APPENDIX A

RAINFALL LOSSES

(Draft of section of Maricopa County, Arizona, Hydrologic Design Manual)

4

Rainfall Losses

4.1 General

Rainfall excess is that portion of the total rainfall depth that drains directly from the land surface by overland flow. By a mass balance, rainfall excess plus rainfall loss equals precipitation. When performing a flood analysis using a rainfall-runoff model, the determination of rainfall excess is of utmost importance. Rainfall excess integrated over the entire watershed results in runoff volume, and the temporal distribution of the rainfall excess will, along with the hydraulics of runoff, determine the peak discharge. Therefore, the estimation of the magnitude and time distribution of rainfall losses should be performed with the best practical technology, considering the objective of the analysis, economics of the project, and consequences of inaccurate estimates.

Rainfall losses are generally considered to be the result of evaporation of water from the land surface, interception of rainfall by vegetal cover, depression storage on the land surface (paved or unpaved), and infiltration of water into the soil matrix. A schematic representation of rainfall losses for a uniform intensity rainfall is shown in Figure 4.1. As shown in the figure, evaporation can start at an initially high rate depending on the land surface temperature, but the rate decreases very rapidly and would eventually reach a low, steady-state rate. From a practical standpoint, the magnitude of rainfall loss that can be realized from evaporation during a storm of sufficient magnitude to cause flood runoff is negligible.

Interception, also illustrated in Figure 4.1, varies depending upon the type of vegetation, maturity, and extent of canopy cover. Experimental data on interception have been collected by numerous investigators (Linsley and others, 1982), but little is known of the interception values for most hydrologic problems. Estimates of interception for various vegetation types (Linsley and others, 1982) are:

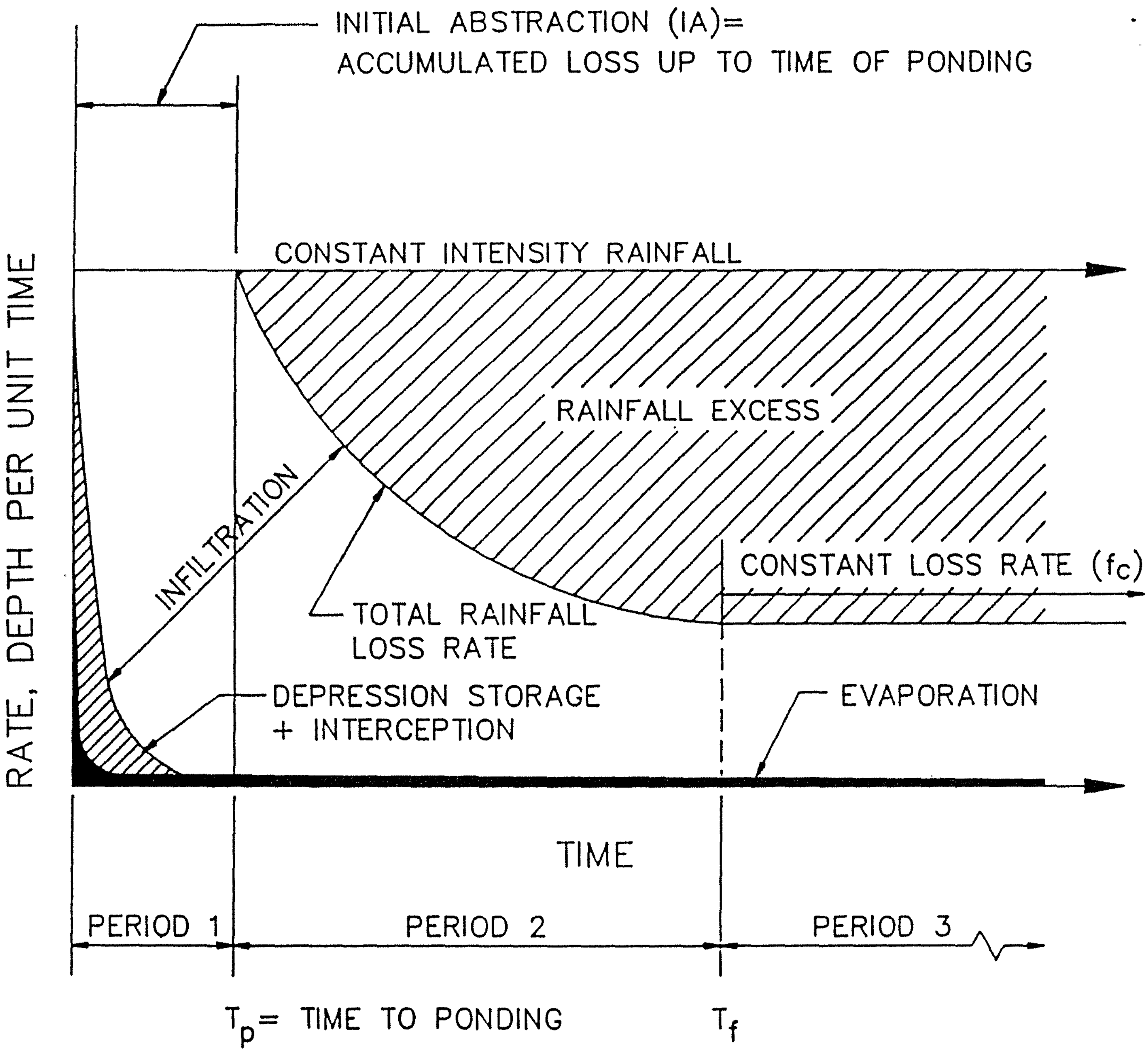

Figure 4.1
Schematic Representation of Rainfall Losses for a Uniform Intensity Rainfall

Vegetation Type	Interception, Inches
hardwood tree	0.09
cotton	0.33
alfalfa	0.11
meadow grass	0.08

No interception estimates are known for natural vegetation that occurs in Maricopa County. For most applications in Maricopa County the magnitude of interception losses is essentially 0.0, and for practical purposes interception is not considered for flood hydrology in Maricopa County.

Depression storage and infiltration losses comprise the majority of the rainfall loss as illustrated in Figure 4.1. The estimates of these two losses will be discussed in more detail in later sections of this manual. Three periods of rainfall losses are illustrated in Figure 4.1, and these must be understood and their implications appreciated before applying the procedures in this manual. First, there is a period of initial loss when no rainfall excess (runoff) is produced. During this initial period, the losses are a function of the depression storage, interception, and evaporation rates plus the initially high infiltration capacity of the soil. The accumulated rainfall loss during this period with no runoff is called the *initial abstraction*. The end of this initial period is noted by the onset of ponded water on the surface, and the time from start of rainfall to this time is the *time of ponding* (Tp). It is important to note that losses during this first period are a summation of losses due to all mechanisms including infiltration.

The second period is marked by a declining infiltration rate and generally very little losses due to other factors.

The third, and final, period occurs for rainfalls of sufficient duration for the infiltration rate to reach the *steady-state, equilibrium rate of the soil* (fc). The only appreciable loss during the final period is due to infiltration.

In Figure 4.2, it is assumed

The actual loss process is quite complex and there is a ~~good deal~~ of interdependence of the loss mechanisms on each other and on the ~~rainfall itself~~. Therefore, simplifying assumptions are usually made in the modeling of rainfall losses. Figure 4.2 represents a simplified set of assumptions that can be made; that surface retention loss is the summation of all losses other than those due to infiltration, and that this loss occurs from the start of rainfall and ends when the accumulated rainfall equals the magnitude of the capacity of the surface retention loss. It is assumed that infiltration does not occur during this time. After the surface retention is satisfied, infiltration begins. If the infiltration capacity exceeds the rainfall intensity, then no rainfall excess is produced. As the infiltration capacity decreases, it may eventually equal the rainfall intensity. This would occur at the time of ponding (Tp) which signals the beginning of surface runoff. As illustrated in both Figures 4.1 and 4.2, after the time of ponding the infiltration rate decreases exponentially and may reach a steady-state, equilibrium rate (fc). It is these simplified assumptions and processes, as illustrated in Figure 4.2, that are to be modeled by the procedures in this manual.

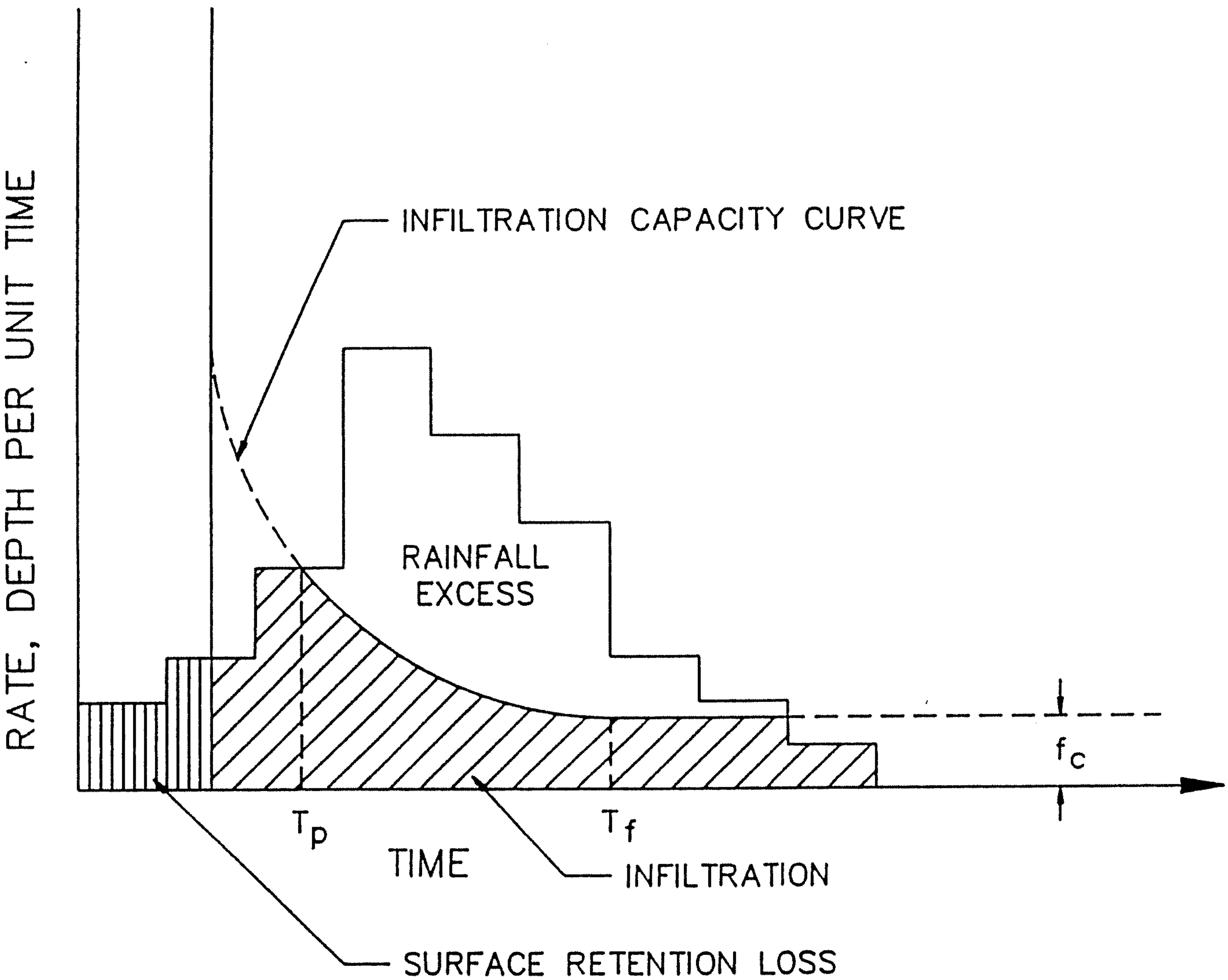

Figure 4.2
Simplified Representation of Rainfall Losses As
A Function of Surface Retention Losses Plus Infiltration

