
114	0.3440	-1.0671	0.3440	-1.0671	7.0425	19.0700
115	0.3420	-1.0729	0.3420	-1.0729	7.1422	21.0700
116	0.3410	-1.0758	0.3410	-1.0758	7.2329	23.0700
117	0.3110	-1.1679	0.3110	-1.1679	7.7870	40.1499
118	0.3060	-1.1841	0.3060	-1.1841	7.8337	42.0700
119	0.3070	-1.1809	0.3070	-1.1809	7.8801	44.0700
120	0.2970	-1.2140	0.2970	-1.2140	8.3149	68.0700
121	0.2940	-1.2241	0.2940	-1.2241	8.6150	91.8999
122	0.2860	-1.2517	0.2860	-1.2517	8.8406	115.1500
123	0.2740	-1.2946	0.2740	-1.2946	9.0124	136.7300
124	0.2720	-1.3019	0.2720	-1.3019	9.1793	161.5701
125	0.2660	-1.3242	0.2660	-1.3242	9.3228	186.4999
126	0.2690	-1.3130	0.2690	-1.3130	9.4315	207.9299
127	0.2580	-1.3548	0.2580	-1.3548	9.5489	233.8199
128	0.2570	-1.3586	0.2570	-1.3586	9.8876	328.0696
129	0.2500	-1.3863	0.2500	-1.3863	10.0214	375.1001
130	0.2390	-1.4313	0.2390	-1.4313	10.3013	496.2299
131	0.2800	-1.2729	0.2800	-1.2729	10.4434	571.9799
132	0.2620	-1.3394	0.2620	-1.3394	10.6322	690.8197
201	0.4537	-.7903	0.4537	-.7903	0.0000	0.0000
202	0.4510	-.7962	0.4510	-.7962	2.9549	0.3200
203	0.4340	-.8347	0.4340	-.8347	3.8959	0.8200
204	0.4323	-.8386	0.4323	-.8386	4.3720	1.3200
205	0.4253	-.8549	0.4253	-.8549	4.6932	1.8200
206	0.4132	-.8838	0.4132	-.8838	5.2160	3.0700
207	0.4097	-.8923	0.4097	-.8923	5.4980	4.0700
208	0.3926	-.9349	0.3926	-.9349	5.8977	6.0700
209	0.3881	-.9464	0.3881	-.9464	6.1825	8.0700

Table 39. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
210	0.3771	-.9752	0.3771	-.9752	6.4039	10.0699
211	0.3731	-.9859	0.3731	-.9859	6.5851	12.0700
212	0.3676	-1.0007	0.3676	-1.0007	6.7384	14.0699
213	0.3631	-1.0130	0.3631	-1.0130	6.9462	17.3199
214	0.3575	-1.0286	0.3575	-1.0286	7.0425	19.0700
215	0.3570	-1.0300	0.3570	-1.0300	7.1422	21.0700
216	0.3521	-1.0438	0.3521	-1.0438	7.2329	23.0700
217	0.3216	-1.1344	0.3216	-1.1344	7.7870	40.1499
218	0.3215	-1.1347	0.3215	-1.1347	7.8337	42.0700
219	0.3201	-1.1391	0.3201	-1.1391	7.8801	44.0700
220	0.3110	-1.1679	0.3110	-1.1679	8.3149	68.0700
221	0.3037	-1.1917	0.3037	-1.1917	8.6150	91.8999
222	0.2952	-1.2201	0.2952	-1.2201	8.8406	115.1500
223	0.2837	-1.2598	0.2837	-1.2598	9.0124	136.7300
224	0.2846	-1.2566	0.2846	-1.2566	9.1793	161.5701
225	0.2786	-1.2779	0.2786	-1.2779	9.3228	186.4999
226	0.2796	-1.2744	0.2796	-1.2744	9.4315	207.9299
227	0.2706	-1.3071	0.2706	-1.3071	9.5489	233.8199
228	0.2667	-1.3216	0.2667	-1.3216	9.8876	328.0696
229	0.2602	-1.3463	0.2602	-1.3463	10.0214	375.1001
230	0.2511	-1.3819	0.2511	-1.3819	10.3013	496.2299
231	0.2916	-1.2323	0.2916	-1.2323	10.4434	571.9799
232	0.2717	-1.3030	0.2717	-1.3030	10.6322	690.8197
301	0.4463	-.8067	0.4463	-.8067	0.0000	0.0000
302	0.4445	-.8108	0.4445	-.8108	2.9549	0.3200
303	0.4307	-.8423	0.4307	-.8423	3.8959	0.8200
304	0.4280	-.8486	0.4280	-.8486	4.3720	1.3200
305	0.4216	-.8637	0.4216	-.8637	4.6932	1.8200
306	0.4134	-.8833	0.4134	-.8833	5.2160	3.0700
307	0.4088	-.8945	0.4088	-.8945	5.4980	4.0700
308	0.3940	-.9314	0.3940	-.9314	5.8977	6.0700
309	0.3874	-.9483	0.3874	-.9483	6.1825	8.0700
310	0.3794	-.9691	0.3794	-.9691	6.4039	10.0699
311	0.3763	-.9773	0.3763	-.9773	6.5851	12.0700
312	0.3697	-.9950	0.3697	-.9950	6.7384	14.0699
313	0.3637	-1.0114	0.3637	-1.0114	6.9462	17.3199
314	0.3593	-1.0236	0.3593	-1.0236	7.0425	19.0700
315	0.3570	-1.0300	0.3570	-1.0300	7.1422	21.0700
316	0.3537	-1.0393	0.3537	-1.0393	7.2329	23.0700
317	0.3227	-1.1310	0.3227	-1.1310	7.7870	40.1499
318	0.3230	-1.1301	0.3230	-1.1301	7.8337	42.0700

