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MODELING INFILTRATION USING TIME-TO-PONDING AND A STORM GENERATOR APPROACH

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MODELING INFILTRATION USING TIME-TO-PONDING AND A STORM GENERATOR APPROACH

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ABSTRACT

MODELING INFILTRATION USING TIME-TO-PONDING AND A STORM GENERATOR APPROACH

By

TIEN-YIN CHOU

Soil productivity is largely determined by the biological, physical, and chemical properties and processes in concert with climate and resource management inputs. Mathematical or physical models are effective for describing the influences of soil erosion and management systems on long-term productivity. Research on developing and applying a functional model of infiltration into a soil profile under rainfall or irrigation conditions is important in both hydrology and agriculture. To provide a rational basis for infiltration prediction during rainfall or irrigation, a nonlinear model was used in this study to calculate cumulative infiltration based on time-to-ponding approach. The cumulative infiltration amount at ponding is a function of water application rate, saturated conductivity, saturated soil water content, antecedent soil water content, and macroscopic capillary length. Soil management practices such as crop types, tillage methods and surface residue cover also influence soil properties and infiltration capacity.

To make this infiltration model functional for strategic applications where it is difficult to obtain or use short-period rainfall data, a relatively simple storm generator was used to generate daily precipitation and to disaggregate it into a discrete number of storms of varying intensity patterns. The generated outcome distribution of rainfall was used as input to the physically based time-to-ponding model.

A field study was conducted on a loamy sand (Eutric Glossoboralf) soil in Michigan with corn and potatoes under various tillage, surface residue, and wheel traffic conditions to determine values of the soil properties needed for the infiltration model. Time-to-ponding was observed for various water application rates using a sprinkling infiltrometer under a variety of soil management situations. Time to ponding curves were established for each management combination of crop, tillage and wheel traffic conditions.

The time-to-ponding approach appears to be a good infiltration predictor under complex rainfall patterns and different soil management conditions. Using the ponding curves, with known soil hydraulic properties, the point source (or localized) runoff are predictable under any type of rainfall or irrigation patterns. This point source runoff is a critical input for the assessment of water erosion.

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LIST OF SYMBOLS

P[w/w]	probabilities of wet day following a wet day.
P[w/d]	probabilities of wet day following a dry day.
α, β	coefficients for gamma distribution function.
q_z	flux, volume of water moving through the soil in the z-direction (L/T).
H	hydraulic head (L).
K	soil-water hydraulic conductivity (L/T).
K_s	saturated hydraulic conductivity (L/T).
ψ	soil water pressure potential (L).
θ	volumetric soil water content (L^3/L^3).
θ_s	saturated soil water content (L^3/L^3).
θ_n	initial soil water content (L^3/L^3).
θ_r	reference soil water content (L^3/L^3).
S	soil sorptivity ($L/T^{.5}$).
D	soil-water diffusivity (L^2/T).
F_c	flux-concentration relation for constant pressure boundary condition (L/T).
V_0	surface water flux (L/T).
t_p	ponding time (T).

I_p	cumulative infiltration amount at ponding (L).
I_{pp}	cumulative infiltration amount post ponding (L).
r_p	rainfall rate (L/T).
R_p	cumulative rainfall amount at ponding (L).
λ_c	macroscopic capillary length (L).
R_0	runoff rate (L/T).

LIST OF TILLAGE ACRONYMS

CMW	Corn, moldboard plowed, wheel track
CMN	Corn, moldboard plowed, non-wheel track
CDW	Corn, disk plowed, wheel track
CDN	Corn, disk plowed, non-wheel track
CNW	Corn, no-tilled, wheel track
CNN	Corn, no-tilled, non-wheel track
PMW	Potato, moldboard plowed, wheel track
PMN	Potato, moldboard plowed, non-wheel track
PPW	Potato, paratill, wheel track
PPN	Potato, paratill, non-wheel track

I. INTRODUCTION

Soil is a valuable natural resource that needs protection from excessive erosion if long term crop productivity is to be maintained. The ability to predict long-term soil productivity in a variety of agricultural management and soil, climate, and plant growth scenarios will allow the assessment of the consequences of various environmental and agricultural policies. Equations that predict soil erosion are widely used tools for dealing with soil conservation issues. Rainfall-runoff models are needed to predict soil infiltration and runoff under different rainfall patterns and soil management. There are several modeling approaches commonly used to simulate infiltration ranging from complex solutions describing water movement in soil to empirical models that must be fitted using measured infiltration data. The more useful models contain variables that are difficult to measure because they have no physical significance (Mein and Larson, 1973; Reeves and Miller, 1975; Parlange et al., 1985).

In several presently used model of crop growth and hydrology, the curve number technique is used for runoff prediction. In 1954 the Conservation Service (SCS) developed this unique procedure for estimating direct runoff from storm rainfall. This procedure, which is frequently referred to as the curve number technique, has proven to be a very useful tool for evaluating effects of changes in land use and treatment on direct runoff. The advantage for the curve number technique is that it requires only the daily rainfall inputs and estimates total runoff somewhat reliably for a season. The limitation of the curve number technique is that it does not accurately predict runoff for individual storm, and it requires empirical inputs which have little physical meaning and are not measurable in the field. Many researchers (Hawkins, 1978; Jackson et. al., 1976) have expressed concern that the curve number procedure does not reproduce measured runoff from specific storm rainfall because time was not incorporated in this method for estimating runoff. Smith in 1978 found that the curve number technique can not be extended to predict infiltration patterns within a storm, and that the procedure can not respond to differences in rainfall intensity.

During a rainfall event there are periods of heavy downpour and periods of light drizzle. When the rainfall intensity is heavy, the ground surface usually becomes ponded. When rainfall intensity is low, there is usually no surface ponding. There are two distinct stages of infiltration during a rainfall event - a stage in which the ground surface is ponded with water and a stage without surface ponding. Under a ponded surface the infiltration process is independent of the effect of the time distribution of rainfall. The rate of infiltration reaches its maximum capacity and is referred to as the infiltration capacity. Without surface ponding, all the rain infiltrates into the soil. The rate of infiltration equals the rainfall intensity, which is less than the infiltration capacity. Many infiltration models have been formulated to describe the infiltration process with the surface ponded. If the time that separates the non ponded and ponded can be determined, the difficulty involved in modeling infiltration during a nonsteady state rainfall is reduced.

Analysis of infiltration data also requires equations that are physically based to insure their applicability for predictive use. That is, they showed fit observations accurately and the parameters used in the equations should not change with different initial and boundary conditions. Under these conditions infiltration concept can be used with confidence to obtain soil properties, e.g. sorptivity and saturated conductivity by measurement of the time to ponding under condition of variable rainfall rates (Broadbridge and White, 1987).

To adopt point source runoff estimation procedures based on infiltration concepts, one major obstacle is the difficulty in obtaining and using short-period or "break-point" rainfall intensity data (Brakensiek et al., 1981). Physically based infiltration models are quite sensitive to the distribution of total storm rainfall within time increments as short as 5 minute (Woolhiser and Osborn, 1985). Although infiltration models allow improved prediction of infiltration, Their practical use has been limited, primarily because of the lack of rainfall intensity. Woolhiser and Osborn (1985) suggested that if parameter-efficient techniques can be developed to disaggregate the commonly available daily rainfall into intermittent rainfall intensities within the day, simulated rainfall intensity could provide input for physically-based runoff models. This study was designed to develop methodology to (1) predict the infiltration of water into soil using a infiltration capacity concept, and to (2) to generate a reasonable pattern of rainfall intensity for use with the infiltration equation when only daily rainfall amount is known.

The specific objectives of this study were:

1. To develop a parameter efficient model to disaggregate daily precipitation into individual storms, and to further disaggregate the storms into short period intensity patterns.
2. To examine a time-to-ponding approach for infiltration and runoff prediction under variable rainfall patterns and for various soil management practices.
3. To conduct field studies to evaluate the soil properties needed in the time-to-ponding equation and how they are influenced by various types of soil management.

4. To determine the sensitivity of the model to the measured variations in the soil type, tillage and residue management, and rainstorm characteristics.

II. LITERATURE REVIEW

A. Rainstorm Generator

To use the time-to-ponding infiltration equation for computing infiltration and thus runoff, rainfall input data must be in the form of breakpoint data. The form is called breakpoint because the data results from numerical differentiation of the cumulative time versus cumulative rainfall depth curve at the changes in slope, or breakpoint.

Using observed weather data has many limitations. Short time rainfall records can be difficult to obtain for a particular location (Carey and Haan, 1978; Haan et al., 1976; Jones et al., 1972; Richardson, 1985) and few sites have hourly rainfall records of 15 or more years duration. Sites with rainfall intensity data often have periods of missing records due to instrument failure. Also, development of data for a long period at a particular location is time consuming, but is needed for developing rainstorm generators. Disaggregation of daily precipitation into rainfall intensity patterns with properties similar to those obtained from analysis of observed breakpoint data can provide the information needed for analysis of infiltration where only daily rainfall records are available. The following sections provide a brief background and describe the method used in deriving approximate rainfall intensity data.

1. Precipitation Occurrence

The first step in generating sequences of daily rainfall is to determine the occurrence of wet and dry days (Srikanthan and McMahon, 1985). Markov chain models have been commonly employed to generate the wet and dry sequences. Gabriel and Nuemann (1962) used a first order Markov chain to model rainfall occurrence at Tel Aviv. Green (1964) described the characteristics of the discrete daily rainfall sequence which results from a continuous, two-state Markov process. In an investigation of Monte Carlo methods, Wiser (1965, 1966) found that a Markov model should be satisfactory if event persistence lasts only from one period to the next. Several modified models to account for extended persistence were proposed. Adamowski and Smith (1972) determined that a first order Markov model was adequate, but not entirely accurate, as a generator of daily rainfall occurrence. Periods of 5 to 6 days, 8 to 10 days, and 16 days were noted in the variance spectrum that were not accounted for by the Markov chain.

Since the publication of Green (1964), a number of studies have examined the probabilistic character of both daily rainfall and short-term event rainfall. Daily rainfall models were described by Roldan and Woolhiser (1982), Yevjevich and Dyer (1983), and Richardson and Wright (1984). Short-term event rainfall models were examined for use in hydrologic applications by Howard (1976), Di Toro and Small (1979), Loganathan and Delleur (1984) Cordova and Rodriquez-Iturbe (1985), and others. Among those daily precipitation simulations, Richardson and Wright (1984) developed a model (WGEN) that simulates daily rainfall, maximum and minimum temperature, and solar radiation. Rainfall occurrence is simulated using a first order Markov chain model. Rainfall amount on a wet day was determined using a two coefficients gamma generation procedure described by Haan (1977). Simulation coefficients for the Markov probabilities of wet day following a wet day (P[w/w]) and wet day following a dry day (P[w/d]) and gamma distribution (α and β) were estimated for 13 unique seasons within a calendar year.

2. Individual Rainstorm Occurrence

Markov models have also been applied to a generation of short term rainfall sequences. Pattison (1965) produced synthetic hourly rainfall amount for the Stanford Watershed Model. His model was a mixed, first and second order Markov model. A transition probability matrix determined the amount of rainfall in an hour, based on the amount of rainfall occurring in the previous hour.

Nguyen and Rousselle (1981) represented the hourly rainfall sequence with first and second order, two state, Markov chains. Their second order model described the sequence of wet hours only slightly better than the first order model. Rainfall depth of individual rain hours within a storm sequence were assumed to be independent and distributed exponentially. The probabilities of accumulated rainfall within the storm were calculated with a function describing the distribution of the sum of a random number of exponentially distributed random variables.

Srikanthan and McMahon (1983) generated rainfall on hourly and six-minute intervals. Their procedure was to generate daily wet-dry sequences using transition probability matrices (TPM). Several methods of generating hourly rainfall rates on wet days were tested. The best model was a two-state Markov chain with two separate hourly TPM conditioned on a critical daily rainfall depth.

Croley et al. (1978) presented a six season, exponentially distributed interarrival time model to simulate hourly precipitation. Intrastorm structure was described in terms of storm segments. Storms segments were characterized by duration, peak hour, and rainfall accumulation. Normalized hyetographs of storms were used to simulate hourly rainfall within a storm. Raudkivi and Lawgun (1973) noted a serious limitation of Markov chain models. They found that these models only reproduce transitions which have been observed in the historic record and the extreme events may be inadequately represented. They modeled rainfall as a time dependent autoregressive series with a random component. Rainfall was simulated in 10-minute time units.

With the increased focus on short-term, event-scale precipitation, additional attempts to establish links between the continuous and discrete occurrence models have appeared. In particular, methods have been developed to estimate the statistical properties of event precipitation when only daily records are available. The increased focus on event models has led to the recognition that rainfall in many areas does not follow the Markov property. Events may exhibit temporal dependence, as represented in the point process cluster models of Kavvas and Delleur (1981), Waymire et al. (1984), and Smith and Karr (1983). The sequential simulation of rainstorms is but one method of obtaining short term sequences. These sequences can also be obtained through disaggregation of large time interval rainfall depths.

3. Disaggregation Modeling for Storm Intensity Pattern

Several investigators have developed stochastic models of short-time storm intensity patterns at a single point (Pattison, 1965; Grace and Eagleson, 1966; Raudkivi and Lawgun, 1973; Knisel and Snyder, 1975; Nguyen and Rousselle, 1981). A review of this work reveals that the models either were not designed to accommodate intervals of less than an hour or they require a large number of empirically determined coefficients that make them difficult to use in other locations. Most of them focus on the disaggregation of annual to seasonal, seasonal to monthly, and monthly to daily amounts. Hershenhorn and Woolhiser (1987) reviewed rainfall disaggregation methods proposed by Betson, et al. (1980) and Srikanthan and McMahon (1985), found both methods need large numbers of transition probability estimates. Hershenhorn and Woolhiser (1987) disaggregated daily rainfall into one or more individual storms and then disaggregated the individual storms into rainfall intensity patterns. The disaggregated data included starting time of each storm event on wet days as well as the time-intensity data within each event. The accumulated storm precipitation process was nondimensionalized by dividing the precipitation at any time by the total storm precipitation, and the elapsed time by the total duration. The process was divided into 10 equal dimensionless time increments, and the depth increments were rescaled to range between 0 and 1 by dividing each increment by the fraction of the precipitation that occurred between the beginning of that time period and the end of the storm.

Flanagan, et al. (1987) studied the influence of storm pattern (time to peak intensity and the maximum intensity) on runoff, and erosion loss using a programmable rainfall simulator. Six rainfall patterns and three maximum intensities were used. The storm patterns were constant, triangular, and compound consisting of four straight line segments. All patterns could be described fairly well by a double exponential function. The double exponential function or distribution describes rainfall intensity as exponentially increasing with time until peak intensity is reached and then exponentially decreasing with time until the end of the storm.

The Water Erosion Prediction Project (WEPP) User Requirements (Foster and Lane, 1987) suggested that the maximum information required to represent a simulated storm consists of the following: (a) storm amount, (b) average intensity, (c) ratio of peak intensity to average intensity, and (d) time to peak intensity. Examination of appropriate functions to describe a rainfall intensity pattern, given this information, suggest consideration of a triangular distribution and a double exponential distribution.

Nicks and Lane (1989) demonstrated that the rainfall depth-duration-frequency relationship produced by a weather generator they produced for WEPP, is sensitive to the peak storm intensity, and the duration of the event. Although the disaggregated intensity pattern does not fit the observed intensity pattern, the calculated runoff agreed quite well with measured runoff. When using the disaggregated intensity patterns as input to their calibrated infiltration-runoff model, the model could explain some 90% of the variance in runoff computed using the observed rainfall intensity patterns.

B. Infiltration Model Using Time-to-ponding Approach

Infiltration is controlled primarily by the factors governing water movement in the soil. The basic relationship for describing soil water movement was derived from experiments by Darcy in 1856. He found that the flow rates in porous materials is directly proportional to the hydraulic gradient, or, for the one-dimensional case:

$$q_z = -K\ (dH/dz) \qquad [2.1]$$

where: q_z = flux, or volume of water moving through the soil in the z-direction per unit area per unit time (L/t).

H = hydraulic head (L).

dH/dz = hydraulic gradient in the z direction.

K = hydraulic conductivity (L/t).

A second relationship needed to describe water movement in soil is the principle of conservation of mass for the soil water system:

$$d\theta/dt = - \nabla \cdot q \qquad [2.2]$$

where: θ = volumetric soil water content (L^3/L^3)

t = time (t)

q = flux vector

∇ = del operator = $\partial/\partial x + \partial/\partial y + \partial/\partial z$.

Combining equations [2.1] and [2.2] yields the general equation of flow in porous media, or Richards' equation, which can be expressed as:

$$d\theta/dt = -\nabla \cdot (-K\nabla H) \qquad [2.3]$$

Richards' equation indicates that soil water movement, and thus infiltration, depends on the hydraulic conductivity and the hydraulic gradient of the soil. The hydraulic gradient depends on the force of gravity plus the capillary suction exerted by the soil. Both hydraulic conductivity and capillary suction are functions of the water content of the soil.

When hydraulic conductivity and capillary suction are single-valued functions of water content, equation [2.3] can be written as (Philip, 1969):

$$d\theta/dt = \nabla\cdot(D\nabla\theta) + dK/dz \qquad [2.4]$$

where: $D = K(d\Psi/d\theta)$ = diffusivity (L^2/t).

z = flow direction, taken as positive upward (L).

Hanks and Bowers (1963) studied the influence of the shapes of the soil water characteristic curve (suction versus water content) and the hydraulic conductivity and water content relationship in infiltration. They showed that variations in the soil-water diffusivity at low water contents have negligible effect on infiltration from a ponded water surface. However, variations in either the diffusivity or soil water characteristic at water contents near saturation have a strong influence on predicted infiltration. Thus, errors in measuring soil hydraulic properties have greater impact for water contents near saturation than for drier conditions as far as infiltration is concerned (Skaggs and Khaleel, 1982).

1. Quasi-Analytic Theory of Rainfall Infiltration

The infiltration process can be calculated for most initial and boundary conditions by solving the governing differential equations using numerical methods. These solutions provide a physically consistent means of quantifying infiltration in terms of the soil properties governing movement of water and air. Developing and applying quasi-analytical descriptions of the transport of water in soil during rainfall has received considerable attention for the past 30 years. A common approach to rainfall infiltration treats rainfall as a flux boundary condition and assumes that flow in the soil can be described by Darcy's Equation (Rubin, 1966; Smith, 1972; White et al., 1979). Numerical solutions for the highly nonlinear flow equation that result from this procedure have been available since the pioneering work of Rubin and Steinhardt (1963). Their study has led to finite-difference solutions for a variety of complex conditions (Whisler and Klute, 1967; Smith, 1972; Smith, 1982). The desire to produce solutions that are appropriate for field use has led to the application of simplified models of soil-water movement (Mein and Larson, 1973; Braester, 1973; Swartzendruber, 1974; Ahuja and Romkens, 1974; Chu, 1978). Parlange (1972) removed the necessity for these simplified models when he introduced a general and integral solution method. Philip and Knight (1974) improved this method by producing quasi-analytical solutions of the flow equation to any desired accuracy through the use of a concept called the flux-concentration relation (Philip, 1973).

The use of such quasi-analytical solutions has the advantage of a physical-based in situ process which may be used for the measurement of soil hydraulic properties. All parameters in the theory are found from soil properties and need to be determined only once for each soil type. Other empirical infiltration equations require new coefficients for each set of soil conditions. This theory also describes the change of water-pressure potential profile or the water-content profile of the soil surface with time during rainfall. Despite its attendant assumptions and simplifications, the theory has proven to adequately describe water movement into uniform, stable, nondisturbed field soils during rainfall. It also provided a rational basis for making approximations that are readily useable in field studies.

The infiltration model of Parlange et al. (1985,1988) is an example of a mechanistic model, in that it characterizes infiltration as a function of several field-measurable variables: initial and saturated volumetric soil water content (θ_n and θ_s, respectively), depth of ponding (h), and infiltration rate (q). The functional relationship of these variables and infiltration parameters is $q = f(K_s, S, \theta_n, \theta_s, t)$, where

K_s and S are saturated conductivity and sorptivity respectively.

Broadbridge and White (1987) described physically reasonable, analytic solutions to a nonlinear model of constant-rate rainfall infiltration. In their model, soil-water hydraulic properties were simply varied from those of the slightly nonlinear Burgers' equation to those of the popular Green-Ampt model. At the limit when soil-water diffusivity and hydraulic conductivity approach the properties of a Green-Ampt-like model, their analytic solution reduces exactly to the Parlange and Smith (1976) approximation:

$$I_* \tau_p = 0.5 \cdot \ln \{ [R_*(\tau_p) / [R_*(\tau_p) - 1] \} \qquad [2.5]$$

where I_* is time-averaged dimensionless rainfall rate at ponding, R_* is dimensionless rainfall rate which equals to $\{[R(t)-K_n]/[K_s-K_n]\}$, and τ_p is dimensionless ponding time, K_s is the saturated conductivity.

Comparison of the exact solution with approximations derived from the quasi-analytic approach gave good agreement for the same general form:

$$I_* \tau_p = M \cdot \ln \{ [R_*(\tau_p) / [R_*(\tau_p) - 1] \} \qquad [2.6]$$

Here the factor M is a soil specific property determined by the "shape" of the soil-water diffusivity function and lies in the approximate range $0.55 \leq M \leq 0.66$. Broadbridge and White (1987) found that equation [2.6] described both exact solutions and experimental observations.

2. Approximate Solutions

With the limited number and scope of exact solutions, approximations must be sought for the integral solution. These approximations involve simplifications for the various flux-concentration relations, short-time approximations, and assumptions about the nature of the soil hydraulic properties. These approximate solutions were confined to consider only time to incipient ponding, and recognized that such approximations also apply to the water potential and water content profiles.

From White et al. (1982), short-time, gravity-free approximations can be used for the early stages of rainfall infiltration provided the time $t \leq t_g$, where in uniform soils:

$$t_g = \{ S^2(\theta_s,\theta_n) \,/\, [2(\theta_s-\theta_n)\cdot K_s] \} \,/\, V_0 \qquad [2.7]$$

where θ_s and θ_n are volumetric saturated and initial soil water content, respectively, S is soil sorptivity, K_s is saturated hydraulic conductivity, and V_0 is water flux. In uniform soils, by combining the short time approximation and the assumption that the flux concentration relation for the flux boundary condition equals that for the constant pressure boundary condition, equation [2.7] can be written as (Perroux et al, 1981):

$$V_0(t_p)\int_0^{t_p} V_0(t)\ dt = S^2(0,\Psi)/2 \qquad [2.8]$$

where t_p is the ponding time, and ψ is soil water pressure potential which for constant rate is

$$t_p = S^2(0,\Psi_n)\ /\ 2\cdot V_0^2 \qquad [2.9]$$

Equation [2.8] and [2.9] involve the recognition that

$$S^2(0,\Psi_n) = 2\int^0_{\Psi n}(\theta - \theta_n)\ K(\Psi)\ d\Psi/F_c \qquad [2.10]$$

For the delta function diffusivity soil equation [2.7] is exact; for a soil with constant soil-water diffusivity, $D(\theta)$, the factor 1/2 in [2.8] is replaced by $(\pi/4)^2$. F_c is the flux-concentration relation for constant-pressure boundary conditions. For $V_0/K_s \geq 5$, equation [2.7] is in good agreement with the full solution of constant rainfall rate (Broadbridge and White, 1987).

3. Time-to-ponding

For one-dimensional downward infiltration from a water-ponded surface into a uniform nonswelling soil, the literature abounds with single-form equations for expressing the cumulative quantity I of water infiltrated versus time t after the initial and instantaneous ponding of the water, where I is the volume of water per unit cross-sectional bulk area of soil. Most of these infiltration equations (Green and Ampt, 1911; Philip, 1957, 1969; Philip and Knight, 1974; Parlange, 1975; Brutsaert, 1977; Parlange et al., 1982; Swartzendruber, 1987) have some kind of basis in physical-mathematical flow theory that leads to $I \propto t^{1/2}$ and near-zero times and ,with dI/dt approaching the constant, sated hydraulic conductivity K at large times.

Time-to-ponding has received considerable attention because of its importance in hydrologic and agricultural processes. Broadbridge and White (1987) defined the time-to-ponding as that moment during rainfall or sprinkler irrigation when free water first appears at the soil surface. This time marks a period beyond which both runoff and erosion may be initiated. They followed Rubin's (1966) work and predicted the time-to-incipient-ponding, t_p, which is defined as the time at which the water pressure potential at the soil surface, Ψ_0, becomes zero, i.e. $\Psi_0(t_p) = 0$. The time-course of Ψ_0 during rainfall or irrigation can be measured in the field

(Clothier et al., 1981; White et al., 1982; Zegelin and White, 1982; Hamilton et al., 1983). Surface runoff will not occur until $\Psi_0 = 0$.

Infiltration depends on the rainfall rate as well as soil conditions. If the rainfall rate, R, is less than K_s for a deep homogeneous soil, infiltration will continue indefinitely at a rate equal to the rainfall rate without ponding at the surface. The water content of the soil in this case will not reach saturation at any point but approaches a value that depends on rainfall intensity. For soils with restricting layers, infiltration at $R < K_s$ will not always continue indefinitely without surface ponding. Thus, surface ponding and runoff may occur as a result of the soil properties of the restricting layer, its initial water content, and its lower boundary condition, as well as the rate of drainage in the lateral direction. For the case of rainfall rate greater than saturated conductivity ($R > K_s$), water infiltrates initially at the application rate. After some time, the infiltration capacity falls below R, surface ponding begins, and water becomes available for runoff. The time to surface ponding decreases with increasing R, and the infiltration rate-time relationships are clearly dependent on the rainfall intensity.

Quantitative descriptions of t_p for variable rainfall rates, R(t), have been available for some time

(Parlange and Smith, 1976; Chu,1978; Morel-Seytoux, 1974; Broadbridge and White, 1987). The only restriction on R(t) is that it should not produce hysteretic flow. White et al. (1989) used a nondimensional, analytic approximation for time-to-incipient-ponding, t_p, that proved to be quite accurate even for variable rainfall rates. Sensitivity tests employing the approximation showed that t_p is hydrologically robust whenever the rainfall rate at ponding is greater than twice the soil-saturated hydraulic conductivity.

4. Soil Management Effect on Infiltration

Tillage, residue placement, cover crop, and other cultural conditions are known to influence infiltration (Mannering and Meyer, 1963). Tillage may increase (Burwell and Larson, 1969) or decrease (Ehlers, 1975) infiltration and may increase or decrease (Allmaras, 1967) soil water storage depending on climatic conditions and soil properties. Infiltration into homogeneous or layered soils with flat stable surfaces is generally well understood and can be satisfactorily modeled on a wide variety of soil types (Mein and Larson, 1971; Moore and Larson, 1979). The infiltration-runoff behavior of soils with disturbed surfaces, e.g., tilled soils, however, is poorly understood. A model to predict infiltration into these soils would be a valuable tool in developing solutions to count the effect of tillage, residue cover and crop management.

Tillage affects the soil surface directly by altering residue placement, random roughness, fillable porosity, bulk density, size and stability of aggregates, and runoff patterns in a non-uniform way (Johnson and Moldenhauer, 1979; Burwell and Larson, 1969; Lindstrom et al., 1981; Klute, 1982). Tillage can destroy surface crusts, and change soil structure and pore size distribution as well as remove weeds and the competition for soil water. Additionally, tillage can create compaction at the surface through the action of wheel traffic.

Soil surface roughness is an important property of tillage systems because it forms the soil-atmosphere interface and influences the exchange of energy and mass between them. Roughness may also influence soil water storage because of the temporary storage of water in surface depressions. It is a means of keeping ponded water on the land and allowing it to infiltrate. Roughness condition indexes have been measured and have been shown to be highly related to several hydrologic phenomenon, including depression storage (Mitchell and Jones, 1976). The process in quantifying depression storage from microrelief elevation data was difficult to generalize for use in hydrologic models and requires modification for sloping lands. A model was developed by

Linden (1979) which defined the upper limit to depression storage as a function of a "roughness index" (RR) and the general land slope (L). The model analysis did not result in a simple functional relationship but could be expressed in general as:

$$D = f\ (RR, L) \qquad [2.11]$$

where D is the upper limit to depression storage, RR is the roughness index (standard deviation of height measurements) and L is the land slope. Depression storage has a maximum value of about 10 mm and decreases as roughness and land slope increases (Linden, 1979).

Another important factor influencing infiltration of water into the soil profile is the initial water content, The higher the initial water content, the lower the initial infiltration rate. The dependence on initial water content decreases with time. If infiltration continues indefinitely, the infiltration rate will eventually approach the saturated hydraulic conductivity, K_s, regardless of the initial water content. Infiltration rates are higher at low initial water contents because of higher hydraulic gradients and more available storage volume (Skaggs and Khaleel, 1982). Philip (1969) showed that for all times during infiltration, the wetting front advances more rapidly for higher initial water contents.

An important non-soil surface condition that affects both preponded and ponded infiltration is the degree to which the soil surface is protected by vegetative cover or residue. Mulches and crop residues placed or left on the surface of the soil protect the soil surface from direct droplet impact, thus preventing or retarding crust formation. The quantity and quality of the residues both determine the extent of soil protection and the rate of material decomposition. These are determined by the crop type and tillage method. Burwell et al. (1968) reported that the percentage of the soil covered with residue was more important than random roughness, porosity, or the amount of residue in explaining the differences in the amounts of energy needed to induce runoff. Stein et al. (1986) calculated that the placement of residue on a field can increase overall infiltration by absorbing and retarding runoff in critical pathways more than the absolute amount can.

III. DEVELOPMENT OF THE RAINSTORM GENERATOR

A rainstorm event is defined for use in this analysis as any period in which the rainfall intensity is greater than or equal to 0.25 mm (0.01 inch) per hour, and does not contain an intervening period of zero intensity exceeding 10 minutes in duration. Any period of greater than 10 minutes, in which no precipitation is measured, signifies the end of a storm event.

Given past weather raingauge breakpoint data from 1956 to 1985 (30 years weather records from the Deer-Sloan Watershed raingauge stations #10 and #18, Michigan), stochastic models were developed to simulate the number of rainstorm events per wet day and the amount, duration, and peak intensity of each rainstorm occurrence. A final step was to disaggregate the storms into intensity patterns.

A. Rainstorm Occurrences in One Wet Day

Raingauge data were collected at station #10 from the Deer-Sloan Watershed for 30 years. In this study, only the data from the months of April to September were used because it is the growing season for crop in this area and the existence of frozen soils complicates the process.

Precipitation records for each day were broken at midnight. The data set consisted of 2145 storms observed from 1956 to 1985 during the period of April to September. A Fortran source code for observed storm intensity calculation from raingauge data record is listed in Appendix 1. Some general statistics describing the complete storm data set of rainstorms per wet day, amount, duration and peak intensity of each rainstorm are presented in Table 1. Because the groups differ statistically, they were separated by month.

The first step in disaggregating daily rainfall into one or more individual storms was to generate the number of storms, N_j, given the conditional probability of a wet day following a dry day, P[w/d], and a dry day following a wet day P[d/w]. The parameters of P[w/d] and P[d/w] for each month from April to September were derived from recorded data. Any day containing one or more rainstorms where the total precipitation exceeds 0.25 mm was counted as a wet day. A uniform distributed random number was generated each day to determine a wet or dry day using the first-order Markov Chain model. Point precipitation was assumed to be a random time series of discrete storm events which under certain restrictions was assumed to be mutually independent (Eagleson, 1978). In this study, the number of rainstorm events in one wet day and the daily rainfall amount were assumed to be independent. Pearson's correlation coefficient was used to test the assumption. The coefficients were less than 0.3 for

Table 1. Monthly statistics for observed 30 years rainstorm record (1956-1985) for Deer-Sloan Watershed station #10, Michigan.

	Mean	St.d.	Min.	Max.
Apr. (470 rainstorms)				
Rainstorms per wet day	3.13	1.94	1.00	12.00
Amount per rainstorm (mm)	3.30	6.86	0.25	106.17
Duration per rainstorm (hr)	1.28	1.48	0.05	11.33
Max. Rate per rainstorm (mm/hr)	11.43	25.15	0.25	243.84
May (367 rainstorms)				
Rainstorms per wet day	3.01	2.02	1.00	12.00
Amount per rainstorm (mm)	4.06	6.60	0.25	44.20
Duration per rainstorm (hr)	1.36	1.58	0.02	11.30
Max. Rate per rainstorm (mm/hr)	16.26	34.80	0.25	365.76
June (370 rainstorms)				
Rainstorms per wet day	2.62	1.68	1.00	9.00
Amount per rainstorm (mm)	5.08	7.87	0.25	68.83
Duration per rainstorm (hr)	1.06	1.34	0.02	15.98
Max. Rate per rainstorm (mm/hr)	27.94	47.50	0.25	365.76
July (228 rainstorms)				
Rainstorms per wet day	2.37	1.46	1.00	7.00
Amount per rainstorm (mm)	6.35	9.65	0.25	86.36
Duration per rainstorm (hr)	1.08	1.12	0.05	7.35
Max. Rate per rainstorm (mm/hr)	34.80	49.78	0.25	228.60
Aug. (329 rainstorms)				
Rainstorms per wet day	2.47	1.69	1.00	11.00
Amount per rainstorm (mm)	5.33	8.38	0.25	64.77
Duration per rainstorm (hr)	1.03	1.03	0.02	6.87
Max. Rate per rainstorm (mm/hr)	32.26	51.05	0.25	304.80
Sep. (381 rainstorms)				
Rainstorms per wet day	2.97	2.15	1.00	13.00
Amount per rainstorm (mm)	4.06	6.10	0.25	54.61
Duration per rainstorm (hr)	1.13	1.17	0.02	7.15
Max. Rate per rainstorm (mm/hr)	19.81	32.77	0.25	167.64

most of the monthly data sets, supporting the assumption of independence.