4.2 Surface Retention Loss

Surface retention loss, as used herein, is the summation of all rainfall losses other than infiltration. The major component of surface retention loss is depression storage; relatively minor components of surface retention loss are due to interception and evaporation, as previously discussed. Depression storage is considered to occur in two forms. First, in-place depression storage occurs at, and in the near vicinity of, the raindrop impact. The mechanism for this depression storage is the microrelief of the soil and soil cover. The second form of depression storage is the retention of surface runoff that occurs away from the point of raindrop impact in surface depressions such as puddles, roadway gutters and swales, roofs, irrigation bordered fields and lawns, and so forth.

A relatively minor contribution by interception is also considered as a part of the total surface retention loss. Estimates of surface retention loss are difficult to obtain and are a function of the physiography and land-use of the area.

The surface retention loss on impervious surfaces has been estimated to be in the range 0.0625 inch to 0.125 inch by Tholin and Keefer (1960), 0.11 inch for 1 percent slope to 0.06 inch for 2.5 percent slopes by Viessman (1967), and 0.04 inch based on rainfall-runoff data for an urban watershed in Albuquerque by Sabol (1983). Hicks (1944) provides estimates of surface retention losses during intense storms as 0.20 inch for sand, 0.15 inch for loam, and 0.10 inch for clay. Tholin and Keefer (1960) estimated the surface retention loss for turf to be between 0.25 to 0.50 inch. Based on rainfall simulator studies on undeveloped alluvial plains in the Albuquerque area, the surface retention loss was estimated as 0.1 to 0.2 inch (Sabol and others, 1982a). Rainfall simulator studies in New Mexico result in estimates of 0.39 inch for eastern plains rangelands and 0.09 inch for pinon-juniper hillslopes (Sabol and others, 1982b). Surface retention losses for various land-uses and surface cover conditions in Maricopa County have been extrapolated from these reported estimates and these are shown in Table 4.1.

4.3 Infiltration

Infiltration is the movement of water from the land surface into the soil. Gravity and capillary forces drawing water into and through the pore spaces of the soil matrix are the two forces that drive infiltration. Infiltration is controlled by soil properties, by vegetation influences on the soil structure, by surface cover of rock and vegetation, and by tillage practices. The distinction between infiltration and percolation is that percolation is the movement of water through the soil *subsequent to* infiltration.

Table 4.1
Surface Retention Loss for
Various Land Surfaces in Maricopa County

Land-use and/or Surface Cover (1)	Surface Retention Loss IA, inches (2)
Natural	
Desert and rangeland, flat slope	0.35
Hillslopes, Sonoran Desert	0.15
Mountain, with vegetated surface	0.25
Developed (Residential and Commercial)	
Lawn and turf	0.20
Desert landscape	0.10
Pavement	0.05
Agricultural	
Tilled fields and irrigated pasture	0.50

Infiltration can be controlled by percolation if the soil does not have a sustained drainage capacity to provide access for more infiltrated water. However, before percolation can be assumed to restrict infiltration for the design rainfalls being considered in Maricopa County, the extent by which percolation can restrict infiltration of rainfall should be carefully evaluated. SCS soil scientists have defined hydrologic soil group D as:

> "Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material."

This definition indicates that hydrologic soil groups A, B, or C could be classified as D if a near impervious strata of clay, caliche, or rock is beneath them. When these soils are considered in regard to long-duration rainfalls (the design events for many parts of the United States) this definition may be valid. However, when considered for short-duration and relatively small design rainfall depths in Maricopa County, this definition could result in underestimation of the rainfall losses. This is because even a relatively shallow horizon of soil overlaying an impervious layer still has the ability to store a significant amount of infiltrated rainfall.

For example, consider the situation where only 4 inches of soil covers an impervious layer. If the effective porosity is 0.30, then 1.2 inches (4 inches x 0.30) of water can be infiltrated and stored in the shallow soil horizon. For design rainfalls in Maricopa County, this represents a significant storage volume for infiltrated rainfall and so when using ~~drainage studies~~ for Maricopa County that contain significant areas classified as hydrologic soil group D, the reason for that classification should be determined.

soils reports
or
performing drainage studies

Hydrologic soil group D should be retained only for:

» clay soils,

» soils with a permanent high water table, and

» rock outcrop.

Hydrologic soil group D should probably *not* be retained in all situations where the classification is based on shallow soils over nearly impervious layers; site specific studies and sensitivity analyses should be performed to estimate the loss rates to be used for such soils.

4.4 Recommended Methods for Estimating Rainfall Losses

Many methods have been developed for estimating rainfall losses; five are listed as options in the HEC-1 Flood Hydrology Package. They are:

1. Holtan Infiltration Equation

2. Exponential Loss Rate

3. SCS Curve Numbers (CN) Loss Rate

4. Green and Ampt Infiltration Equation

5. Initial Loss Plus Uniform Loss Rate (IL+ULR)

Of these five, however, only two—Green and Ampt and IL+ULR—are recommended for estimating rainfall losses in Maricopa County for the reasons discussed below.

The **Holtan Infiltration Equation** is an exponential decay type of equation for which the rainfall loss rate asymptotically diminishes to the minimum infiltration rate (fc). The Holtan equation is not extensively used and there is no known application of this method in Arizona. Data and procedures to estimate the parameters for use in Maricopa County are not available. Therefore, the Holtan equation is not recommended for general use in Maricopa County.

The **Exponential Loss Rate Method** is a four parameter method that is not extensively used, but it is a method preferred by of the U.S. Army Corps of Engineers. Data and procedures are not available to estimate the parameters for this method for all physiographic regions in Maricopa County, but Exponential loss rate parameters have been developed from the reconstitution of flood events for a flood hydrology study ~~in~~ for a portion of Maricopa County (U.S. Army Corps of Engineers, 1982). However, adequate data ~~is~~ are not available to estimate the necessary parameters for all soil types and land uses in Maricopa County, and this method is not recommended for general use in Maricopa County.

The **SCS CN** method is the most extensively used rainfall loss ~~rate~~ method in Maricopa County and Arizona and it has wide acceptance among many agencies, consulting engineering firms, and individuals throughout the community. This method is limited, however, by both theoretical and practical deficiencies, and thus is not recommended for general use in Maricopa County. Deficiencies of the SCS CN method include:

1. Rainfall losses are independent of the duration of rainfall. That is, for a given depth of rainfall, the same rainfall loss results (regardless of the duration of rainfall) and the same rainfall excess would be estimated for a given rainfall depth occurring in, for example, either 1 hour or 24 hours.

2. The estimated rainfall loss rate is a function of rainfall intensity. Short periods of high intensity rainfall would often result in large estimates of rainfall losses. This is contrary to the generally accepted infiltration relation as illustrated in Figure 4.2.

3. The infiltration rate approaches zero rather than a minimum infiltration rate (fc).

4. The initial abstraction is equal to 0.2S

   where $S = 1000/CN - 10$

   This equation is not theoretically justified nor is it based on data for hydrologic conditions that are representative of Maricopa County.

5. The selection of CN is too subjective and is often based more on traditional acceptance of CN values rather than on scientifically substantiated findings.

6. At low rainfalls (less than 4 inches), the estimate of rainfall loss is very sensitive to the selection of CN.

As mentioned previously, the two recommended methods for estimating rainfall losses in Maricopa County are the Green and Ampt infiltration equation and the initial loss and uniform loss rate (IL+ULR) method. Both methods, as programmed into HEC-1, can be used to simulate the rainfall loss model as depicted in Figure 4.2. (For a full discussion of these methods, see Sections 4.4.1 and 4.4.2.) The IL+ULR is a simplified model that has been used extensively for flood hydrology and data are ~~is~~ available to estimate the two parameters for this method. The Green and Ampt infiltration equation is a physically based model that has been in existence since 1911, and has recently been incorporated as an option in HEC-1.

Procedures have been developed to estimate the three parameters of the Green and Ampt infiltration equation. The preferred method, and the most theoretically accurate, is the Green and Ampt infiltration equation. The IL+ULR is recommended as an alternative if it is not possible to estimate the Green and Ampt equation parameters, or for other valid reasons. It should be realized, as explained later, that the use of the Green and Ampt equation and parameters, as defined herein, will probably result in lower peak discharges and runoff volumes than the use of the IL+ULR.

Other methods should be used only if there is technical justification for a variance from this recommendation and if adequate information is available to estimate the necessary parameters. Use of rainfall loss methods other than those recommended should not be undertaken unless previously approved by the Flood Control District and the local regulatory agency.

4.4.1 Green and Ampt Infiltration Equation

This model, first developed in 1911 by W.H. Green and G.A. Ampt, has since the early 1970s, received increased interest for estimating rainfall infiltration losses. The model has the form:

$$f = K_S \left(1 + \frac{\psi\theta}{F}\right) \qquad \text{for } f < i \tag{1}$$

$$f = i \qquad \text{for } f \geq i$$

where

f	=	infiltration rate (L/T),
i	=	rainfall intensity (L/T),
K_S	=	hydraulic conductivity, wetted zone, steady-state rate (L/T)
Ψ	=	average capillary suction in the wetted zone (L),
θ	=	soil moisture deficit (dimensionless), equal to effective soil porosity times the difference in final and initial volumetric soil saturations, and
F	=	depth of rainfall that has infiltrated into the soil since the beginning of rainfall (L).