Table 39. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
319	0.3204	-1.1381	0.3204	-1.1381	7.8801	44.0700
320	0.3113	-1.1670	0.3113	-1.1670	8.3149	68.0700
321	0.3038	-1.1913	0.3038	-1.1913	8.6150	91.8999
322	0.2942	-1.2235	0.2942	-1.2235	8.8406	115.1500
323	0.2851	-1.2549	0.2851	-1.2549	9.0124	136.7300
324	0.2870	-1.2482	0.2870	-1.2482	9.1793	161.5701
325	0.2797	-1.2740	0.2797	-1.2740	9.3228	186.4999
326	0.2788	-1.2772	0.2788	-1.2772	9.4315	207.9299
327	0.2704	-1.3078	0.2704	-1.3078	9.5489	233.8199
328	0.2648	-1.3287	0.2648	-1.3287	9.8876	328.0696
329	0.2598	-1.3478	0.2598	-1.3478	10.0214	375.1001
330	0.2514	-1.3807	0.2514	-1.3807	10.3013	496.2299
331	0.2852	-1.2545	0.2852	-1.2545	10.4434	571.9799
332	0.2721	-1.3015	0.2721	-1.3015	10.6322	690.8197
401	0.4410	-.8187	0.4410	-.8187	0.0000	0.0000
402	0.4394	-.8223	0.4394	-.8223	2.9549	0.3200
403	0.4281	-.8484	0.4281	-.8484	3.8959	0.8200
404	0.4250	-.8556	0.4250	-.8556	4.3720	1.3200
405	0.4210	-.8651	0.4210	-.8651	4.6932	1.8200
406	0.4121	-.8864	0.4121	-.8864	5.2160	3.0700
407	0.4098	-.8920	0.4098	-.8920	5.4980	4.0700
408	0.3972	-.9233	0.3972	-.9233	5.8977	6.0700
409	0.3910	-.9390	0.3910	-.9390	6.1825	8.0700
410	0.3812	-.9644	0.3812	-.9644	6.4039	10.0699
411	0.3797	-.9683	0.3797	-.9683	6.5851	12.0700
412	0.3737	-.9843	0.3737	-.9843	6.7384	14.0699
413	0.3652	-1.0073	0.3652	-1.0073	6.9462	17.3199
414	0.3632	-1.0128	0.3632	-1.0128	7.0425	19.0700
415	0.3609	-1.0191	0.3609	-1.0191	7.1422	21.0700
416	0.3582	-1.0266	0.3582	-1.0266	7.2329	23.0700
417	0.3265	-1.1193	0.3265	-1.1193	7.7870	40.1499
418	0.3249	-1.1242	0.3249	-1.1242	7.8337	42.0700
419	0.3227	-1.1310	0.3227	-1.1310	7.8801	44.0700
420	0.3125	-1.1631	0.3125	-1.1631	8.3149	68.0700
421	0.3056	-1.1854	0.3056	-1.1854	8.6150	91.8999
422	0.2978	-1.2113	0.2978	-1.2113	8.8406	115.1500
423	0.2868	-1.2489	0.2868	-1.2489	9.0124	136.7300
424	0.2882	-1.2441	0.2882	-1.2441	9.1793	161.5701
425	0.2805	-1.2711	0.2805	-1.2711	9.3228	186.4999
426	0.2806	-1.2708	0.2806	-1.2708	9.4315	207.9299
427	0.2710	-1.3056	0.2710	-1.3056	9.5489	233.8199