To perform curve fitting with probability and cumulative distribution functions, four discrete distribution functions (binomial, geometric, hypergeometric, and uniform) were compared to obtain the marginal distribution of the number of storms on one wet day. The geometric probability mass function was found to give a good fit to the observed distribution. This cumulative probability function can be written as

$$P\{N_j = n\} = F\{n\} = p \cdot (1-p)^{n-1}, \; n = 1,2,\cdots \qquad [3.1]$$

where p is the geometric probability coefficient. Figures 1 and 2 respectively show the observed and simulated distribution for number of storms on one wet day for each month. The chi-square goodness-of-fit test indicated that the positive hypothesis cannot be rejected at the 95% level for each month. Each month's value p for the geometric distribution is graphed in Figure 3 for the station #10 and station #18 data sets. Both stations show a similar monthly pattern on storm event number on one wet day. April, May, and September have the tendency of higher storm event number while summer season (June, July, and August) show a lower possibility for storm event on one wet day. The number of storms on one wet day was generated by the inverse function:

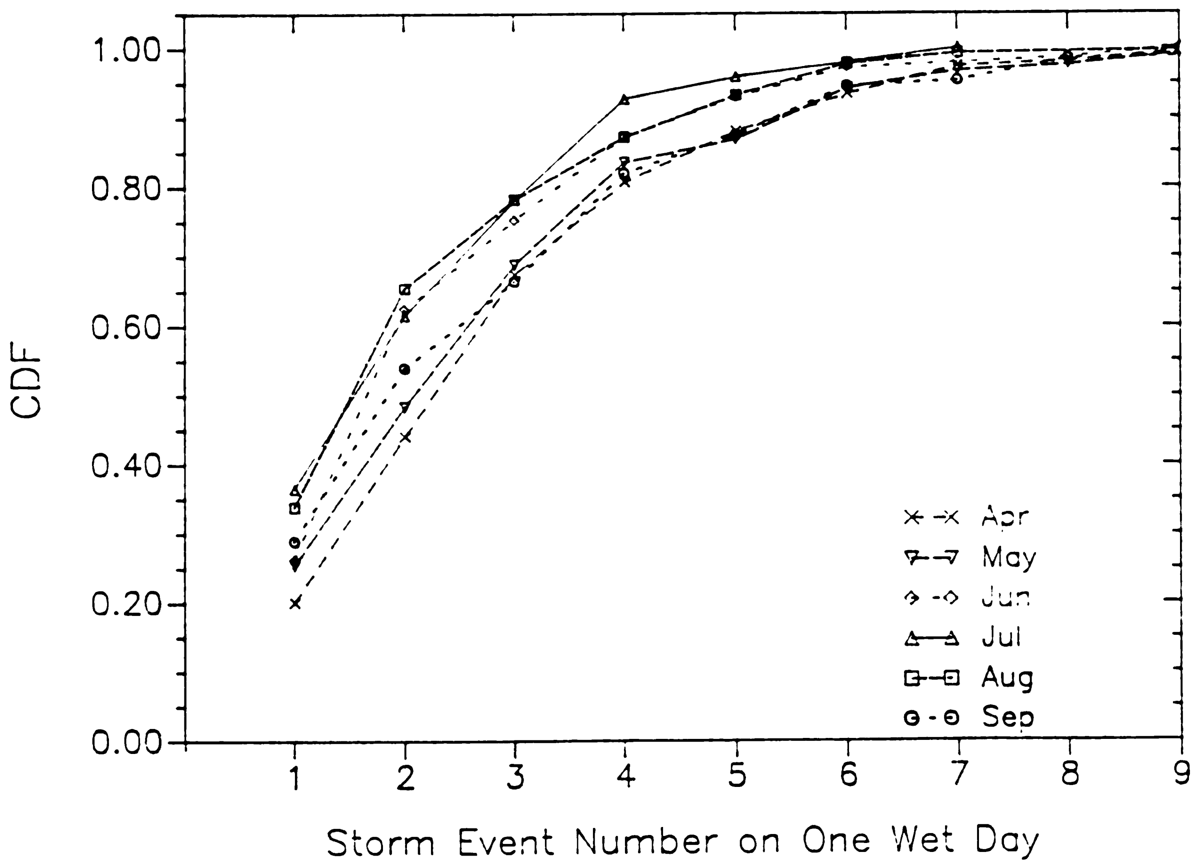

Figure 1. Cumulative Density Function (CDF) for 30 years (1956-1985) observed storm event number on one wet day from Deer-Sloan Watershed station #10, Michigan. Separate CDF are shown for each months analyzed.

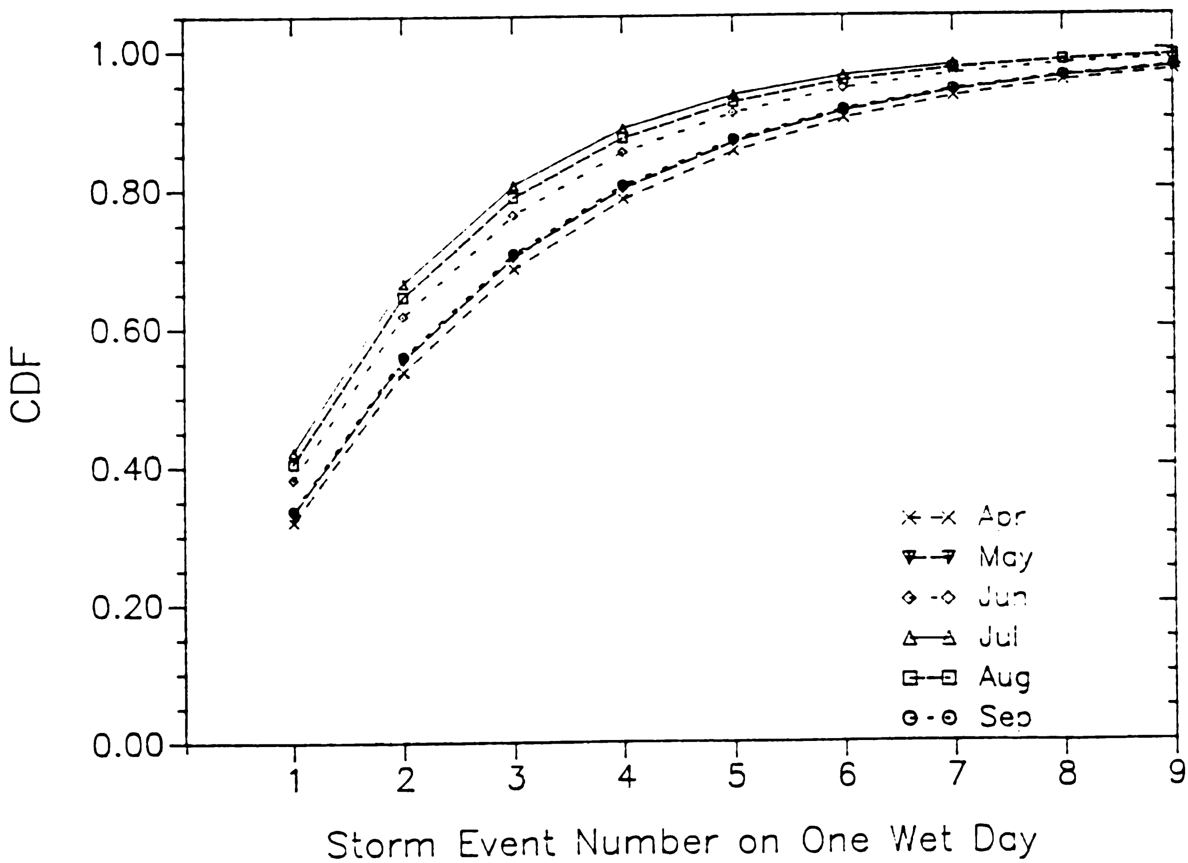

Figure 2. Cumulative Density Function (CDF) for simulated storm event number on one wet day using geometric distribution functions for Deer-Sloan Watershed station #10, Michigan. Separate CDF are shown for each months simulated.

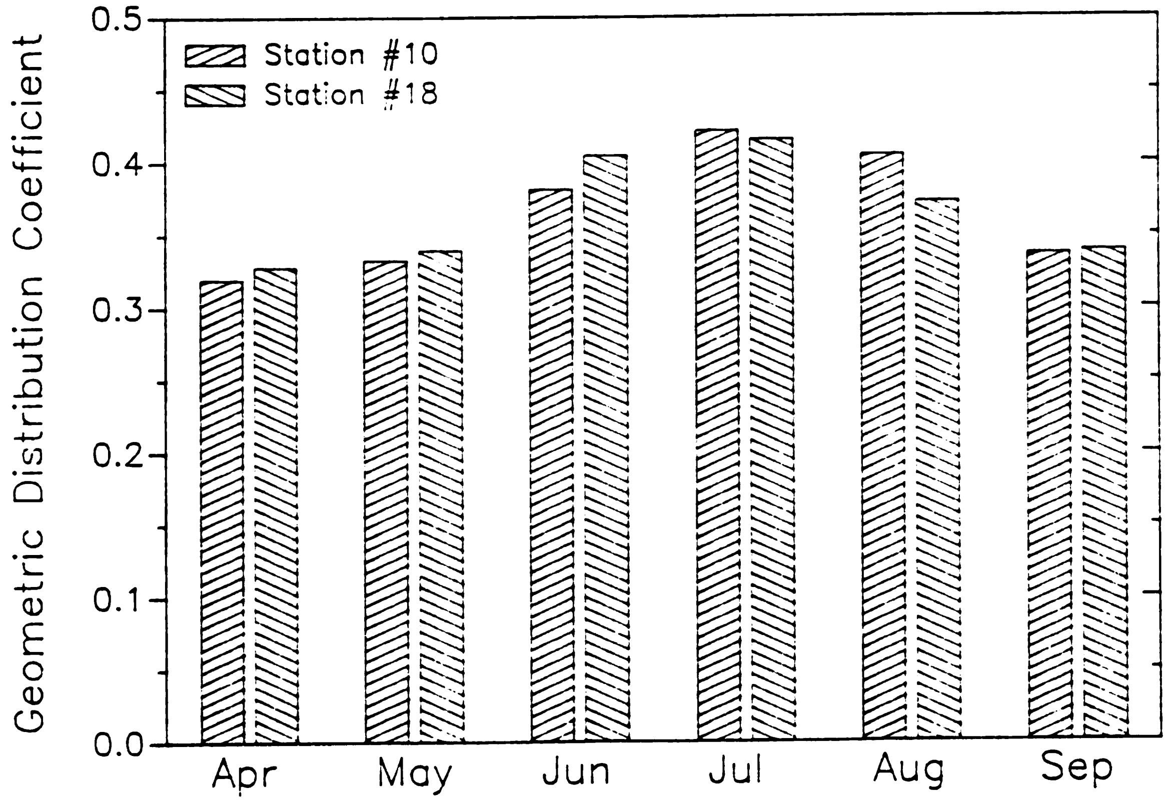

Figure 3. Geometric distribution coefficients for simulated storm event number on one wet day for Deer-Sloan Watershed stations #10 and #18, Michigan.

$$N_j = 1 + [\ \log U / \log (1-p)\ ] \qquad [3.2]$$

where U is a generated random number.

B. Amount and Distribution of Individual Storms

Individual amounts, A, of N_j storms on one wet day are assumed to be independent random variables. While this assumption may not be strictly valid, it makes the problem tractable, and gives reasonable results. Four continuous distributions (exponential, gamma, lognormal, and weibull) were compared to obtain the marginal distribution of storm amount. The two-parameter gamma distribution had the maximum likelihood function value and minimum Akaike Information Criterion, or AIC (Akaike, 1974), and therefore was selected as the best choice. The marginal distribution of storm amount is written as:

$$P\{A_{Nj} \le a\} = F\{a\} = 1 - \Gamma(b;a/c) \,/\, \Gamma(b) \qquad [3.3]$$

where a is the precipitation amount of N_j storm, and b and c are distribution parameters for shape and scale, respectively, for the gamma distribution. Figures 4 and 5 show the observed and simulated storm amount distributions, respectively. The rainstorms occurred on summer season have a higher possibility of higher storm amount than those on other months.

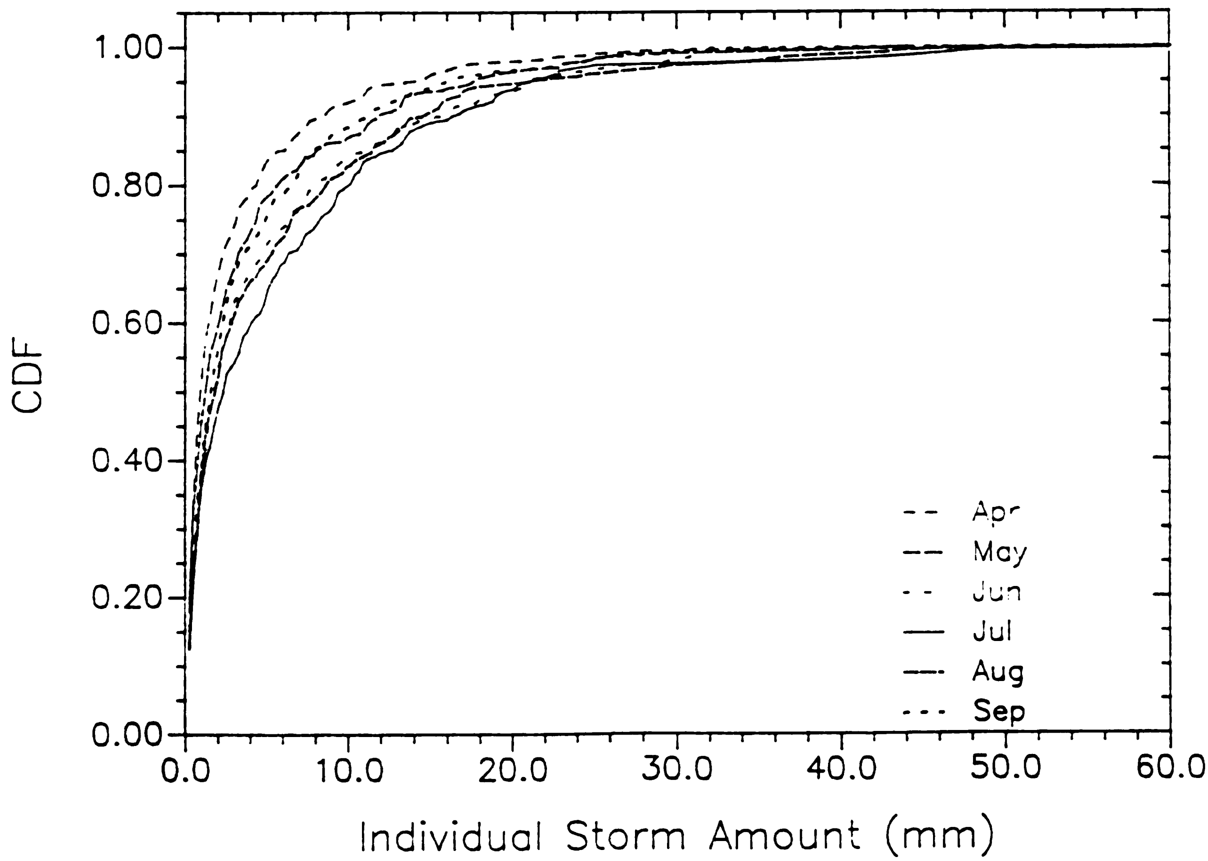

Figure 4. Cumulative Density Function (CDF) for 30 years (1956-1985) observed individual storm amounts from Deer-Sloan Watershed station #10, Michigan. Separate CDF are shown for each months analyzed.

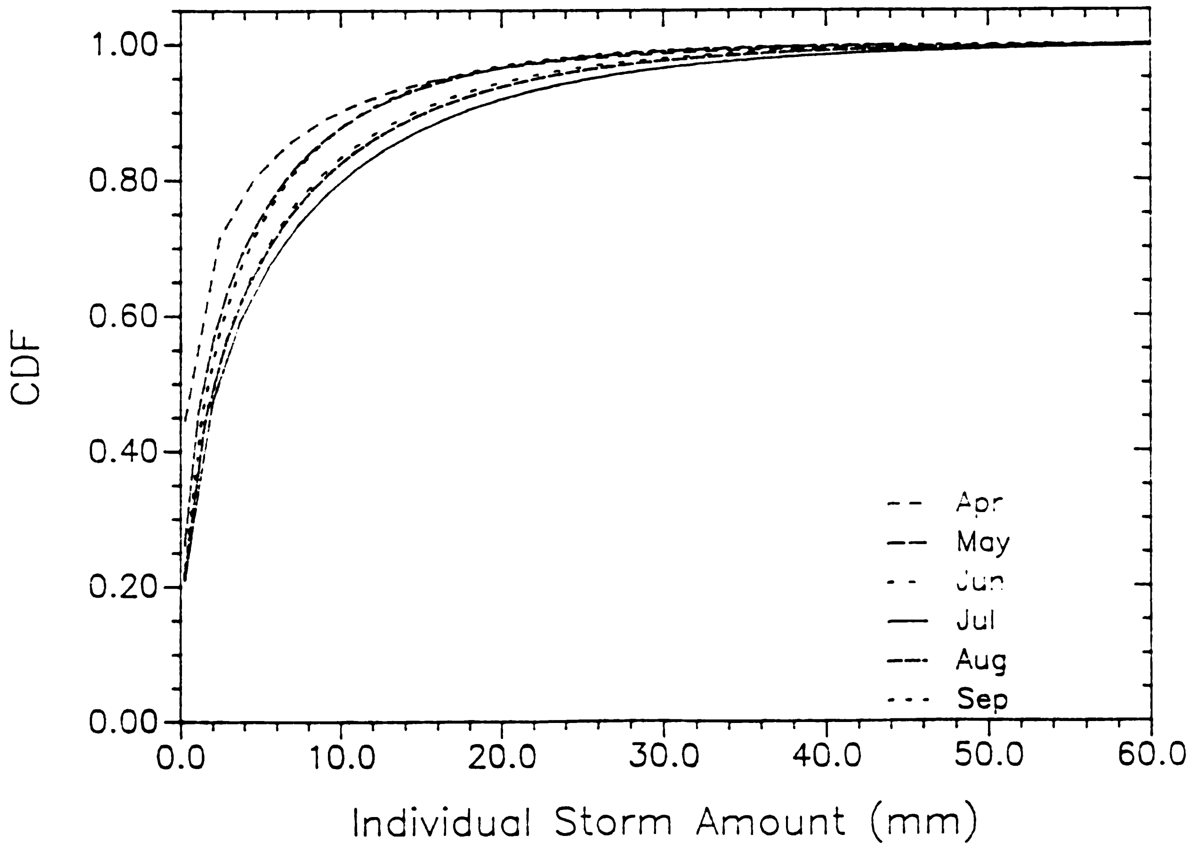

Figure 5. Cumulative Density Function (CDF) for simulated individual storm amount using gamma distribution functions for Deer-Sloan Watershed station #10, Michigan. Separate CDF are shown for each months simulated.

The Chi-square goodness-of-fit test showed that the null hypothesis cannot be rejected at the 95% level for each monthly data set.

C. Joint Probability Distribution of Storm Duration and Amount

After individual storm amounts were obtained by the Gamma distribution, it was necessary to simulate the durations D_{Nj} associated with each event amount, A_{Nj}. The joint density function of event amount and duration can be written as a product of the conditional and marginal density functions:

$$f(A_{Nj} \le a,\ D_{Nj} \le d) = f(A_{Nj} \le x) \cdot f(D_{Nj} \mid A_{Nj}) \qquad [3.4]$$

Many researchers have suggested that D_{Nj} and A_{Nj} are jointly dependent for most rainfall events (Woolhiser and Osborn, 1985). In identifying a form for the conditional distribution, it was assumed that the distribution of the duration, given a particular amount, was the same for all events. To define two new random variables: let $a' = \log_e a$, and $d' = \log_e d$. Assume that the conditional density of d', given a', is normal, with an expected value function which is a linear function of a':

$$E[d'|a'] = \alpha + \beta \cdot a' \qquad [3.5]$$

Linear regression functions were obtained from the above equation. Figures 6 and 7 show the regression lines of data sets from station #10 for April and July, respectively. Using a correlation ratio test (Kendall and Stuart, 1979) to test the hypothesis of linearity of the regression, the hypothesis cannot be rejected at 95% level. To test the hypothesis that the conditional density of d', given a', is normal, the values of a' were separated into four classes based on magnitude, and a chi-square test was run on the residuals, a' - E[a'], for each class. The positive hypothesis could not be rejected at 95% level in each case. The conditional density can be written as:

$$f(D_{Nj}' \mid A_{Nj}') = \alpha + \beta \cdot a' + \varepsilon \qquad [3.6]$$

where ε is the standard error of the estimate.
The storm duration can be obtained by the transformation:

$$D_{Nj} = \exp(D_{Nj}') \qquad [3.7]$$

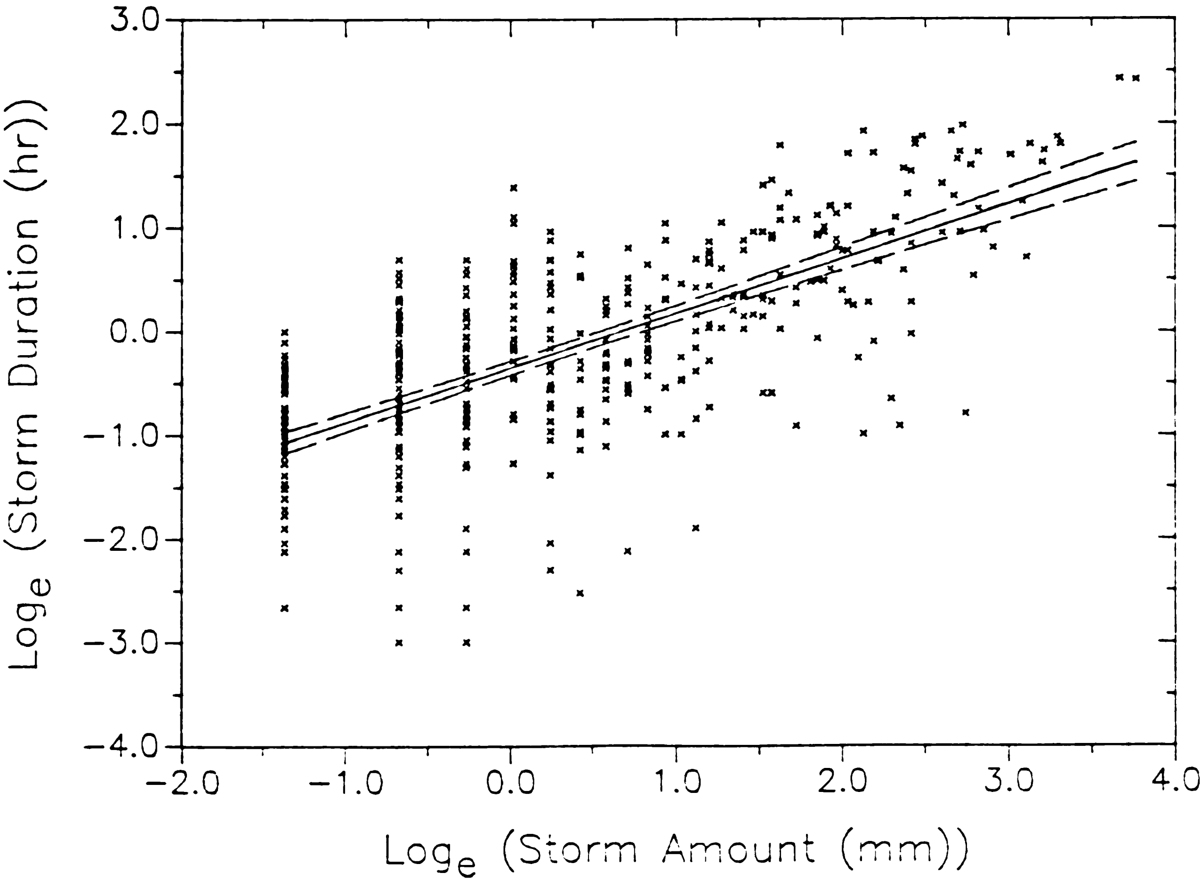

Figure 6. Regression for 30 years (1956-1985) observed individual storm duration and amount for April from Deer-Slone Watershed station #10, Michigan.

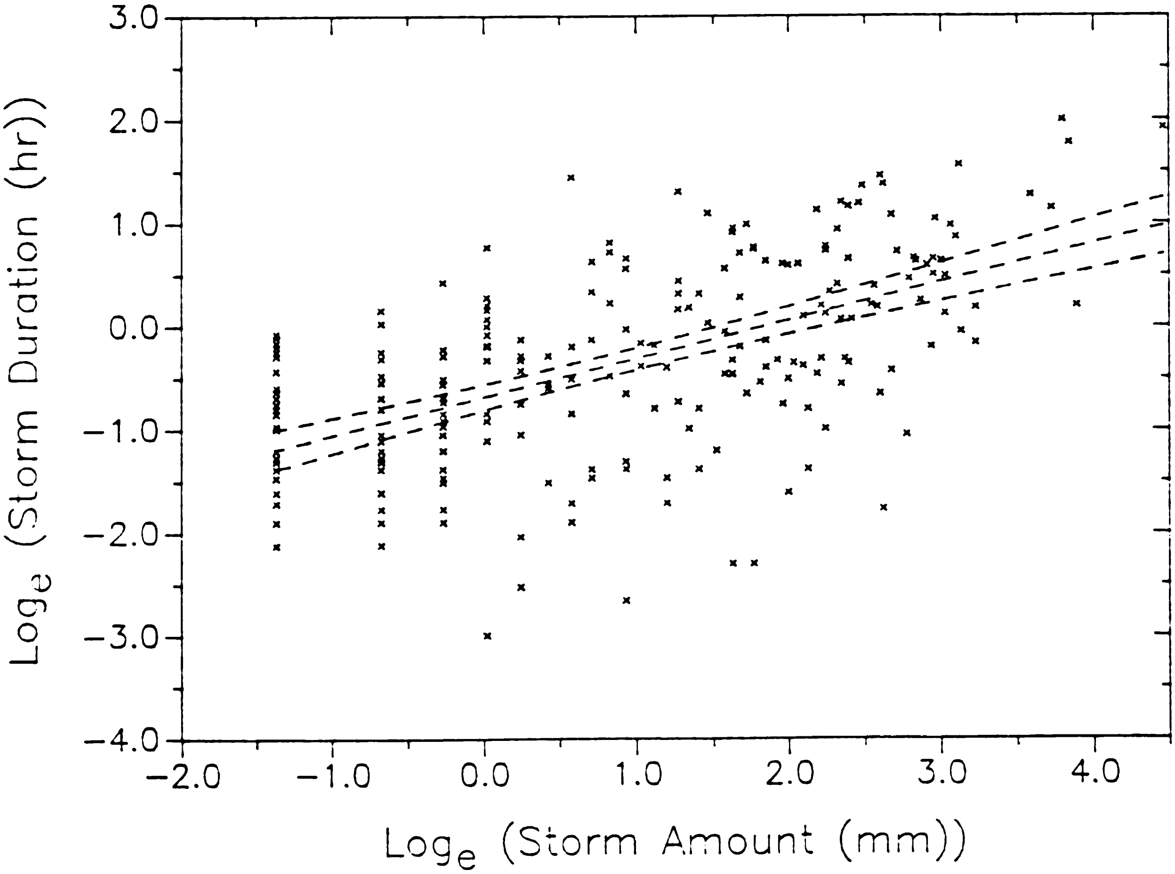

Figure 7. **Regression for 30 years (1956-1985) observed individual storm duration and amount for July from Deer-Slone Watershed station #10, Michigan.**

D. Peak Storm Intensity

Empirical distribution functions for the peak intensity, r_p, were found to be described best by exponential distributions in varying storm amount classes.

$$P\{r_p \le r\} = 1 - \exp(-r/p) \qquad [3.8]$$

Figures 8 and 9 show the observed and simulated peak intensities for each storm amount class. Higher storm amount classes have the tendency of higher peak intensity. Figure 10 shows that the parameters, p, are described by a linear pattern within varying classes. Chi-square tests were performed for each class and none could be rejected at 95% level. The peak intensity can be estimated by the inverse function within a known storm amount class:

$$r_p = -p \cdot \log U \qquad [3.9]$$

where U is a uniform random variable from 0 to 1.

The time from the beginning of the storm to the peak intensity, t_p, was estimated by fitting the normalized time scale distribution.

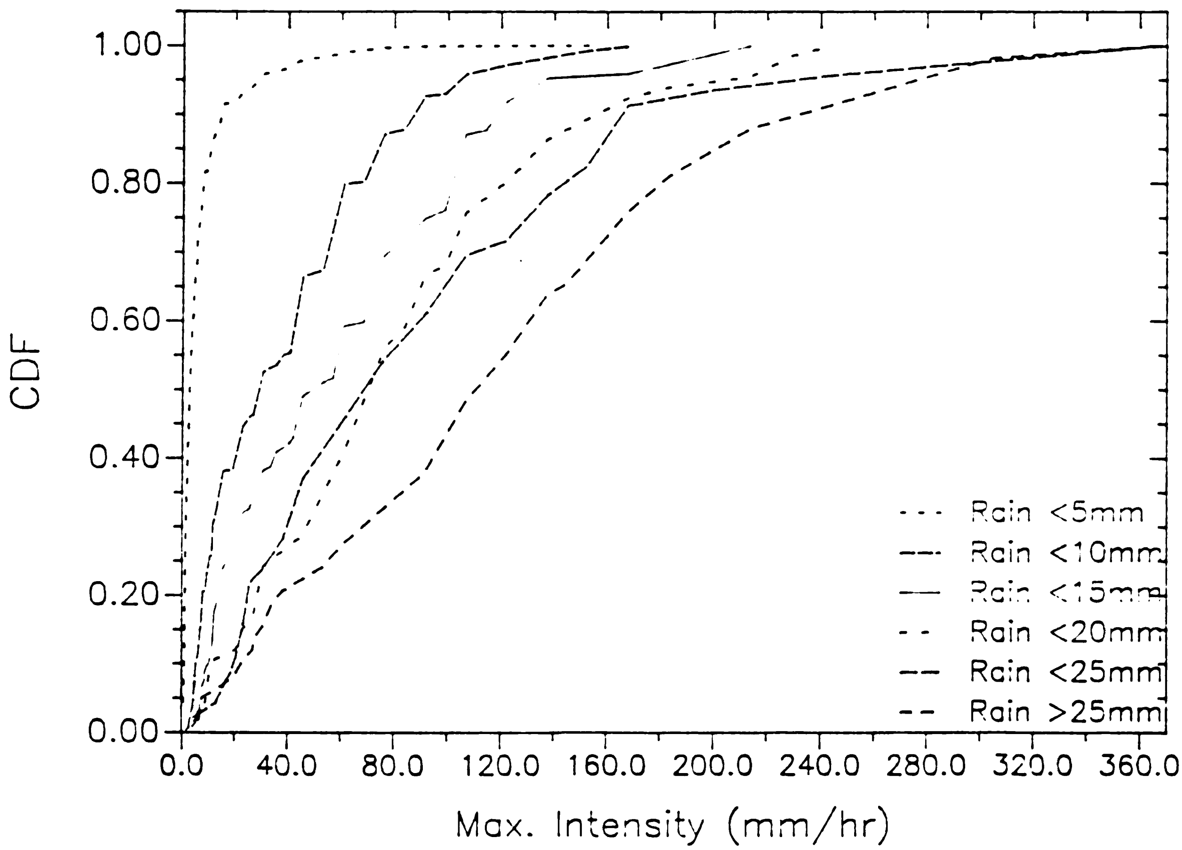

Figure 8. Cumulative Density Function (CDF) for 30 years (1956-1985) observed peak intensity for individual rainstorm amount classes from Deer-Sloan Watershed station #10, Michigan.

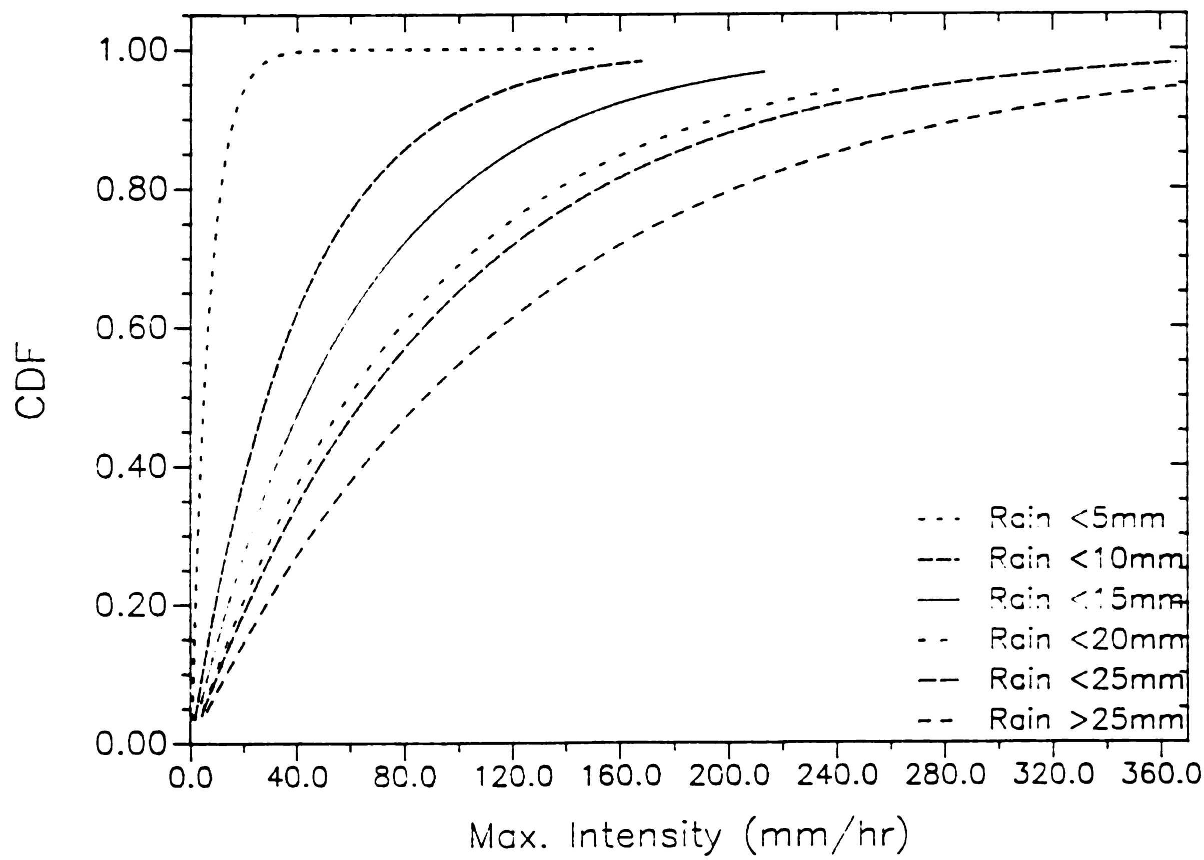

Figure 9. Cumulative Density Function (CDF) for simulated peak intensity for individual rainstorm amount classes using exponential distribution functions for Deer-Sloan Watershed station #10, Michigan.

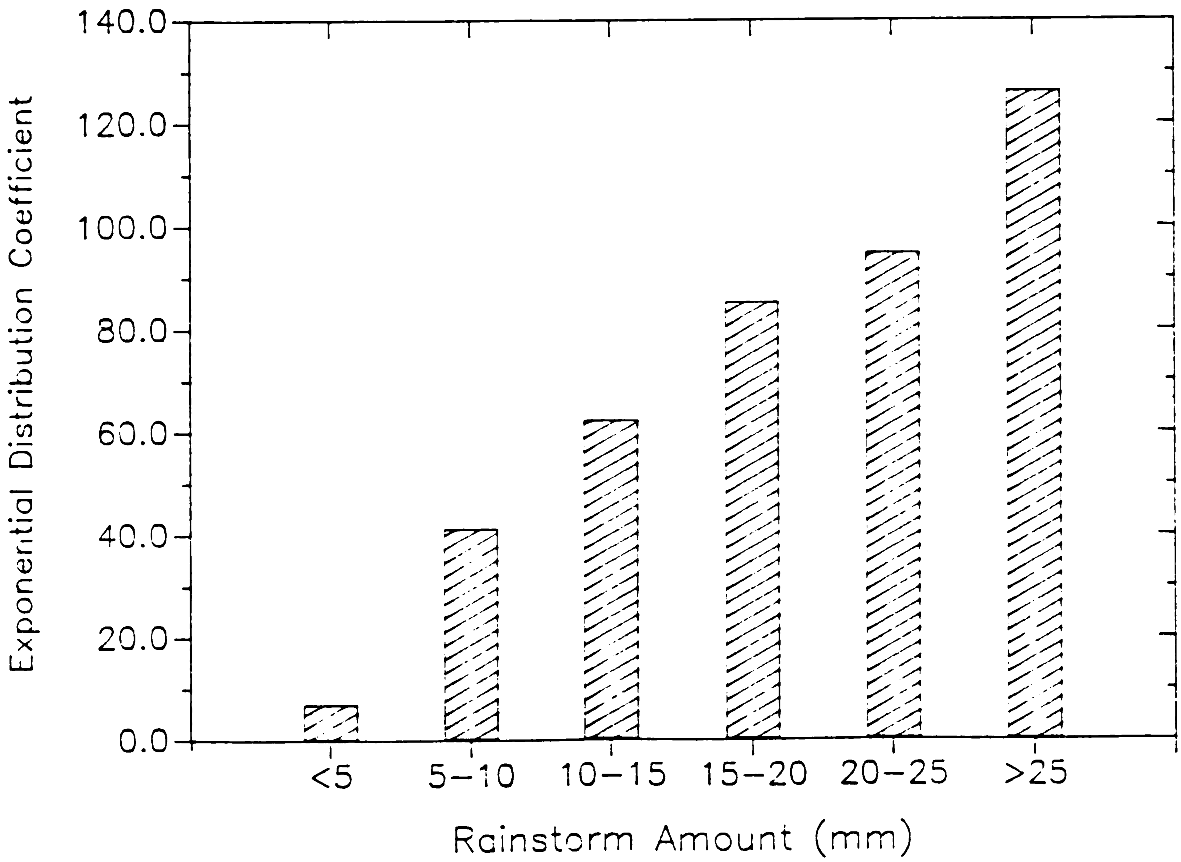

Figure 10. Exponential distribution coefficients for simulated peak intensity for individual rainstorm amount classes for Deer-Sloan Watershed station #10, Michigan.