A sound and concise explanation of the Green and Ampt equation is provided by Bedient and Huber (1988).

It is important to note that as rain continues, F increases and f approaches K_S, and therefore, f is inversely related to time. Equation 1 is implicit with respect to f which causes computational difficulties. Eggert (1976) simplified Equation 1 by expanding the equation in a power series and truncating all but the first two terms of the expansion. The simplified solution (Li and others, 1976) is:

$$F = -0.5\,(2F - K_S\,\Delta t) + 0.5\,[(2F - K_S\,\Delta t)^2 + 8K_S\Delta t\,(\theta\psi + F)]^{1/2} \tag{2}$$

where

Δt = the computation interval

F = accumulated depth of infiltration at the start of Δt.

The average infiltration rate is:

$$f = \frac{\Delta F}{\Delta t} \tag{3}$$

Use of the Green and Ampt equation as coded in HEC-1 involves the simulation of rainfall loss as a two phase process, as illustrated in Figure 4.2. The first phase is the simulation of the surface retention loss as previously described; this loss is called the initial loss (IA) in HEC-1. During this first phase, all rainfall is lost (zero rainfall excess generated) during the period from the start of rainfall up to the time that the accumulated rainfall equals the value of IA. It is assumed, for modeling purposes, that no infiltration of rainfall occurs during this first phase. Initial loss (IA) is primarily a function of land-use and surface cover, and recommended values of IA for use with the Green and Ampt equation are presented in Table 4.1. For example, about 0.35 inches of rainfall will be lost to runoff due to surface retention for desert and rangelands on relatively flat slopes in Maricopa County.

The second phase of the rainfall loss process is the infiltration of rainfall into the soil matrix. For modeling purposes, the infiltration begins immediately after the surface retention loss (IA) is completely satisfied, as illustrated in Figure 4.2. The three Green and Ampt equation infiltration parameters as coded in HEC-1 are:

» hydraulic conductivity at natural saturation (XKSAT) equal to K_S in Equation 1;

» wetting front capillary suction (PSIF) equal to Ψ in Equation 1; and

» volumetric soil moisture deficit at the start of rainfall (DTHETA) equal to θ in Equation 1.

The three infiltration parameters are functions of soil characteristics, ground surface characteristics, and land management practices. The soil characteristics of interest are particle size distribution (soil texture), organic matter, and bulk density. The primary soil surface characteristics are vegetation canopy cover, ground cover, and soil crusting. The land management practices are identified as various tillages as they result in changes to soil porosity.

Values of Green and Ampt equation parameters as a function of soil characteristics alone (bare ground condition) have been obtained from published reports (Rawls and others, 1983; Rawls and Brakensiek, 1983). Average values of XKSAT and PSIF for each of the soil texture classes from Rawls and Brakensiek (1983) are shown in Columns (2) and (3) of Table 4.2. Values of XKSAT and PSIF (as a function of percent of sand and percent of clay for soil with 0.5 percent organic matter and base value [unaltered] soil porosity) are shown in Figures 4.3 and 4.4, respectively (Rawls and Brakensiek, 1983). The values of XKSAT and PSIF from Table 4.2 should be used if

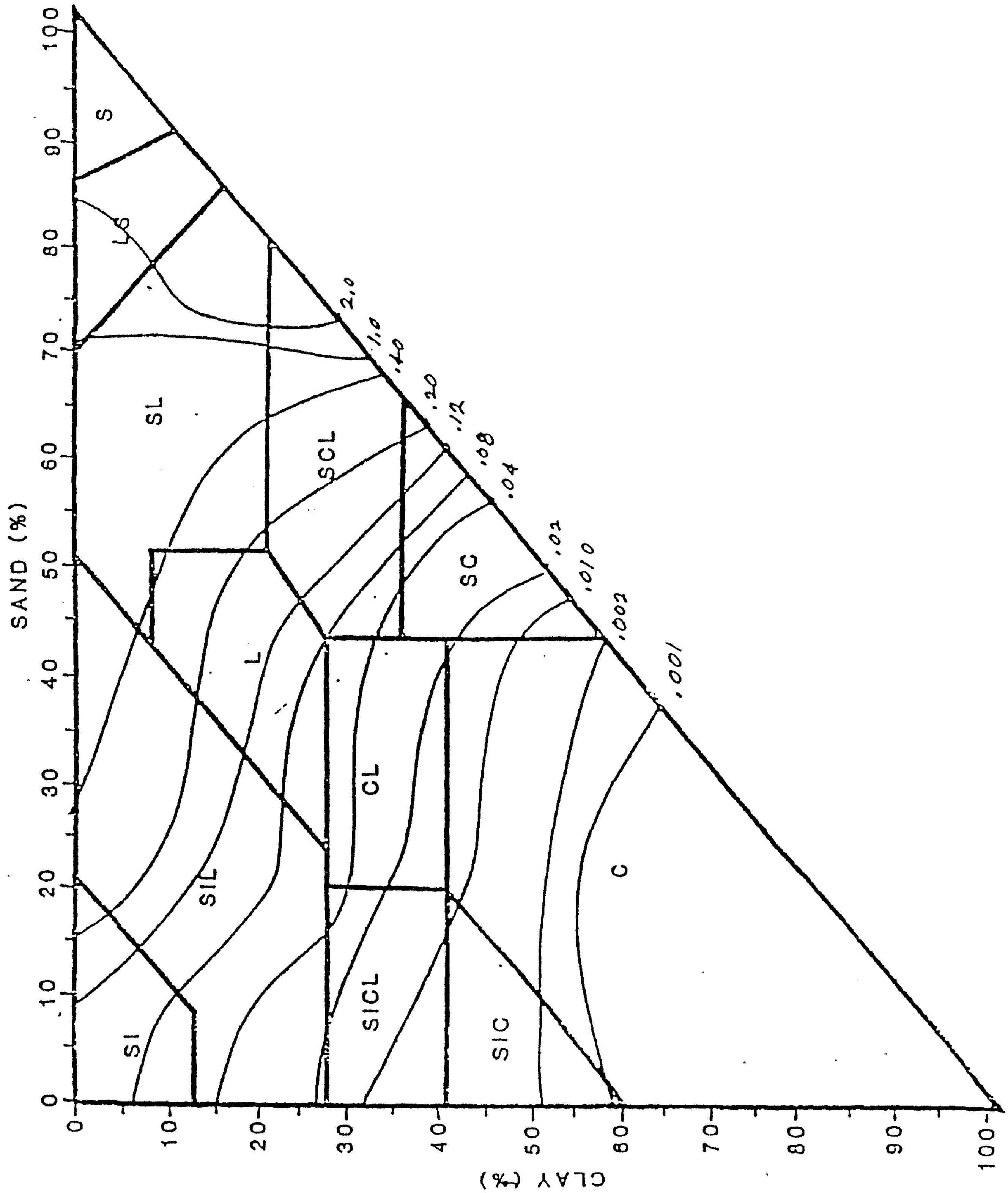

Figure 4.3
Green and Ampt Loss Rate
Hydraulic Conductivity at natural saturation in inches/hour
XKSAT (0.5% organic matter)

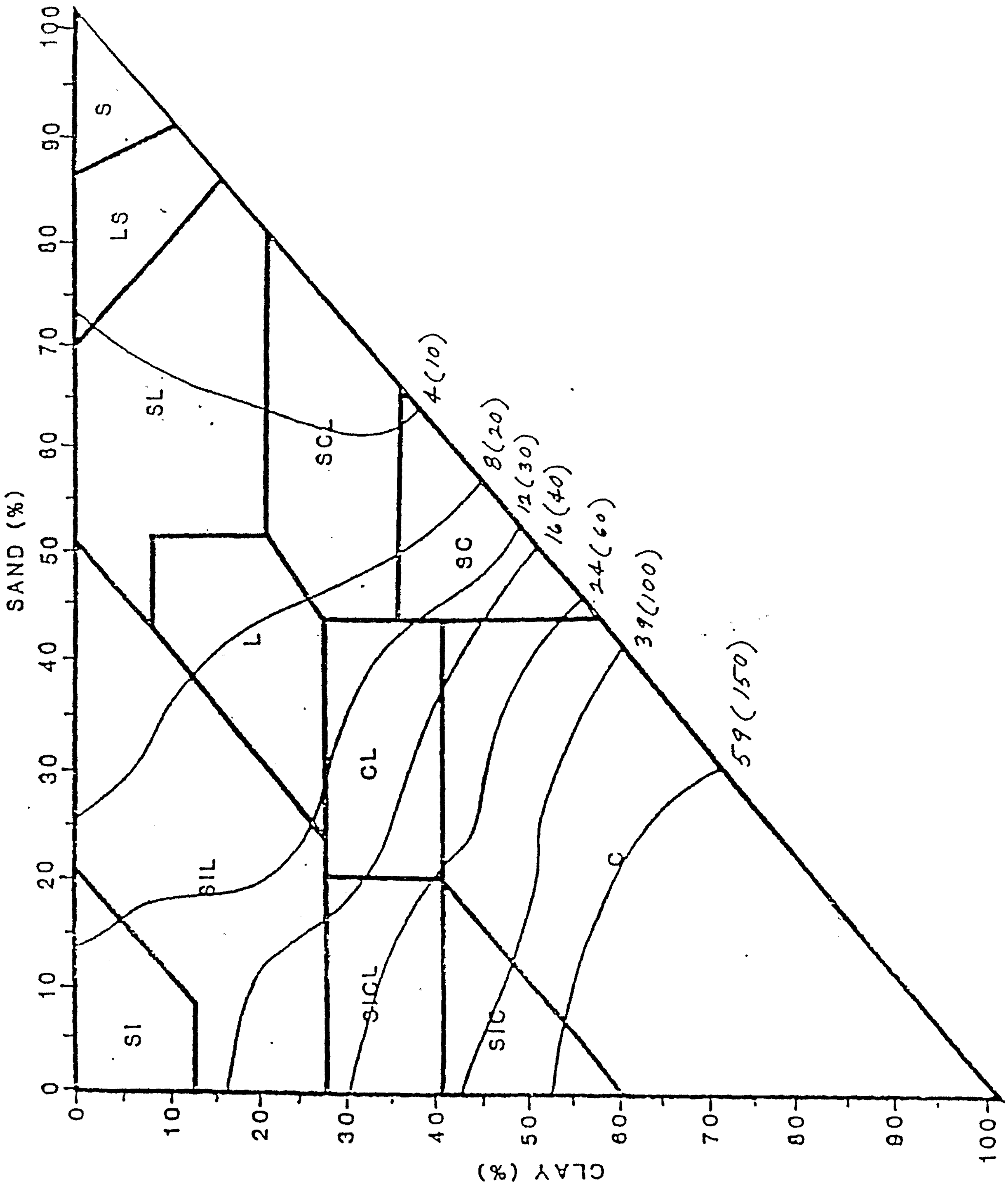

Figure 4.4
Green and Ampt Loss Rate
Wetting Front Suction in Inches (cm)
PSIF

general soil texture classification of the drainage area is available. The values of XKSAT and PSIF from Figures 4.3 and 4.4 can be used if more specific soil texture classification is available from a detailed soil survey for which the percentages of sand and clay have been determined by an appropriate field soil survey. The use of the information in Figures 4.3 and 4.4 will require an extensive study of the soil for the drainage area, and for most drainage studies only general soil texture classification will be known so the values from Table 4.2 should be used.