Table 39. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
428	0.2649	-1.3284	0.2649	-1.3284	9.8876	328.0696
429	0.2601	-1.3466	0.2601	-1.3466	10.0214	375.1001
430	0.2528	-1.3751	0.2528	-1.3751	10.3013	496.2299
431	0.2815	-1.2676	0.2815	-1.2676	10.4434	571.9799
432	0.2696	-1.3108	0.2696	-1.3108	10.6322	690.8197
501	0.4359	-.8303	0.4359	-.8303	0.0000	0.0000
502	0.4336	-.8356	0.4336	-.8356	2.9549	0.3200
503	0.4243	-.8573	0.4243	-.8573	3.8959	0.8200
504	0.4207	-.8658	0.4207	-.8658	4.3720	1.3200
505	0.4186	-.8708	0.4186	-.8708	4.6932	1.8200
506	0.4105	-.8903	0.4105	-.8903	5.2160	3.0700
507	0.4089	-.8942	0.4089	-.8942	5.4980	4.0700
508	0.3980	-.9213	0.3980	-.9213	5.8977	6.0700
509	0.3936	-.9324	0.3936	-.9324	6.1825	8.0700
510	0.3840	-.9571	0.3840	-.9571	6.4039	10.0699
511	0.3831	-.9594	0.3831	-.9594	6.5851	12.0700
512	0.3767	-.9763	0.3767	-.9763	6.7384	14.0699
513	0.3693	-.9961	0.3693	-.9961	6.9462	17.3199
514	0.3665	-1.0037	0.3665	-1.0037	7.0425	19.0700
515	0.3647	-1.0086	0.3647	-1.0086	7.1422	21.0700
516	0.3627	-1.0141	0.3627	-1.0141	7.2329	23.0700
517	0.3305	-1.1071	0.3305	-1.1071	7.7870	40.1499
518	0.3281	-1.1144	0.3281	-1.1144	7.8337	42.0700
519	0.3267	-1.1187	0.3267	-1.1187	7.8801	44.0700
520	0.3167	-1.1498	0.3167	-1.1498	8.3149	68.0700
521	0.3096	-1.1724	0.3096	-1.1724	8.6150	91.8999
522	0.3018	-1.1979	0.3018	-1.1979	8.8406	115.1500
523	0.2902	-1.2371	0.2902	-1.2371	9.0124	136.7300
524	0.2907	-1.2354	0.2907	-1.2354	9.1793	161.5701
525	0.2836	-1.2601	0.2836	-1.2601	9.3228	186.4999
526	0.2832	-1.2616	0.2832	-1.2616	9.4315	207.9299
527	0.2746	-1.2924	0.2746	-1.2924	9.5489	233.8199
528	0.2673	-1.3193	0.2673	-1.3193	9.8876	328.0696
529	0.2622	-1.3386	0.2622	-1.3386	10.0214	375.1001
530	0.2544	-1.3688	0.2544	-1.3688	10.3013	496.2299
531	0.2806	-1.2708	0.2806	-1.2708	10.4434	571.9799
532	0.2701	-1.3089	0.2701	-1.3089	10.6322	690.8197
601	0.4297	-.8446	0.4297	-.8446	0.0000	0.0000
602	0.4273	-.8502	0.4273	-.8502	2.9549	0.3200
603	0.4193	-.8691	0.4193	-.8691	3.8959	0.8200
604	0.4158	-.8775	0.4158	-.8775	4.3720	1.3200