E. Disaggregation for Storm Rainfall Intensity Patterns

Sample calculations for a storm event occurring on July 11, 1984, are summarized in Table 2. The total was 17.5 mm (A) and occurred in 1.283 hour (D) from station #10 raingauge data. The rainfall rates are graphed in Figure 11. Column 1 from Table 2 is the cumulative time (hr) from the start of the storm and column 4 is the cumulative storm depth (mm) at the given times. Column 8 is the storm intensity calculated from columns 2 and 3. A dimensionless process can be defined by the normalization of storm and intensity. A normalized time scale was developed by dividing each period of storm duration (t) by the total storm duration (D) and intensity values were normalized by the average intensity. The result is called a normalized time, T*, and normalized intensity pattern, Int*. These values are given in column 7 and 9 in Table 2, respectively. The normalized time until the peak intensity, is 0.14 from Table 2, and the normalized peak intensity, is 6.56 for the example data.

Thus, the intensity pattern within a storm can be described by the dimensionless stochastic process { Int*(t*); $0 \le t^* \le 1$ }. This process of intensity over the time scale (Int* versus T*) was fit to a double exponential function as shown in Figure 12.

Table 2. Example calculation of storm intensity pattern for an observed storm record from Deer-Sloan Watershed station #10, Michigan on July 11,1985.

Time(hr)	Duration	Amt(mm)	Cum. Amt(mm)	Amt*	Cum. Dur.(hr)	Dur*	Int(mm/hr)	Int*
0.000	0.000	0.000	0.000	0	0.000	0	0	0
0.000	0.066	0.254	0.254	0.0145	0.066	0.0514	3.848	0.2817
0.066	0.050	0.762	1.016	0.0580	0.116	0.0904	15.240	1.1157
0.116	0.034	1.016	2.032	0.1159	0.150	0.1169	29.882	2.1876
0.150	0.016	1.270	3.302	0.1884	0.166	0.1294	79.375	5.8108
0.166	0.017	1.524	4.826	0.2754	0.183	0.1426	89.647	6.5627
0.183	0.017	0.508	5.334	0.3043	0.200	0.1559	29.882	2.1876
0.200	0.016	0.508	5.842	0.3333	0.216	0.1684	31.750	2.3243
0.216	0.017	0.508	6.350	0.3623	0.233	0.1816	29.882	2.1876
0.233	0.050	0.762	7.112	0.4058	0.283	0.2206	15.240	1.1157
0.283	0.017	0.762	7.874	0.4493	0.300	0.2338	44.824	3.2814
0.300	0.033	0.762	8.636	0.4928	0.333	0.2595	23.091	1.6904
0.333	0.017	0.508	9.144	0.5217	0.350	0.2728	29.882	2.1876
0.350	0.033	0.508	9.652	0.5507	0.383	0.2985	15.394	1.1269
0.383	0.050	0.508	10.160	0.5797	0.433	0.3375	10.160	0.7438
0.433	0.017	0.762	10.922	0.6232	0.450	0.3507	44.824	3.2814
0.450	0.050	0.508	11.430	0.6522	0.500	0.3897	10.160	0.7438
0.500	0.033	0.762	12.192	0.6957	0.533	0.4154	23.091	1.6904
0.533	0.067	0.762	12.954	0.7391	0.600	0.4677	11.373	0.8326
0.600	0.033	0.254	13.208	0.7536	0.633	0.4934	7.697	0.5635
0.633	0.100	0.508	13.716	0.7826	0.733	0.5713	5.080	0.3719
0.733	0.100	1.016	14.732	0.8406	0.833	0.6493	10.160	0.7438
0.833	0.050	0.508	15.240	0.8696	0.883	0.6882	10.160	0.7438
0.883	0.017	0.762	16.002	0.9130	0.900	0.7015	44.824	3.2814
0.900	0.033	0.762	16.764	0.9565	0.933	0.7272	23.091	1.6904
0.933	0.100	0.254	17.018	0.9710	1.033	0.8051	2.540	0.1859
1.033	0.100	0.254	17.272	0.9855	1.133	0.8831	2.540	0.1859
1.133	0.150	0.254	17.526	1.0000	1.283	1.0000	1.693	0.1240
1.283	0.000	0.000	0.000	0.0000				

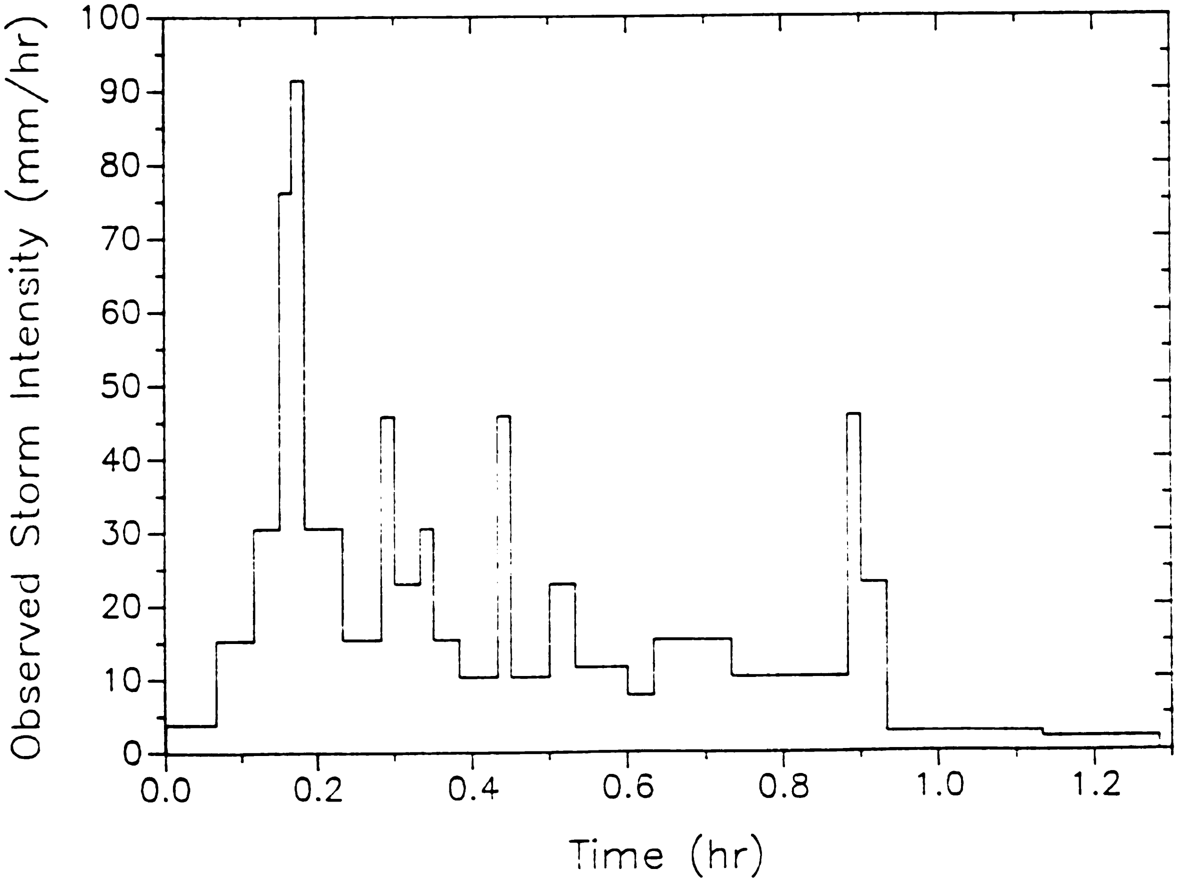

Figure 11. Observed storm intensity of one rainstorm event on July 11, 1985 from Deer-Sloan Watershed station #10, Michigan.

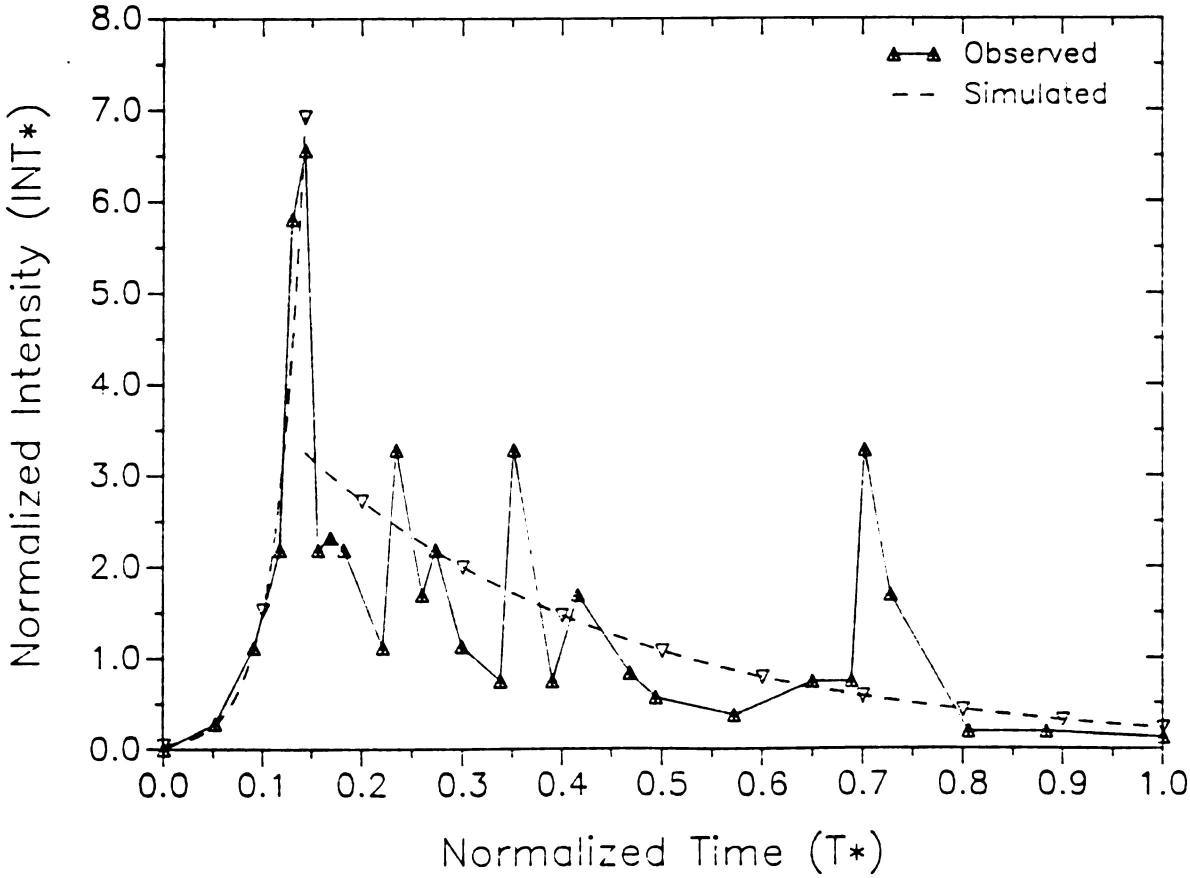

Figure 12. Observed and simulated normalized storm intensity for one rainstorm event on July 11, 1985 from Deer-Sloan Watershed station #10, Michigan.

A double exponential function fitted to the normalized intensity pattern is then:

$$i(t) = \begin{cases} a\,e^{bt} & 0 \le t \le t_p \\ c\,e^{-dt} & t_p \le t \le 1.0 \end{cases} \qquad [3.10]$$

which is an equation with four parameters (a,b,c,d) to be determined. If the area under the curve defined by equation [3.10] from 0.0 to t_p is assumed to be equal to t_p, then the area under the curve from t_p to 1.0 is 1.0 - t_p. Using this assumption and the fact that $i(t=t_p) = i_p$, equation [3.10] can be rewritten as:

$$i(t) = \begin{cases} i_p\,e^{b(t-tp)} & 0 \le t \le t_p \\ i_p\,e^{d(tp-t)} & t_p \le t \le 1.0 \end{cases} \qquad [3.11]$$

which is now an equation with two parameters (b,d) to be determined. If I(t) is defined as the integral of i(t), then:

$$I(t_p) = \int_0^{t_p} i_p\, e^{b(t-tp)}\, dt = t_p \qquad [3.12]$$

and

$$I(1.0) = \int_{t_p}^{1.0} i_p\, e^{d(tp-t)}\, dt = 1 - t_p \qquad [3.13]$$

Evaluation of these integral results in two equations:

$$i - e^{btp} = bt_p / i_p \qquad [3.14]$$

and

$$i - e^{d(1-tp)} = d(1-t_p) / i_p \qquad [3.15]$$

which must be solved for b and d. With the above assumptions i(0) is equal to i(1.0) so that $d = b\ t_p\ /\ (1-t_p)$. Now, equation [3.14] need only be solved for b for the entire solution. The integral I(t) of equation [3.10] and [3.11] can be written as

$$i(t) = \begin{cases} a/b \quad (e^{bt}-1) & 0 \le t \le t_p \\ -c/d \ (e^{d(tp-t)}-1) & t_p \le t \le 1.0 \end{cases} \qquad [3.16]$$

where, from above $a=i_p e^{-btp}$, $c=i_p e^{dtp}$, and $0.0 \le I(t) \le 1.0$.

Dividing this dimensionless process into n equal-time increments, the storm intensity pattern can be calculated by inverting the process function. Tables 3 and 4 and Figure 13 show the results for n=10 equal time increments. Note that the peak intensity in Table 4 is 37.1 mm/hr rather than 89.6 mm/hr from the observed one. This is because the intensity is averaged over the period and the average intensity is always less than the instantaneous maximum. A way of eliminating this error requires another value, the duration for the peak intensity (D_{ip}). The results of combining the intensity pattern with peak intensity and duration are shown on Table 5

Table 3. Simulated output from double exponential distribution for normalized storm time (T*) and intensity (Int*) with 10 equal time increments for Deer-Sloan Watershed station #10 on July 11, 1985.

T*	Int*
0.000	0.044
0.100	1.528
0.143	6.930
0.200	2.722
0.300	1.996
0.400	1.464
0.500	1.074
0.600	0.788
0.700	0.578
0.800	0.424
0.900	0.311
1.000	0.228

Table 4. Simulated output for real storm time and intensity with 10 equal time increments for Deer-Sloan Watershed station #10 on July 11, 1985.

Time (hr)	Intensity (mm/hr)
0.000	0.601
0.128	20.872
0.257	37.180
0.385	27.265
0.513	19.998
0.642	14.670
0.777	10.764
0.898	7.895
1.026	5.792
1.155	4.248
1.283	3.114

Table 5. Simulated output for real storm time and intensity with peak intensity and 10 equal time increments for Deer-Sloan Watershed station #10 on July 11, 1985.

Time (hr)	Intensity (mm/hr)
0.000	0.601
0.128	20.872
0.166	94.660
0.183	42.629
0.257	37.180
0.385	27.265
0.513	19.998
0.642	14.670
0.770	10.764
0.898	7.895
1.026	5.792
1.155	4.248
1.283	3.114

and Figure 13 with peak intensity simulated. The maximum intensity is 94.6 mm/hr for this calculation. Both simulated outputs fit reasonably well with the observed intensity pattern. But the simulation with peak intensity produced better fit to the observed storm intensity.

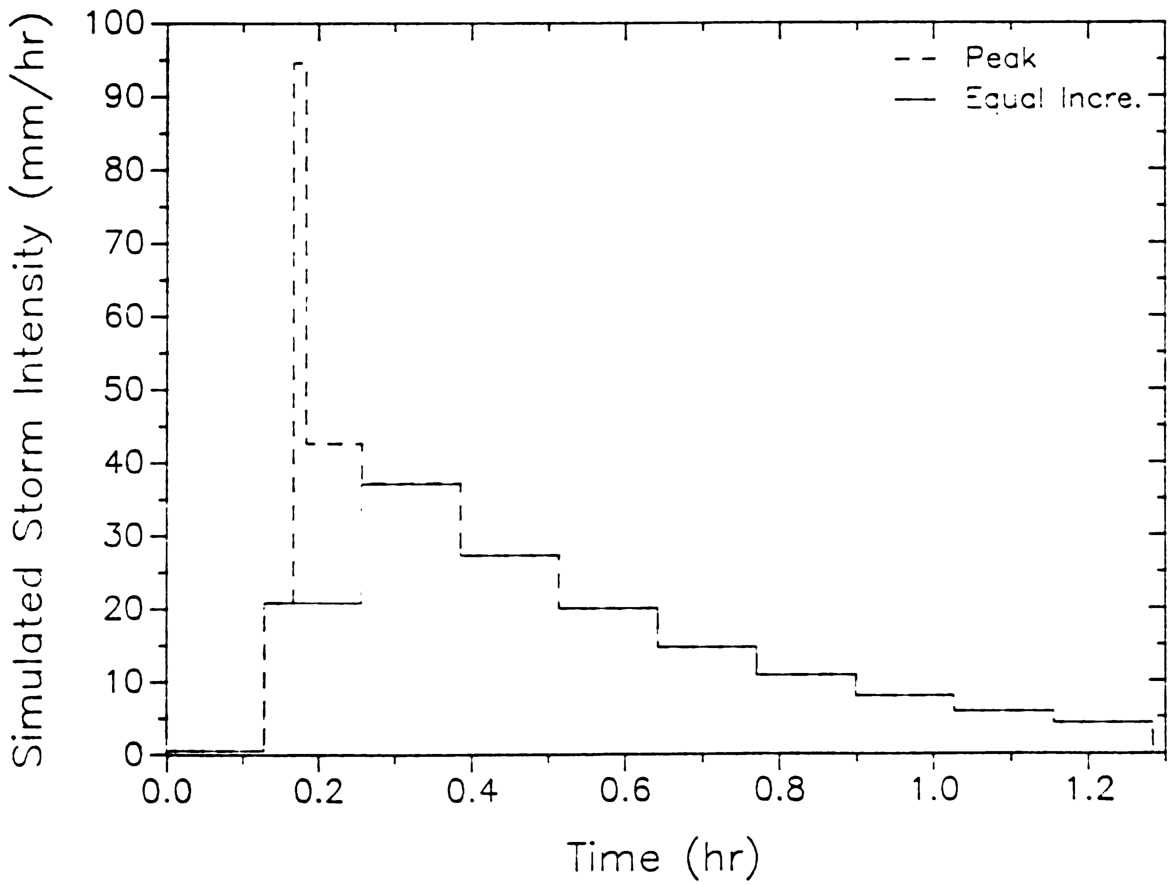

Figure 13. A comparison of simulated storm intensities with peak intensity and 10 equal time increments for one rainstorm event on July 11, 1985 for Deer-Sloan Watershed station #10, Michigan.

IV. TIME-TO-PONDING MODEL DEVELOPMENT

Mathematical representations of water flow in porous media involves assumptions that usually idealize or simplify the complexity of the real system. The principal simplifying assumptions of the time-to-ponding model used in this study are as follows:

1. The soil is assumed to be uniform and there is with depth no surface storage and detention storage.
2. The air phase is assumed to move freely, thus the water table is assumed to be deep and air pressure changes under infiltration are neglected.
3. Soil hysteretic behavior and raindrop impact are neglected, soil is nonswelling and nonhydrophobic.

From those assumptions listed above, infiltration during an irrigation application or a rainfall event can be divided into two distinct cases or stages: a stage in which the ground surface is ponded with water and a stage without surface ponding. During an unsteady rainfall the infiltration process may change from one stage to another and shift back to the original stage. Under a ponded surface the infiltration process is independent of the effect of the time distribution of r

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of rainfall. At this point the infiltration rate reaches its maximum capacity and is referred to as the infiltration capacity. At this stage rainfall excess is computed as the difference between rainfall rate and infiltration capacity. Without surface ponding, all the rainfall infiltrates into the soil. The infiltration rate equals the rainfall intensity, which is less than the infiltration capacity, and rainfall excess is zero. The mathematical equations used in the infiltration component are presented below.

A. Pre-ponding

Assume a soil system with uniform hydraulic properties and initially uniform volumetric water content θ_n and pressure potential Ψ_n. The rainfall rate $r_p(t)$ is time, t, dependent. Before ponding, all the rainfall infiltrates into the soil, the cumulative soil infiltration amount (I_p) is equal to the cumulative rainfall amount, and no excess water occurs on the soil surface.

Initially, when time equals zero:

$$t = 0; \quad \theta = \theta_n, \ \Psi = \Psi_n; \ z > 0.$$

where z is the vertical one dimension positive downwards. Darcy's equation describes the flux density $V(\Psi,t)$ as:

$$V(\Psi,t) = - K(\Psi)\ \partial\Psi/\partial z + K(\Psi). \qquad [4.1]$$

As $t > 0$, the boundary condition is:

$$V_0(t) = -K(\Psi)\ \partial\Psi/\partial z + K(\Psi);$$

where $\Psi = \Psi_0(t)$; $\theta = \theta_0(t)$; $z = 0$. Here $\Psi_0(t)$ and $\theta_0(t)$ are measured at the soil surface.

B. **Ponding**

Ponding time (t_p) is the moment during rainfall or irrigation application when the soil-surface pressure potential first becomes zero ($\Psi_0(t) = 0$). At this point, water begins to accumulate on the soil surface. This marks the beginning of ponding and decline of the infiltration rate. The cumulative infiltration amount at ponding (I_p) is equal to the cumulative rainfall or irrigation amount (R_p). The time to ponding is a function of saturated hydraulic conductivity (K_s), saturated soil water content (θ_s), antecedent soil water content (θ_n) or reference soil water content (θ_r), soil sorptivity (S_n), macroscopic capillary length (λ_c), and rainfall rate (r_p) at ponding time. The time to ponding is described in the following equation:

$$I_p = R_p = 0.55 \cdot (S_n^2 / K_s) \cdot \ln[r_p / (r_p - K_s)] \qquad [4.2]$$

$$= m \cdot \lambda_c \cdot \ln[r_p / (r_p - K_s)] \qquad [4.3]$$

where m is calculated from

$$m = [\ (\ \theta_s - \theta_n\ )\ /\ (\ \theta_s - \theta_r)\ ]^{1.5} \cdot (\ \theta_s - \theta_r\ ) \qquad [4.4]$$

The parameter λ_c in [4.3] is termed the macroscopic capillary length that provides a scaling length to simplify the treatment of soil-water flow (Philip, 1985). It depends weakly on the hydraulic properties. For stable soils, the range of m values are within the range of $0.50 \leq m < 0.66$ (Broadbridge and White, 1987). In laboratory studies conducted by White and Broadbridge (1988) on dry repacked soil samples, m was found to be close to 0.5. For field situations where there is evidence that hydraulic properties are different from those of repacked soils, m is expected to be close to 0.6. Where the hydraulic properties are unknown, it is reasonable to take m = 0.55. This assumption will generate errors of no more than ± 10% in predicting the time-to-ponding.

White and Sully (1987) described a simple method to estimate λ_c in the field. Their method was based on the equation

$$\lambda_c = 0.55 \cdot S_r^2\ /\ [\ (\ \theta_s - \theta_r\ ) \cdot K_s\ ] \qquad [4.5]$$

Where S_r is the sorptivity at a reference soil water content (θ_r). The sorptivity is a measure of the ability of the porous media to absorb a wetting liquid (Philip, 1969). The larger the sorptivity value, the greater the volume of liquid that can be absorbed and the more rapidly it is absorbed.

C. Post-ponding

Once ponding starts on the soil surface, rainfall is partitioned into infiltration and runoff. Total infiltration amount (I) at any time (t) during this stage is no longer controlled by the rainfall rate (Rubin, 1966) but by the water flux (V_0) at the soil surface.

$$I = I_p + I_{pp} = 0.55 \cdot (S_n^2/K_s) \cdot \ln[\, V_0 / (\, V_0 - K_s)\,] \quad [4.6]$$

$$= m \cdot \lambda_c \cdot \ln[\, V_0 / (V_0 - K_s)\,] \quad [4.7]$$

where I_{pp} is the cumulative infiltration amount post-ponding. The cumulative infiltration can be described as a function of time:

$$[\, (I - I_p) / (m \cdot \lambda_c)\,] - \{\, [\, (t - t_p) \cdot K_s\,] / (m \cdot \lambda_c)\, \}$$
$$= \exp^{[\, -Ip / (m \cdot \lambda c)\,]} - \exp^{[\, -I / (m \cdot \lambda c)\,]} \quad [4.8]$$

where t_p is the ponding time, and both infiltration rate (V_0) and runoff rate (R_0) can be described as:

$$V_0(t) = K_s / \{\, 1 - EXP[\, -I / (m \cdot \lambda_c)\,]\} \quad [4.9]$$

$$R_0(t) = r_p(t) - V_0(t) \quad [4.10]$$

When surface storage is considered, the runoff is computed as the excess water generated from the infiltration model minus the maximum depression storage. The concept of depression storage used in this model is the maximum amount of water that can be retained on the surface that will eventually infiltrate. The retention volume on the surface can be computed from microrelief data or it can be evaluated for rainstorms that start abruptly with intensities in excess of infiltration capacity. A reasonable assumption for the capacity of this storage volume as a function of random roughness (RR) and the general land slope L was developed from concepts of Linden. The accumulated rainstorm less the mass infiltration, in the interval between the beginning of rainstorm excess and the start of direct runoff, is equal to depression storage plus the amount of detention required to initiate runoff.

With the storm intensity and the three stage time to ponding approach, a model for infiltration is complete. The necessary input soil properties are K_s, S_n, for each soil condition, the rainfall intensity r_p, and the initial water content of surface soil. Since K_s is a soil property associated only with the microporous space in a soil, it may be relatively uniform over a large area of similar soil type. Soils having similar mineral composition and organic matter content may well have similar K_s value.

V. FIELD MEASUREMENT OF TIME-TO-PONDING

Field experiments were conducted to provide data for model development and verification. Fifty sets of field tests were conducted on Montcalm loamy sand (Eutric Glossoboralf) in Michigan with corn (C) and potato (P) crops under different tillage and wheel traffic conditions. Soil texture, bulk density, initial soil water content, and surface crop residue were measured on each plot. Tillage systems included moldboard plow (M), disc plowed (D), and no till (N) for corn and moldboard plow and paraplow (P) for potato.

A. Sprinkling Infiltrometer

Time-to-ponding was determined with minimal disturbance to soil surface conditions by the use of a sprinkling infiltrometer (Figure 14). This infiltrometer satisfies the criteria for the design of a sprinkling simulator as set forth by Bubenzer (1979) with irrigation characteristics substituted for rainfall characteristics. The modified Bubenzer criteria are: 1) Drop size distribution similar to that of sprinkler irrigation; 2) drop velocity at impact near sprinkler irrigation drop velocity; 3) intensity corresponding to

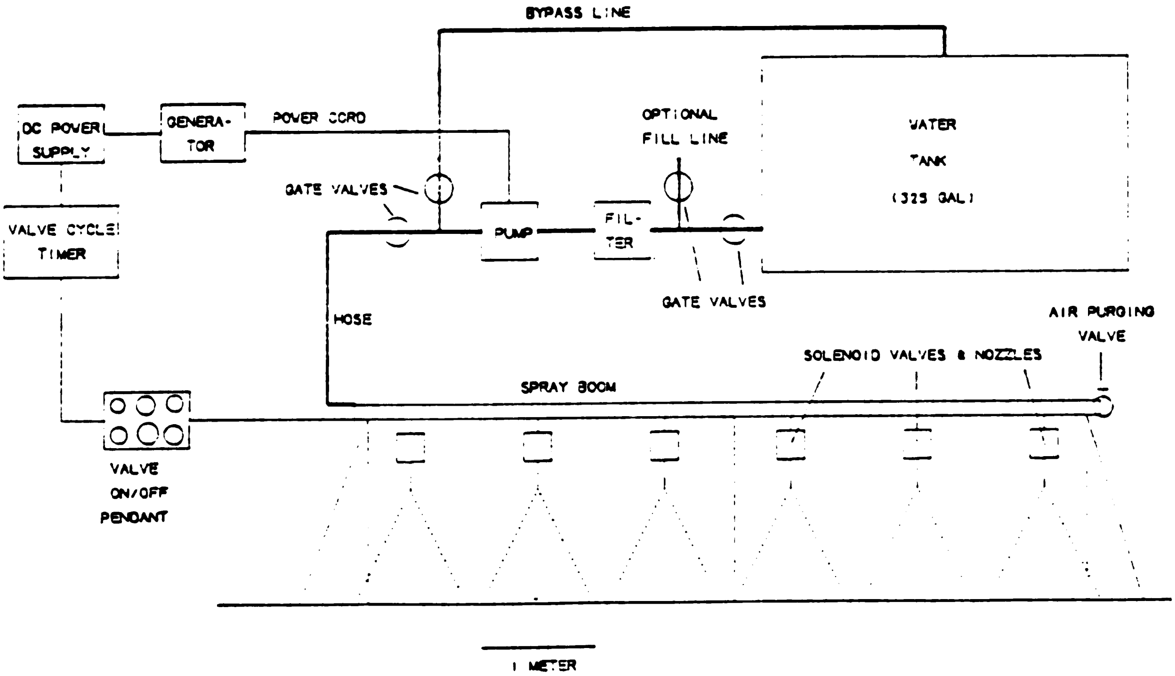

Figure 14. Schematic diagram of sprinkling infiltrometer used for field time-to-ponding measurement.

sprinkler irrigation; 4) uniform application and random drop size distribution; 5) total energy applied near that of sprinkler irrigation; and 6) reproducible patterns of application like sprinkler irrigation.

The infiltrometer consists of six nozzles mounted on a horizontal boom that is supported about 1 m above the soil surface. The boom is divided into two sections, each carrying three nozzles, 1.37 m apart. Each section is about 3.7 m long and made of square steel tubing connected by a quick-coupler. The boom is seated on two tripods and a center support which are adjustable so that the boom can be make parallel to the terrain. A polypropylene tank (1230 L) supplies water to the system and the 4 kw gas generator supplies power to the pump and the timing circuit. A by-pass line and gate valve are used to control the nozzle pressure and two additional gate valves allow the tank to be filled from a nearby lake or stream. A 80 meter hose extends the water supply to the spray boom. solenoids and spray nozzles. The boom, water tank, generator, pump, and control unit are transported on a trailer.

The six nozzles mounted on the boom are controlled by separate solenoid valves that allow the application of different sprinkling rates to multiple sites simultaneously. Two Full-Jet nozzles, Spraying Systems 1/4 HH 12W and 1/4 HH 10 W, were selected for the infiltrometer. Both nozzles distribute medium to large sized droplets in a uniform circular pattern. Finer control over low rates is achieved by using the smaller nozzle (10W). The infiltrometer is started up each time from a static pressure of 82 kPa, controlled by the by-pass line and gate valve near the pump.

The rate of application is regulated by timers which control the solenoid valves on each nozzle. Application rates used in the field ranged from 10 to 95 mm/hr and were achieved by controlling the off time of the nozzle while the on time is held constant at about 0.6 s for each nozzle. The actual rate of application is determined after the test is completed by dividing the application depth by the total elapsed time. The appearance of small puddles, 1 to 3 cm, in diameter, was chosen as an indicator of the occurrence of ponding. Time-to-ponding was recorded under each nozzle, and the application rate and cumulative amount at time-to-ponding from each nozzle was measured by catching water in three small containers below the nozzles on the ground.

B. Field Procedure

Experimental sites were chosen near the edge of a field were a trailer with a water tank could be easily parked. At the site, any leaves and weeds that interfered with the discharge pattern of the nozzle were removed, but the residue was left in place. In the corn crop when plants were tall, the end tripod and center supports were set up among the plants. The boom section was lifted over the plants and attached to the tripod and center support. The second tripods was placed at the end of the plot, and the second section installed. Circular observation areas were located side-by-side under the nozzle pattern and the boom height adjusted so that water from the nozzles would not overlap. Three cups were placed in a triangle within the observation area so that an average application rate could be obtained. Before the nozzles were turned on, the air from the hose and boom was purged.

Each combination of treatments contained three to five replicates. Measurements were made before and after each infiltrometer application to determine the changes in soil properties and the time-to-ponding under variable application rates. After the time to ponding was determined, the water was turned off and the final time noted. The volume in the cups was measured and the application rate and the total water infiltrated at ponding was calculated. A Fortran source code for calculation of the water application rate and time-to-ponding from field operation of sprinkling infiltrometer is listed in Appendix 2.

Soil samples taken in the field was used to determine soil texture, and bulk density. Residue cover for each plot was also measured before each rainfall application. Soil water content was determined immediately before and after each rainfall application from samples obtained at the surface. The texture and bulk density of each sample was measured in the laboratory. A Fortran source code for crop residue, bulk density, and initial water content calculation for each plot is listed in Appendix 3. The bulk density and texture data were used to estimate the saturated water content assuming that it was equal to 85% of the total porosity (Ritchie, Ratliff and Cassel, 1987). A Fortran source code for saturated water content calculation is listed in Appendix 4.

Fifty sprinkling infiltrometer tests were performed in the summer of 1989, under four tillage practices and two crops. Ten tests were done on each soil x tillage x crop combination. A sprinkling infiltrometer test plot consisted of one target row section, about 10 m in length, and two adjacent row sections, used for access and observation. An average of two infiltrometer tests were performed per day. A different crop x tillage treatment was tested each day so as to get maximum variability in soil water over a season and similar average values between treatments.

Field experiments were carried on three field sites. Field #1, Montcalm sandy loam (Eutric Glossoboralf, coarse-loamy, mixed) is located NE1/4, SW1/4, Section 18, T9N, R7W of the Michigan meridian, southeast of Greenville in Montcalm County. Moldboard and disk plowed plots were installed in this field that had been in corn for three years. Moldboard plow ia a primary tillage implement which cuts, partially or completely inverts a layer of soil to bury surface materials, and pulverized the soil. Disk plow is also a primary tillage implement with individually mounted concave disk blades which cut, partially or completely invert a layer of soil to bury surface material, and pulverize the soil. The disking was done on May 1 and the moldboard plowing was done on May 8.

The corn was planted on May 9. One half of the furrows were wheel tracks. The field was irrigated by a center pivot system and application were scheduled through the Michigan Energy Conservation Program. The period of sprinkling infiltrometer and soil testing was between June 28 and August 3, during which time 16.9 to 33.2 cm of water was added to the field since tillage.

Field #2, Montcalm loamy sand, is located about 200 m from field #1, in an alfalfa field which had been established for five years. The alfalfa in a small section was killed with 2,4 D and Roundup and it was planted with corn on May 9. All of the corn received some damage from deer grazing. These no-till plots were irrigated by the same center pivot as in field #1, and one half of the furrows were wheel track furrow.