The soil moisture deficit (DTHETA) is a volumetric measure of the soil moisture storage capacity that is available at the start of the rainfall. DTHETA is a function of the effective porosity of the soil. The range of DTHETA is 0.0 to the effective porosity. If the soil is effectively saturated at the start of rainfall then DTHETA equals 0.0; if the soil is devoid of moisture at the start of rainfall then DTHETA equals the effective porosity of the soil. The porosity of soil as a function of soil texture (percent of sand and percent of clay) is shown in Figure 4.5 (Brakensiek and others, 1984).

Under natural conditions, soil seldom reaches a state of soil moisture less than the wilting point of vegetation. Figure 4.6 is a graph of volumetric soil moisture at wilting point as a function of soil texture. Due to the rapid drainage capacity of most soils in Maricopa County, at the start of a design storm the soil would not be expected to be in a state of soil moisture greater than the field capacity. Figure 4.7 is a graph of volumetric soil moisture at field capacity as a function of soil texture.

Table 4.2
Green and Ampt Loss Rate Parameter Values for Bare Ground

Soil Texture Classification (1)	XKSAT inches/hour (2)	PSIF inches (3)	DTHETA[1]		
			Dry (4)	Normal (5)	Saturated (6)
sand	4.6	1.9	0.35	0.30	0
loamy sand	1.2	2.4	0.35	0.30	0
sandy loam	0.40	3.5	0.35	0.25	0
loam	0.25	4.3	0.35	0.25	0
silty loam	0.15	6.6	0.40	0.25	0
silt	0.10	7.5	0.35	0.15	0
sandy clay loam	0.06	8.6	0.25	0.15	0
clay loam	0.04	8.2	0.25	0.15	0
silty clay loam	0.04	10.8	0.30	0.15	0
sandy clay	0.02	9.4	0.20	0.10	0
silty clay	0.02	11.5	0.20	0.10	0
clay	0.01	12.4	0.15	0.05	0

[1] Selection of DTHETA:
Dry = Nonirrigated lands, such as desert and rangeland;
Normal = Irrigated lawn, turf, and permanent pasture;
Saturated = Irrigated agricultural land.

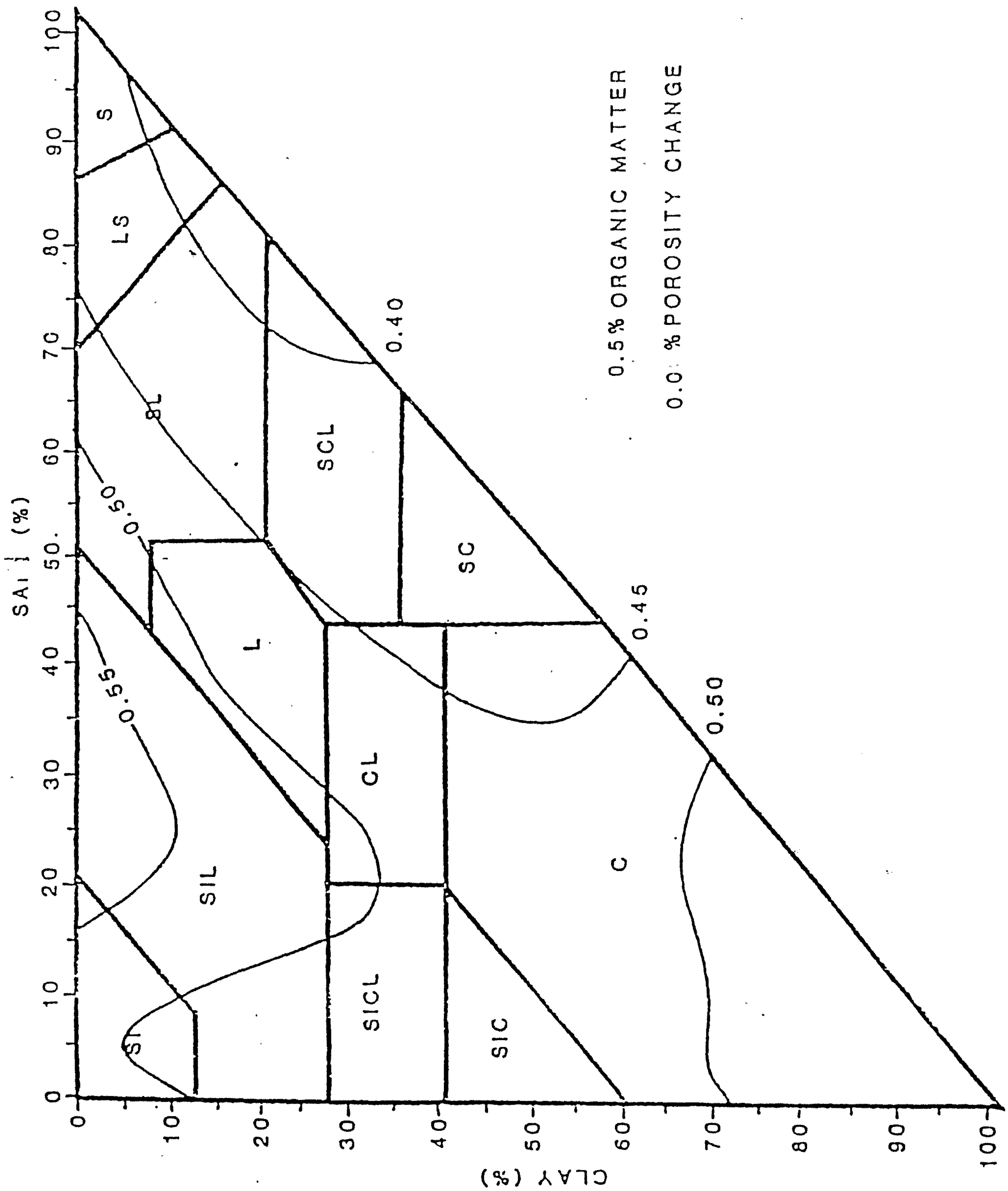

Figure 4.5
Porosity

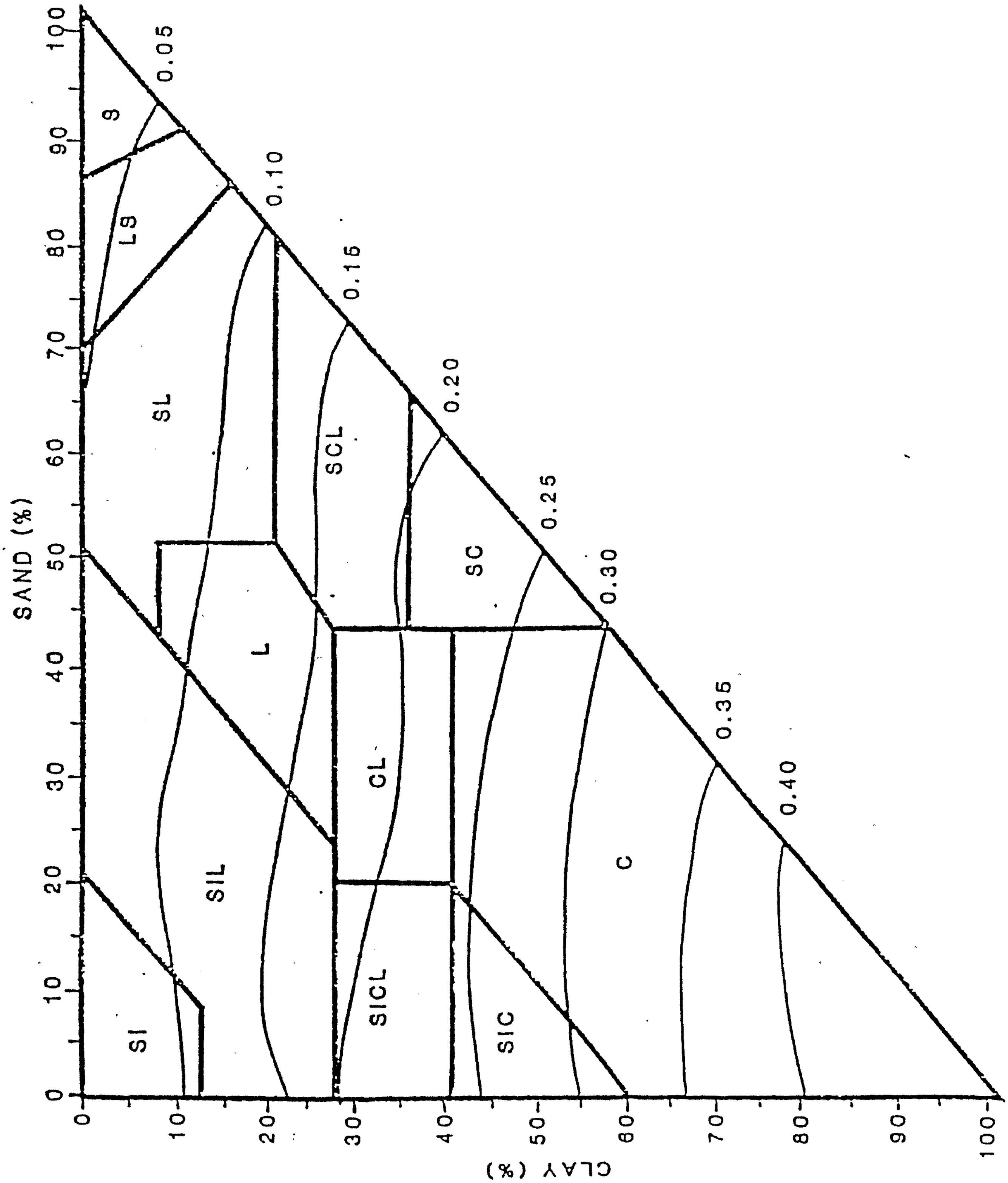

Figure 4.6
Green and Ampt Loss Rate
15-Bar Soil Moisture by Volume (assumed wilting point)