Table 39. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
605	0.4134	-.8833	0.4134	-.8833	4.6932	1.8200
606	0.4070	-.8989	0.4070	-.8989	5.2160	3.0700
607	0.4059	-.9016	0.4059	-.9016	5.4980	4.0700
608	0.3962	-.9258	0.3962	-.9258	5.8977	6.0700
609	0.3933	-.9331	0.3933	-.9331	6.1825	8.0700
610	0.3840	-.9571	0.3840	-.9571	6.4039	10.0699
611	0.3831	-.9594	0.3831	-.9594	6.5851	12.0700
612	0.3773	-.9747	0.3773	-.9747	6.7384	14.0699
613	0.3709	-.9918	0.3709	-.9918	6.9462	17.3199
614	0.3689	-.9972	0.3689	-.9972	7.0425	19.0700
615	0.3671	-1.0021	0.3671	-1.0021	7.1422	21.0700
616	0.3642	-1.0100	0.3642	-1.0100	7.2329	23.0700
617	0.3351	-1.0933	0.3351	-1.0933	7.7870	40.1499
618	0.3322	-1.1020	0.3322	-1.1020	7.8337	42.0700
619	0.3297	-1.1095	0.3297	-1.1095	7.8801	44.0700
620	0.3212	-1.1356	0.3212	-1.1356	8.3149	68.0700
621	0.3156	-1.1532	0.3156	-1.1532	8.6150	91.8999
622	0.3069	-1.1812	0.3069	-1.1812	8.8406	115.1500
623	0.2954	-1.2194	0.2954	-1.2194	9.0124	136.7300
624	0.2959	-1.2177	0.2959	-1.2177	9.1793	161.5701
625	0.2906	-1.2358	0.2906	-1.2358	9.3228	186.4999
626	0.2901	-1.2375	0.2901	-1.2375	9.4315	207.9299
627	0.2798	-1.2736	0.2798	-1.2736	9.5489	233.8199
628	0.2730	-1.2982	0.2730	-1.2982	9.8876	328.0696
629	0.2680	-1.3167	0.2680	-1.3167	10.0214	375.1001
630	0.2603	-1.3459	0.2603	-1.3459	10.3013	496.2299
631	0.2831	-1.2619	0.2831	-1.2619	10.4434	571.9799
632	0.2754	-1.2895	0.2754	-1.2895	10.6322	690.8197
701	0.4226	-.8613	0.4226	-.8613	0.0000	0.0000
702	0.4214	-.8641	0.4214	-.8641	2.9549	0.3200
703	0.4129	-.8845	0.4129	-.8845	3.8959	0.8200
704	0.4102	-.8911	0.4102	-.8911	4.3720	1.3200
705	0.4085	-.8952	0.4085	-.8952	4.6932	1.8200
706	0.4022	-.9108	0.4022	-.9108	5.2160	3.0700
707	0.4018	-.9118	0.4018	-.9118	5.4980	4.0700
708	0.3940	-.9314	0.3940	-.9314	5.8977	6.0700
709	0.3914	-.9380	0.3914	-.9380	6.1825	8.0700
710	0.3835	-.9584	0.3835	-.9584	6.4039	10.0699
711	0.3814	-.9639	0.3814	-.9639	6.5851	12.0700
712	0.3778	-.9733	0.3778	-.9733	6.7384	14.0699
713	0.3717	-.9896	0.3717	-.9896	6.9462	17.3199

Table 39. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
714	0.3700	-.9942	0.3700	-.9942	7.0425	19.0700
715	0.3675	-1.0010	0.3675	-1.0010	7.1422	21.0700
716	0.3651	-1.0075	0.3651	-1.0075	7.2329	23.0700
717	0.3375	-1.0861	0.3375	-1.0861	7.7870	40.1499
718	0.3340	-1.0966	0.3340	-1.0966	7.8337	42.0700
719	0.3318	-1.1032	0.3318	-1.1032	7.8801	44.0700
720	0.3242	-1.1264	0.3242	-1.1264	8.3149	68.0700
721	0.3192	-1.1419	0.3192	-1.1419	8.6150	91.8999
722	0.3109	-1.1682	0.3109	-1.1682	8.8406	115.1500
723	0.2993	-1.2063	0.2993	-1.2063	9.0124	136.7300
724	0.3002	-1.2033	0.3002	-1.2033	9.1793	161.5701
725	0.2956	-1.2187	0.2956	-1.2187	9.3228	186.4999
726	0.2945	-1.2224	0.2945	-1.2224	9.4315	207.9299
727	0.2845	-1.2570	0.2845	-1.2570	9.5489	233.8199
728	0.2775	-1.2819	0.2775	-1.2819	9.8876	328.0696
729	0.2732	-1.2975	0.2732	-1.2975	10.0214	375.1001
730	0.2656	-1.3257	0.2656	-1.3257	10.3013	496.2299
731	0.2864	-1.2503	0.2864	-1.2503	10.4434	571.9799
732	0.2804	-1.2715	0.2804	-1.2715	10.6322	690.8197
0	8.0700	2.0881	8.0700	2.0881	0.0000	0.0000
629	0.2680	-1.3167	0.2680	-1.3167	10.0214	375.1001
630	0.2603	-1.3459	0.2603	-1.3459	10.3013	496.2299
631	0.2831	-1.2619	0.2831	-1.2619	10.4434	571.9799
632	0.2754	-1.2895	0.2754	-1.2895	10.6322	690.8197

Table 40. Regression data, site 6.