Field #3, Montcalm loamy sand, is located NW1/4, SE1/4, SW1/4, Section 8, T11N, R7W of the Michigan meridian, west of Entrican in Montcalm county on the Michigan State University Potato Farm. A moldboard tillage plot area and a paratill over moldboard tillage plot area were established in 1989 on a section which had been in soybeans the year before, with a fall rye cover crop plowed under on May 1. The paratill operation was done on May 18, as was the planting of the potatoes. On June 8, the plots were hilled. These plots were irrigated by a fixed sprinkler irrigation set. One half the furrows were wheel tracks. The period of sprinkling infiltrometer and soil testing was between June 30 and August

7, during which time 12.6 cm of water was added to the field after hilling.

C. Ponding Curves

Ponding curves were established for each management combination of crop x tillage x wheel traffic condition by plotting the water application rate (r_p) versus cumulative infiltration amount (I_p) at ponding for each plot. The soil parameters such as saturated conductivity, K_s, capillary length , λ_c, and sorptivity, S_n were determined by best-fitting [4.2] and [4.3] to the ponding curves. Appendix 5 lists a Complex algorithm program which was used for finding the best-fit ponding curve for each plot. For many continous system application it has been found that the very straightforward method using Euler's formula for numerical integration is not only adequate but preferred. The program for implementing the Complex algorithm was modified from "Optimization Techniques with Fortran" by James L. Kuester and Joe H. Mize, chapter 10. Field observed time-to-ponding data and plot soil water content were used as input for optimization process to find the least square error of soil physical properties K_s and S_n from [4.2] and [4.3]. With known soil hydraulic properties, prediction of infiltration and runoff under any type of rainfall pattern was possible.

VI. RESULTS AND DISCUSSION

A. Rainstorm Generator

To make the time-to-ponding model functional for practical strategic applications, a relatively simple rainstorm generator is needed to generate storm intensities data when short-time period precipitation records are not available. A parameter-efficient way to simulate the number of storm events in a day and the individual storm intensity patterns is needed.

The objective here was to develop a simple model to simulate the number of storm rainfall events per day and the amount, duration, and short time intensity pattern of each event. A stochastic storm model was defined that consists of a geometric marginal probability distribution for the storm event, a two-parameter Gamma marginal distribution for the event amount, and an exponential conditional distribution for the peak intensity for a given amount. A joint distribution of storm event depth and duration was constructed. A stochastic model for the dimensionless accumulated storm process was proposed. The dimensionless process was divided into 10 equal time increments, and the intensities were rescaled to be normalized by the average intensity. This sequence of rescaled increments was found to be best-fit by a double exponential function. The process of this rainstorm generator simulation is shown in Figure 15. The simulated 30 years rainstorm data set output analysis is shown in Table 6. A Fortran source code for this storm generator is listed in Appendix 6. The simulated storm characteristics match reasonably well with the observed rainstorm data set from Table 1.

An analysis of observed storms data at the Deer-Sloan Watershed stations #10 and #18 in southeastern Michigan suggests that the proposed model structure provides an acceptable approximation for storm rainfall. The number of parameters in this approach is few when compared with alternative methods, yet the approach does an adequate job of simulating storm intensities. The simulation procedure developed requires 10 parameters for each month. The simulated distribution of numbers of storms during one wet day and storm amounts, duration, and peak intensity compared favorably with observed data. The number of model parameters could be reduced by approximating gamma, geometric, and exponential parameter as seasonal power series functions. The seasonal variation of the model structure and parameter values were also investigated in this study.

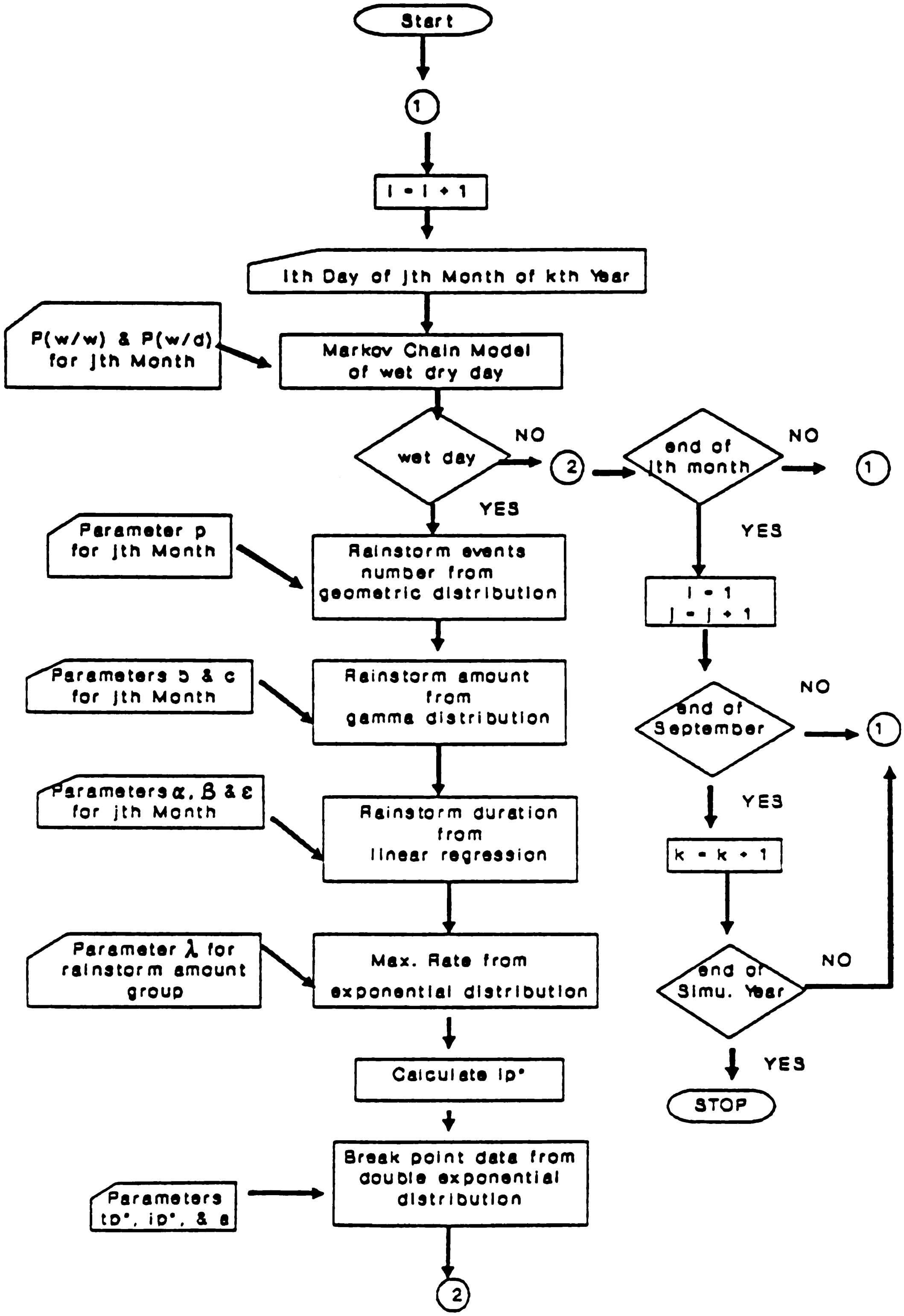

Figure 15. Flow chart of the rainstorm generator used in this study.

Table 6. Monthly statistics for simulated 30 years rainstorm record for Deer-Sloan Watershed station #10, Michigan.

	Mean	St.d.	Min.	Max.
Apr. (448 rainstorms)				
Rainstorms per wet day	3.11	2.31	1.00	11.00
Amount per rainstorm (mm)	3.32	2.99	0.27	19.53
Duration per rainstorm (hr)	1.52	1.51	0.14	10.80
Max. Rate per rainstorm (mm/hr)	19.55	31.32	0.56	218.57
May (383 rainstorms)				
Rainstorms per wet day	3.16	2.42	1.00	13.00
Amount per rainstorm (mm)	4.73	5.76	0.25	35.69
Duration per rainstorm (hr)	1.71	2.11	0.06	18.40
Max. Rate per rainstorm (mm/hr)	27.49	43.90	0.51	357.97
June (352 rainstorms)				
Rainstorms per wet day	2.57	1.91	1.00	12.00
Amount per rainstorm (mm)	5.72	6.64	0.25	45.64
Duration per rainstorm (hr)	1.23	1.27	0.05	11.46
Max. Rate per rainstorm (mm/hr)	32.12	46.75	0.28	264.20
July (252 rainstorms)				
Rainstorms per wet day	2.54	1.73	1.00	9.00
Amount per rainstorm (mm)	6.58	8.62	0.27	53.33
Duration per rainstorm (hr)	1.20	1.28	0.07	9.29
Max. Rate per rainstorm (mm/hr)	35.07	57.92	0.77	373.19
Aug. (329 rainstorms)				
Rainstorms per wet day	2.24	1.54	1.00	8.00
Amount per rainstorm (mm)	5.91	7.34	0.26	46.15
Duration per rainstorm (hr)	1.20	1.52	0.03	15.02
Max. Rate per rainstorm (mm/hr)	35.25	53.43	0.54	344.05
Sep. (406 rainstorms)				
Rainstorms per wet day	3.34	2.78	1.00	15.00
Amount per rainstorm (mm)	4.67	5.34	0.26	30.98
Duration per rainstorm (hr)	1.34	1.50	0.06	13.10
Max. Rate per rainstorm (mm/hr)	28.36	46.08	0.47	317.30

The developed model provides a source of storm event data that can be used as input for the time-to-ponding infiltration model. Further research should be done to examine spatial variations in disaggregation structure and parameters, and criteria governing model transferability should be developed.

B. Field Measurements of time-to-ponding

To determine the kind of variation expected for infiltration calculations as related to tillage, a field study to measure time-to-ponding using an sprinkling infiltrometer was conducted on a loamy sand (Eutric Glossoboralf) soil in Michigan with corn and potatoes under different tillage and wheel traffic conditions to determine values of the properties needed for this model. Time to ponding curves were established for each management combination of crop, tillage and wheel traffic conditions. Values for the soil properties needed for the model were derived from best-fit ponding curves.Several sets of field time-to-ponding measurements (five plots for each combination of crop x tillage x wheel track combination) were made during the growing season of 1989. Appendice 7 to 9 show the results of field measurement and derived soil properties for each plot. The measured residue cover, initial water content, and bulk density are listed in Table 7 columns 2 to 4. The saturated water content was estimated from the texture and bulk density of each site. Appendix 8 shows the field measured bulk density and initial water content for each plot. Bulk density for plots with wheel track conditions were higher than that of non-wheel track conditions except for the no till system (Figure 16). Reduced macropore space was associated with higher bulk densities, that diminished the K_s values.

Appendix 9 shows the observed ponding time and the water applied depth at ponding time from each nozzle for the infiltrometer experiment. Ponding curves for each plot can be established by the best-fit data set using the modified Complex optimization program. Examples of ponding curves for the corn (CMW2, CMN5, CDW5, CDN5, CNW5, CNN5) and potato (PMW2, PMN2, PPW6, PPN2) plots for each tillage x wheel track treatments are shown in Figures 17 and 18, respectively, by best-fitted time-to-ponding model:

$$I_p = R_p = 0.55 \cdot (S_n^2 / K_s) \cdot \ln[r_p / (r_p - K_s)] \qquad [6.1]$$

$$= m \cdot \lambda_c \cdot \ln[r_p / (r_p - K_s)] \qquad [6.2]$$

where m is calculated from

$$m = [(\theta s - \theta n) / (\theta s - \theta r)]^{1.5} \cdot (\theta s - \theta r) \qquad [6.3]$$

Noted here is the r^2 for each best-fitted ponding curve as shown in column 8 from Table 7. Example runs for corn under moldboard plow and disc plow and potato under moldboard and paraplow produced r^2 values between 0.546 to 0.756. The corn with no tillage had low r^2 because few points were collected in the field experiment. From the model above,

Table 7. Field measurements of time-to-ponding for soil with potato and corn crops with various tillage and surface residue treatments for Montcalm County, Michigan.

Exp.	Residue %	θ_{ini} %	BD g/cm^3	θ_{sat} %	K_s mm/hr	S_n mm/hr$^{.5}$	r^2
CMW2	3	11.5	1.47	37.8	6.45	12.42	.68
CMN5	3	10.9	1.28	43.9	20.90	13.06	.74
CDW5	1	7.9	1.58	34.3	7.80	13.86	.55
CDN5	10	12.9	1.35	41.7	20.63	10.41	.57
CNW5	72	7.6	1.44	38.8	53.81	14.27	.07
CNN5	73	17.5	1.43	39.1	41.91	21.52	.48
PMW2	7	16.0	1.60	33.7	13.50	10.20	.76
PMN2	7	14.2	1.30	43.3	14.74	12.88	.70
PMN4	0	10.8	1.33	42.3	7.03	15.19	.53
PMN5	20	5.9	1.32	42.7	6.88	22.34	.91
PPW1	25	7.0	1.56	35.0	16.33	17.76	.49
PPW6	0	14.2	1.58	34.3	12.21	11.64	.72
PPN1	33	6.5	1.34	42.0	13.74	20.10	.83
PPN2	0	10.9	1.29	43.6	19.88	11.67	.65

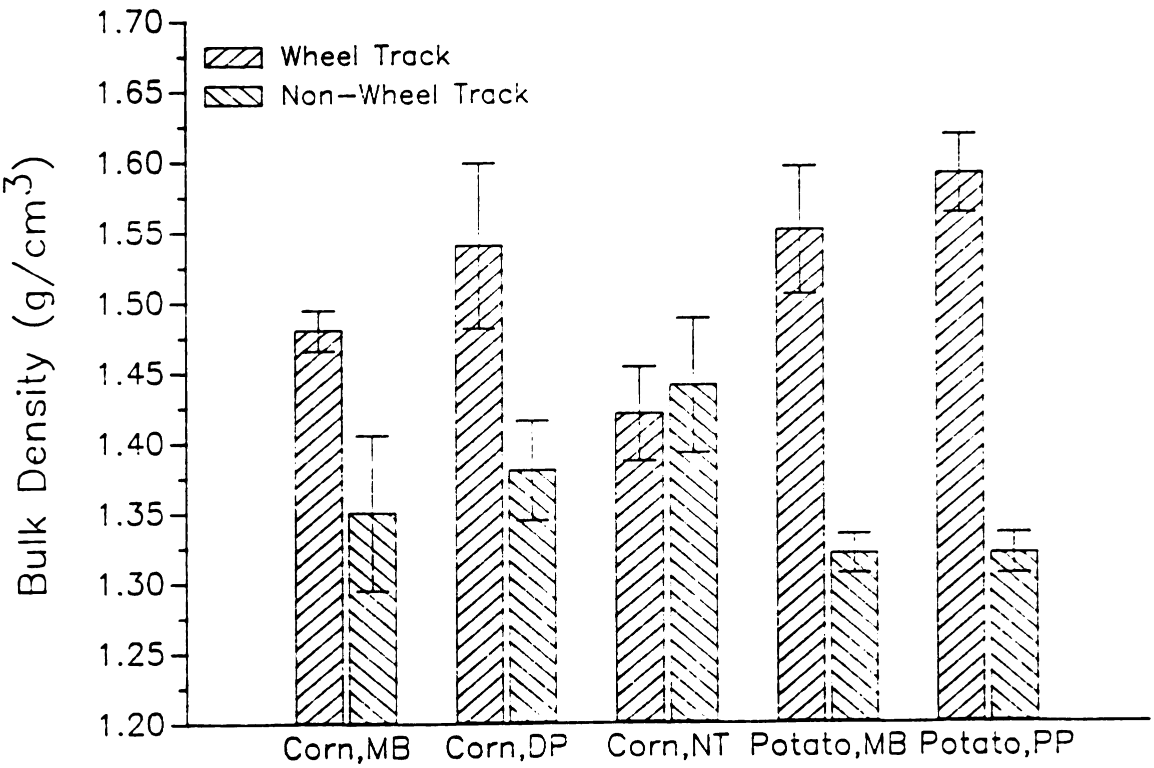

Figure 16. Mean bulk density of surface soil for various crop and tillage plots (MB: moldboard, DP: disc plow, NT: no till, PP: paraplow). The bar above each mean shows one standard deviation.

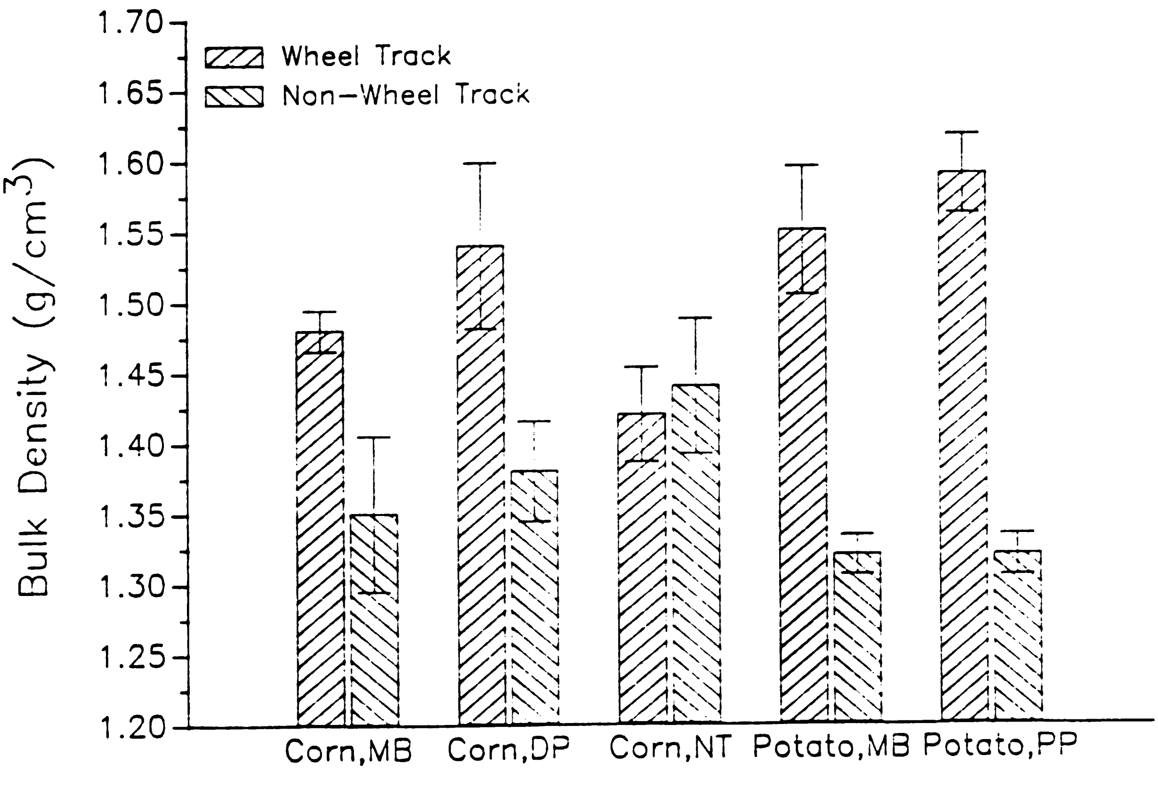

Figure 16. Mean bulk density of surface soil for various crop and tillage plots (MB: moldboard, DP: disc plow, NT: no till, PP: paraplow). The bar above each mean shows one standard deviation.

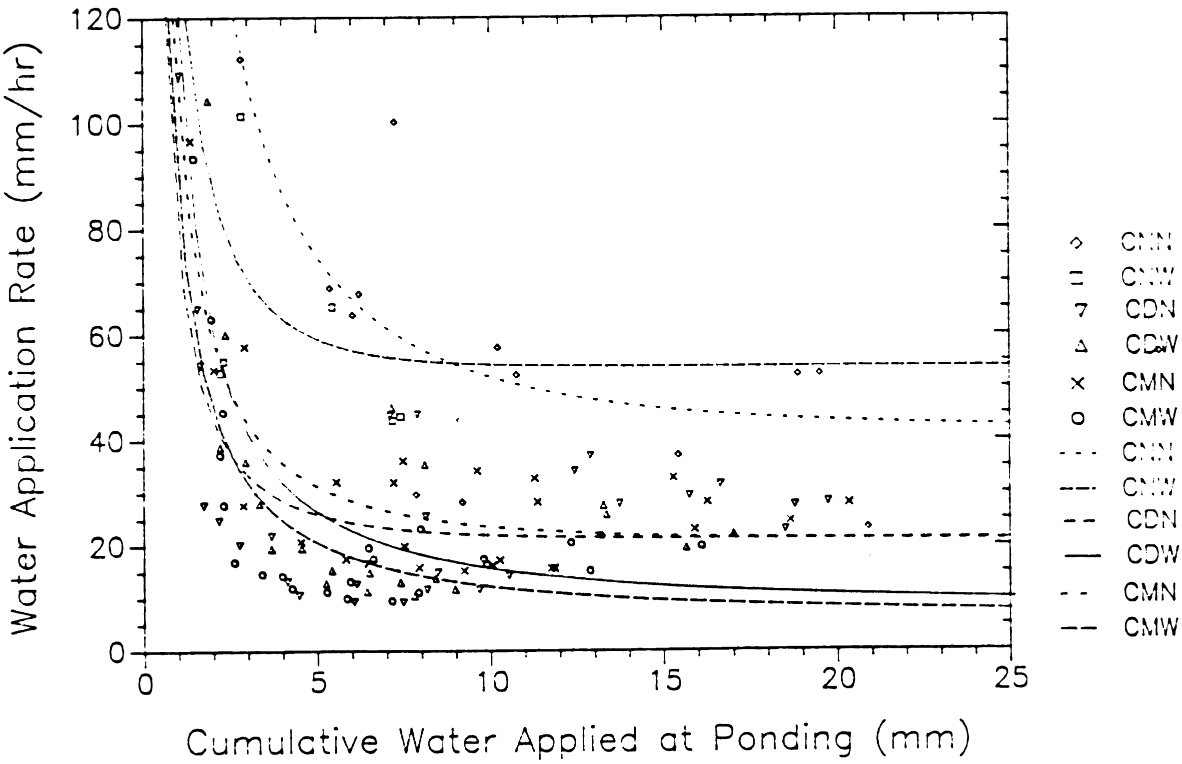

Figure 17. Best-fit ponding curves derived from observed time-to-ponding data for corn plots with various tillage and wheel track conditions.

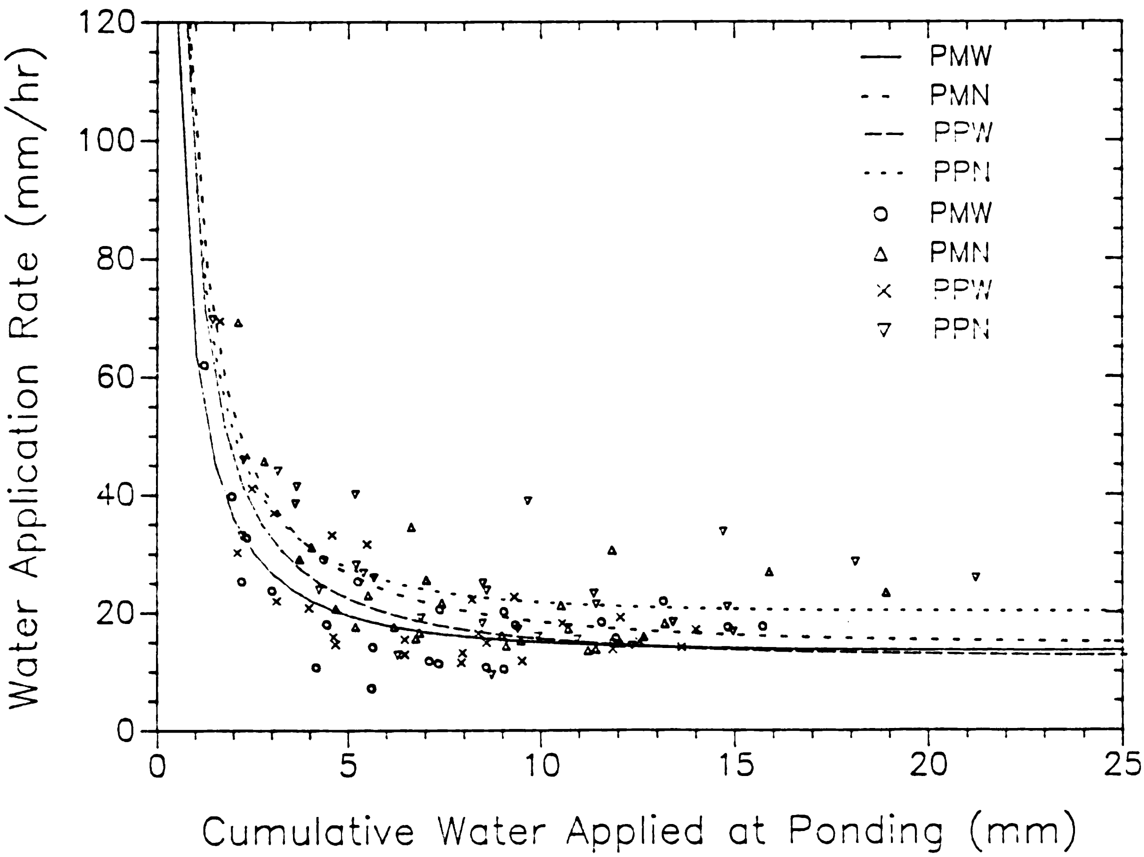

Figure 18. **Best-fit ponding curves derived from observed time-to-ponding data for potato plots with various tillage and wheel track conditions.**

the constant state tail on the X axis at large values of cumulative infiltration of each ponding curve represent the K_s values. Wheel track compaction reduced K_s in the moldboard plow and disc plow system. The derived K_s values were highest for the no till system.

The influence of surface residue on the ponding curves is shown in Figure 19 as an example for potato under paraplow tillage system (PPW1, PPW6, PPN1, and PPN2). Surface residue shifted the ponding curves to the right indicating time-to-ponding was delayed and soil sorptivity was higher. This can be explained by the tendency for the residue to retain water without infiltrating the soil. Drier initial soil water conditions had the same tendency to delay time-to-ponding and increase sorptivity as shown in Figure 20 for potato with moldboard tillage. Soil sorptivity and macroscopic capillary length are key factors in these changes.

There are several direct management benefits in using time to ponding to predict soil infiltration. For sprinkler irrigation, controlling the irrigation rate or keeping the application rate lower than the ponding time curve can help reduce runoff so that water enters the root zone slowly and minimizes any preferential flow below the root zone (Clothier et al., 1981). This can help lower or prevent movement of fertilizers and pesticides to groundwater. Also, the best soil management for erosion prevention can be determined by knowing the possibility of rainstorm intensity.

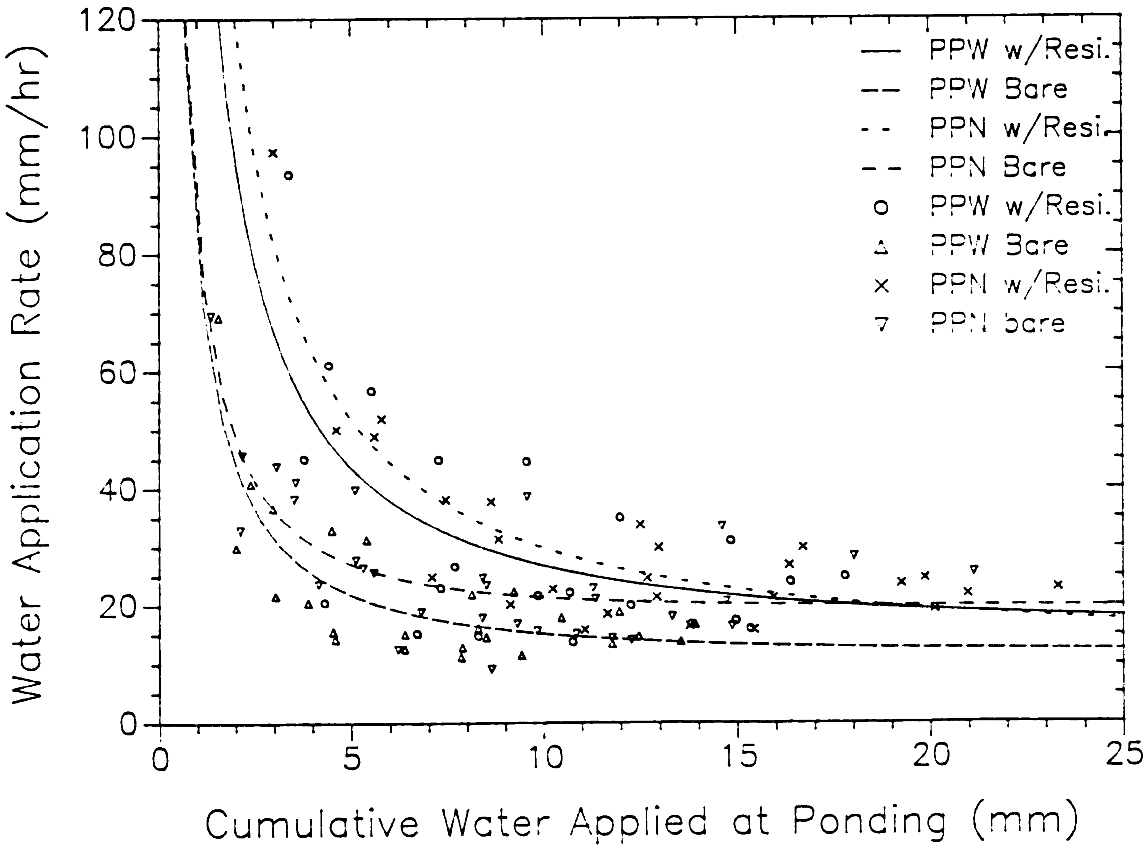

Figure 19. Surface residue effects on best-fit ponding curves derived from observed time-to-ponding data for potato plots with paraplowed soil and various wheel track conditions .

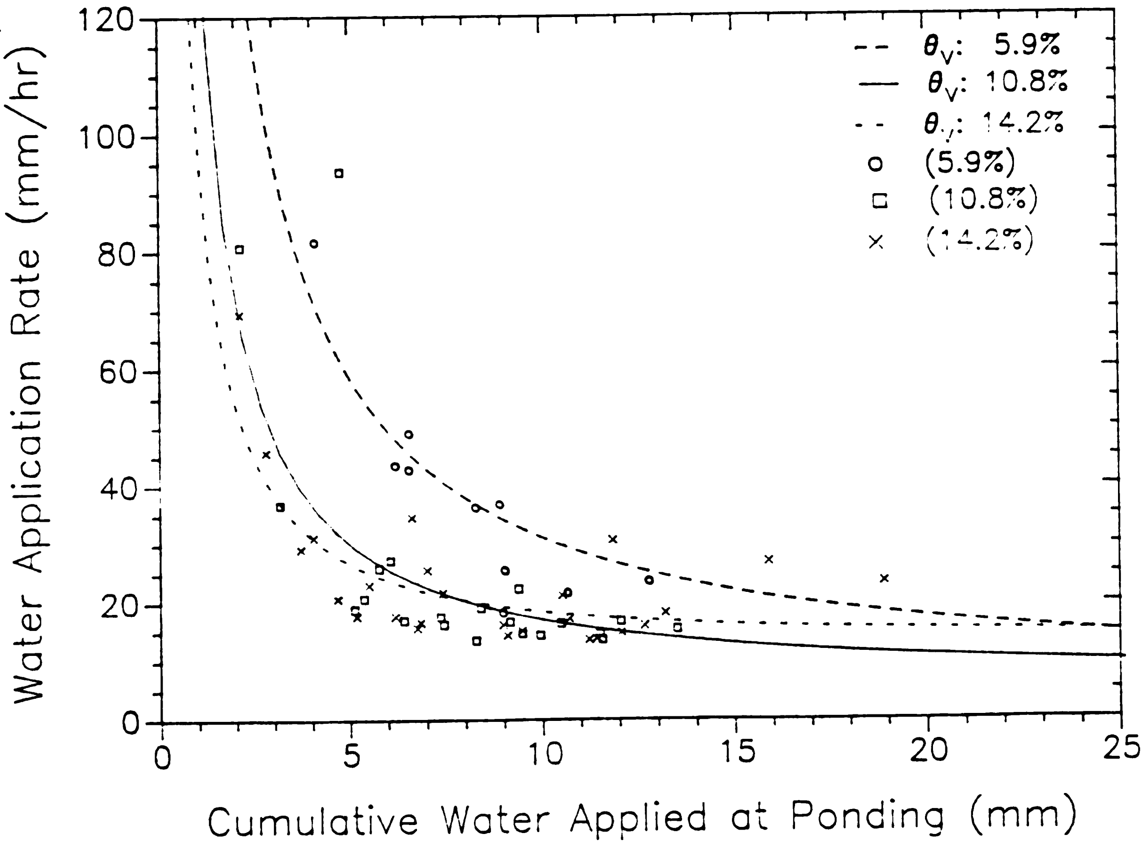

Figure 20. Influence of initial soil water content on best-fit ponding curves derived from observed time-to-ponding data for potato plots with moldboard plowed soil and various wheel track condition.

C. Some Limitations of Time-to-ponding Model

There are several factors related to the time-to-ponding model that affect its prediction capability. The model developed was only one-dimensional. Thus, it neglects the roughness of the tilled soil surface. Ignoring the roughness implies that the entire soil surface smooth, which is usually not true. This assumption also ignores the horizontal flow that can occur on these rough surfaces. Ignoring the flow that occurs in other than the vertical direction could lead to underprediction of infiltration. Another limitation of this one-dimensional model is that only one form of diffusivity and conductivity is allowed and the upper boundary condition is limited to a constant flux density. Some further generalizations may be possible, for example, and initial profile of piecewise step functions and perhaps other forms. This would allow simulation of cyclic conditions.

The spatial variability of soil properties is a common problem in dealing with soil properties. For example, the bulk density and initial water content of a plot was characterized by measurements made on averaging 10 soil cores obtained from each plot. This assumes that the core samples were uniformly representative of the plot.

The major difficulty in applying the theory of time-to-ponding to a field experiment lies in the identification and measurement of the necessary hydraulic properties. Under certain conditions the heterogeneity of field soils may be such that a meaningful Darcy scale on which to apply the theory may not exist. Where it does, field variability usually means that the characterization of the site by its basic hydraulic properties on a useful scale is a lengthy and not economically feasible operation. Because of this, rapid techniques must be used for site characterization or basic parameters must be expressed in terms of more readily measured soil-water properties. Although the soil hydraulic parameters in the model are all measurable, or based on measurable quantities, they proved difficult to determine accurately in many cases in the field experiment. This is not unusual for soil properties. For example, saturated hydraulic conductivity and sorptivity are characteristically subject to high variability for natural soils. The properties of tilled soils vary both spatially and temporally, and are ignored in the calculations.

Considering the difficulties involved, the results of best-fitted ponding curves and soil properties under different soil management still indicates that the time-to-ponding model has good potential in predicting infiltration into soils.

D. Demonstration of Use of Ponding Curves and Simplified Storm Patterns

Consider four types of rainfall rate distribution in which a total amount of 30 mm of rain falls in 1.5 hour (Figure 21). A moldboard tilled potato crop under wheel traffic conditions with surface residue management was examined for the prediction of surface runoff. As shown in

Figures 22 to 29, infiltration and runoff are influenced by rainfall distribution patterns as well as soil management. Figures 22 to 25 show the ponding curve derived from residue surface and bare surface with and without wheel track. The intersection of the ponding curve and rainfall pattern on the rate versus cumulative amount graph represents the time-to-ponding. For rainfall type A, the ponding curve of PMN with surface residue treatment has no intersection with storm distribution. Thus all rainfall would infiltrate and no surface runoff would occur for this treatment. The wheel-track with bare surface treatment had the lowest cumulative infiltration amount and thus the highest runoff. For rainfall type B and C, runoff occurred for each treatment. For rainfall type D, a constant rate, only the wheel-track treatments ponding curves intersect with rainfall distribution. Cumulative infiltration amount can be calculated from the model as a function of time (Figures 26 to 29). The runoff can be calculated from the difference between cumulative rainfall and infiltration amount. This demonstration shows the sensitivity of the overall model to both rainfall patterns and soil properties.