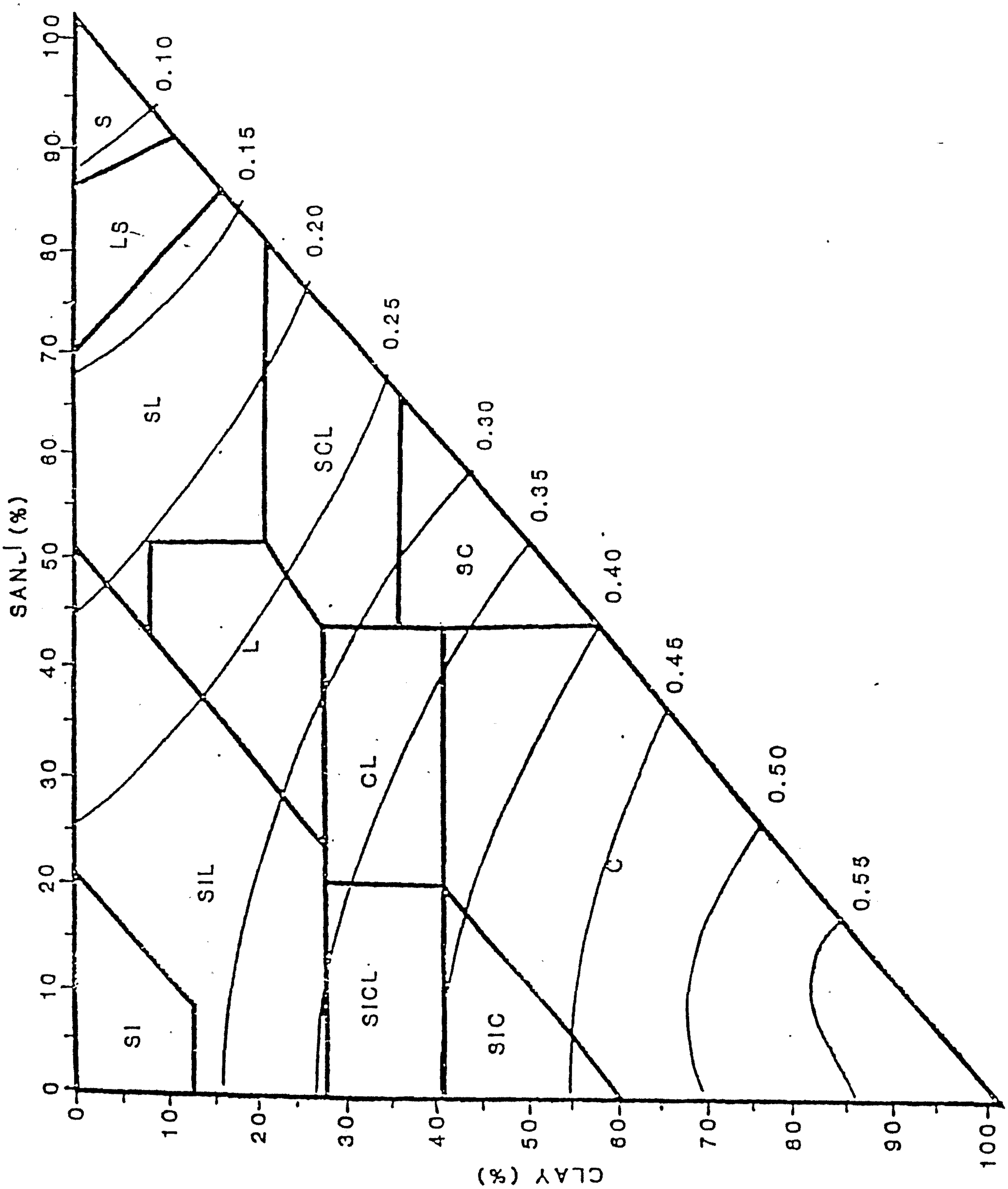

Figure 4.7
Green and Ampt Loss Rate
1/3 Bar Soil Moisture by Volume (assumed field capacity)

However, Maricopa County also has a large segment of its land area under irrigated agriculture, and it is reasonable to assume that the design frequency storm could occur during or shortly after certain lands have been irrigated. Therefore, it would be reasonable to assume that soil moisture for irrigated lands could be at or near effective saturation during the start of the design rainfall.

Three conditions for DTHETA have been defined for use in Maricopa County based on the antecedent soil moisture condition that could be expected to exist at the start of the design rainfall. These three conditions are:

» "Dry" for antecedent soil moisture near the vegetation wilting point;

» "Normal" for antecedent soil moisture condition near field capacity due to previous rainfall or irrigation applications ~~on~~ of nonagricultural lands; and

» "Saturated" for antecedent soil moisture near effective saturation due to recent irrigation of agricultural lands.

Values of DTHETA have been estimated by subtracting the initial volumetric soil moisture for each of the three conditions from the soil porosity.

The value of DTHETA "Dry" as a function of soil texture is shown in Figure 4.8. This figure was prepared by subtracting the wilting point soil moisture in Figure 4.6 from the soil porosity in Figure 4.5. The value of DTHETA "Normal" as a function of soil texture is shown in Figure 4.9. This figure was prepared by subtracting the field capacity soil moisture in Figure 4.7 from the soil porosity in Figure 4.5. The value of DTHETA "Saturated" is always equal to 0.0 because for this condition there is no available pore space in the soil matrix at the start of rainfall. Values of DTHETA for the three antecedent soil moisture conditions are shown in Table 4.2. DTHETA "Dry" should be used for soil that is usually in a state of low soil moisture such as would occur in the desert and rangelands of Maricopa County. DTHETA "Normal" should be used for soil that is usually in a state of moderate soil moisture such as would occur in irrigated lawns, golf courses, parks, and irrigated pastures. DTHETA "Saturated" should be used for soil that can be expected to be in a state of high soil moisture such as irrigated agricultural land.

The hydraulic conductivity (XKSAT) can be affected by several factors besides soil texture. For example, hydraulic conductivity is reduced by soil crusting, increased by tillage, and increased by the influence of ground cover and canopy cover. The values of XKSAT that have been presented for bare ground as a function of soil texture alone should be adjusted under certain soil cover conditions.

Ground cover, such as grass, litter, and rock will generally increase the infiltration rate over that of bare ground conditions. Similarly, canopy cover—such as from trees, brush, and tall grasses—can also increase the bare ground infiltration rate. The procedures and data that have been presented are for estimating the Green and Ampt parameters based solely on soil texture and would be applicable for bare ground conditions. Past research has shown that the wetting front capillary suction

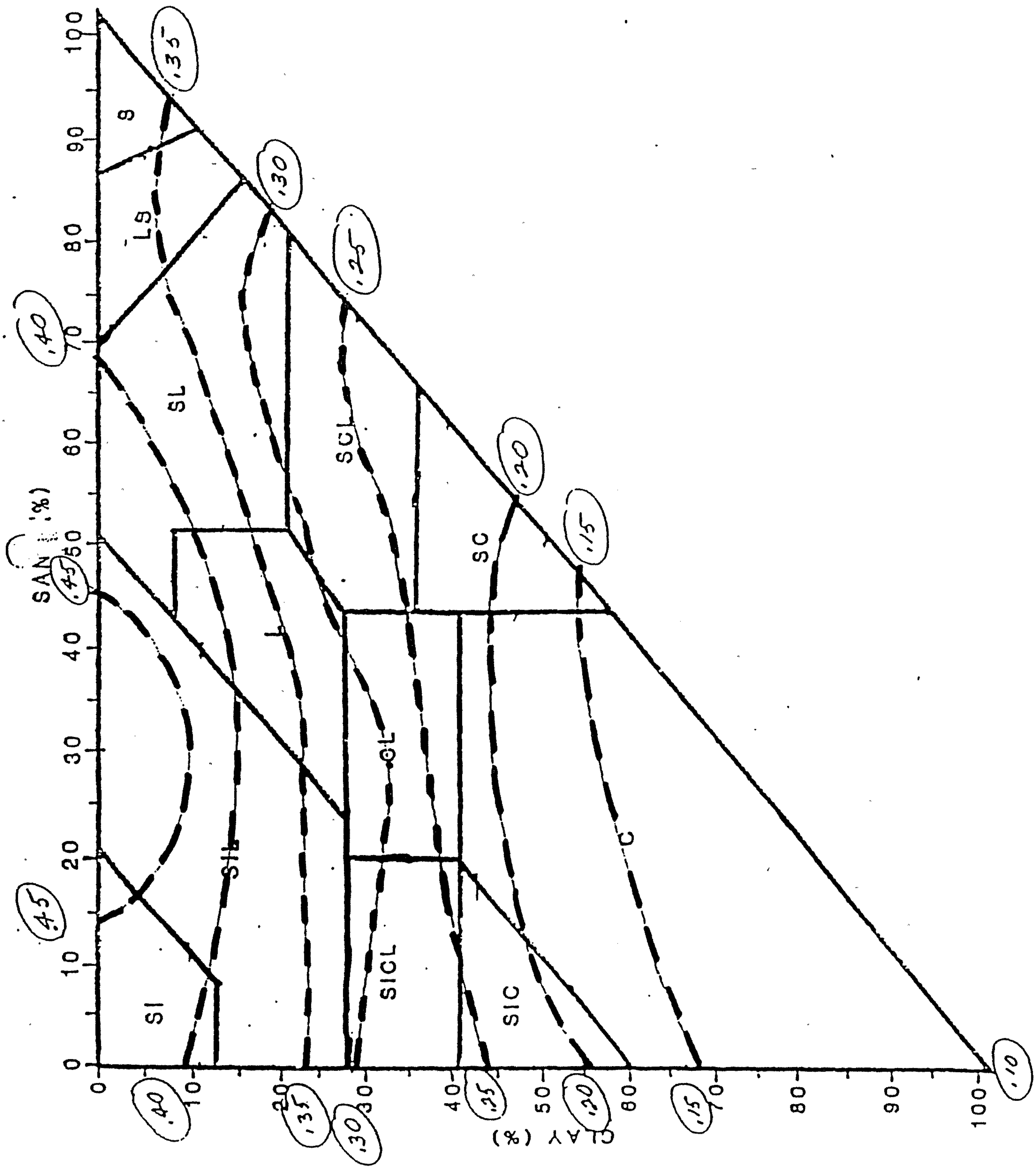

Figure 4.8
DTHETA "Dry"
for Initially Dry Soil Moisture Condition (wilting point)