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
101	0.4680	-.7592	0.4680	-.7592	0.0000	0.0000
102	0.4500	-.7985	0.4500	-.7985	3.8330	0.7700
103	0.4410	-.8187	0.4410	-.8187	4.8919	2.2200
104	0.4250	-.8556	0.4250	-.8556	5.3973	3.6800
105	0.4110	-.8891	0.4110	-.8891	5.6525	4.7500
106	0.4100	-.8916	0.4100	-.8916	5.9615	6.4700
107	0.3910	-.9390	0.3910	-.9390	6.2600	8.7200
108	0.3530	-1.0412	0.3530	-1.0412	7.2101	22.5499
109	0.3470	-1.0584	0.3470	-1.0584	7.3020	24.7200
110	0.3440	-1.0671	0.3440	-1.0671	7.3318	25.4700
111	0.3520	-1.0441	0.3520	-1.0441	7.4736	29.3499
112	0.3330	-1.0996	0.3330	-1.0996	7.9374	46.6700
113	0.3270	-1.1178	0.3270	-1.1178	8.0295	51.1700
114	0.3260	-1.1208	0.3260	-1.1208	5.0613	2.6300
115	0.3140	-1.1583	0.3140	-1.1583	8.3490	70.4299
116	0.3110	-1.1679	0.3110	-1.1679	8.3907	73.4299
117	0.3130	-1.1615	0.3130	-1.1615	8.6920	99.2499
118	0.3030	-1.1940	0.3030	-1.1940	8.9022	122.4700
119	0.2970	-1.2140	0.2970	-1.2140	9.0795	146.2200
120	0.2890	-1.2413	0.2890	-1.2413	9.2092	166.4699
121	0.2850	-1.2552	0.2850	-1.2552	9.3412	189.9700
122	0.2800	-1.2729	0.2800	-1.2729	9.4668	215.4001
123	0.2820	-1.2658	0.2820	-1.2658	9.5838	242.1300
124	0.2700	-1.3093	0.2700	-1.3093	9.8333	310.7501
125	0.2730	-1.2982	0.2730	-1.2982	9.9848	361.5802
126	0.2610	-1.3432	0.2610	-1.3432	10.1062	408.2202
127	0.2640	-1.3318	0.2640	-1.3318	10.3132	502.1297
128	0.2600	-1.3470	0.2600	-1.3470	10.4033	549.4695
129	0.2510	-1.3823	0.2510	-1.3823	10.6022	670.3800
130	0.2690	-1.3130	0.2690	-1.3130	10.7089	745.8797
131	0.2590	-1.3509	0.2590	-1.3509	10.8300	841.8798
201	0.4641	-.7676	0.4641	-.7676	0.0000	0.0000
202	0.4490	-.8007	0.4490	-.8007	3.8330	0.7700
203	0.4357	-.8308	0.4357	-.8308	4.8919	2.2200
204	0.4240	-.8580	0.4240	-.8580	5.3973	3.6800
205	0.4120	-.8867	0.4120	-.8867	5.6525	4.7500
206	0.4056	-.9023	0.4056	-.9023	5.9615	6.4700
207	0.3939	-.9316	0.3939	-.9316	6.2600	8.7200
208	0.3564	-1.0317	0.3564	-1.0317	7.2101	22.5499
209	0.3518	-1.0446	0.3518	-1.0446	7.3020	24.7200
210	0.3484	-1.0544	0.3484	-1.0544	7.3318	25.4700