The time-to-ponding curves appear to be a good infiltration-runoff process predictor under variable rainfall patterns and different management conditions. The model proved to be capable of predicting differences in infiltration and runoff due to management condition of the soil by differences in soil properties.

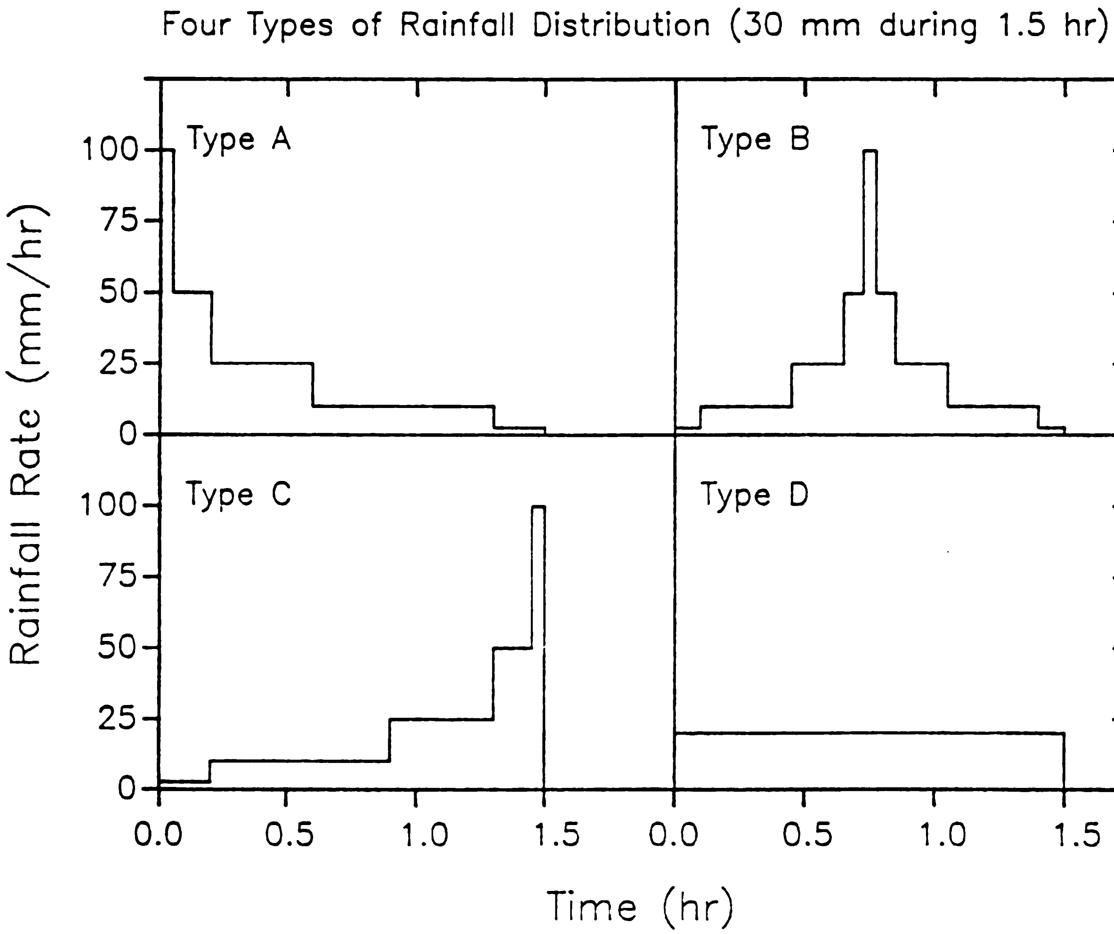

Figure 21. Four types of assumed rainfall distributions for a 30 mm rain in 1.5 hour as a demonstration for infiltration prediction.

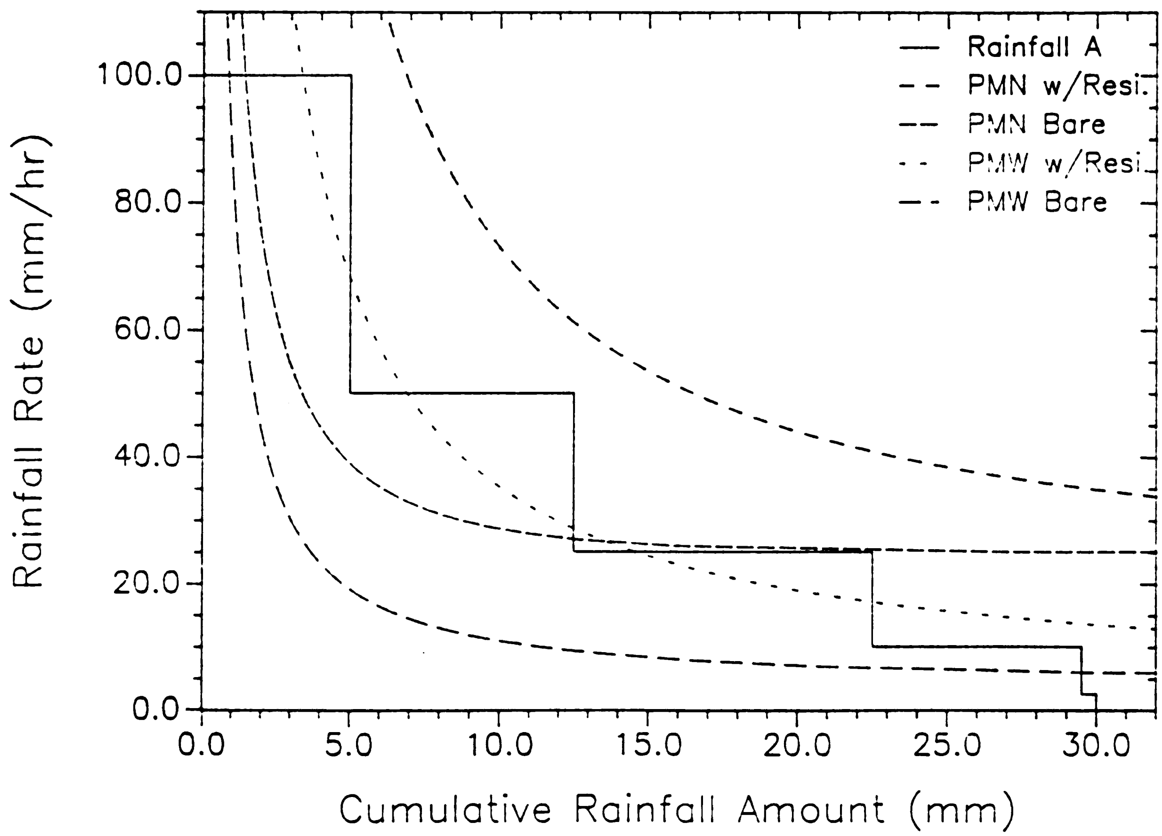

Figure 22. Ponding curves for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type A rainfall distribution.

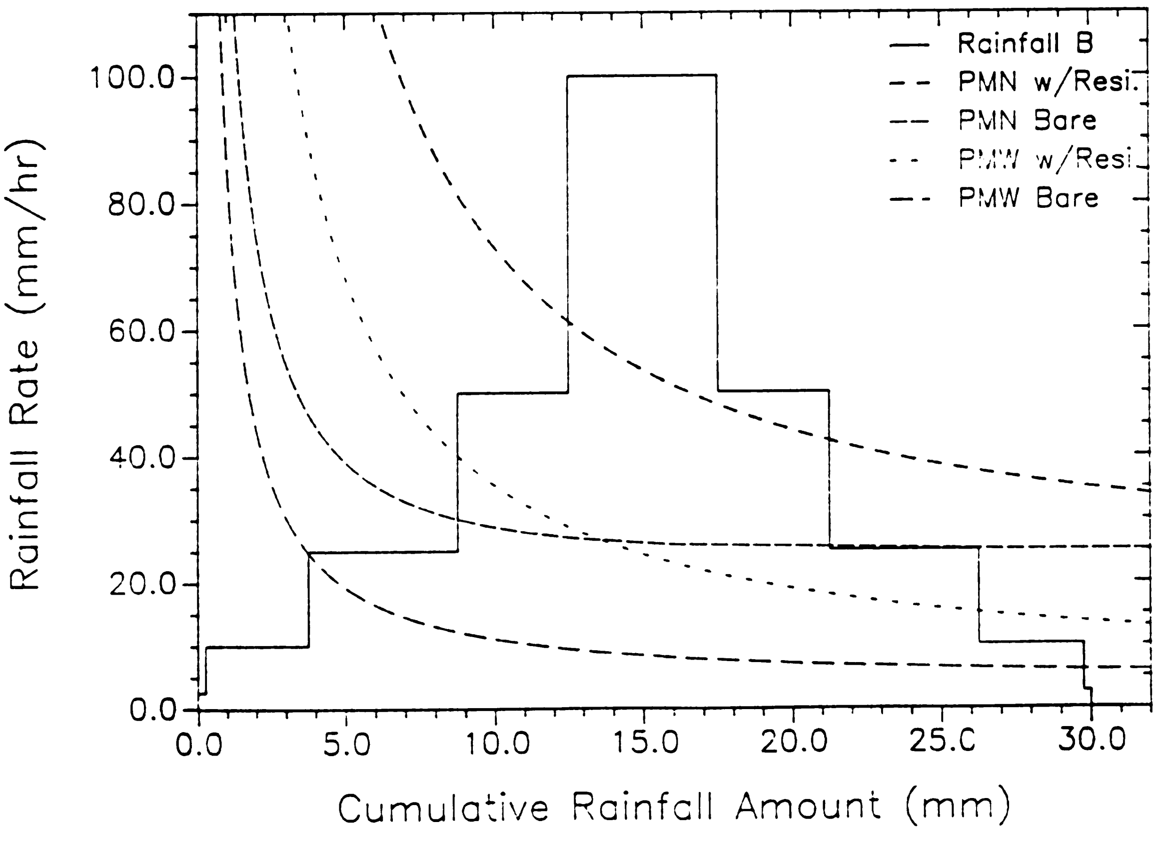

Figure 23. Ponding curves for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type B rainfall distribution.

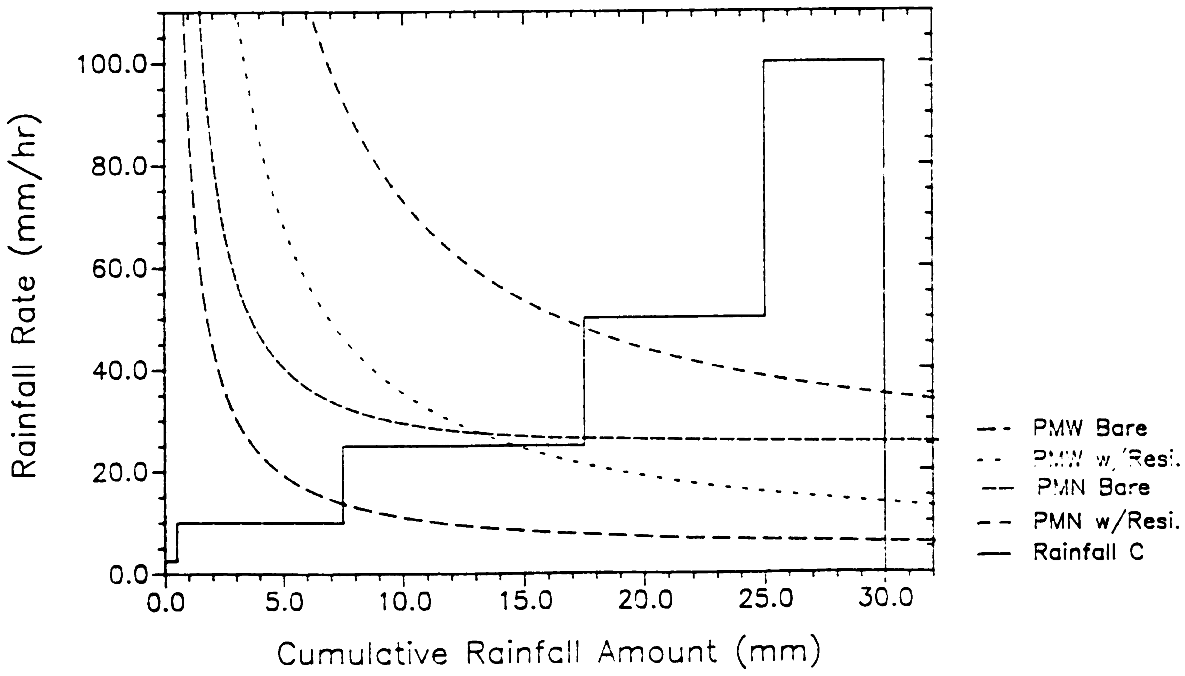

Figure 24. Ponding curves for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type C rainfall distribution.

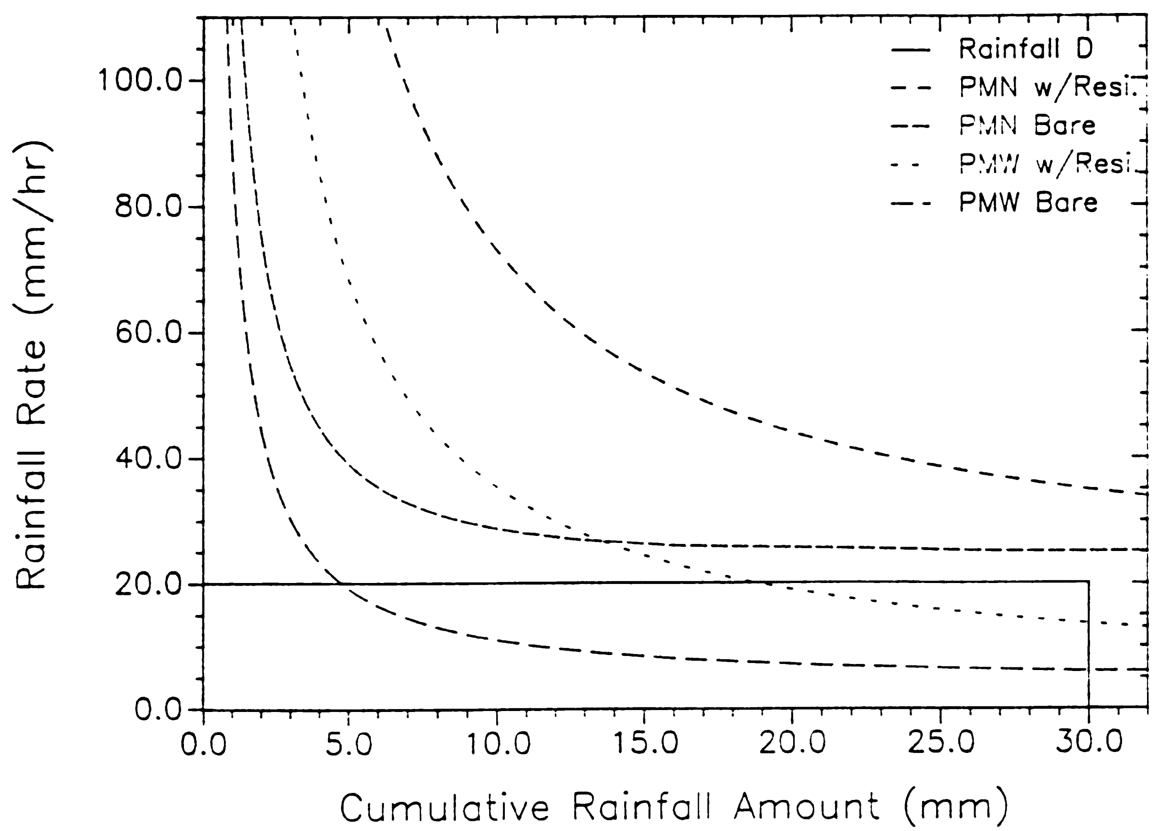

Figure 25. Ponding curves for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type D rainfall distribution.

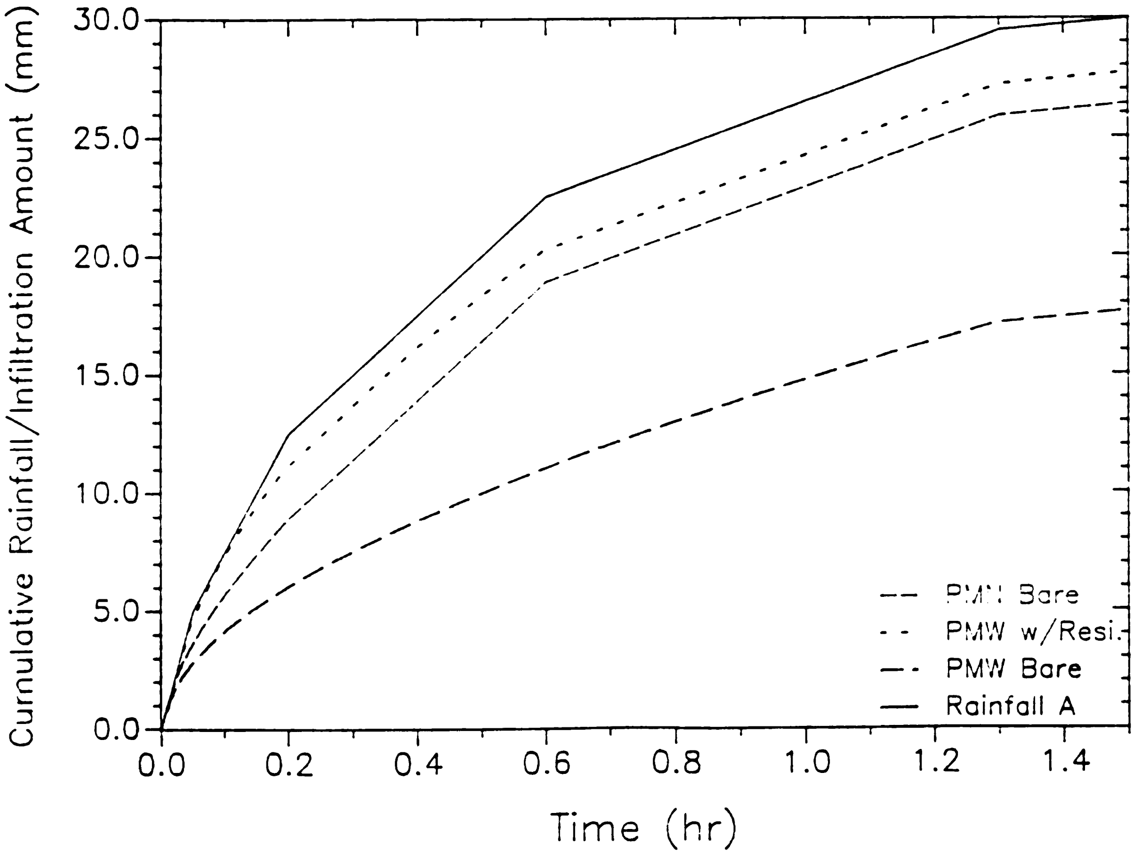

Figure 26. Calculated cumulative infiltration amount and cumulative rainfall amount for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type A rainfall distribution.

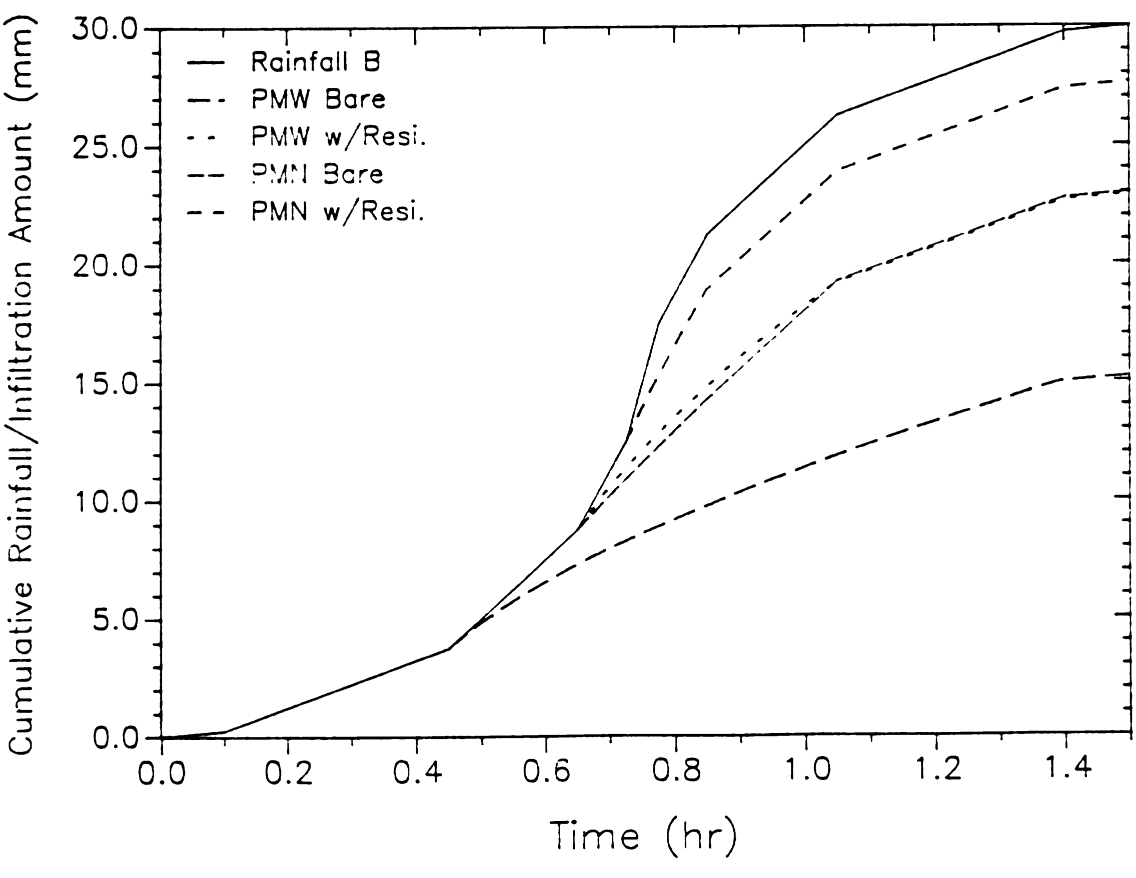

Figure 27. Calculated cumulative infiltration amount and cumulative rainfall amount for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type B rainfall distribution.

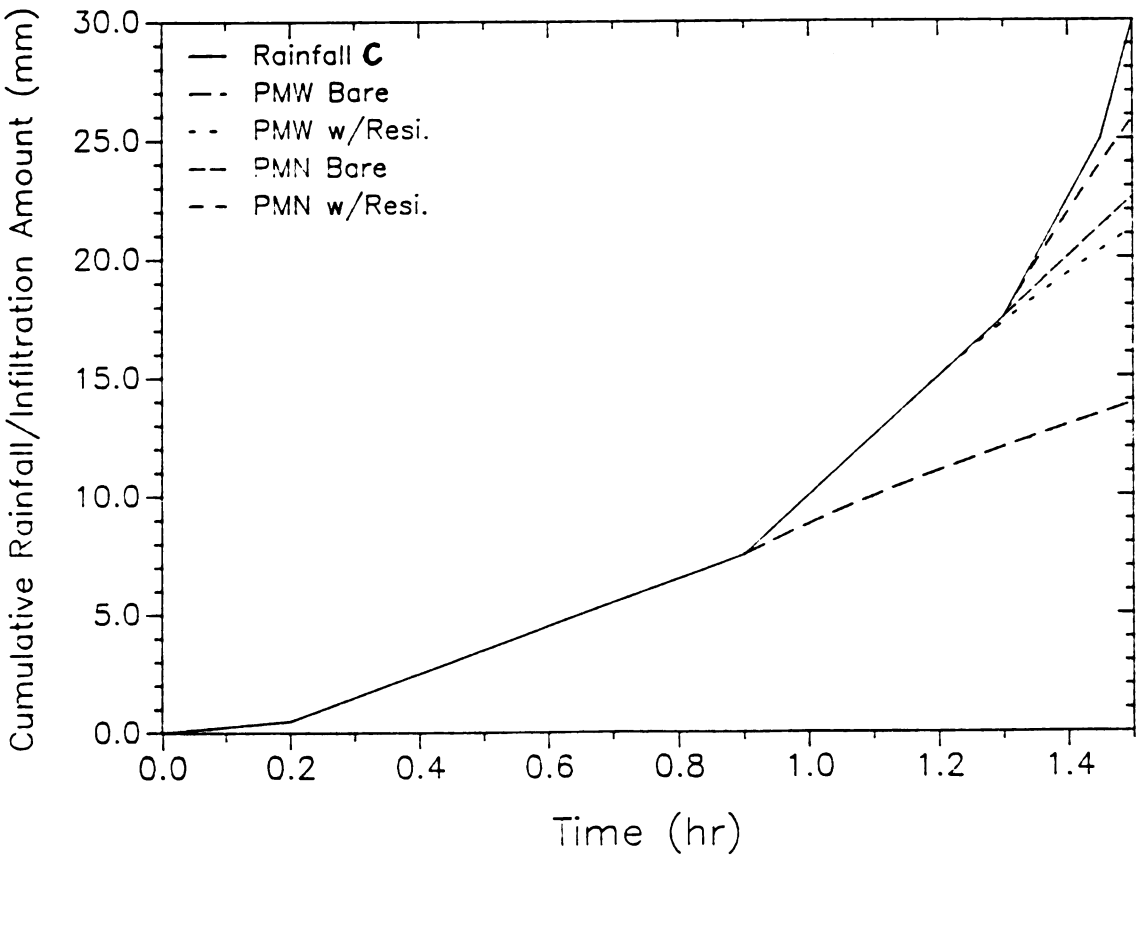

Figure 28. Calculated cumulative infiltration amount and cumulative rainfall amount for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type C rainfall distribution.

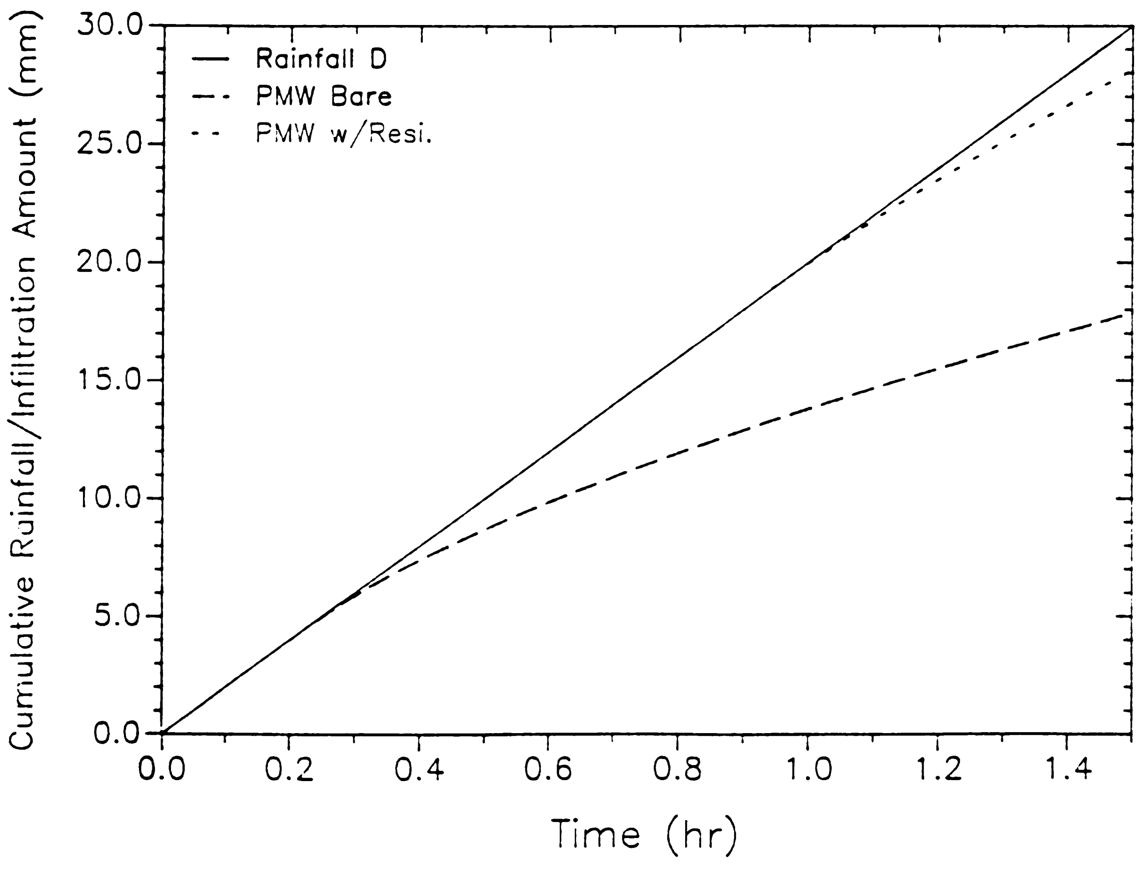

Figure 29. Calculated cumulative infiltration amount and cumulative rainfall amount for moldboard tilled soil with a potato crop with various surface residue treatments and wheel traffic conditions with type D rainfall distribution.

Applying this model to individual rainfall events involves relatively simple calculations. The field measurements suggest that setting up time-to-ponding families of curves for variable soil management to predict infiltration and runoff prediction is possible.

There are useful applications of this model for in sprinkler irrigation assessment. Management of both the surface soil and sprinkler application rates permit controlled water entry under unsaturated conditions. There are several direct benefits in being able to predict t_p. Keeping $\Psi_0 < 0$, or keeping the application time less than t_p, should help maintain soil surface structure; it efficiently places water in the root zone by minimizing any preferential flow under saturated conditions below the root zone, thus decreasing the possibility of leaching of fertilizers and pesticides to groundwater.

E. Example of Runoff Prediction for One Rainstorm

As an example for linkage between rainstorm generator and time-to-ponding approach for long-term infiltration and runoff prediction, the observed and simulated rainstorm on July 11, 1985 from Deer-Sloan Watershed, Michigan are shown from Figures 30 to 35. The ponding curves of paratilled potato crop with surface residue (PPW1) and bare surface treatments (PPW6) were established by derived field experiment from Table 7. The observed rainstorm rate has five intersections with the ponding curve of both treatments (Figure 30). Five ponding times and five non-ponding time can be observed from the graph. The cumulative infiltration amount can be calculated from [4.8] with derived soil physical properties and rainfall intensity. Figure 31 shows the calculated results of cumulative rainfall and infiltration amount. The difference between cumulative rainfall and infiltration is runoff (Table 8). Figures 32 shows the simulated rainstorm with peak intensity appearing at normalized time .17 during rainstorm process. The calculated runoff from Figure 33 for both treatments are higher than the results from Figure 31. Figure 34 shows the ponding curve intersect with 10 equal time increments simulated rainstorm. Without a peak intensity simulation, the calculated runoff (Figure 35 and Table 8) is lower than the results from Figure 33.

Soil surface storage is an important property of infiltration and runoff process because of the temporary storage of excess water in surface depressions without runoff initiation. A model of surface depressions has been developed by Linden in 1979 and was used in developing a functional relationship for the upper limit to depression storage as a function of roughness RR and the general land slope L. The decreasing of runoff by presence of surface residue indicates the influence of residue cover.

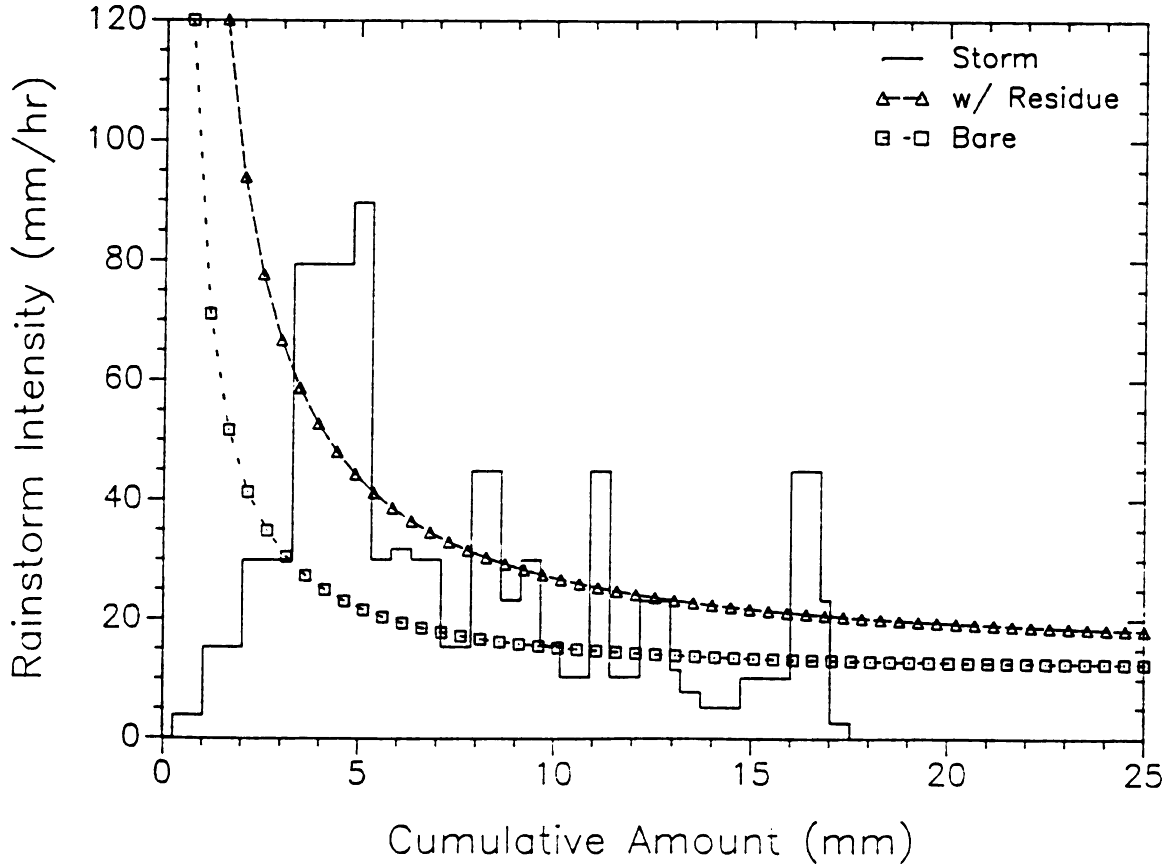

Figure 30. Ponding curves for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and observed rainstorm on July 11, 1985 from Deer-Sloan Watershed station #10, Michigan.