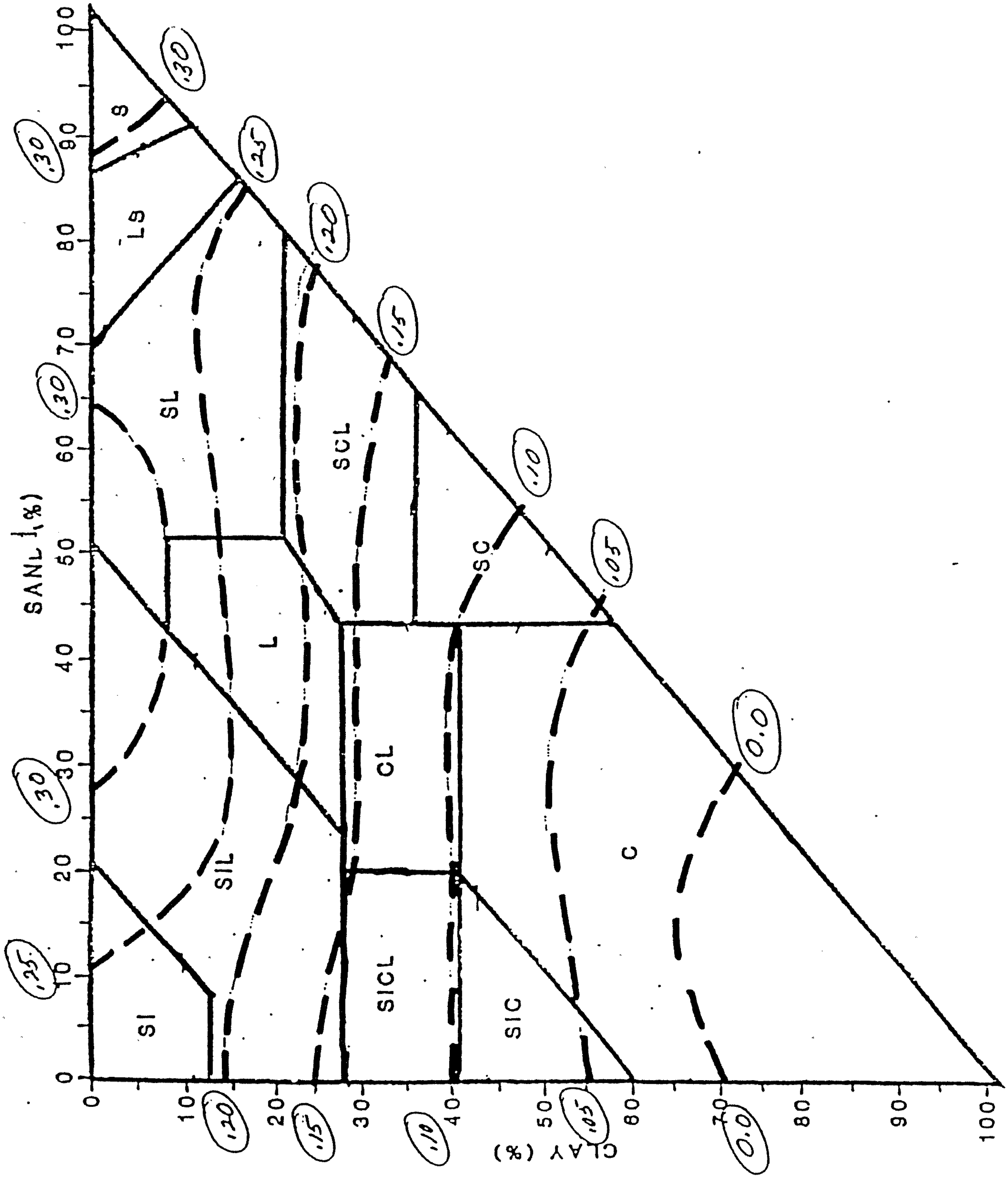

Figure 4.9
DTHETA "Normal"
for Initially Wet Soil Moisture Condition (field capacity)

parameter (PSIF) is relatively insensitive in comparison with the hydraulic conductivity parameter (XKSAT); therefore only the hydraulic conductivity parameter is adjusted for the influences of cover over bare ground.

Procedures have been developed (Rawls and others, 1988) for incorporating the effects of soil crusting, ground cover, and canopy cover into the estimation of hydraulic conductivity for the Green and Ampt equation; however, those procedures are not recommended for use in Maricopa County at this time. A simplified procedure to adjust the bare ground hydraulic conductivity for vegetation cover is shown in Figure 4.10. This figure is based on the documented increase in hydraulic conductivity due to various soil covers as reported by investigators using rainfall simulators on native western rangelands (Kincaid and others, 1964; Sabol and others, 1982a; Sabol and others, 1982b; Bach, 1984; Ward, 1986; Lane and others, 1987; Ward and Bolin, 1989). This correction factor can be used based on an estimate of vegetation cover as used by the Soil Conservation Service in soil surveys; that is, vegetation cover is evaluated on basal area for grasses and forbs, and is evaluated on canopy cover for trees and shrubs. Note that this correction can be applied only to soils other than sand and ~~sandy loam.~~ loamy sand.

The influence of tillage results in a change in total porosity and therefore a need to modify the three Green and Ampt equation infiltration parameters. The effect of tillage systems on soil porosity and the corresponding changes to hydraulic conductivity, wetting front capillary suction, and water retention is available (Rawls and Brakensiek, 1983). Although this information is available, it is not presented in this manual, nor is it recommended that these adjustments be made to the infiltration parameters for design purpose use in Maricopa County, because for most flood ~~prediction~~ estimation purposes it cannot be assumed that the soil will be in any particular state of tillage at the time of storm occurrence and therefore the base condition infiltration parameters, as presented, should be used for flood ~~prediction~~ estimation purposes. However, appropriate adjustments to the infiltration parameters can be made, as necessary, for special flood studies such as reconstitution of storm events.

The necessary soils information may not be available for all areas of Maricopa County for the purpose of estimating the Green and Ampt equation parameters based on soil texture, but the SCS CN method has been used extensively in Maricopa County to estimate rainfall losses. Estimates of CN can be obtained by comparison of watersheds for which no general soils reports are available to watersheds for which soils data are available. Brakensiek and Rawls (1983) have grouped soil according to texture into the four hydrologic soil groups as shown below:

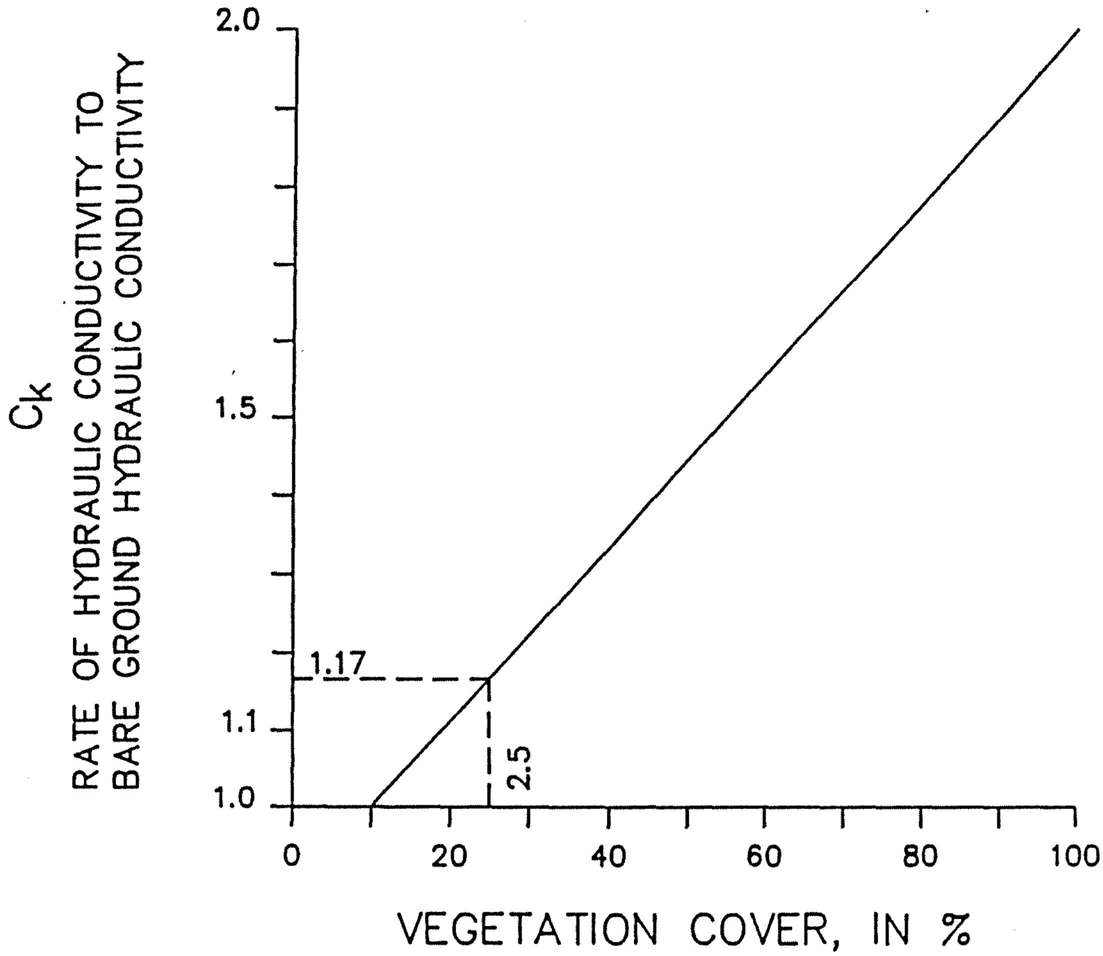

Figure 4.10
Effect of Vegetation Cover on Hydraulic Conductivity
For Hydraulic Soil Groups B, C, and D, and
For all Soil Textures *other than*
Sand and ~~Sandy Loam~~.
Loamy Sand

Hydrologic Soil Group, Soil Texture	
A	sand ~~sandy~~ loamy sand
B	silt loam loam
C	sandy loam silt
D	clay loam silty clay loam sandy clay silty clay clay

This grouping of soils is based on the four hydrologic soil groups as defined by SCS soil scientists, with limits for each group established by the minimum infiltration rate as defined by Musgrave (1955). This classification system assumes that the hydraulic conductivity (XKSAT) of the Green and Ampt equation corresponds to the minimum infiltration rate (fc).

Classification of soil according to hydrologic soil group involves some large scale lumping of soils. For example, silt loam is placed in hydrologic soil group B based on soil texture classification, whereas using particle size percentages (and percent organic matter) can place silt in any of the four groups. The A and D soil groups are most nearly invariant with respect to soil texture classification, and the B and C soils are less definitive in regard to soil texture. This classification indicates that the SCS hydrologic soil groups are not uniquely related to soil hydraulics and hydrologic properties; but it does indicate that Green and Ampt equation parameters can be estimated with some degree of confidence and reproducibility from readily available soil properties and from an estimate of CN.