Table 40. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
211	0.3505	-1.0484	0.3505	-1.0484	7.4736	29.3499
212	0.3364	-1.0894	0.3364	-1.0894	7.9374	46.6700
213	0.3294	-1.1104	0.3294	-1.1104	8.0295	51.1700
214	0.3318	-1.1032	0.3318	-1.1032	5.0613	2.6300
215	0.3164	-1.1507	0.3164	-1.1507	8.3490	70.4299
216	0.3134	-1.1602	0.3134	-1.1602	8.3907	73.4299
217	0.3140	-1.1583	0.3140	-1.1583	8.6920	99.2499
218	0.3040	-1.1907	0.3040	-1.1907	8.9022	122.4700
219	0.2960	-1.2174	0.2960	-1.2174	9.0795	146.2200
220	0.2929	-1.2279	0.2929	-1.2279	9.2092	166.4699
221	0.2879	-1.2451	0.2879	-1.2451	9.3412	189.9700
222	0.2815	-1.2676	0.2815	-1.2676	9.4668	215.4001
223	0.2854	-1.2538	0.2854	-1.2538	9.5838	242.1300
224	0.2681	-1.3164	0.2681	-1.3164	9.8333	310.7501
225	0.2720	-1.3019	0.2720	-1.3019	9.9848	361.5802
226	0.2649	-1.3284	0.2649	-1.3284	10.1062	408.2202
227	0.2625	-1.3375	0.2625	-1.3375	10.3132	502.1297
228	0.2585	-1.3528	0.2585	-1.3528	10.4033	549.4695
229	0.2500	-1.3863	0.2500	-1.3863	10.6022	670.3800
230	0.2646	-1.3295	0.2646	-1.3295	10.7089	745.8797
231	0.2537	-1.3716	0.2537	-1.3716	10.8300	841.8798
301	0.4625	-.7711	0.4625	-.7711	0.0000	0.0000
302	0.4526	-.7927	0.4526	-.7927	3.8330	0.7700
303	0.4374	-.8269	0.4374	-.8269	4.8919	2.2200
304	0.4253	-.8549	0.4253	-.8549	5.3973	3.6800
305	0.4152	-.8790	0.4152	-.8790	5.6525	4.7500
306	0.4087	-.8947	0.4087	-.8947	5.9615	6.4700
307	0.3988	-.9193	0.3988	-.9193	6.2600	8.7200
308	0.3631	-1.0130	0.3631	-1.0130	7.2101	22.5499
309	0.3591	-1.0241	0.3591	-1.0241	7.3020	24.7200
310	0.3580	-1.0272	0.3580	-1.0272	7.3318	25.4700
311	0.3582	-1.0266	0.3582	-1.0266	7.4736	29.3499
312	0.3431	-1.0697	0.3431	-1.0697	7.9374	46.6700
313	0.3391	-1.0814	0.3391	-1.0814	8.0295	51.1700
314	0.3397	-1.0797	0.3397	-1.0797	5.0613	2.6300
315	0.3264	-1.1196	0.3264	-1.1196	8.3490	70.4299
316	0.3237	-1.1279	0.3237	-1.1279	8.3907	73.4299
317	0.3238	-1.1276	0.3238	-1.1276	8.6920	99.2499
318	0.3151	-1.1548	0.3151	-1.1548	8.9022	122.4700
319	0.3038	-1.1913	0.3038	-1.1913	9.0795	146.2200
320	0.3007	-1.2016	0.3007	-1.2016	9.2092	166.4699

Table 40. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
321	0.2971	-1.2136	0.2971	-1.2136	9.3412	189.9700
322	0.2898	-1.2385	0.2898	-1.2385	9.4668	215.4001
323	0.2915	-1.2327	0.2915	-1.2327	9.5838	242.1300
324	0.2772	-1.2830	0.2772	-1.2830	9.8333	310.7501
325	0.2805	-1.2711	0.2805	-1.2711	9.9848	361.5802
326	0.2708	-1.3063	0.2708	-1.3063	10.1062	408.2202
327	0.2673	-1.3193	0.2673	-1.3193	10.3132	502.1297
328	0.2649	-1.3284	0.2649	-1.3284	10.4033	549.4695
329	0.2546	-1.3680	0.2546	-1.3680	10.6022	670.3800
330	0.2667	-1.3216	0.2667	-1.3216	10.7089	745.8797
331	0.2570	-1.3586	0.2570	-1.3586	10.8300	841.8798
401	0.4601	-.7763	0.4601	-.7763	0.0000	0.0000
402	0.4554	-.7865	0.4554	-.7865	3.8330	0.7700
403	0.4393	-.8225	0.4393	-.8225	4.8919	2.2200
404	0.4267	-.8516	0.4267	-.8516	5.3973	3.6800
405	0.4203	-.8667	0.4203	-.8667	5.6525	4.7500
406	0.4134	-.8833	0.4134	-.8833	5.9615	6.4700
407	0.4048	-.9043	0.4048	-.9043	6.2600	8.7200
408	0.3719	-.9891	0.3719	-.9891	7.2101	22.5499
409	0.3696	-.9953	0.3696	-.9953	7.3020	24.7200
410	0.3671	-1.0021	0.3671	-1.0021	7.3318	25.4700
411	0.3660	-1.0051	0.3660	-1.0051	7.4736	29.3499
412	0.3551	-1.0353	0.3551	-1.0353	7.9374	46.6700
413	0.3499	-1.0501	0.3499	-1.0501	8.0295	51.1700
414	0.3516	-1.0452	0.3516	-1.0452	5.0613	2.6300
415	0.3366	-1.0888	0.3366	-1.0888	8.3490	70.4299
416	0.3339	-1.0969	0.3339	-1.0969	8.3907	73.4299
417	0.3359	-1.0909	0.3359	-1.0909	8.6920	99.2499
418	0.3264	-1.1196	0.3264	-1.1196	8.9022	122.4700
419	0.3154	-1.1539	0.3154	-1.1539	9.0795	146.2200
420	0.3121	-1.1644	0.3121	-1.1644	9.2092	166.4699
421	0.3093	-1.1734	0.3093	-1.1734	9.3412	189.9700
422	0.2989	-1.2076	0.2989	-1.2076	9.4668	215.4001
423	0.3039	-1.1910	0.3039	-1.1910	9.5838	242.1300
424	0.2880	-1.2448	0.2880	-1.2448	9.8333	310.7501
425	0.2907	-1.2354	0.2907	-1.2354	9.9848	361.5802
426	0.2812	-1.2686	0.2812	-1.2686	10.1062	408.2202
427	0.2768	-1.2844	0.2768	-1.2844	10.3132	502.1297
428	0.2725	-1.3001	0.2725	-1.3001	10.4033	549.4695
429	0.2628	-1.3363	0.2628	-1.3363	10.6022	670.3800
430	0.2724	-1.3004	0.2724	-1.3004	10.7089	745.8797