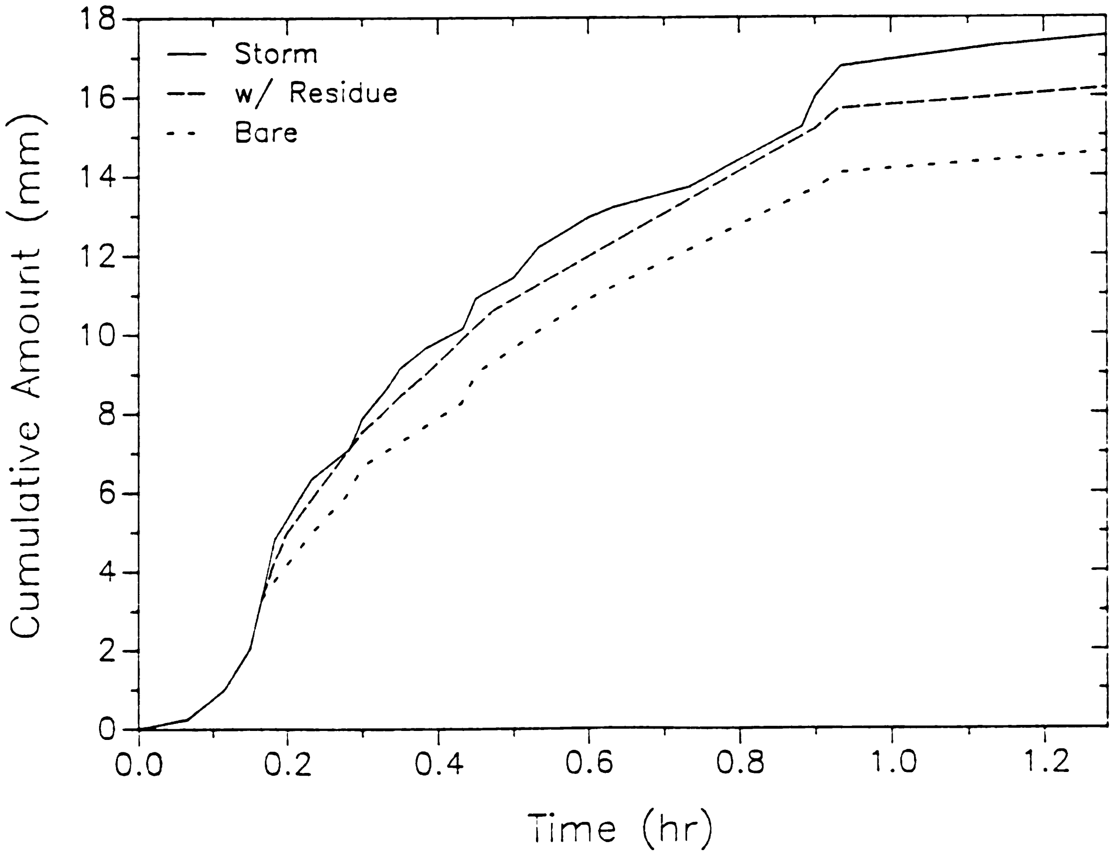

Figure 31. Calculated cumulative infiltration amount and cumulative rainfall amount for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and an observed rainstorm.

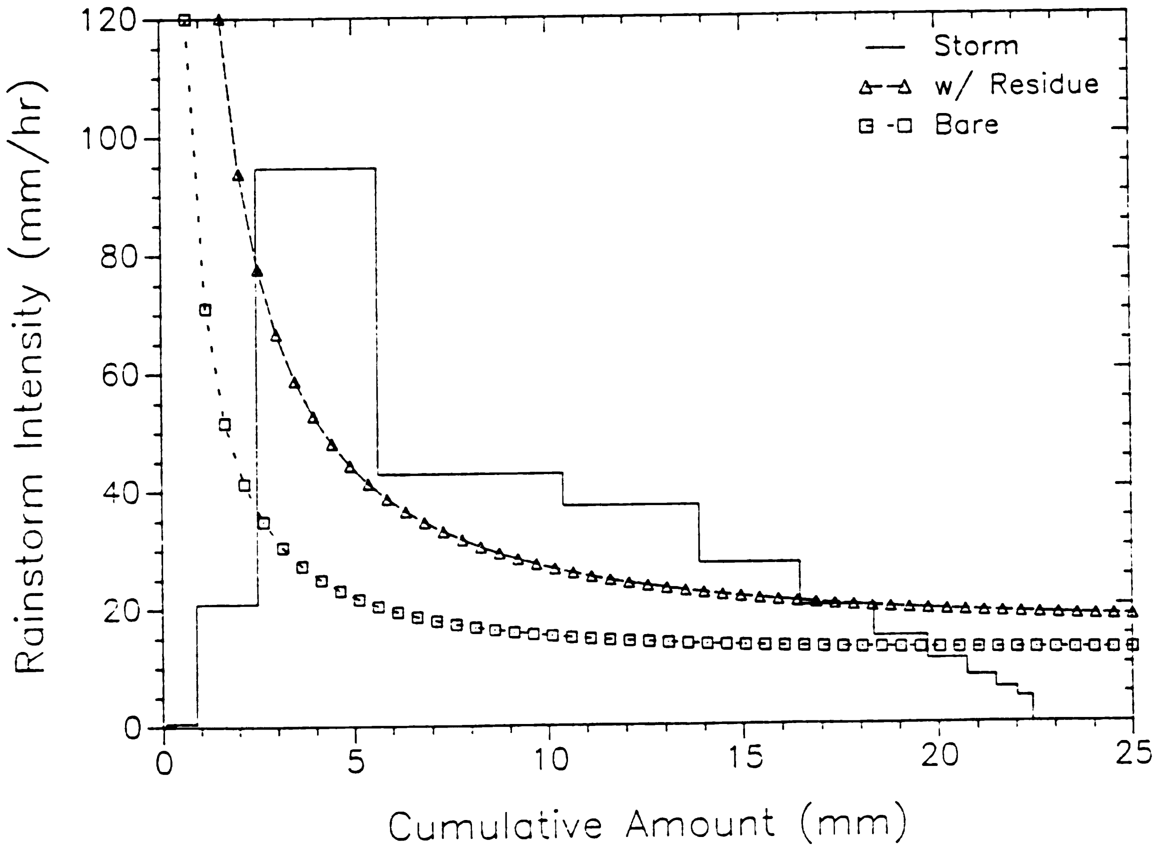

Figure 32. Ponding curves for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and simulated rainstorm using peak intensity on July 11, 1985 from Deer-Sloan Watershed station #10, Michigan.

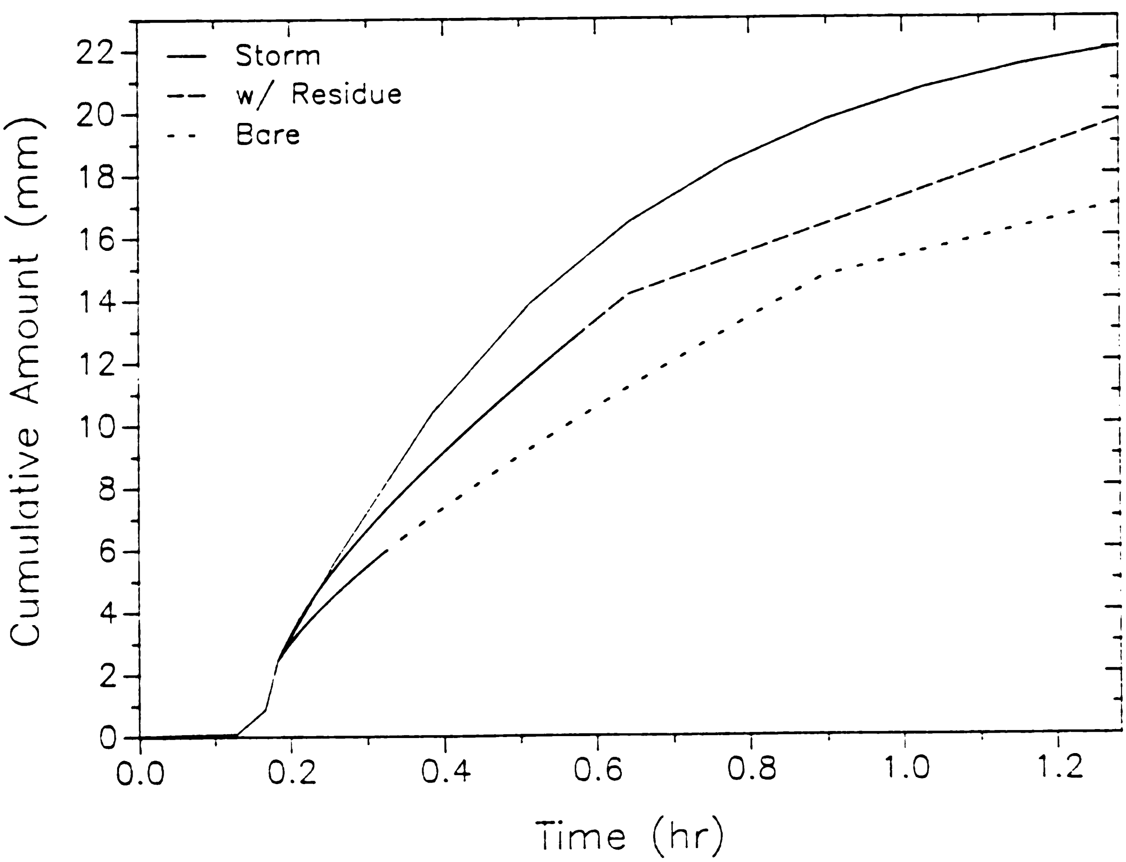

Figure 33. Calculated cumulative infiltration amount and cumulative rainfall amount for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and a simulated rainstorm using peak intensity.

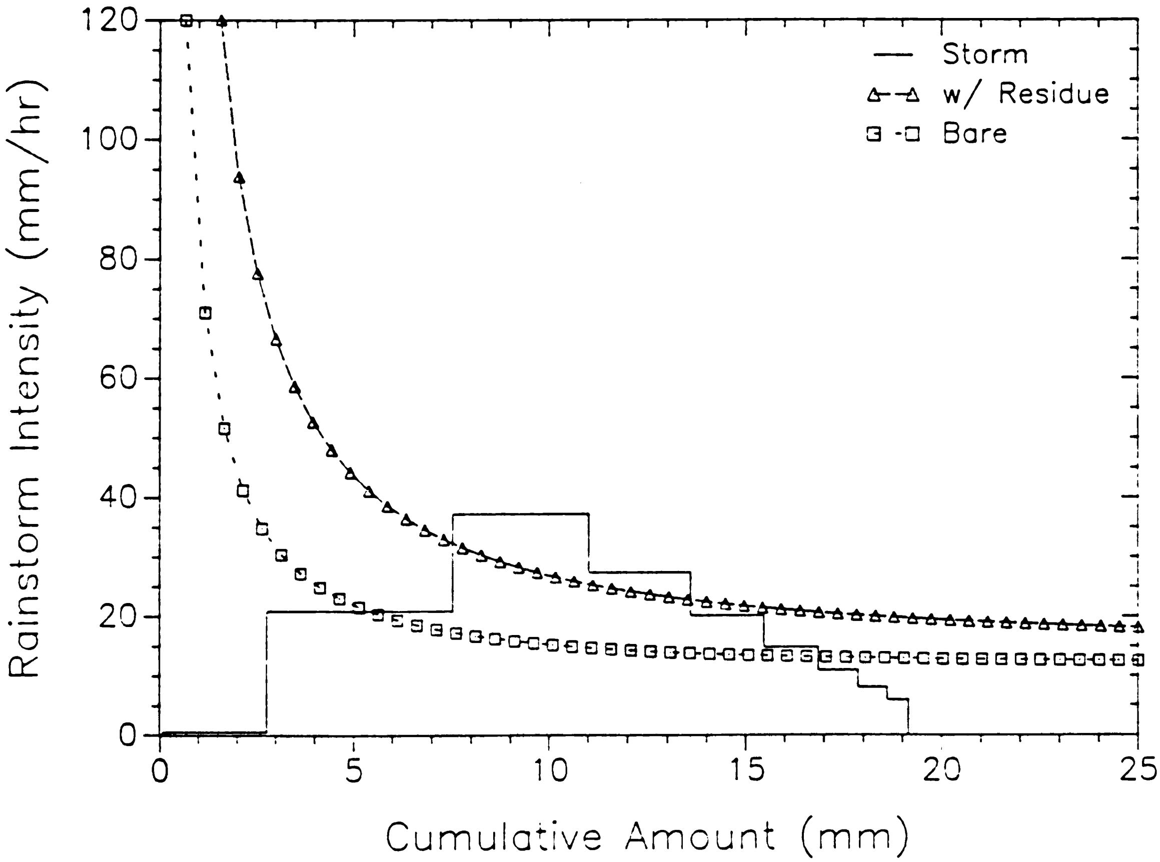

Figure 34. Ponding curves for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and simulated rainstorm using 10 equal increments on July 11, 1985 from Deer-Sloan Watershed station #10, Michigan.

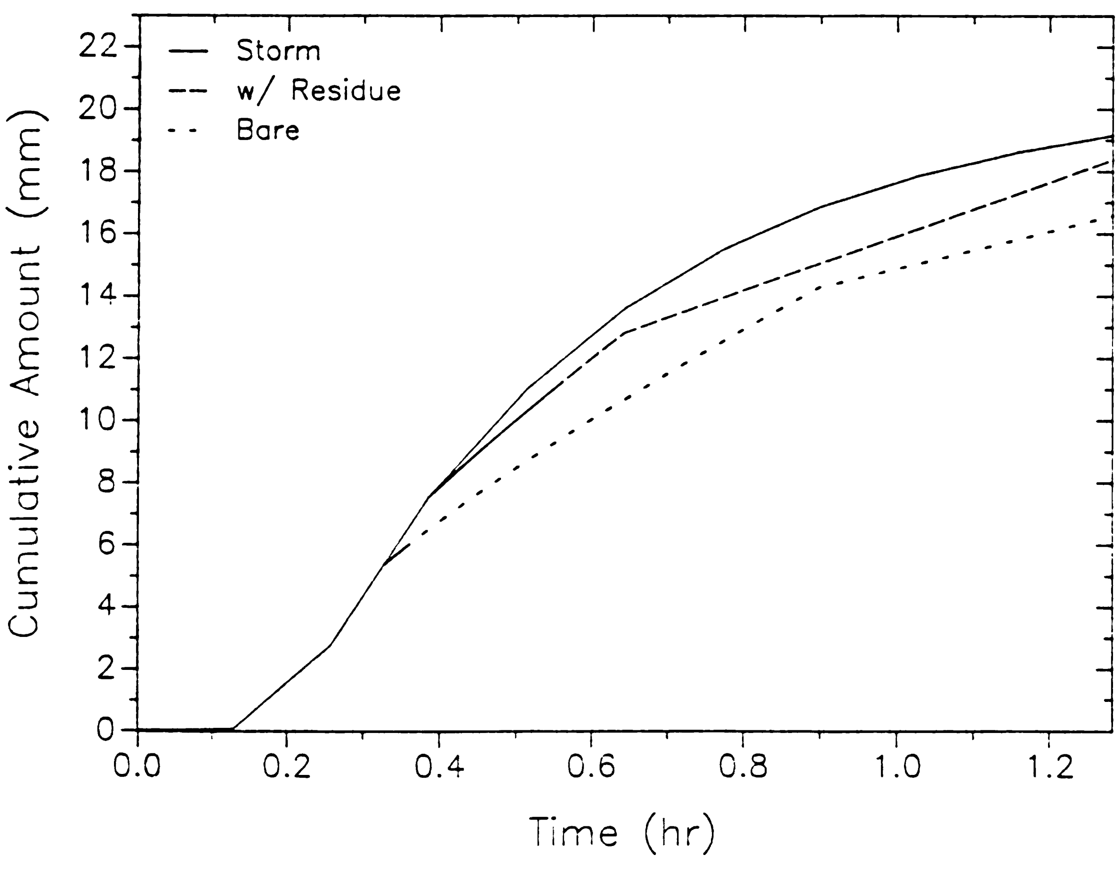

Figure 35. Calculated cumulative infiltration amount and cumulative rainfall amount for paraplowed soil with a potato crop under wheel track condition for various surface residue treatments and a simulated rainstorm using 10 equal time increments.

Table 8. Calculated runoff (mm) from cumulative infiltration and cumulative rainstorm amounts for different surface treatment of a paratilled soil with a potato crop with wheel track condition.

soil condition storm intensity	Residue cover	Bare surface
Observed storm	1.18	2.76
Simulated storm with peak intensity	2.32	5.00
Simulated storm with 10 increments	0.77	2.57

VII. SUMMARY AND CONCLUSIONS

Soil infiltration profoundly influences runoff and soil erosion. The research discussed for this study used a physical-based infiltration model to assess the effects of irrigation and variable rainfall rate patterns on the hydrologic behavior for different types of soil management. A field study was conducted at three sites in Michigan to determine soil properties needed for assessment of infiltration. Field time-to-ponding was measured for various water application rates using a sprinkling infiltrometer for a variety of soil management and initial conditions. Soil parameters were derived from best-fit ponding curves to predict soil infiltration. The soil properties needed for predicting time to ponding were sorptivity, $S(\theta_s,\theta_n)$, and hydraulic conductivity at field saturation, K_s. The model consists basically of equations to predict the time of surface ponding and the infiltration rate under variable rainfall patterns or sprinkling irrigation applications.

The ease and speed with which sprinkler infiltrometer can be used in the field suggests that their use for measuring soil hydraulic properties is probably more appropriate and less variable than taking cores for laboratory measurements. The analytic expression for time-to-ponding in the inverse sense can be used to determine the soil sorptivity, hydraulic conductivity, and point source runoff during rainfall. These properties are proportional to the characteristic mean pore size of soils which is affected by cultivation and management. Thus, the model provides a rational basis for estimating water infiltration under different management conditions.

The rainstorm generator developed in this study required relatively few parameters to disaggregate the daily precipitation into individual storm event and intensity patterns. Thirty years rain gauge data from Deer-Sloan Watershed, Michigan was used to evaluate the number of variables needed to make the model work. A first-order Markov chain was used for prediction of wet or dry day. For a wet day, the number of rainstorm events and the amount, duration, peak intensity and short-period intensity pattern of each event were disaggregated from stochastic distributions. Marginal and conditional distributions were fitted to simulate the peak intensity pattern of each storm. A multivariate double exponential model for dimensionless storm event was used to disaggregate individual storms into short-period rainfall intensities. Thus, given a simulated storm amount, duration, and ratio of peak distribution, approximate storm intensity patterns were developed. An analysis of 30 years of storms observed at the Deer-Sloan Watershed station #10 in Michigan suggests that the proposed model structure provided an acceptable prediction of storms from April to September. The rainstorm generator provided the required information for the time-to-ponding infiltration model. A case study was used to demonstrate the sensitivity of point source runoff estimation from different rainfall patterns.

The relationship of point source runoff to rainfall intensity was greatly affected by soil hydraulic properties, which were influenced by soil management, residue cover, and initial soil water content. The decreasing of runoff by the presence of surface residue cover indicated that infiltration is not just a physical process, but a biophysical one. The mulching material, crop residue left on the surface, and plant roots protect surface soil from the impact of raindrop erosion and increase the absorption of applied water. Soil management techniques, especially tillage, have been linked to the creation of low-permeability surface soil, which reduce infiltration capacity and increase runoff and soil erosion on these agricultural soils. Heavy wheel track tillage practices increase the opportunity from movement of surface-applied chemicals to runoff water while decreasing the opportunity for leaching because of reduced infiltration capacity.

The time-to-ponding model has several noteworthy features. First, it represents the actual infiltration process and therefore predicts infiltration as a function of measurable soil characteristics, currently for a rather limited conditions but potentially for a wider range. Empirical infiltration equations and models, on the other hand, require the use of fitted parameters. Second, applying the model to individual rainfall events involves very simple calculations comparable to those with common infiltration equations.

There is a difference between modeling infiltration for a steady rain and modeling infiltration for an unsteady rain. For a steady rain, infiltration starts with an unponded surface and later changes to a stage with surface ponding, which lasts until the end of the rainfall event. There is at most one ponding time in a steady rain. For an unsteady rainfall event, there may be several periods when the rainfall intensity exceeds the infiltration rate. The infiltration process may change from one stage to another and shift back to the original stage in a recurrent style. Though the time-to-ponding infiltration model used in this study is a simplified representation of the infiltration process in the field.

Because of the practical limitations and difficulties often attendant to evaluating more that several constants by least squares fitting, particularly when the numerical data contain experimental error, it is expected that the least number of parameters required will be most useful for the least squares fitting process. Therefore for describing and fitting field measurements of time-to-ponding data, the infiltration estimation procedure used in this study offers a useful and reasonable simplicity. The sorptivity and hydraulic conductivity are both well defined physical properties.

The results of this study has suggested the need for other research to make the system work under many practical conditions. The following suggestion are made for further research need:

1. The criteria governing storm generator transferability, and the sensitivity of point source runoff hydrographs to various types of rainfall data input. If the distribution functions and coefficients have linear spatial variation, the storm generator model will be able to apply to other location.
2. Sensitivity of derived quantities, such as peak runoff rate or volumes to the structure of disaggregation models, may lead to further simplifications of this storm generator.
3. The actual situation at the soil surface during rainfall is undoubtedly much more complex than the infiltration model assumed in this study. The runoff or rainfall significance of water at the ponding stage observed in this investigation requires further study. Uptakes associated with the commencement of ponding are important where even localized runoff is to be prevented during a rainstorm. On the other hand, when runoff relatively far from the source of applied water is of primary interest. It should be pointed out that this study was concerned with rainfall infiltration

into soil, the structure of which was affected but little by water percolation or by raindrop impacts. Such considerations were necessary in order to throw some light on the purely hydrodynamic aspects of the rain infiltration phenomenon. In further field situations the effects of soil structure transformations must also be taken into account.

4. This infiltration model assumes a homogeneous soil profile and a uniform distribution of initial soil water content. The movement of water in the soil is assumed to be in the form of an advancing wetting front, and the diffusion of soil moisture is neglected. But this equation is one of the best models available to describe infiltration during an unsteady rainfall event. The assumption of a homogeneous soil profile and a uniform distribution of initial soil water content needs further study to explore the potential of the time-to-approach in modeling infiltration during a rainfall event.

APPENDICES

APPENDIX 1

Fortran source code for observed storm intensity calculation from rain gauge data record.

APPENDIX 1. Fortran source code for observed storm intensity calculation from rain gauge data record.

```
      PROGRAM RAINSTORM
c
c     program to read in raingauge data record and out put individual
c     storm intensiy patterns for 30 years weather files from Deer-Sloan
c     Watershed station #10, Michigan
c
      character*1 cd
c
      OPEN(11,FILE='d10data.txt',STATUS='OLD')
      OPEN(12,FILE='d10apr.wth',STATUS='UNKNOWN')
      OPEN(13,FILE='d10may.wth',STATUS='UNKNOWN')
      OPEN(14,FILE='d10jun.wth',STATUS='UNKNOWN')
      OPEN(15,FILE='d10jul.wth',STATUS='UNKNOWN')
      OPEN(16,FILE='d10aug.wth',STATUS='UNKNOWN')
      OPEN(17,FILE='d10sep.wth',STATUS='UNKNOWN')
      OPEN(18,FILE='d10oct.wth',STATUS='UNKNOWN')
      OPEN(19,FILE='d10all.wth',STATUS='UNKNOWN')
c
      dcount=0.
      iswtch=1
      m=0
      d=0
      y=0
c
10    read(11,101,end=999)cd,sta,m1,d1,y1,starth1,startm1,dur1,amount
      if(m1.lt.4..or.m1.gt.10.) goto 10
      if(starth1.ge.24.) starth1=starth1-24.
101   format(a1,6i2,i4,i2)
      start1=starth1+startm1/60.
      start=start1
      dur1=dur1/60.
      amount=amount/100.
      end=start1+dur1
c
20    if((amount/dur1).lt..01) goto 10
      if(m1.lt.4..or.m1.gt.10.) goto 10
      if(m.ne.m1.or.d.ne.d1.or.y.ne.y1) dcount=0.
30    read(11,101,end=999)cd,sta,m2,d2,y2,starth2,startm2,dur2,amount2
      if(starth2.ge.24.) starth2=starth2-24.
      start2=starth2+startm2/60.
      dur2=dur2/60.
      amount2=amount2/100.
c
      if(y1.ne.y2.or.m2-m1.gt.1) goto 35
      dc=d2-d1
       if(m2-m1.eq.1) then
       if(m2.eq.5.and.dc.ne.-29.) goto 35
       if(m2.eq.6.and.dc.ne.-30.) goto 35
       if(m2.eq.7.and.dc.ne.-29.) goto 35
       if(m2.eq.8.and.dc.ne.-30.) goto 35
       if(m2.eq.9.and.dc.ne.-30.) goto 35
       if(m2.eq.10.and.dc.ne.-29.) goto 35
       if(m2.eq.11.and.dc.ne.-30.) goto 35
       endif
      if(dc.eq.0..or.dc.eq.1..or.dc.eq.-29..or.dc.eq.-30.) then
       check=start2
       if(d1.ne.d2.and.iswtch.eq.1) then
        check=check+24.
        iswtch=0
       endif
       if((start1+dur1+10./60.).ge.check.and.(amount2/dur2).ge..01) then
        amount=amount+amount2
        end=start2+dur2
        start1=start2
```

APPENDIX 1 (cont'd)

```
          dur1=dur2
          goto 30
         endif
        endif

35      iswtch=1
        dcount=dcount+1.
        dura=end-start
40      if(dura.le.0.) then
        dura=dura+24.
        goto 40
        endif
        ioutf=m1+8.
        write(ioutf,103)sta,m1,d1,y1,dcount,start,dura,amount
103     format(i2,4(x,i2),x,3(x,f6.2))
        write(19,102)sta,m1,d1,y1,dcount,start,dura,amount
102     format('D',i2,x,3i2,x,i2,2f6.2,f5.2)
c
        m=m1
        d=d1
        y=y1
        end=start2+dur2
        m1=m2
        d1=d2
        y1=y2
        start1=start2
        start=start1
        dur1=dur2
        amount=amount2
        goto 20
c
999     stop
        end
```

APPENDIX 2

Fortran source code for time-to-ponding calculation for sprinkling infiltrometer experiment.

APPENDIX 2. Fortran source code for time-to-ponding calculation for sprinkling infiltrometer experiment.

```
      PROGRAM INFILTRO
C     ******************************************************
C     *   Main program for Summer 1989 field experiment. *
C     *   Part I: Infiltrometer                          *
C     ******************************************************
C
      integer type,noz
      real ontime,offtime,vol1,vol2,vol3,pondtime
      real elapstime,avgvol,rate1(4,100),rate2(4,100)
      real timetop(4,100),cumam1(4,100),cumam2(4,100)
      integer count(4),nozzle(4,100)
      integer i,iontime,iofftime,ipondtime
      character*12  outfname

      call clear
      write(*,800)
      read(*,'(A)') outfname
      open(10,FILE = outfname,STATUS = 'NEW',IOSTAT = ios)
      if (ios .ne. 0) then
        write(*,'(/15x,A,A,A)') 'I/O Error! The file : ',outfname,
     &                           'already existed.'
        stop '   Please check the output file name first.'
      endif
      open(11,FILE = 'plot\dryf',STATUS = 'UNKNOWN',IOSTAT = ios)
      open(12,FILE = 'plot\wetf',STATUS = 'UNKNOWN',IOSTAT = ios)
      open(13,FILE = 'inputf1',STATUS = 'UNKNOWN',IOSTAT = ios)
      write(13,'(A)') outfname
      i = 0
      count(1) = 0
      count(2) = 0
      count(3) = 0
      count(4) = 0
      write (10,'(20x,A,/)') outfname
      write(10,*) ' TYPE NOZ# ONTIME OFFTIME   VOL1     VOL2     VOL3
     +PONDTIME'

C *** Repeat reading infiltrometer data until the end
 100    call clear
        i = i + 1
        write(*,'(15x,A,i2,/)') 'INFILTROMETER INPUT DATA ',i
C ***   Repeat until a correct input
 110       write(*,900)
           read(*,'(I2)',IOSTAT = ierr) type
           call selpro(0,4,type,index,ierr)
        if (index .eq. 2) goto 110
        write(13,'(i2)') type

        if (type .ne. 0) then
           count(type) = count(type) + 1
C ***      Repeat until a correct input
 115          write(*,950)
              read(*,'(i2)',IOSTAT = ierr) noz
              call selpro(1,6,noz,index,ierr)
           if (index .eq. 2) goto 115
           write(13,'(i2)') noz

C ***      Repeat until a correct input
 120          write(*,1000)
              read(*,*,IOSTAT = ierr) ontime
              call fselpro(0.,120.,ontime,index,ierr)
           if (index .eq. 2) goto 120
           write(13,'(f6.2)') ontime
```

APPENDIX 2 (cont'd)

```
C ***       Repeat until a correct input

  130          write(*,1100)
               read(*,*,IOSTAT = ierr) offtime
               call fselpro(0.,200.,offtime,index,ierr)
            if (index .eq. 2) goto 130
            if (offtime .lt. ontime) then
               write(*,1150)
               goto 130
            endif
            write(13,'(f6.2)') offtime

C ***       Repeat until a correct input
  140          write(*,1200)
               read(*,*,IOSTAT = ierr) vol1
               call fselpro(0.,200.,vol1,index,ierr)
            if (index .eq. 2) goto 140
            write(13,'(f8.4)') vol1

C ***       Repeat until a correct input
  150          write(*,1300)
               read(*,*,IOSTAT = ierr) vol2
               call fselpro(0.,200.,vol2,index,ierr)
            if (index .eq. 2) goto 150
            write(13,'(f8.4)') vol2

C ***       Repeat until a correct input
  160          write(*,1400)
               read(*,*,IOSTAT = ierr) vol3
               call fselpro(0.,200.,vol3,index,ierr)
            if (index .eq. 2) goto 160
            write(13,'(f8.4)') vol3

            if (type .eq. 1 .or. type .eq. 2) then
C ***          Repeat until a correct input
  170             write(*,1500)
                  read(*,*,IOSTAT = ierr) pondtime
                  call fselpro(0.,200.,pondtime,index,ierr)
               if (index .eq. 2) goto 170
               if (pondtime .lt. ontime .or. pondtime.gt.offtime) then
                  write(*,1550)
                  goto 170
               endif
               write(13,'(f6.2)') pondtime
            else
               pondtime = offtime
            endif

      write (10,999) type,noz,ontime,offtime,vol1,vol2,vol3,pondtime
999   format(2x,i2,3x,i2,2x,f6.2,2x,f6.2,3(3x,f6.2),2x,f6.2)

C ***       Change the unit of time into min.
            iontime = int(ontime)
            ontime = iontime + (ontime - iontime) / .6
            iofftime = int(offtime)
            offtime = iofftime + (offtime - iofftime) / .6
            ipondtime = int(pondtime)
            pondtime = ipondtime + (pondtime - ipondtime) / .6

C ***       Calculate the result
            j = count(type)
            nozzle(type,j) = noz
            elapstime = offtime - ontime
            avgvol = (vol1 + vol2 + vol3) / 3.0
            if (elapstime .ne. 0.0) then
               rate1(type,j) = avgvol / elapstime * 0.56401
               rate2(type,j) = rate1(type,j) * 25.4
            else
               rate1(type,j) = 0.0
               rate2(type,j) = 0.0
```

APPENDIX 2 (cont'd)

```
            endif
            timetop(type,j) = pondtime - ontime

            cumam1(type,j) = (timetop(type,j) / 60.0) * rate1(type,j)
            cumam2(type,j) = (timetop(type,j) / 60.0) * rate2(type,j)
         endif
      if (type .ne. 0) goto 100

C *** Write the calculation results into the output file
      write(11,1700)
      write(12,1700)
      do 200 i = 1,4
         if (count(i) .gt. 0) then
            if (i .eq. 1) then
               write(10,1600) 'PONDED PRIMARY'
            else if (i .eq. 2) then
               write(10,*)
               write(10,1600) 'PONDED SECONDARY'
            else if (i .eq. 3) then
               write(10,*)
               write(10,1600) 'NON-PONDED PRIMARY'
            else if (i .eq. 4) then
               write(10,*)
               write(10,1600) 'NON-PONDED SECONDARY'
            endif
            write(10,1700)
            do 300 j = 1,count(i)
               write(10,1800) rate1(i,j),timetop(i,j),rate2(i,j),
     &                        cumam1(i,j),cumam2(i,j),nozzle(i,j)
               if (i .eq. 1) then
                  write(11,1800) rate1(i,j),timetop(i,j),rate2(i,j),
     &                        cumam1(i,j),cumam2(i,j),nozzle(i,j)
               else if (i .eq. 2) then
                  write(12,1800) rate1(i,j),timetop(i,j),rate2(i,j),
     &                        cumam1(i,j),cumam2(i,j),nozzle(i,j)
               endif
  300       continue
         endif
  200 continue

      close(10)
      close(11)
      close(12)
      close(13)

  800 format(15X,'****************************************',/,
     1       15X,'*   SOIL WATER INFILTRATION SYSTEM *',/,
     2       15x,'*      Part I : Infiltrometer      *',/,
     2       15X,'****************************************',////,
     3       10x,'Please type the output file name ',
     4       '(eq. CDW2) : ',\)
  900 format(
     1       15x,'0 -- End of input.',/,
     2       15x,'1 -- Ponded  Primary.',/,
     3       15x,'2 -- Ponded  Secondary.',/,
     4       15x,'3 -- Non-Ponded  Primary.',/,
     5       15x,'4 -- Non-Ponded  Secondary.',//,
     6       15x,'Input the choice : ',\)
  950 format(/,10x,'       Nozzle Number (1 - 6) : ',\)
 1000 format(10x,'   Clock "ON"  Time (min.sec) : ',\)
 1100 format(10x,'   Clock "OFF" Time (min.sec) : ',\)
 1150 format(/10x,'OFFTIME < ONTIME ! Please input offtime again')
 1200 format(10x,'                         VOL1 (ml) : ',\)
 1300 format(10x,'                         VOL2 (ml) : ',\)
 1400 format(10x,'                         VOL3 (ml) : ',\)
 1500 format(10x,'Clock "PONDED" Time (min.sec) : ',\)
 1550 format(/10x,'PONDTIME out of range ! Please input again')
 1600 format(/,25x,15A)
 1700 format(4x,'RATE(in/hr)   TP(min)   RATE(mm/hr)  CUM_AMT(in) ',
     &       ' CUM_AMT(mm)  NOZZLE#')
```

APPENDIX 2 (cont'd)

```
 1800 format(4x,f8.4,5x,f6.2,6x,f8.4,4x,f8.4,5x,f8.4,6x,i2)

      call clear

      write (*,'(15x,A,/,A,A,A,/,A,/,A,/,A)')
     &       'Calculation completed',

     &       '     Output file is "',outfname,'"',
     &       '     Input data stores in "INPUTF1"',
     &       '     Plotit files are "PLOT\DRYF" and "PLOT\WETF"'
      end
```

APPENDIX 3

Fortran source code for bulk density and initial water content calculation for sprinkling infiltrometer experiment.