Brakensiek, Rawls, and Stephenson (1984) extended this general classification of soils into a procedure for estimating hydrologic soil groups and CN based on soils data. Their analysis resulted in a procedure to relate CN to saturated hydraulic conductivity of the soil. This procedure has been modified so that hydraulic conductivity for the Green and Ampt equation can be estimated from the CN for the soil-cover complex and percentage of vegetation cover. This is shown in Figure 4.11, and this figure can be used to estimate hydraulic conductivity from an estimate of CN. Capillary suction (PSIF) is usually inversely related to the value of hydraulic conductivity (XKSAT), as illustrated in Figure 4.12. Figure 4.12 can be used in conjunction with Figure 4.11 to estimate the Green and Ampt equation parameters. DTHETA should be selected from Table 4.2 based on the assumption of initial soil moisture and estimated XKSAT and PSIF.

HYDROLOGIC CONDITION	AVERAGE VEGETATIONCOVER (%)
BARE	0-5
POOR	6-25
FAIR	26-50
GOOD	50-100

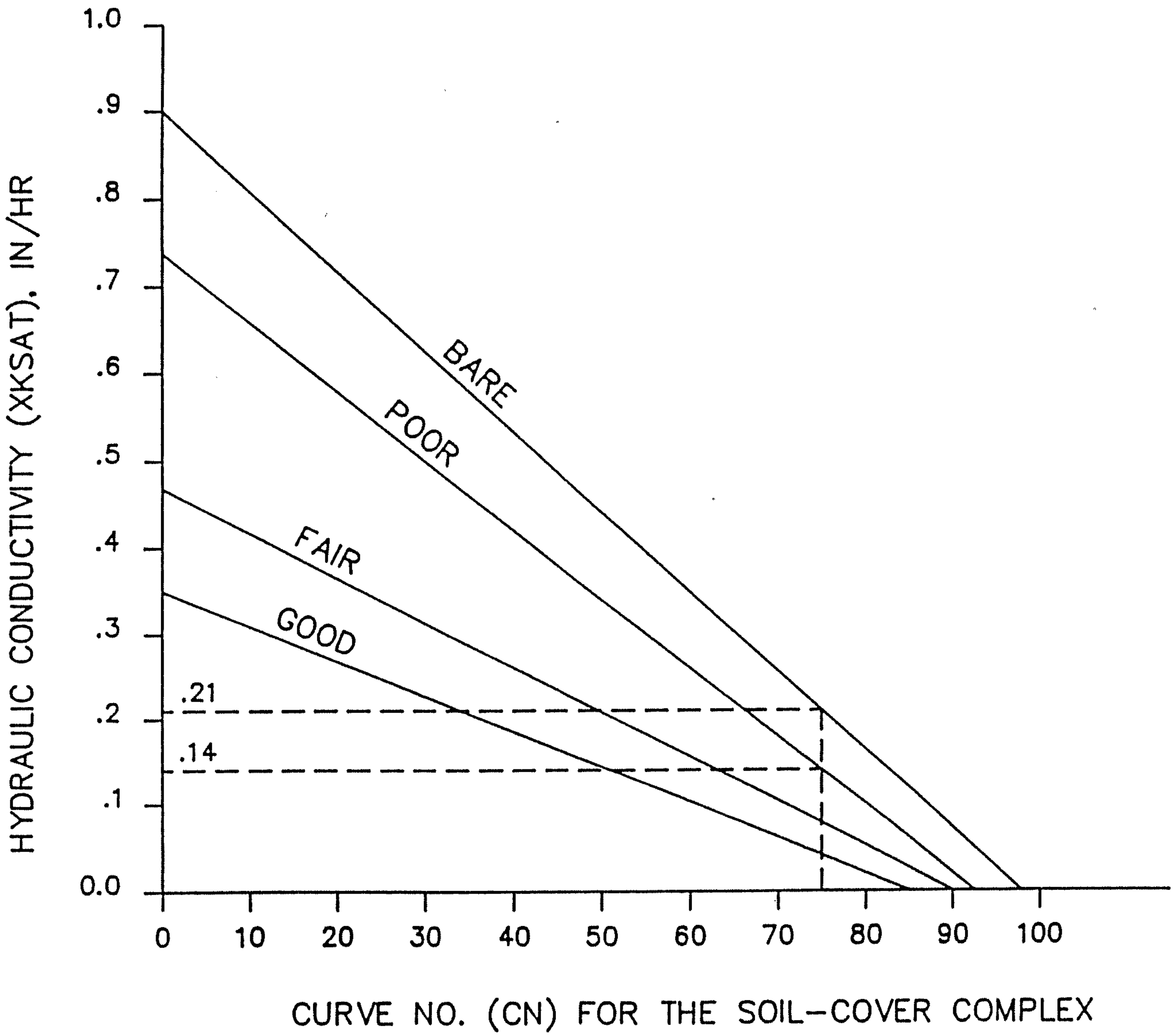

Figure 4.11
Hydraulic Conductivity (XKSAT) for Undeveloped Watersheds in Arizona as a Function of Curve Number (CN)

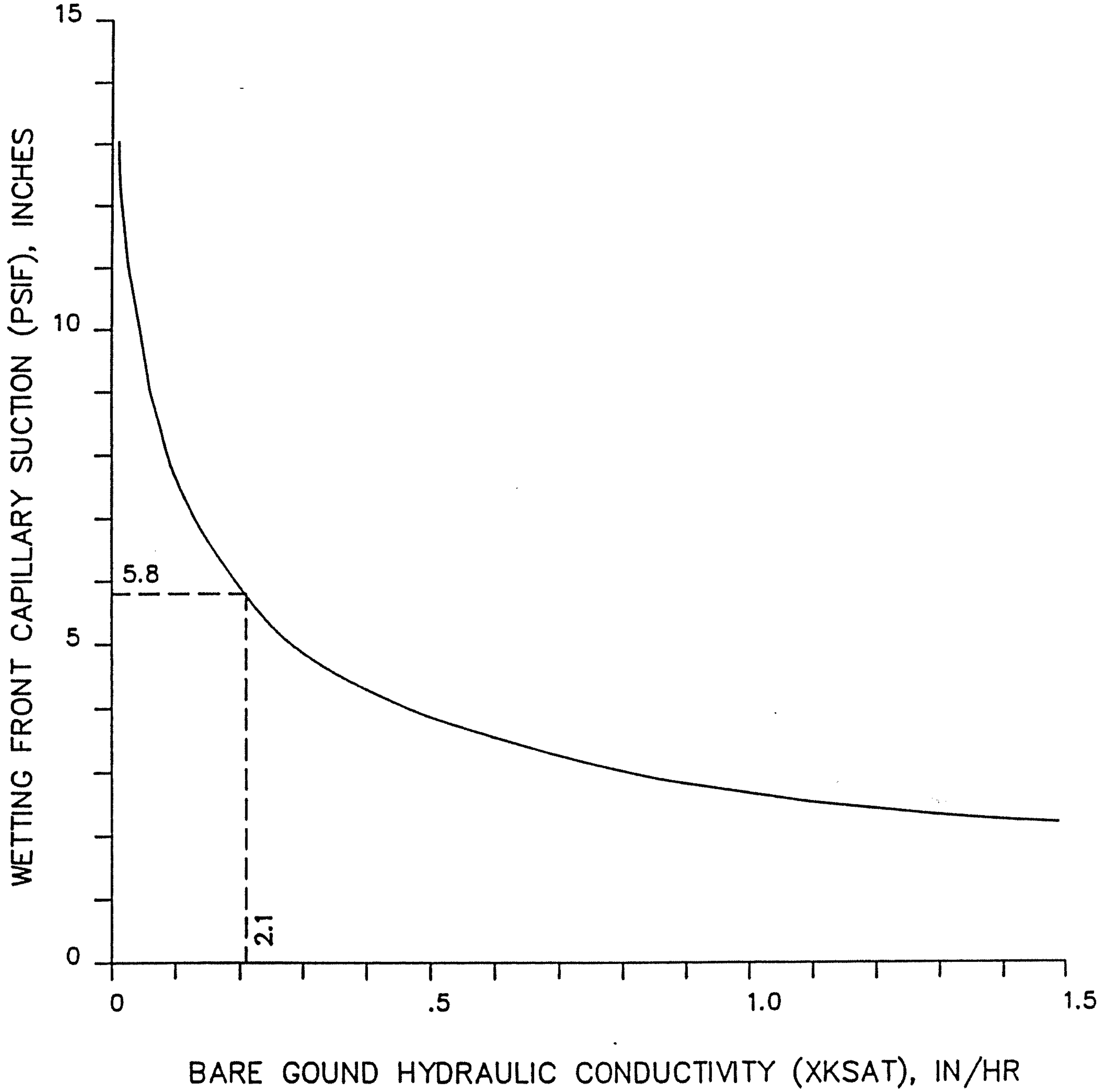

Figure 4.12
Relation of Capillary Suction (PSIF) as a Function at Bare Soil Hydraulic Conductivity (XKSAT)

4.4.2 Initial Loss Plus Uniform Loss Rate (IL+ULR)

This is a simplified rainfall loss method that is often used, and generally accepted, for flood hydrology. In using this simplified method it is assumed that the rainfall loss process can be simulated as a two-step procedure, as illustrated in Figure 4.13. First, all rainfall is lost to runoff until the accumulated rainfall is equal to the initial loss; and second, after the initial loss is satisfied, a portion of all future rainfall is lost at a uniform rate.

According to HEC-1 nomenclature, two parameters are needed to use this method; the initial loss (STRTL) and the uniform loss rate (CNSTL). The initial loss (STRTL) is the sum of all losses prior to the onset of runoff and is made up of surface retention loss (IA) and an initial amount of infiltration (IL); therefore, STRTL = IA + IL. Values of the infiltration component (IL) of STRTL for bare ground according to soil texture classification are shown in Columns (3) through (5) in Table 4.3. These values have been derived from the Green and Ampt infiltration equation and parameter values that are shown in Table 4.2.

The value of IL "Dry" should be used for soil that is usually in a state of low soil moisture at or near the wilting point for vegetation. This is a reasonable assumption for most nonirrigated lands in Maricopa County because of the infrequency of rainfall and because of the rapid drainage of these soils after rainfall. The value of IL "Normal" should be used for soil that is usually in a state of moderate soil moisture such as occurs for irrigated lawns, turf, and permanent pastures. The value of IL "Saturated" is used for a soil maintained in a state of high soil moisture, such as in irrigated agricultural lands.