Table 40. (Cont'd)

Depth and Reading	W/z	ln W/z	Θ'	ln Θ'	ln t (min)	t (hr)
431	0.2644	-1.3302	0.2644	-1.3302	10.8300	841.8798
501	0.4566	-.7839	0.4566	-.7839	0.0000	0.0000
502	0.4520	-.7940	0.4520	-.7940	3.8330	0.7700
503	0.4392	-.8228	0.4392	-.8228	4.8919	2.2200
504	0.4268	-.8514	0.4268	-.8514	5.3973	3.6800
505	0.4219	-.8629	0.4219	-.8629	5.6525	4.7500
506	0.4155	-.8782	0.4155	-.8782	5.9615	6.4700
507	0.4090	-.8940	0.4090	-.8940	6.2600	8.7200
508	0.3789	-.9704	0.3789	-.9704	7.2101	22.5499
509	0.3770	-.9755	0.3770	-.9755	7.3020	24.7200
510	0.3748	-.9813	0.3748	-.9813	7.3318	25.4700
511	0.3743	-.9827	0.3743	-.9827	7.4736	29.3499
512	0.3626	-1.0144	0.3626	-1.0144	7.9374	46.6700
513	0.3607	-1.0197	0.3607	-1.0197	8.0295	51.1700
514	0.3611	-1.0186	0.3611	-1.0186	5.0613	2.6300
515	0.3462	-1.0607	0.3462	-1.0607	8.3490	70.4299
516	0.3436	-1.0682	0.3436	-1.0682	8.3907	73.4299
517	0.3458	-1.0619	0.3458	-1.0619	8.6920	99.2499
518	0.3367	-1.0885	0.3367	-1.0885	8.9022	122.4700
519	0.3252	-1.1233	0.3252	-1.1233	9.0795	146.2200
520	0.3210	-1.1363	0.3210	-1.1363	9.2092	166.4699
521	0.3174	-1.1476	0.3174	-1.1476	9.3412	189.9700
522	0.3080	-1.1776	0.3080	-1.1776	9.4668	215.4001
523	0.3126	-1.1628	0.3126	-1.1628	9.5838	242.1300
524	0.2976	-1.2120	0.2976	-1.2120	9.8333	310.7501
525	0.2977	-1.2116	0.2977	-1.2116	9.9848	361.5802
526	0.2886	-1.2427	0.2886	-1.2427	10.1062	408.2202
527	0.2831	-1.2619	0.2831	-1.2619	10.3132	502.1297
528	0.2789	-1.2769	0.2789	-1.2769	10.4033	549.4695
529	0.2686	-1.3145	0.2686	-1.3145	10.6022	670.3800
530	0.2767	-1.2848	0.2767	-1.2848	10.7089	745.8797
531	0.2703	-1.3082	0.2703	-1.3082	10.8300	841.8798
601	0.4497	-.7991	0.4497	-.7991	0.0000	0.0000
602	0.4452	-.8092	0.4452	-.8092	3.8330	0.7700
603	0.4337	-.8354	0.4337	-.8354	4.8919	2.2200
604	0.4240	-.8580	0.4240	-.8580	5.3973	3.6800
605	0.4191	-.8696	0.4191	-.8696	5.6525	4.7500
606	0.4140	-.8818	0.4140	-.8818	5.9615	6.4700
607	0.4067	-.8996	0.4067	-.8996	6.2600	8.7200
608	0.3776	-.9739	0.3776	-.9739	7.2101	22.5499
609	0.3777	-.9736	0.3777	-.9736	7.3020	24.7200