APPENDIX 3. Fortran source code for bulk density and initial water content calculation for sprinkling infiltrometer experiment

```
      PROGRAM BUKDDEN
C     ****************************************************
C     *   Main program for Summer 1989 field experiment. *
C     *   Part II:                                       *
C     *   A. Crop Residue                                *
C     *   B. Grossman Compliant Cavity Method            *
C     *   C. Madera Sampler Method                       *
C     ****************************************************
C
      integer resi,beads,iflag,jflag
      real residue,
     &     iniv, finv1, finv2, cont, wet,
     &     dry, dry2, diff, vol2, tbd(2), pbd(2), twv(2), pwv(2),
     &     avetbd, avetwv, avepbd, avepwv,
     &     macon, mawet, madry, mabd, mawv, mabdi(10),mawvi(10)
      character*12  outfname

      call clear
      write(*,800)
      read(*,'(A)') outfname
      open(10,FILE = outfname,STATUS = 'NEW',IOSTAT = ios)
      if (ios .ne. 0) then
        write(*,'(/15x,A,A,A)') 'I/O Error! The file : ',outfname,
     &                          'already existed.'
        stop '   Please check the output file name first.'
      endif
      open(13,FILE = 'inputf2',STATUS = 'UNKNOWN',IOSTAT = ios)
      write(13,'(A)') outfname

C ***  Reading data until the end
  100    call clear
         write(*,'(15x,A,/)') 'A. CROP RESIDUE'
C ***    Repeat until a correct input
  115          write(*,950)
               read(*,*,IOSTAT = ierr) resi
               call selpro(-1,60,resi,index,ierr)
            if (index .eq. 2) goto 115
            write(13,'(i2)') resi

C ***       Repeat until a correct input
c 120          write(*,1000)
c              read(*,*,IOSTAT = ierr) beads
c              call selpro(0,200,beads,index,ierr)
c           if (index .eq. 2) goto 120
c           write(13,'(i2)') beads
            beads = 60

C ***    Crop Residule Calculation  ***
      residue = (float(resi)/float(beads))*100.

      write (10,'(20x,A,/)') outfname
      write(10,'(A,i2,/)') 'RESIDUE READING : ',resi
      if (resi .lt. 0) then
      write (10,'(A,f8.2,/)') ' Crop Residue (%):  ? '
      else
      write (10,'(A,f8.2,/)') ' Crop Residue (%):  ',residue
      endif

         call clear
         write(*,'(15x,A)') 'B. GROSSMAN COMPLIANT CAVITY METHOD'
         write(10,*) 'GROSSMAN COMPLIANT CAVITY METHOD READING: '
      WRITE(10,*)'SET INIV   FINALV1 FINALV2   CON WETS+CON DRYS+CON  <2
     +MM     Ov       BD'
```

APPENDIX 3 (cont'd)

```
      write(*,'(15x,A)') '   First set of data'
      iflag = 1
      goto 130
  125 write(*,'(/,15x,A)') '   Second set of data'

      iflag = 2
C ***    Repeat until a correct input
  130       write(*,1100)
            read(*,*,IOSTAT = ierr) iniv
            call fselpro(0.,700.,iniv,index,ierr)
         if (index .eq. 2) goto 130
         write(13,'(f5.1)') iniv

C ***    Repeat until a correct input
  140       write(*,1200)
            read(*,*,IOSTAT = ierr) finv1
            call fselpro(0.,1000.,finv1,index,ierr)
         if (index .eq. 2) goto 140
         write(13,'(f5.1)') finv1

C ***    Repeat until a correct input
  150       write(*,1300)
            read(*,*,IOSTAT = ierr) finv2
            call fselpro(0.,1000.,finv2,index,ierr)
         if (index .eq. 2) goto 150
         write(13,'(f5.1)') finv2

C ***    Repeat until a correct input
  160       write(*,1400)
            read(*,*,IOSTAT = ierr) cont
            call fselpro(0.,30.,cont,index,ierr)
         if (index .eq. 2) goto 160
         write(13,'(f4.1)') cont

C ***    Repeat until a correct input
  170       write(*,1500)
            read(*,*,IOSTAT = ierr) wet
            call fselpro(0.,1500.,wet,index,ierr)
         if (index .eq. 2) goto 170
         write(13,'(f6.1)') wet

C ***    Repeat until a correct input
  180       write(*,1600)
            read(*,*,IOSTAT = ierr) dry
            call fselpro(0.,1500.,dry,index,ierr)
         if (index .eq. 2) goto 180
         write(13,'(f6.1)') dry

C ***    Repeat until a correct input
  190       write(*,1700)
            read(*,*,IOSTAT = ierr) dry2
            call fselpro(-1.,1500.,dry2,index,ierr)
         if (index .eq. 2) goto 190
         write(13,'(f6.1)') dry2

C *** Grossman Compliant Cavity Method Calculation ***
      diff = finv1 + finv2 - iniv
      vol2 = (dry2 - cont)/2.65
      tbd(iflag) = (dry - cont)/diff
      twv(iflag) = (wet - dry)*100./diff
      pbd(iflag) = (dry - dry2)/(diff - vol2)
      pwv(iflag) = (dry - dry2)*100./(diff - vol2)
      if (dry2 .le. 0.) then
         pbd(iflag) = 0.
         pwv(iflag) = 0.
      endif
      write(10,'(i2,9(f8.2))') iflag,iniv,finv1,finv2,cont,wet,dry,dry2,
     +                         twv(iflag),tbd(iflag)
      if (iflag .eq. 1) goto 125
```

APPENDIX 3 (cont'd)

```
      avetbd = (tbd(1) + tbd(2))/2.

      avetwv = (twv(1) + twv(2))/2.
      avepbd = (pbd(1) + pbd(2))/2.
      avepwv = (pwv(1) + pwv(2))/2.

      write (10,*)
      write (10,*) '    Total Sample'
      write (10,'(7x,A,f6.2,A,f6.2,/)')
     +        'Ov(%): ',avetwv,'       BD(g/cm**3):',avetbd

      if (avepbd .le. 0. .or. avepwv .le. 0.) goto 199
      write (10,*) '    Less than 2mm Sample'
      write (10,'(7x,A,f6.2,A,f6.2,/)')
     +        'Ov(%): ',avepwv,'       BD(g/cm**3):',avepbd

199   mabd = 0.0
      mawv = 0.0
      iset = 0
      ierror = 0
      write(10,'(/,A)') 'MADERA METHOD READING AND INDIVIDUAL OUTPUT:'
      WRITE(10,*)' SET    CON  WETS+CON DRYS+CON   Ov      BD'
      do 400 iflag = 1,5
         do 300 jflag = 1,2
         call clear
         write(*,'(15x,A)') 'C. MADERA METHOD'

         write(*,'(15x,A,i2,A,i2)')
     &         '   Input number : ',iflag,'-',jflag
C ***    Repeat until a correct input
  200       write(*,1800)
            read(*,*,IOSTAT = ierr) macon
            call fselpro(-1.,170.,macon,index,ierr)
         if (index .eq. 2) goto 200
         write(13,'(f6.1)') macon

C ***    Repeat until a correct input
  210       write(*,1900)
            read(*,*,IOSTAT = ierr) mawet
            call fselpro(-1.,400.,mawet,index,ierr)
         if (index .eq. 2) goto 210
         write(13,'(f6.1)') mawet

C ***    Repeat until a correct input
  220       write(*,2000)
            read(*,*,IOSTAT = ierr) madry
            call fselpro(-1.,400.,madry,index,ierr)
         if (index .eq. 2) goto 220
         write(13,'(f6.1)') madry

C ***    C. Madera Sampler Method   ***
         ierror = ierror + 1
         iset = iset + 1
         mabdi(iset) = (madry - macon)/60.
         mawvi(iset) = (mawet - madry)*100./60.
         if (madry .le. 0. .or. mawet .le. 0.) then
            ierror = ierror - 1
            mabdi(iset) = 0.
            mawvi(iset) = 0.
         endif

         mabd = mabdi(iset) + mabd
         mawv = mawvi(iset) + mawv
 222  WRITE(10,'(I2,A,I2,5(F8.1))')IFLAG,'-',JFLAG,MACON,MAWET,MADRY,
     +                             MAWVI(ISET),MABDI(ISET)
 300  continue
 400  continue

      mabd = mabd / float(ierror)
      mawv = mawv / float(ierror)
```

APPENDIX 3 (cont'd)

```
      SSBD = 0.
      SSWV = 0.
      DO 401 I = 1,10

      if (mabdi(i) .eq. 0. .or. mawvi(i) .eq. 0.) goto 401
      SSBD = (MABDI(I) - MABD)**2 + SSBD
      SSWV = (MAWVI(I) - MAWV)**2 + SSWV
 401  CONTINUE
      STDBD = (SSBD/(ierror-1))**.5
      STDWV = (SSWV/(ierror-1))**.5
      write (10,*)
      write (10,'(7x,4(A,f6.2))')
     +       'Ov(%): ',mawv,'    Std:',stdwv,'       BD(g/cm**3):',
     +mabd,'    Std:',stdbd

  800 format(15X,'**************************************',/,
     1       15X,'* BULK DENSITY COMPUTATION SYSTEM *',/,
     2       15X,'**************************************',////,
     3       10x,'Please type the output file name ',
     4       '(eq. CMW6BD) : ',\)
  950 format(/,10x,'           Beads with residue : ',\)
 1000 format(10x,'         Total number of beads: ',\)
 1100 format(10x,'    Grossman initial vol (ml) : ',\)
 1200 format(10x,'    Grossman final vol 1 (ml) : ',\)
 1300 format(10x,'    Grossman final vol 2 (ml) : ',\)
 1400 format(10x,'      Weight of container (g) : ',\)
 1500 format(10x,'Weight of wet soil+container(g) : ',\)
 1600 format(10x,'Weight of dry soil+container(g) : ',\)
 1700 format(10x,'Weight of dry soil ( >2mm ) +container(g) : ',\)
 1800 format(10x,'        Weight of container (g) : ',\)
 1900 format(10x,'        Weight of wet soil+container(g) : ',\)
 2000 format(10x,'        Weight of dry soil+container(g) : ',\)

      call clear
      write (*,'(15x,A,/,A,A,A,/,A)')
     &      'Calculation Completed',
     &      '     Output file is "', outfname,'"',
     &      '     Input data stores in "INPUTF2"'
      close (10)
      close (13)
      end
```

APPENDIX 4

Soil water content estimation from texture and bulk density.

APPENDIX 4. Soil water content estimation from texture and bulk density

```
      PROGRAM SOILW
C
C     PROGRAM TO CALCULATE SOIL WATER CONTENT FROM SOIL TEXTURE
C     BY Dr. J. RITCHIE AND JIMMY T. CHOU, FEB. 22, 1988
C     A87, PSS BUILDING, MICHIGAN STATE UNIVERSITY, MI 48824
C     (517) 353-8537
C
      REAL LOLM,LOLC
C
C     CLAY   : CLAY CONTENT(%)
C     SAND   : SAND CONTENT(%)
C     OC     : ORGANIC CARBON
C     DF     : FIELD BULK DENSITY
C     RFW    : ROCK FRAGMENTS BY WEIGHT (%)
C
111   write(*,*)'     Please input clay content (%): '
      read (*,*)clay
      write(*,*)'     Please input sand content (%): '
      read (*,*)sand
      silt=100.-sand-CLAY
      if (silt .lt. 0.) then
         write (*,*) '     Wrong data, Please re-input '
         goto 111
      endif
      write(*,*)'     Please input Bulk Density (g/cm**3):'
      read (*,*) DF
      write(*,*)'     Please input organic carbon content (%):'
      read (*,*) OC
      write(*,*)'     Please input rock fragments by weight (%):'
      read (*,*) RFW
C
C     ASSUME THE ORGANIC MATTER CONTENT IS 1.72 TIMES ORGANIC CARBON
C     IF THERE IS NO ORGANIC CARBON DATA, ASSUME OC=0.
C
      IF(OC.LT.0.) OC=0.
      OM=OC*1.72
C
      IF(SAND.LE.75)GOTO 62
      LOLM=0.188-0.00168*SAND
      PLEXWM=0.423-0.00381*SAND
      GOTO 65
   62 LOLM=0.0362+0.00444*CLAY
      IF(SILT.LT.70)GOTO 63
      LOLM=0.05+0.000244*CLAY**2.
   63 PLEXWM=0.1079+0.0005004*SILT
C
   65 IF (SAND.GT.80.)   DM= 1.709- 0.01134*CLAY
C
      IF(SAND.GE.20..AND.SAND.LE.80.) THEN
        DM=1.118+0.00816*SAND+CLAY*(0.00834-0.36056/(SILT+CLAY))
      ENDIF
C
      IF (SAND.LT.20.)   DM= 1.45314 - 0.00433*SAND
C
C     DFC : CACULATED BULK DENSITY
C
      DFC=(OM*0.224 + (100-OM)*DM) /100.
C
C     IF THERE IS NO DATA ON BULK DENSITY, USE THE CALCULATED VALUE
C     SAVE FIELD MEASURED DF TO DFO AS AN OUTPUT
C
      DFO=DF
      IF(DF.LT.0.01) DF=DFC
C
```

APPENDIX 4 (cont'd)

```
C     LOLC    : CALCULATED SOIL-WATER LOWER LIMIT
C     PLEXWC  : CALCULATED SOIL-WATER EXTRACTABLE
C     DULC    : CALCULATED SOIL-WATER DRAINED UPPER LIMIT
C     SATC    : CALCULATED SOIL-WATER SATURATION
C
      DULC=LOLM+PLEXWM-0.17*(DM-DF)+0.0023*OM
      PLEXWC=PLEXWM+0.035*(DM-DF)+0.0055*OM
      LOLC=DULC-PLEXWC
C
C     ADJUST THE SOIL-WATER BY ROCK FRAGMENTS (RFW)
C     RFV   :ROCK FRAGMENTS BY VOLUME (%)
C     SV    :SOIL VOLUME EXCLUDING ROCK FRAGMENTS(%)
C
      IF (RFW.GT.0.) THEN
         RFV=100./(1+2.65*((100.-RFW)/(RFW*DF)))
         SV=100.-RFV
         LOLC=LOLC*SV/100.
         DULC=DULC*SV/100.
      ENDIF
C
C     ASSUME SATC EQUAL TO 85% OF SOIL POROSITY
C
      SATC=.85*(1-DF/2.65)
      IF(SATC-DULC.LT.0.015) SATC=DULC+0.015
C
C
      WRITE(*,'(/,3(A,F6.3),/)') ' Lower Limit :',lolc,
     +'   Drained Upper Limit :',dulc,'   Saturated Content :',satc
      write (*,*) 'Another set of data ? (Y or N)'
      read (*,'(A)') answer
      if (answer .eq. 'Y' .or. answer .eq. 'y') goto 111
C
999   STOP
      END
```

APPENDIX 5

Optimization Complex program for best-fit ponding curves estimation.

APPENDIX 5 Optimization Complex program for best-fit ponding curves estimation

```
      PROGRAM ESTIMATE
C **************************************************************************
C      This is a parameter estimation fortran program developed to       *
C      estimate the soil infiltration parameters (moisture status and    *
C      saturated hydraulic conductivity) using the Complex (non-linear   *
C      optimization) algorithm by M.J. Box (Kuester, J.L. and J.H. Mize*
C      1973) Optimization Techniques with Fortran                       *
C **************************************************************************
C      Complex algorithm adapted from Kuester and Mize, pp. 375-380.    *
C **************************************************************************
C
C     Description of parameters:
C     N = number of explicit independent variables; defined in main program
C     M = number of sets of constraints; defined in main program
C     K = number of points in the complex; defined in main program
C     ITMAX = maximum number of iterations; defined in main program
C     IC = number of implicit variables; defined in main program
C     ALPHA = reflection factor; defined in main program
C     BETA = convergence parameter; defined in main program
C     GAMMA = convergence iteration; defined in main program
C     DELTA = explicit constraint violation correction; defined in main program
C     IPRINT = code to control printing of intermediate iterations.
C              IPRINT=1 causes intermediate values to print on each iteration.
C              IPRINT=0 suppresses printing until final solution is obtained.
C              Defined in main program.
C     X = independent variables; define initial values in main program
C     R = random numbers between 0 and 1; defined in main program
C     F = objective function; defined in subroutine FUNC
C     IT = iteration index; defined in subroutine CONSX
C     IEV2 = index of point with maximum function value; defined in
C            subroutine CONSX
C     IEV1 = index point with minimum function value; defined in
C            subroutines CONSX and CHECK
C     G = lower constraint; defined in subroutine CONST
C     H = upper constraint; defined in subroutine CONST
C     XC = centroid; defined in subroutine CENTR
C     I = point index; defined in subroutine CONSX
C     KODE = key used to determine if implicit constraints are provided;
C            defined in subroutines CONSX and CHECK
C     K1 = Do loop limit; defined in subroutine CONSX
C
C     The user-supplied subroutines are:
C        FUNC - specifies the objective functions
C       CONST - specifies the explicit and implicit constraints
C
C     The dimensions are: X(K,M), R(K,N), F(K), G(M), H(M), XC(N)
C
C ******************************************************************************
C
      DIMENSION X(10,10), R(10,10), F(10), G(10), H(10), XC(10)
      INTEGER GAMMA
      character*12 file(0:8)
C
      OPEN (150,FILE='re.out',ACCESS='SEQUENTIAL',STATUS='UNKNOWN')
      open (90,file='re.in',status='unknown')
      write (*,'(//,10x,A,//)') 'COMPLEX PROGRAM FOR BEST FITTNESS'
      write (*,*) 'Please input the estimated variables number (3-10):'
      read (*,'(i2)') n
      write (90,*) n
      file(0) = 'Ks'
c
      do 1000 ifile = 1,n-1
      write (*,'(A,i2,A)') 'File name for ',ifile,' data set:'
      read (*,'(A)') file(ifile)
```

APPENDIX 5 (cont'd)

```
      write (90,'(A)') file(ifile)
      ifilen=ifile+9
      open (ifilen,file=file(ifile),status='old')
1000  continue
c
      m = n
      k=10
      itmax=1000
      ic=0
      iprint=0
      alpha=1.3
      beta=.00001
      gamma=5
      DELTA=0.00001
c
      write (*,*) 'Initial value for Ks (mm/hr):'
      read (*,*) x(1,1)
      write (90,*) x(1,1)
      do 2000 ifile = 2,n
      write (*,'(A,i2,A)') 'Initial value for ',ifile-1,' m.ca:'
      read (*,*) x(1,ifile)
      write (90,*) x(1,ifile)
2000  continue
c
      DO 100 II=2,K
         DO 101 JJ=1,N
            CALL RANDN (YFL)
            R(II,JJ) = YFL
 101     CONTINUE
 100  CONTINUE
C
      WRITE (150,010)
 010  FORMAT (4X,'PARAMETER ESTIMATION BY THE COMPLEX METHOD',//,
     +1X,'ESTIMATION OF INFILTRATION MODEL (TIME-TO-PONDING) ',///,
     +  1X,'PARAMETERS')
      WRITE (150,011) N,M,K,ITMAX,IC,ALPHA,BETA,GAMMA,DELTA
 011  FORMAT (/,3X,'N=',I2,3X,'M=',I2,3X,'K=',I2,3X,'ITMAX=',I3,
     +3X,'IC=',I2,/,3X,'ALPHA=',F5.2,3X,'BETA=',F10.5,3X,'GAMMA=',
     +I2,3X,'DELTA=',F6.4)
C
      write (*,'(/,15x,A,/)') 'Program is running !'
  50  CALL CONSX (N,M,K,ITMAX,ALPHA,BETA,GAMMA,DELTA,X,R,F,IT,
     +    IEV2,G,H,XC,IPRINT)
C     IF (IT-ITMAX) 20,20,30
  20  WRITE (150,018) IT
 018  FORMAT (//,1X,'FINAL ITERATION: ',I5)
      WRITE (150,014) F(IEV2)
      write (*,14) f(iev2)
 014  FORMAT (//,1X,'FINAL VALUE OF THE FUNCTION (r square) =',F8.4)
      WRITE (150,015)
      write (*,15)
 015  FORMAT (/,1X,'FINAL X VALUES')
      DO 300 J=1,N
      WRITE (150,016) J,X(IEV2,J),file(j-1)
      write (*,16) j,x(iev2,j),file(j-1)
 016  FORMAT (3X,'X(',I2,') = ',F8.2,3x,A)
 300  CONTINUE
      GOTO 999
  30  WRITE (150,017) IT
 017  FORMAT (1X,'The number of iterations has exceeded',I3,
     +  '.  Program is terminated.')
 999  write (*,'(//,15x,A)') 'Program completed'
      write (*,'(15x,A)') 'Output file is "re.out"'
      write (*,'(15x,A)') 'Input data stores in "re.in"'
      STOP
      END
C
C *****************************************************************
C     SUBROUTINE CONSX is called from the main program and
C     coordinates all special purpose subroutines (CHECK,
```

APPENDIX 5 (cont'd)

```
C     CENTR, FUNC, and CONST).
C *******************************************************************
      SUBROUTINE CONSX (N,M,K,ITMAX,ALPHA,BETA,GAMMA,DELTA,X,R,F,
     +   IT,IEV2,G,H,XC,IPRINT)
C
C     IT = ITERATION INDEX
C     IEV1 = INDEX OF POINT WITH MINIMUM FUNCTION VALUE
C     IEV2 = INDEX OF POINT WITH MAXIMUM FUNCTION VALUE
C     I = POINT INDEX
C     KODE = CONTROL KEY USED TO DETERMINE IF IMPLICIT CONSTRAINTS
C          ARE PROVIDED
C     K1 = DO LOOP LIMIT
C
      DIMENSION X(10,10), R(10,10), F(10), G(10), H(10), XC(10)
      INTEGER GAMMA
C
      IT = 1
      KODE = 0
      IF (M-N) 20,20,10
   10 KODE = 1
   20 CONTINUE
      DO 40 II=2,K
      DO 30 J=1,N
   30 X(II,J) = 0.0
   40 CONTINUE
C
C     CALCULATE COMPLEX POINTS AND CHECK AGAINST CONSTRAINTS
C
      DO 65 II=2,K
      DO 50 J=1,N
      I=II
      CALL CONST (N,M,K,X,G,H,I)
      X(II,J) = G(J) + R(II,J)*(H(J)-G(J))
   50 CONTINUE
      K1 = II
      CALL CHECK (N,M,K,X,G,H,I,KODE,XC,DELTA,K1)
      IF (II-2) 51,51,55
   51 WRITE (150,018)
  018 FORMAT (/,1X,'COORDINATES OF INITIAL COMPLEX')
      IO = 1
      WRITE (150,019) (IO, J, X(IO,J), J=1,N)
  019 FORMAT (1X,3(3X,'XC(',I2,',',I2,') = ',F8.2))
   55 IF (IPRINT) 56,65,56
   56 WRITE (150,019) (II, J, X(II,J), J=1,N)
   65 CONTINUE
      K1 = K
      DO 70 I=1,K
      CALL FUNC (N,M,K,X,F,I)
   70 CONTINUE
      KOUNT = 1
      IA = 0
C
C     FIND POINT WITH LOWEST FUNCTION VALUE
C
      IF (IPRINT) 72,80,72
   72 WRITE (150,021) (J,F(J), J=1,K)
  021 FORMAT (/,1X,'VALUES OF THE FUNCTION',/,
     + 1X,3(3X,'F(',I2,') = ',F8.2))
   80 IEV1 = 1
      DO 100 ICM=2,K
      IF (F(IEV1)-F(ICM)) 100,100,90
   90 IEV1 = ICM
  100 CONTINUE
C
      F(ITEMP)=F(IEV1)
C
C     FIND POINT WITH HIGHEST FUNCTION VALUE
C
      IEV2 = 1
```

APPENDIX 5 (cont'd)

```
      DO 120 ICM=2,K
      IF (F(IEV2)-F(ICM)) 110,110,120
 110  IEV2 = ICM

 120  CONTINUE
C
C     CHECK CONVERGENCE CRITERIA
C
      IF (F(IEV2)-(F(IEV1)+BETA)) 140,130,130
 130  KOUNT = 1
      GO TO 150
 140  KOUNT = KOUNT + 1
      IF (KOUNT-GAMMA) 150,240,240
C
C     REPLACE POINT WITH LOWEST FUNCTION
C
 150  CALL CENTR (N,M,K,IEV1,I,XC,X,K1)
      DO 160 JJ=1,N
 160  X(IEV1,JJ) = (1.0+ALPHA)*(XC(JJ))-ALPHA*(X(IEV1,JJ))
      I = IEV1
      CALL CHECK (N,M,K,X,G,H,I,KODE,XC,DELTA,K1)
      CALL FUNC (N,M,K,X,F,I)
C
C     REPLACE NEW POINT IF IT REPEATS AS LOWEST FUNCTION VALUE
C
      ICOUNT=0
 170  IEV = 1
      DO 190 ICM=2,K
      IF (F(IEV)-F(ICM)) 190,190,180
 180  IEV = ICM
 190  CONTINUE
      IF (IEV-IEV1) 220,200,220
 200  DO 210 JJ=1,N
      X(IEV1,JJ)=(X(IEV1,JJ) + XC(JJ))/2.0
 210  CONTINUE
      I=IEV1
      CALL CHECK (N,M,K,X,G,H,I,KODE,XC,DELTA,K1)
      CALL FUNC (N,M,K,X,F,I)
      ICOUNT=ICOUNT+1
      IF (ICOUNT-5) 170,170,215
 215  IF (F(ITEMP).GE.F(IEV1)) CALL HELP(N,M,K,X,F,IEV1,
     +   R,G,H,KODE,XC,DELTA,K1)
C
 220  CONTINUE
C
      IF (IPRINT) 230,228,230
 230  WRITE (150,023) IT
 023  FORMAT (//,1X,'ITERATION NUMBER ',I5)
      WRITE (150,024)
 024  FORMAT (/,1X,'COORDINATES OF CORRECTED POINT')
      WRITE (150,019) (IEV1,JC,X(IEV1,JC), JC=1,N)
      WRITE (150,021) (I,F(I), I=1,K)
      WRITE (150,025)
 025  FORMAT (/,1X,'COORDINATES OF THE CENTROID')
      WRITE (150,026) (JC,XC(JC), JC=1,N)
 026  FORMAT (1X,3(3X,'X(',I2,') = ',F14.6))
 228  IT = IT + 1
      IF (IT-ITMAX) 80,80,240
 240  RETURN
      END
C
C ********************************************************************
C     Subroutine CHECK checks all points against explicit and        *
C     implicit constraints and applies correction if violations      *
C     are found.                                                     *
C ********************************************************************
      SUBROUTINE CHECK (N,M,K,X,G,H,I,KODE,XC,DELTA,K1)
      DIMENSION X(10,10), G(10), H(10), XC(10)
C
  10  KT = 0
```

APPENDIX 5 (cont'd)

```
      CALL CONST (N,M,K,X,G,H,I)
C
C     CHECK AGAINST EXPLICIT CONSTRAINTS
C
      DO 50 J=1,N

      IF (X(I,J)-G(J)) 20,20,30
   20 X(I,J) = G(J) + DELTA
      GO TO 50
   30 IF (H(J)-X(I,J)) 40,40,50
   40 X(I,J) = H(J) - DELTA
   50 CONTINUE
C
      IF (KODE) 110,110,60
C
C     CHECK AGAINST THE IMPLICIT CONSTRAINTS
C
   60 NN = N + 1
      DO 100 J=NN,M
      CALL CONST (N,M,K,X,G,H,I)
      IF (X(I,J)-G(J)) 80,70,70
   70 IF (H(J)-X(I,J)) 80,100,100
   80 IEV1 = I
      KT = 1
      CALL CENTR (N,M,K,IEV1,I,XC,X,K1)
      DO 90 JJ=1,N
      X(I,JJ) = (X(I,JJ) + XC(JJ))/2.0
   90 CONTINUE
  100 CONTINUE
      IF (KT) 110,110,10
  110 RETURN
      END
C
C ****************************************************************
C     Subroutine CENTR calculates the centroid of points.        *
C ****************************************************************
C
      SUBROUTINE CENTR (N,M,K,IEV1,I,XC,X,K1)
      DIMENSION X(10,10), XC(10)
      DO 20 J=1,N
      XC(J) = 0.0
      DO 10 IL=1,K1
   10 XC(J) = XC(J) + X(IL,J)
      RK = K1
   20 XC(J) = (XC(J)-X(IEV1,J))/(RK-1.0)
      RETURN
      END
C
C ********************************************************************
C     Subroutine FUNC specifies objective function (user supplied).*
C ********************************************************************
C
      SUBROUTINE FUNC (N,M,K,X,F,I)
      DIMENSION X(10,10), F(10)
C
      iend = n+8
      do 1000 irewind = 10,iend
      rewind irewind
 1000 continue

      icount=0
      srys=0.
      sry=0.
      ses=0.
      se=0.
      sery=0.
C
      do 002 im=10,iend
001      read (im,*,end=002) junk,cumw,rate
         icount=icount+1
```

APPENDIX 5 (cont'd)

```
            iforx = im -10 +2
            yrate=x(i,1)/(1-exp(-cumw/x(i,iforx)))
          diff =rate-yrate
          srys=srys+rate**2
          sry=sry+rate
          ses=ses+diff**2
          se=se+diff

          sery=sery+diff*rate
        goto 001
002   continue
C
      siys=srys/icount-(sry/icount)**2
      sies=ses/icount-(se/icount)**2
      siyes=sery/icount-(sry/icount)*(se/icount)
      f(i)=((siys-siyes)**2)/(siys*(siys+sies-2*siyes))
C
      RETURN
      END
C
C *******************************************************************
C     Subroutine CONST specifies explicit and implicit constraint   *
C     limits (user supplied), order explicit constraints first.     *
C *******************************************************************
C
      SUBROUTINE CONST (N,M,K,X,G,H,I)
      DIMENSION X(10,10), G(10), H(10)
C
C     CONSTRAINTS ON Ks, m.Cr
C
      G(1)=15.0
      H(1)=20.00
      do 1000 iconst = 2,n
      G(iconst) = 1.0
      H(iconst) = 50.0
1000  continue
C
      RETURN
      END

C ***********************************************************************
C     Subroutine RANDN generates a uniform random number on the
C     interval 0-1.
C ***********************************************************************
C
      SUBROUTINE RANDN(YFL)
      DIMENSION K(4)
      DATA K/2510,7692,2456,3765/
      K(4) = 3*K(4)+K(2)
      K(3) = 3*K(3)+K(1)
      K(2)=3*K(2)
      K(1) = 3*K(1)
      I=K(1)/1000
      K(1)=K(1)-I*1000
      K(2)=K(2) + I
      I = K(2)/100
      K(2)=K(2)-100*I
      K(3) = K(3)+I
      I = K(3)/1000
      K(3)=K(3)-I*1000
      K(4)=K(4)+I
      I = K(4)/100
      K(4)=K(4)-100*I
      YFL=(((FLOAT(K(1))*.001+FLOAT(K(2)))*.01+FLOAT(K(3)))*.001+FLOAT
     *(K(4)))*.01
      RETURN
      END
C
C *******************************************************************
C     Subroutine HELP will identify a new complex point when the
```

APPENDIX 5 (cont'd)

```
C     minimum point is not able to get out of the complex for some
C     reasons.*
C ***********************************************************************
C
      SUBROUTINE HELP(N,M,K,X,F,IEV1,R,G,H,KODE,XC,DELTA,K1)
      DIMENSION X(10,10), R(10,10), F(10), G(10), H(10)
      DO 10 J=1,N
         CALL RANDN(YFL)
         R(IEV1,J)=YFL

         CALL CONST(N,M,K,X,G,H,I)
         X(IEV1,J)=G(J) + R(IEV1,J)*(H(J)-G(J))
   10 CONTINUE
         CALL CHECK(N,M,K,X,G,H,IEV1,KODE,XC,DELTA,K1)
         CALL FUNC(N,M,K,X,F,IEV1)
      RETURN
      END
```

APPENDIX 6

Fortran source code of storm generator program.

APPENDIX 6. Fortran source code of storm generator program

```
      PROGRAM STORM_GEN
c
c     rainstorm generator
c
      REAL PWW(6),PWD(6),A(6),B(6),P1,P2,P3,P4,P5,P6,RN,LDURA,DURA(20),
     +     RNNOR,AMOUNT(20),PEAK(20),IP(20),TP(20)
      INTEGER PP,ID,IM,IY,LIMONTH(6),EVENTN,LYEAR
C
C
      OPEN (12,FILE='georanapr.d',status='old')
      OPEN (13,FILE='gamranapr.d',status='old')
      OPEN (14,FILE='norranapr.d',status='old')
      OPEN (15,FILE='simuapr.wth',status='unknown')
      OPEN (16,FILE='simuapr.eve',status='unknown')
      OPEN (22,FILE='georanmay.d',status='old')
      OPEN (23,FILE='gamranmay.d',status='old')
      OPEN (24,FILE='norranmay.d',status='old')
      OPEN (25,FILE='simumay.wth',status='unknown')
      OPEN (26,FILE='simumay.eve',status='unknown')
      OPEN (32,FILE='georanjun.d',status='old')
      OPEN (33,FILE='gamranjun.d',status='old')
      OPEN (34,FILE='norranjun.d',status='old')
      OPEN (35,FILE='simujun.wth',status='unknown')
      OPEN (36,FILE='simujun.eve',status='unknown')
      OPEN (42,FILE='georanjul.d',status='old')
      OPEN (43,FILE='gamranjul.d',status='old')
      OPEN (44,FILE='norranjul.d',status='old')
      OPEN (45,FILE='simujul.wth',status='unknown')
      OPEN (46,FILE='simujul.eve',status='unknown')
      OPEN (52,FILE='georanaug.d',status='old')
      OPEN (53,FILE='gamranaug.d',status='old')
      OPEN (54,FILE='norranaug.d',status='old')
      OPEN (55,FILE='simuaug.wth',status='unknown')
      OPEN (56,FILE='simuaug.eve',status='unknown')
      OPEN (62,FILE='georansep.d',status='old')
      OPEN (63,FILE='gamransep.d',status='old')
      OPEN (64,FILE='norransep.d',status='old')
      OPEN (65,FILE='simusep.wth',status='unknown')
      OPEN (66,FILE='simusep.eve',status='unknown')

      PWW(1)=.467
      PWD(1)=.107
      PWW(2)=.402
      PWD(2)=.090
      PWW(3)=.340
      PWD(3)=.123
      PWW(4)=.234
      PWD(4)=.103
      PWW(5)=.406
      PWD(5)=.099
      PWW(6)=.352
      PWD(6)=.108
      A(1)=-.354
      B(1)=.526
      A(2)=-.449
      B(2)=.526
      A(3)=-.734
      B(3)=.424
      A(4)=-.687
      B(4)=.371
      A(5)=-.687
      B(5)=.381
      A(6)=-.547
      B(6)=.445

      P1=6.8
```

appendix 6 (CONT'D)

```
      P2=41.
      P3=62.1

      P4=84.9
      P5=94.5
      P6=126.

      LYEAR = 30
      LIMONTH(1)=30
      LIMONTH(2)=31
      LIMONTH(3)=30
      LIMONTH(4)=31
      LIMONTH(5)=31
      LIMONTH(6)=30

      DO 1000 IY=1,LYEAR
         PP=0
         DO 2000 IM=1,6
            ireve=im*10 + 2
            iramo=im*10 + 3
            irnor=im*10 + 4
            iout=im*10 + 5
            iouteve=im*10 + 6
            DO 3000 ID=1,LIMONTH(IM)

      CALL RANDOM(RN)

      IF (((PP.GT.0) .AND. (RN.GT.PWW(IM))) .OR.
     +    ((PP.LE.0) .AND. (RN.GT.PWD(IM)))) THEN
         PP = 0
      ELSE
         PP = 1
10       READ (ireve,*) JUNK,EVENTN
         IF (EVENTN .LT. 1) GOTO 10
         DO 100 I=1,EVENTN
20          READ (iramo,*) JUNK, AMOUNT(I)
            IF (AMOUNT(I) .LT. 0.254) GOTO 20
30          READ (irnor,*) JUNK, RNNOR
            LDURA = A(IM) + B(IM) * LOG(AMOUNT(I)) + RNNOR
            DURA(I) = EXP(LDURA)
            IF (DURA(I) .LE. 0.) GOTO 30
            IF (AMOUNT(I) .LT. 5.) P=P1
            IF (AMOUNT(I) .GE. 5. .AND. AMOUNT(I) .LT. 10.) P=P2
            IF (AMOUNT(I) .GE. 10. .AND. AMOUNT(I) .LT. 15.) P=P3
            IF (AMOUNT(I) .GE. 15. .AND. AMOUNT(I) .LT. 20.) P=P4
            IF (AMOUNT(I) .GE. 20. .AND. AMOUNT(I) .LT. 25.) P=P5
            IF (AMOUNT(I) .GE. 25.) P=P6
40          CALL RANDOM(RN)
            PEAK(I) = -P * LOG(RN)
            IF (PEAK(I) .LT. AMOUNT(I) .OR. PEAK(I) .GT. 400.) GOTO 40
            IP(I) = PEAK(I) / (AMOUNT(I)/DURA(I))
            CALL RANDOM(RN)
            TP(I) = RN
            WRITE (iout,101) IY,IM+3,ID,I,AMOUNT(I),DURA(I),PEAK(I),
     +                       IP(I),TP(I)
            if (i.eq.eventn) then
               write(iouteve,101) iy,im+3,id,i
            endif
101         FORMAT (4I5,3F10.2,2F10.3)
100      CONTINUE
      ENDIF

3000  continue
2000  continue
1000  continue

999   STOP
      END
```

APPENDIX 6 (cont'd)

```
      subroutine random(ranf)
      REAL      ranf
      INTEGER   TEMP
      DIMENSION K(4)
      DATA K/2510,7692,2456,3765/
      K(4) = 3*K(4)+K(2)
      K(3) = 3*K(3)+K(1)
      K(2) = 3*K(2)
      K(1) = 3*K(1)
      TEMP = K(1)/1000
      K(1) = K(1)-TEMP*1000
      K(2) = K(2) + TEMP
      TEMP = K(2)/100
      K(2) = K(2)-100*TEMP
      K(3) = K(3)+TEMP
      TEMP = K(3)/1000
      K(3) = K(3)-TEMP*1000
      K(4) = K(4)+TEMP
      TEMP = K(4)/100
      K(4) = K(4)-100*TEMP
      RANF = (((FLOAT(K(1))*.001+FLOAT(K(2)))*.01+FLOAT(K(3)))*.001+
     +           FLOAT(K(4)))*.01
      return
      END
```

APPENDIX 7

Field measurement and derived soil properties from ponding curves for infiltrometer experiment.