Values of IL for bare ground that have been classified according to hydrologic soil group are shown in Table 4.4. These values within each hydrologic soil group have been derived from the data in Table 4.3 for the various soil texture classifications.

The uniform loss rate (CNSTL) represents the long-term, equilibrium infiltration capacity of the soil. The values of CNSTL shown in Column (2) of Table 4.3 for soils classified according to soil texture ~~classification~~ are equivalent to the hydraulic conductivity at natural saturation (XKSAT) as determined for the Green and Ampt equation (Table 4.2). The values of CNSTL for soils classified according to hydrologic soil groups are shown in Table 4.~~2~~4. These values within each hydrologic soil group have been selected from inspection of XKSAT values in Table 4.2 for the various soil texture classifications. Values of CNSTL shown in Table 4.4 are consistent with general information available for estimating CNSTL as shown in Table 4.5. Figure 4.11 can be used to estimate CNSTL based on an estimate of CN if adequate soils data is not available.

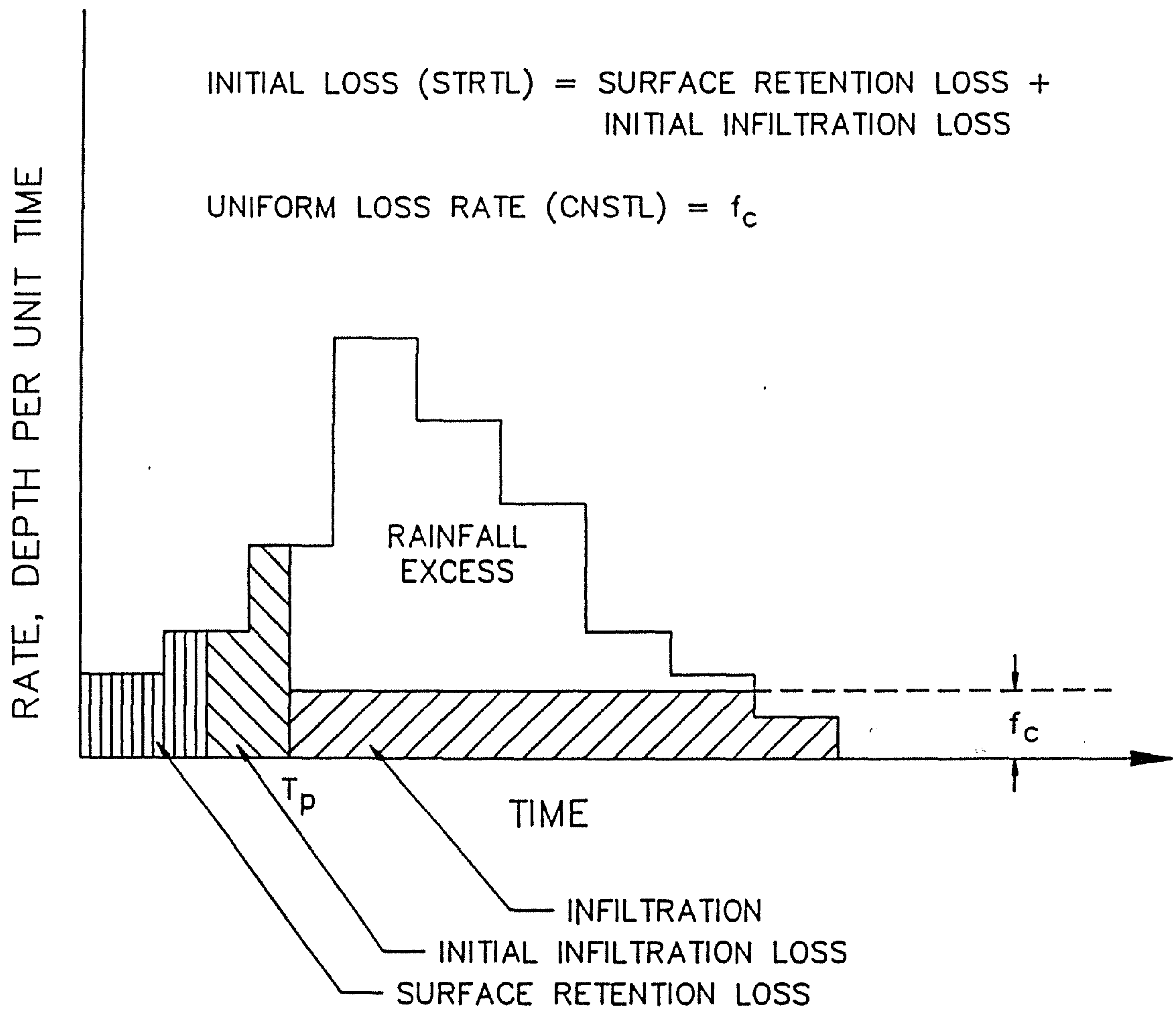

Figure 4.13
Representation of Rainfall Loss According to the Initial Loss Plus Uniform Loss Rate (IL+ULR)

Table 4.3
Initial Loss Plus Uniform Loss Rate Parameter Values for Bare Ground according to Soil Texture Classification

Soil Texture Classification (1)	Uniform Loss Rate CNSTL (2)	Initial Loss, Inches IL[1]		
		Dry (~~4~~)3	Normal (~~5~~)4	Saturated (~~6~~)5
sand	4.6	1.3	1.3	0
loamy sand	1.2	0.8	0.8	0
sandy loam	0.40	0.7	0.6	0
loam	0.25	0.8	0.7	0
silty loam	0.15	0.6	0.5	0
sandy clay loam	0.06	0.6	0.5	0
clay loam	0.04	0.5	0.4	0
silty clay loam	0.04	0.6	0.5	0
sandy clay	0.02	0.4	0.3	0
silty clay	0.02	0.4	0.3	0
clay	0.01	0.3	0.2	0

[1] Selection of IL:
Dry = Nonirrigated lands such as desert and rangeland;
Normal = Irrigated lawn, turf, and permanent pasture;
Saturated = Irrigated agricultural land.

Table 4.4
Initial Loss Plus Uniform Loss Rate Parameter Values for Bare Ground according to Hydrologic Soil Group

Hydrologic Soil Group (1)	Uniform Loss Rate CNSTL (2)	Initial Loss, Inches IL[1]		
		Dry (~~4~~)3	Normal (~~5~~)4	Saturated (~~6~~)5
A	0.4	0.6	0.5	0
B	0.25	0.5	0.3	0
C	0.15	0.5	0.3	0
D	0.05	0.4	0.2	0

[1] Selection of IL:
Dry = Nonirrigated lands such as desert and rangeland;
Normal = Irrigated lawn, turf, and permanent pasture;
Saturated = Irrigated agricultural land.

Table 4.5
Published Values of Uniform Loss Rates

Hydrologic Soil Group (1)	Uniform Loss Rate, inches/hour		
	Musgrave (1955) (2)	USBR (1975)[1] (3)	USBR (1988)[2] (4)
A	0.30 - 0.45	0.40	0.30 - 0.50
B	0.15 - 0.30	0.24	0.15 - 0.30
C	0.05 ~~0.50~~ - 0.15	0.12	0.05 - ~~0 - 0.05~~ 0.15
D	0 - 0.05	0.08	0 - 0.05

[1] *Design of Small Dams*, Second Edition, 1975, Appendix A
[2] *Design of Small Dams*, Third Edition, 1988

4.5 Procedure for Estimating Loss Rates

4.5.1 Green and Ampt Method

A. When soils data are available:

1. Determine the soil texture classification. Soils reports such as those of the Soil Conservation Service can be used if available, or laboratory analysis of appropriate soil samples from the drainage area can be used if adequate documentation on the sampling and laboratory procedure is provided and approved.

2. Estimate the hydraulic conductivity (XKSAT) for bare ground from Table 4.2 if general soil texture classification is available or from Figure 4.3 if adequate soil texture data is available from an approved sampling program.

3. If desired, adjust the value of XKSAT for the influences of vegetation cover using Figure 4.10.

4. Estimate the wetting front capillary suction parameter (PSIF) from Table 4.2 if general soil texture classification is available or from Figure 4.4 if adequate soil texture data is available from an approved sampling program.

5. Estimate the value of DTHETA from Table 4.2 if general soil texture classification is available or from either Figure 4.8 or 4.9 if adequate soil texture data is available from an approved sampling program. The value of DTHETA must be selected based on the appropriate antecedent soil moisture condition: "Dry" for nonirrigated lands such as desert and rangeland; "Normal" for soil that would be expected to be near soil moisture field capacity such as irrigated lawn, turf, and permanent pasture; and, "Saturated" for irrigated agricultural land.

6. Determine the land-use and/or soil cover for the drainage area and use Table 4.1 to estimate the surface retention loss (IA).

B. When soils data are not available:

1. Estimate the CN based on data for similar watersheds or regional experience. Estimate the percent vegetation cover.

2. Use Figure 4.11 to estimate XKSAT based on CN and hydrologic condition.

3. Use Figure 4.11 to estimate XKSAT for bare ground.

4. Use the bare ground XKSAT and Figure 4.12 to estimate PSIF.

5. Use the bare ground XKSAT and PSIF with Table 4.2 to estimate DTHETA.

C. Alternative methods:

As an alternative to the above procedures, Green and Ampt loss rate parameters can be estimated by reconstitution of recorded rainfall-runoff events on the drainage area or hydrologically similar watersheds, or parameters can be estimated by use of rainfall simulators in field experiments. Plans and procedures for estimating Green and Ampt loss rate parameters by either of these procedures should be approved by the Flood Control District and the local agency before initiating these procedures.

4.5.2 Initial Loss Plus Uniform Loss Rate Method

A. When soils data are available:

1. Determine the soil texture classification and/or the hydrologic soil group. Soils reports such as those of the Soil Conservation Service can be used if available, or laboratory analysis of appropriate soil samples from the drainage area can be used to classify the soil if adequate documentation on the sampling and laboratory procedure is provided and approved.

2. Use values of CNSTL and IL from Table 4.3 if the losses are to be based on soil texture classification.

3. Use values of CNSTL and IL from Table 4.4 if the losses are to be based on hydrologic soil group.

4. Determine the land-use and/or soil cover and use Table 4.1 to estimate the surface retention loss (IA).

5. STRTL = IA + IL.

B. When soils data are not available:

1. Estimate the CN based on data for similar watersheds or regional experience.

2. Estimate the percent vegetation cover.

3. Use Figure 4.11 to estimate CNSTL based on CN and hydrologic condition.

4. Use Table 4.3 to estimate IL based on the value of CNSTL.

5. Use Table 4.1 to estimate the surface retention loss (IA).

6. STRTL = IA + IL

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