Table 40. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
610	0.3738	-.9840	0.3738	-.9840	7.3318	25.4700
611	0.3736	-.9845	0.3736	-.9845	7.4736	29.3499
612	0.3630	-1.0133	0.3630	-1.0133	7.9374	46.6700
613	0.3596	-1.0227	0.3596	-1.0227	8.0295	51.1700
614	0.3596	-1.0227	0.3596	-1.0227	5.0613	2.6300
615	0.3450	-1.0642	0.3450	-1.0642	8.3490	70.4299
616	0.3425	-1.0714	0.3425	-1.0714	8.3907	73.4299
617	0.3448	-1.0647	0.3448	-1.0647	8.6920	99.2499
618	0.3363	-1.0897	0.3363	-1.0897	8.9022	122.4700
619	0.3217	-1.1341	0.3217	-1.1341	9.0795	146.2200
620	0.3193	-1.1416	0.3193	-1.1416	9.2092	166.4699
621	0.3158	-1.1526	0.3158	-1.1526	9.3412	189.9700
622	0.3079	-1.1779	0.3079	-1.1779	9.4668	215.4001
623	0.3107	-1.1689	0.3107	-1.1689	9.5838	242.1300
624	0.2960	-1.2174	0.2960	-1.2174	9.8333	310.7501
625	0.2959	-1.2177	0.2959	-1.2177	9.9848	361.5802
626	0.2874	-1.2468	0.2874	-1.2468	10.1062	408.2202
627	0.2806	-1.2708	0.2806	-1.2708	10.3132	502.1297
628	0.2763	-1.2862	0.2763	-1.2862	10.4033	549.4695
629	0.2670	-1.3205	0.2670	-1.3205	10.6022	670.3800
630	0.2741	-1.2942	0.2741	-1.2942	10.7089	745.8797
631	0.2672	-1.3197	0.2672	-1.3197	10.8300	841.8798
701	0.4410	-.8187	0.4410	-.8187	0.0000	0.0000
702	0.4368	-.8282	0.4368	-.8282	3.8330	0.7700
703	0.4261	-.8530	0.4261	-.8530	4.8919	2.2200
704	0.4181	-.8720	0.4181	-.8720	5.3973	3.6800
705	0.4131	-.8840	0.4131	-.8840	5.6525	4.7500
706	0.4083	-.8957	0.4083	-.8957	5.9615	6.4700
707	0.4002	-.9157	0.4002	-.9157	6.2600	8.7200
708	0.3704	-.9931	0.3704	-.9931	7.2101	22.5499
709	0.3706	-.9926	0.3706	-.9926	7.3020	24.7200
710	0.3673	-1.0015	0.3673	-1.0015	7.3318	25.4700
711	0.3660	-1.0051	0.3660	-1.0051	7.4736	29.3499
712	0.3551	-1.0353	0.3551	-1.0353	7.9374	46.6700
713	0.3520	-1.0441	0.3520	-1.0441	8.0295	51.1700
714	0.3519	-1.0444	0.3519	-1.0444	5.0613	2.6300
715	0.3372	-1.0870	0.3372	-1.0870	8.3490	70.4299
716	0.3345	-1.0951	0.3345	-1.0951	8.3907	73.4299
717	0.3355	-1.0921	0.3355	-1.0921	8.6920	99.2499
718	0.3276	-1.1159	0.3276	-1.1159	8.9022	122.4700
719	0.3138	-1.1590	0.3138	-1.1590	9.0795	146.2200

Table 40. (Cont'd)

Depth and Reading	W/z	ln W/z	θ'	ln θ'	ln t (min)	t (hr)
720	0.3108	-1.1686	0.3108	-1.1686	9.2092	166.4699
721	0.3071	-1.1805	0.3071	-1.1805	9.3412	189.9700
722	0.3009	-1.2009	0.3009	-1.2009	9.4668	215.4001
723	0.3020	-1.1973	0.3020	-1.1973	9.5838	242.1300
724	0.2884	-1.2434	0.2884	-1.2434	9.8333	310.7501
725	0.2881	-1.2444	0.2881	-1.2444	9.9848	361.5802
726	0.2800	-1.2729	0.2800	-1.2729	10.1062	408.2202
727	0.2736	-1.2960	0.2736	-1.2960	10.3132	502.1297
728	0.2691	-1.3126	0.2691	-1.3126	10.4033	549.4695
729	0.2603	-1.3459	0.2603	-1.3459	10.6022	670.3800
730	0.2667	-1.3216	0.2667	-1.3216	10.7089	745.8797
731	0.2600	-1.3470	0.2600	-1.3470	10.8300	841.8798

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