APPENDIX 7. Field measurement and derived soil properties from ponding curves for infiltrometer experiment

File	Date	Residue	θini	BD	θsat	Ks	Sn	r^2
CMW1	7/13	0	2.7	1.5	36.9	11.8	11.57	0.269
CMW2*	8/03	3	11.5	1.47	37.8	6.45	12.42	0.683
CMW3	7/25	2	7.5	1.47	37.8	21.66	12.47	0.213
CMW5	7/06	0	7.7	1.49	37.2	9.99	12.59	0.243
CMN2	7/06	0	6.0	1.35	41.7	21.26	14.39	0.243
CMM3	7/25	3	5.9	1.28	43.9	29.12	13.65	0.225
CMN4	7/31	2	2.6	1.38	40.7	16.31	16.54	0.485
CMN5*	8/03	3	10.9	1.28	43.9	20.90	13.06	0.735
CDW3	6/28	3	10.1	1.43	39.1	24.82	11.24	0.266
CDW5*	7/10	1	7.9	1.58	34.3	7.8	13.86	0.546
CDW6	7/28	2	11.1	1.54	35.6	10.74	11.95	0.438
CDN1	8/02	5	14.9	1.40	40.1	20.44	10.2	0.348
CDN2	7/10	2	6.0	1.39	40.4	17.53	11.58	0.410
CDN4	6/28	6	12.9	1.43	39.1	15.76	9.84	0.385
CDN5*	7/24	10	12.9	1.35	41.7	20.63	10.41	0.571
CNW5*	7/27	72	7.6	1.44	38.8	53.81	14.27	0.073
CNN3	6/29	43	6.2	1.40	40.1	57.73	18.18	0.431
CNN4	7/24	67	11.9	1.49	37.2	39.86	12.66	0.076
CNN5*	8/02	73	17.5	1.43	39.1	41.91	21.52	0.520
PWW1	7/13	0	12.0	1.49	37.2	18.04	12.84	0.334
PMW2	8/07	7	16.0	1.60	33.7	13.5	10.2	0.756
PMW4	8/01	5	12.0	1.58	34.3	16.14	14.42	0.726
PMW5	6/30	0	13.0	1.58	34.3	11.21	12.26	0.740
PMW6	7/26	57	11.0	1.60	33.7	10.85	14.1	0.590
PMN1	7/13	0	9.3	1.34	42.0	21.16	8.88	0.203
PMN2	8/01	7	14.2*	1.30	43.3	14.74	12.88	0.695
PMN3	8/07	7	14.3	1.31	43.0	11.12	14.45	0.552
PMN4	6/30	0	10.8*	1.33	42.3	7.03	15.19	0.533
PMN5	7/26	20	5.9*	1.32	42.7	6.88	22.34	0.906
PPW1	7/26	25*	7.0	1.56	35.0	16.33	17.76	0.493
PPW2	8/07	17	12.2	1.61	33.4	18.56	12.78	0.445

APPENDIX 7 (cont'd)

PPW4	7/05	0	14.7	1.58	34.3	13.55	10.47	0.420
PPW5	8/01	10	17.0	1.64	32.4	15.6	9.45	0.209
PPW6*	7/14	0*	14.2	1.58	34.3	12.21	11.64	0.717
PPN1	7/26	33*	6.5	1.34	42.0	13.74	20.10	0.828
PPN2*	7/19	0*	10.9	1.29	43.6	19.88	11.67	0.649
PPN3	8/07	5	14.5	1.34	42.0	14.60	12.97	0.720
PPN4	7/05	0	6.0	1.34	41.7	17.54	14.62	0.694
PPN5	8/01	15	16.1	1.28	43.9	12.84	13.24	0.553

APPENDIX 8

Field measured residue cover, initial water content, and bulk density for sprinkling infiltrometer experiment

APPENDIX 8. Field measured residue cover, initial water content, and bulk density for sprinkling infiltrometer experiment.

CMN6BD 26 June 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	602.00	835.00	528.00	14.10	1105.40	1041.80	-1.00	8.36	1.35
2	656.00	750.00	511.00	13.80	1003.20	946.50	-1.00	9.37	1.54

Total Sample
Ov(%): 8.86 BD(g/cm**3): 1.45

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	241.2	237.9	5.50	1.39
1- 2	154.5	249.7	245.4	7.17	1.51
2- 1	153.9	259.1	253.8	8.83	1.67
2- 2	-1.0	-1.0	-1.0	.00	.00
3- 1	153.7	256.0	251.9	6.83	1.64
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	-1.0	-1.0	-1.0	.00	.00
4- 2	153.7	255.0	251.0	6.67	1.62
5- 1	155.1	253.4	249.6	6.33	1.58
5- 2	-1.0	-1.0	-1.0	.00	.00

Ov(%): 6.89 Std: 1.11 BD(g/cm**3): 1.57 Std: .10

Remarks : None

CDN4BD 28 June 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	575.00	790.00	275.00	14.10	800.40	739.30	-1.00	12.47	1.48
2	590.00	740.00	425.00	14.30	939.60	854.90	-1.00	14.73	1.46

Total Sample
Ov(%): 13.60 BD(g/cm**3): 1.47

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.8	250.1	243.2	11.50	1.44
1- 2	155.5	245.8	238.0	13.00	1.38
2- 1	156.6	252.1	243.9	13.67	1.45
2- 2	156.5	252.8	245.1	12.83	1.48
3- 1	155.4	249.0	241.9	11.83	1.44
3- 2	155.2	251.1	243.7	12.33	1.48
4- 1	156.4	248.5	241.1	12.33	1.41
4- 2	156.3	252.9	244.4	14.17	1.47
5- 1	155.4	249.8	241.1	14.50	1.43

APPENDIX 8 (cont'd)

5- 2	156.4	242.4	234.7	12.83	1.31

Ov(%): 12.90 Std: .97 BD(g/cm**3): 1.43 Std: .05

Remarks : Leaks in Grossman samples.

CDW2BD 28 June 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	605.00	670.00	510.00	14.40	1024.20	942.50	-1.00	14.21	1.61
2	605.00	670.00	510.00	14.40	1024.20	942.50	-1.00	14.21	1.61

Total Sample
Ov(%): 14.21 BD(g/cm**3): 1.61

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.4	257.7	249.5	13.67	1.57
1- 2	156.4	251.9	244.5	12.33	1.47
2- 1	156.0	254.5	247.0	12.50	1.52
2- 2	155.2	254.8	247.8	11.67	1.54
3- 1	156.6	255.7	248.4	12.17	1.53
3- 2	156.8	261.4	253.9	12.50	1.62
4- 1	155.6	255.8	248.2	12.67	1.54
4- 2	156.9	250.6	243.4	12.00	1.44
5- 1	156.7	254.7	247.4	12.17	1.51
5- 2	155.1	253.8	246.2	12.67	1.52

Ov(%): 12.43 Std: .53 BD(g/cm**3): 1.53 Std: .05

Remarks : None

CMW6BD 26 June 1989

RESIDUE READING : 0

Crop Residue (%): .00

Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	625.00	505.00	939.00	28.10	1302.90	1209.20	-1.00	11.44	1.44
2	580.00	790.00	338.00	14.00	882.80	827.70	-1.00	10.05	1.48

Total Sample
Ov(%): 10.75 BD(g/cm**3): 1.46

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	-1.0	-1.0	-1.0	.00	.00
1- 2	155.1	268.1	264.1	6.67	1.82
2- 1	154.4	291.2	285.8	9.00	2.19
2- 2	153.9	288.9	281.1	13.00	2.12
3- 1	153.8	245.2	239.6	9.33	1.43

APPENDIX 8 (cont'd)

3- 2	154.3	268.6	262.7	9.83	1.81
4- 1	154.5	238.6	234.6	6.67	1.34
4- 2	155.2	240.8	236.2	7.67	1.35
5- 1	155.2	247.0	241.0	10.00	1.43
5- 2	155.3	252.3	245.3	11.67	1.50

Ov(%): 9.31 Std: 2.14 BD(g/cm**3): 1.66 Std: .33

Remarks : None

CNW2BD 29 JUNE 1989

RESIDUE READING : 40

Crop Residue (%): 66.67

Depth to layer B : 99.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	590.00	795.00	290.00	14.10	772.70	734.50	-1.00	7.72	1.46
2	528.00	690.00	420.00	14.20	820.70	783.40	-1.00	6.41	1.32

Total Sample
Ov(%): 7.06 BD(g/cm**3): 1.39

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	232.5	226.5	10.00	1.19
1- 2	156.0	238.2	234.3	6.50	1.31
2- 1	155.5	241.1	236.9	7.00	1.36
2- 2	155.8	248.1	244.0	6.83	1.47
3- 1	154.9	246.5	242.1	7.33	1.45
3- 2	155.1	235.7	231.3	7.33	1.27
4- 1	145.6	247.5	244.1	5.67	1.64
4- 2	155.1	244.8	240.7	6.83	1.43
5- 1	156.1	245.1	241.1	6.67	1.42
5- 2	155.2	239.2	234.9	7.17	1.33

Ov(%): 7.13 Std: 1.12 BD(g/cm**3): 1.39 Std: .13

Remarks : NONE

CNN3BD 29 JUNE 1989

RESIDUE READING : 43

Crop Residue (%): 71.67

Depth to layer B : 99.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	535.00	675.00	410.00	14.40	857.90	827.80	-1.00	5.47	1.48
2	460.00	682.00	320.00	14.20	807.20	774.30	-1.00	6.07	1.40

Total Sample
Ov(%): 5.77 BD(g/cm**3): 1.44

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD

APPENDIX 8 (cont'd)

1- 1	155.3	246.1	242.5	6.00	1.45
1- 2	154.8	247.0	243.6	5.67	1.48
2- 1	156.4	234.1	229.8	7.17	1.22
2- 2	156.2	241.3	237.0	7.17	1.35
3- 1	155.0	236.7	232.8	6.50	1.30
3- 2	156.3	250.4	246.8	6.00	1.51
4- 1	154.9	247.1	243.6	5.83	1.48
4- 2	154.6	245.7	242.3	5.67	1.46
5- 1	155.2	238.7	235.6	5.17	1.34
5- 2	154.7	243.8	239.6	7.00	1.42

Ov(%): 6.22 Std: .70 BD(g/cm**3): 1.40 Std: .09

Remarks : NONE

CDN5BD 24 JULY 89

Crop Residue (%): 10.00

Depth to layer B : 10.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.4	243.8	235.2	14.33	1.33
1- 2	156.4	249.3	240.8	14.17	1.41
2- 1	-1.0	-1.0	-1.0	.00	.00
2- 2	-1.0	-1.0	-1.0	.00	.00
3- 1	156.6	244.1	237.4	11.17	1.35
3- 2	156.8	242.1	235.7	10.67	1.31
4- 1	155.6	238.7	232.0	11.17	1.27
4- 2	156.9	239.0	232.4	11.00	1.26
5- 1	156.7	248.5	239.6	14.83	1.38
5- 2	155.1	254.4	245.0	15.67	1.50

Ov(%): 12.88 Std: 2.06 BD(g/cm**3): 1.35 Std: .08

Remarks : NONE

CNW4 24 JULY 1989

Crop Residue (%): 88.33

Depth to layer B : 99.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	249.5	243.1	10.67	1.47
1- 2	155.1	250.8	243.2	12.67	1.47
2- 1	154.4	251.7	244.8	11.50	1.51
2- 2	153.9	256.3	248.8	12.50	1.58
3- 1	153.8	250.0	242.4	12.67	1.48
3- 2	154.3	250.5	243.4	11.83	1.48
4- 1	154.5	251.7	245.0	11.17	1.51
4- 2	155.2	244.6	238.5	10.17	1.39
5- 1	155.2	251.4	244.0	12.33	1.48
5- 2	155.3	244.0	237.2	11.33	1.36

Ov(%): 11.68 Std: .87 BD(g/cm**3): 1.47 Std: .06

Remarks : DEER TRACKS

APPENDIX 8 (cont'd)

CNN4BD 24 JULY 1989

Crop Residue (%): 66.67

Depth to layer B : 99.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.5	252.0	244.5	12.50	1.50
1- 2	155.1	254.4	246.8	12.67	1.53
2- 1	154.5	255.0	248.2	11.33	1.56
2- 2	155.6	251.6	245.1	10.83	1.49
3- 1	156.4	253.6	246.3	12.17	1.50
3- 2	154.8	254.7	247.7	11.67	1.55
4- 1	156.4	249.0	241.4	12.67	1.42
4- 2	155.3	250.3	243.4	11.50	1.47
5- 1	154.8	254.0	246.8	12.00	1.53
5- 2	156.3	246.6	239.8	11.33	1.39

Ov(%): 11.87 Std: .63 BD(g/cm**3): 1.49 Std: .06

Remarks : NONE

CMW3BD 25 JULY 1989

Crop Residue (%): 1.67

Depth to layer B : 12.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.3	247.9	243.6	7.17	1.46
1- 2	156.1	250.0	245.9	6.83	1.50
2- 1	155.2	248.6	244.0	7.67	1.48
2- 2	155.2	250.1	245.6	7.50	1.51
3- 1	154.7	247.8	242.7	8.50	1.47
3- 2	155.9	246.4	241.3	8.50	1.42
4- 1	155.0	248.9	244.1	8.00	1.49
4- 2	155.9	244.8	241.1	6.17	1.42
5- 1	154.8	249.9	245.3	7.67	1.51
5- 2	155.9	245.1	240.8	7.17	1.42

Ov(%): 7.52 Std: .73 BD(g/cm**3): 1.47 Std: .04

Remarks : NONE

CMW5 6 JULY 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	580.00	610.00	470.00	13.90	903.80	868.80	-1.00	7.00	1.71
2	640.00	598.00	520.00	13.90	791.80	752.40	-1.00	8.24	1.54

Total Sample
Ov(%): 7.62 BD(g/cm**3): 1.63

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.3	251.6	247.0	7.67	1.51

APPENDIX 8 (cont'd)

1- 2	156.1	250.1	245.4	7.83	1.49
2- 1	155.2	248.2	243.5	7.83	1.47
2- 2	155.2	248.6	243.6	8.33	1.47
3- 1	154.7	248.3	243.9	7.33	1.49
3- 2	155.9	250.3	245.9	7.33	1.50
4- 1	155.0	247.8	243.7	6.83	1.48
4- 2	155.9	250.4	245.7	7.83	1.50
5- 1	154.8	248.6	243.9	7.83	1.48
5- 2	155.9	249.4	244.8	7.67	1.48

Ov(%): 7.65 Std: .40 BD(g/cm**3): 1.49 Std: .01

Remarks : NONE

CMN2BD 6 JULY 1989

RESIDUE READING : 0

Crop Residue (%): .00

Depth to layer B : 14.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	540.00	595.00	562.00	13.90	828.00	794.70	-1.00	5.40	1.27
2	520.00	490.00	510.00	14.00	788.00	760.00	-1.00	5.83	1.55

Total Sample
Ov(%): 5.62 BD(g/cm**3): 1.41

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	244.9	240.5	7.33	1.43
1- 2	154.5	241.7	237.9	6.33	1.39
2- 1	153.9	241.1	237.4	6.17	1.39
2- 2	153.9	236.9	233.6	5.50	1.33
3- 1	153.7	236.5	233.7	4.67	1.33
3- 2	154.5	239.8	236.5	5.50	1.37
4- 1	154.6	232.5	229.4	5.17	1.25
4- 2	153.7	226.8	223.4	5.67	1.16
5- 1	155.1	243.6	239.1	7.50	1.40
5- 2	154.4	243.5	240.1	5.67	1.43

Ov(%): 5.95 Std: .90 BD(g/cm**3): 1.35 Std: .09

Remarks : CRUST 1/4"

CDW5BD 10 JULY 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 11.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	593.00	911.00	248.00	13.90	967.50	928.30	-1.00	6.93	1.62
2	646.00	692.00	550.00	13.90	1064.60	1019.70	-1.00	7.53	1.69

Total Sample
Ov(%): 7.23 BD(g/cm**3): 1.65

APPENDIX 8 (cont'd)

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.4	254.3	249.9	7.33	1.58
1- 2	156.4	257.2	252.5	7.83	1.60
2- 1	156.0	252.5	248.1	7.33	1.54
2- 2	155.2	251.2	247.1	6.83	1.53
3- 1	156.6	259.0	255.1	6.50	1.64
3- 2	156.8	254.9	251.1	6.33	1.57
4- 1	155.6	262.8	256.6	10.33	1.68
4- 2	156.9	255.1	249.8	8.83	1.55
5- 1	156.7	257.1	251.9	8.67	1.59
5- 2	155.1	254.2	248.8	9.00	1.56

Ov(%): 7.90 Std: 1.28 BD(g/cm**3): 1.58 Std: .05

Remarks : NONE

CDN2BD 10 JULY 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	561.00	805.00	510.00	14.00	1082.00	1057.40	-1.00	3.26	1.38
2	620.00	945.00	650.00	27.90	1403.60	1335.00	-1.00	7.04	1.34

Total Sample
Ov(%): 5.15 BD(g/cm**3): 1.36

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.3	234.4	231.3	5.17	1.27
1- 2	154.8	240.0	238.0	3.33	1.39
2- 1	156.4	238.2	235.7	4.17	1.32
2- 2	156.2	248.0	245.7	3.83	1.49
3- 1	155.0	246.2	241.3	8.17	1.44
3- 2	156.3	246.3	242.7	6.00	1.44
4- 1	154.9	238.8	234.5	7.17	1.33
4- 2	154.6	236.1	231.5	7.67	1.28
5- 1	155.2	247.0	243.0	6.67	1.46
5- 2	154.7	249.3	244.7	7.67	1.50

Ov(%): 5.98 Std: 1.76 BD(g/cm**3): 1.39 Std: .09

Remarks : NONE

CNN6BD 11 JULY 1989

RESIDUE READING : 49

Crop Residue (%): 81.67

Depth to layer B : 24.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	598.00	725.00	572.00	13.80	1151.80	1122.50	-1.00	4.19	1.59
2	593.00	815.00	536.00	27.60	1253.50	1227.80	-1.00	3.39	1.58

APPENDIX 8 (cont'd)

Total Sample
Ov(%): 3.79 BD(g/cm**3): 1.58

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	241.6	240.4	2.00	1.39
1- 2	155.7	236.2	234.7	2.50	1.32
2- 1	155.7	237.8	236.5	2.17	1.35
2- 2	156.6	242.7	240.9	3.00	1.40
3- 1	-1.0	-1.0	-1.0	.00	.00
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	155.6	230.4	229.9	.83	1.24
4- 2	-1.0	-1.0	-1.0	.00	.00
5- 1	155.4	246.3	244.9	2.33	1.49
5- 2	156.4	243.3	242.0	2.17	1.43

Ov(%): 2.14 Std: .66 BD(g/cm**3): 1.37 Std: .08

Remarks : SURFACE RESIDUE REMOVED FOR GROSSMAN METHOD

CNW1BD 11 JULY 1989

RESIDUE READING : 50

Crop Residue (%): 83.33

Depth to layer B : 25.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	550.00	645.00	578.00	14.00	941.20	913.50	-1.00	4.12	1.34
2	668.00	725.00	590.00	13.90	1041.70	1026.10	-1.00	2.41	1.56

Total Sample
Ov(%): 3.26 BD(g/cm**3): 1.45

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.8	240.6	237.9	4.50	1.35
1- 2	155.5	238.8	236.7	3.50	1.35
2- 1	156.6	239.5	239.0	.83	1.37
2- 2	156.5	241.1	240.0	1.83	1.39
3- 1	155.4	238.6	237.5	1.83	1.37
3- 2	155.2	245.5	244.4	1.83	1.49
4- 1	156.4	243.6	243.0	1.00	1.44
4- 2	156.3	245.4	244.8	1.00	1.48
5- 1	155.4	230.9	229.9	1.67	1.24
5- 2	156.4	236.4	235.0	2.33	1.31

Ov(%): 2.03 Std: 1.16 BD(g/cm**3): 1.38 Std: .07

Remarks : RESIDUE REMOVED FROM SURFACE FOR GROSSMAN METHOD

CMN3BD 25 JULY 1989

Crop Residue (%): 3.33

Depth to layer B : 12.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD

APPENDIX 8 (cont'd)

1- 1	155.3	239.3	236.0	5.50	1.34
1- 2	154.8	233.3	230.2	5.17	1.26
2- 1	156.4	232.3	229.2	5.17	1.21
2- 2	156.2	238.1	234.6	5.83	1.31
3- 1	155.0	237.1	233.0	6.83	1.30
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	154.9	234.5	230.7	6.33	1.26
4- 2	154.6	229.2	225.6	6.00	1.18
5- 1	155.2	236.2	232.7	5.83	1.29
5- 2	154.7	237.8	234.2	6.00	1.33

Ov(%): 5.85 Std: .54 BD(g/cm**3): 1.28 Std: .05

Remarks : SURFACE CRUST

CDW3BD 25 JULY 1989

Crop Residue (%): 3.33

Depth to layer B : 12.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	248.3	242.4	9.83	1.45
1- 2	156.0	249.6	243.6	10.00	1.46
2- 1	155.5	249.4	243.1	10.50	1.46
2- 2	155.8	248.5	242.0	10.83	1.44
3- 1	154.9	246.1	239.9	10.33	1.42
3- 2	155.1	242.1	235.8	10.50	1.34
4- 1	154.6	243.9	238.0	9.83	1.39
4- 2	155.1	248.4	242.8	9.33	1.46
5- 1	156.1	247.1	241.2	9.83	1.42
5- 2	155.2	248.8	242.6	10.33	1.46

Ov(%): 10.13 Std: .44 BD(g/cm**3): 1.43 Std: .04

Remarks : SURFACE CRUST

CNW5BD 27 JULY 1989

Crop Residue (%): 71.67

Depth to layer B : 99.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	246.1	241.1	8.33	1.43
1- 2	155.1	248.4	243.8	7.67	1.48
2- 1	154.4	249.0	244.9	6.83	1.51
2- 2	153.9	244.6	240.3	7.17	1.44
3- 1	153.8	244.6	240.7	6.50	1.45
3- 2	154.3	245.3	241.4	6.50	1.45
4- 1	154.5	240.8	235.3	9.17	1.35
4- 2	155.2	245.7	240.4	8.83	1.42
5- 1	155.2	247.0	242.3	7.83	1.45
5- 2	155.2	243.2	238.9	7.17	1.39

Ov(%): 7.60 Std: .94 BD(g/cm**3): 1.44 Std: .04

Remarks : EXPT. TERMINATED BECAUSE OF STORM

APPENDIX 8 (cont'd)

CNN1BD 27 JULY 1989

Crop Residue (%): 75.00

Depth to layer B : 25.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	256.9	247.8	15.17	1.51
1- 2	155.7	256.4	247.3	15.17	1.53
2- 1	155.7	258.0	249.4	14.33	1.56
2- 2	156.6	259.4	249.4	16.67	1.55
3- 1	156.5	253.0	244.0	15.00	1.46
3- 2	155.6	252.7	242.8	16.50	1.45
4- 1	155.6	254.7	246.6	13.50	1.52
4- 2	155.2	253.7	245.7	13.33	1.51
5- 1	155.4	245.7	236.4	15.50	1.35
5- 2	156.4	255.3	246.1	15.33	1.50

Ov(%): 15.05 Std: 1.10 BD(g/cm**3): 1.49 Std: .06

Remarks : NO CORN PLANTS ON ONE SIDE

CDN6BD 28 JULY 1989

Crop Residue (%): 3.33

Depth to layer B : 14.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.8	237.0	231.9	8.50	1.25
1- 2	155.5	243.7	237.8	9.83	1.37
2- 1	156.6	244.3	238.8	9.17	1.37
2- 2	156.5	242.1	236.5	9.33	1.33
3- 1	155.4	242.5	236.8	9.50	1.36
3- 2	155.2	240.6	235.0	9.33	1.33
4- 1	156.4	242.6	237.2	9.00	1.35
4- 2	156.3	239.7	234.2	9.17	1.30
5- 1	155.4	237.1	232.3	8.00	1.28
5- 2	156.4	241.5	237.1	7.33	1.35

Ov(%): 8.92 Std: .76 BD(g/cm**3): 1.33 Std: .04

Remarks : NONE

CDW6BD 28 JULY 1989

Crop Residue (%): 1.67

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.4	256.4	249.5	11.50	1.57
1- 2	156.4	257.2	250.2	11.67	1.56
2- 1	156.0	253.5	247.1	10.67	1.52
2- 2	155.2	254.7	247.8	11.50	1.54
3- 1	156.6	253.9	247.4	10.83	1.51
3- 2	156.8	255.5	249.1	10.67	1.54
4- 1	155.6	251.2	244.8	10.67	1.49
4- 2	156.9	253.7	247.4	10.50	1.51
5- 1	156.7	257.9	250.8	11.83	1.57
5- 2	155.1	255.6	248.9	11.17	1.56

APPENDIX 8 (cont'd)

Ov(%): 11.10 Std: .49 BD(g/cm**3): 1.54 Std: .03

Remarks : NONE

CMW2BD 3 AUG 1989

Crop Residue (%): 3.33

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	252.7	246.2	10.83	1.49
1- 2	155.7	251.4	245.1	10.50	1.49
2- 1	155.7	250.3	243.2	11.83	1.46
2- 2	156.6	252.1	245.1	11.67	1.48
3- 1	156.5	252.2	245.0	12.00	1.48
3- 2	155.6	250.3	242.8	12.50	1.45
4- 1	155.6	251.2	244.6	11.00	1.48
4- 2	155.2	247.6	240.6	11.67	1.42
5- 1	155.4	251.7	244.9	11.33	1.49
5- 2	156.4	252.6	245.9	11.17	1.49

Ov(%): 11.45 Std: .60 BD(g/cm**3): 1.47 Std: .02

Remarks : NONE

CMW1BD 31 JULY 1989

Crop Residue (%): .00

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	245.3	244.1	2.00	1.45
1- 2	155.7	252.9	251.5	2.33	1.60
2- 1	155.7	248.4	246.8	2.67	1.52
2- 2	156.6	252.2	250.9	2.17	1.57
3- 1	156.5	240.8	239.1	2.83	1.38
3- 2	155.6	244.0	242.7	2.17	1.45
4- 1	155.6	249.9	247.9	3.33	1.54
4- 2	155.2	242.9	240.9	3.33	1.43
5- 1	155.4	247.0	245.1	3.17	1.50
5- 2	156.4	253.4	251.6	3.00	1.59

Ov(%): 2.70 Std: .51 BD(g/cm**3): 1.50 Std: .07

Remarks : SURFACE CRUST

CMN4BD 31 JULY 1989

Crop Residue (%): 1.67

Depth to layer B : 14.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	239.8	238.0	3.00	1.39
1- 2	154.5	242.2	240.7	2.50	1.44
2- 1	153.9	233.8	232.4	2.33	1.31

APPENDIX 8 (cont'd)

2- 2	153.9	232.3	231.0	2.17	1.29
3- 1	153.7	245.6	243.9	2.83	1.50
3- 2	154.5	242.9	241.4	2.50	1.45
4- 1	154.6	236.1	234.6	2.50	1.33
4- 2	153.7	234.8	233.3	2.50	1.33
5- 1	155.1	235.4	233.6	3.00	1.31
5- 2	154.4	241.7	240.0	2.83	1.43

Ov(%): 2.62 Std: .28 BD(g/cm**3): 1.38 Std: .07

Remarks : SURFACE CRUST 1/4"

CNN5BD 2 AUG 1989

Crop Residue (%): 73.33

Depth to layer B : 99.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	254.7	243.1	19.33	1.47
1- 2	156.0	257.1	246.7	17.33	1.51
2- 1	155.5	249.2	239.0	17.00	1.39
2- 2	155.8	257.8	246.5	18.83	1.51
3- 1	154.9	250.1	239.9	17.00	1.42
3- 2	155.1	248.7	238.4	17.17	1.39
4- 1	154.6	253.6	243.1	17.50	1.48
4- 2	155.1	248.6	237.4	18.67	1.37
5- 1	156.1	251.3	241.4	16.50	1.42
5- 2	155.2	246.6	237.4	15.33	1.37

Ov(%): 17.47 Std: 1.19 BD(g/cm**3): 1.43 Std: .05

Remarks : 1.2" OF IRRIGATION ADDED THIS MORNING

CNW3BD 2 AUG 1989

Crop Residue (%): 81.67

Depth to layer B : 99.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	258.7	249.7	15.00	1.58
1- 2	156.6	254.2	244.2	16.67	1.46
2- 1	156.3	245.1	236.6	14.17	1.34
2- 2	156.0	237.3	228.0	15.50	1.20
3- 1	154.8	250.4	241.3	15.17	1.44
3- 2	155.2	253.1	243.5	16.00	1.47
4- 1	156.4	254.8	246.5	13.83	1.50
4- 2	154.7	246.2	237.9	13.83	1.39
5- 1	156.3	257.9	248.5	15.67	1.54
5- 2	156.0	252.2	242.2	16.67	1.44

Ov(%): 15.25 Std: 1.06 BD(g/cm**3): 1.44 Std: .11

Remarks : 1.2" OF IRRIGATION ADDED THIS MORNING, WINDY

CDN1BD 2 AUG 1989

Crop Residue (%): 5.00

APPENDIX 8 (cont'd)

Depth to layer B : 155.3 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.3	251.3	242.0	15.50	1.44
1- 2	156.2	251.3	241.6	16.17	1.42
2- 1	155.4	243.7	235.7	13.33	1.34
2- 2	156.6	249.7	241.1	14.33	1.41
3- 1	155.3	241.5	233.4	13.50	1.30
3- 2	156.3	253.5	244.1	15.67	1.46
4- 1	155.3	248.3	239.4	14.83	1.40
4- 2	155.7	251.0	241.9	15.17	1.44
5- 1	156.3	249.4	240.1	15.50	1.40
5- 2	-1.0	-1.0	-1.0	.00	.00

Ov(%): 14.89 Std: .98 BD(g/cm**3): 1.40 Std: .05

Remarks : 1.2" OF IRRIGATION ADDED THIS MORNING, WINDY

CMN5BD 3 AUG 1989

Crop Residue (%): 3.33

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.3	234.0	228.4	9.33	1.22
1- 2	154.8	233.5	228.1	9.00	1.22
2- 1	156.4	237.8	231.4	10.67	1.25
2- 2	156.2	235.5	229.2	10.50	1.22
3- 1	155.0	240.0	233.2	11.33	1.30
3- 2	156.3	242.9	235.9	11.67	1.33
4- 1	154.9	237.7	231.1	11.00	1.27
4- 2	154.6	238.2	231.3	11.50	1.28
5- 1	155.2	240.2	233.3	11.50	1.30
5- 2	154.7	247.8	240.3	12.50	1.43

Ov(%): 10.90 Std: 1.07 BD(g/cm**3): 1.28 Std: .06

Remarks : NONE

CDW1BD 3 AUG 1989

Crop Residue (%): .00

Depth to layer B : 14.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.5	259.9	250.7	15.33	1.60
1- 2	155.1	262.0	252.4	16.00	1.62
2- 1	154.5	263.4	253.1	17.17	1.64
2- 2	155.6	255.0	245.4	16.00	1.50
3- 1	156.4	261.7	251.8	16.50	1.59
3- 2	154.8	260.8	251.2	16.00	1.61
4- 1	156.4	261.5	252.0	15.83	1.59
4- 2	155.3	260.8	251.1	16.17	1.60
5- 1	154.8	262.6	252.8	16.33	1.63
5- 2	156.3	262.0	252.6	15.67	1.61

Ov(%): 16.10 Std: .50 BD(g/cm**3): 1.60 Std: .04

Remarks : NONE

APPENDIX 8 (cont'd)

PMW5BD 30 JUNE 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 11.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	480.00	475.00	355.00	13.80	624.60	585.40	-1.00	11.20	1.63
2	430.00	420.00	482.00	13.80	844.50	773.60	-1.00	15.02	1.61

Total Sample
Ov(%): 13.11 BD(g/cm**3): 1.62

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	260.3	252.7	12.67	1.59
1- 2	155.7	257.1	249.6	12.50	1.57
2- 1	155.7	257.6	249.4	13.67	1.56
2- 2	156.6	262.1	254.0	13.50	1.62
3- 1	156.5	258.0	250.3	12.83	1.56
3- 2	155.6	258.4	250.6	13.00	1.58
4- 1	155.6	259.2	251.4	13.00	1.60
4- 2	155.2	254.8	247.3	12.50	1.54
5- 1	155.4	257.0	249.3	12.83	1.57
5- 2	156.4	261.4	254.5	11.50	1.64

Ov(%): 12.80 Std: .60 BD(g/cm**3): 1.58 Std: .03

Remarks : NONE

PMN4BD 30 JUNE 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	530.00	860.00	240.00	13.80	825.40	766.00	-1.00	10.42	1.32
2	585.00	780.00	280.00	13.90	690.50	635.10	-1.00	11.66	1.31

Total Sample
Ov(%): 11.04 BD(g/cm**3): 1.31

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.6	241.7	237.0	7.83	1.36
1- 2	155.1	237.5	232.2	8.83	1.28
2- 1	156.8	242.5	236.7	9.67	1.33
2- 2	155.1	239.3	233.8	9.17	1.31
3- 1	155.3	242.0	234.9	11.83	1.33
3- 2	155.2	237.4	232.0	9.00	1.28
4- 1	156.9	249.2	241.6	12.67	1.41
4- 2	156.9	247.0	239.2	13.00	1.37
5- 1	156.0	245.7	237.9	13.00	1.36
5- 2	155.7	236.0	228.5	12.50	1.21

Ov(%): 10.75 Std: 2.03 BD(g/cm**3): 1.33 Std: .06

APPENDIX 8 (cont'd)

Remarks : CENTER RIDGE REMOVED FOR GROSSMAN

PPW4BD 5 JULY 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 12.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	520.00	612.00	375.00	13.90	824.20	758.50	-1.00	14.07	1.59
2	580.00	590.00	500.00	14.00	886.60	796.90	-1.00	17.59	1.54

Total Sample
Ov(%): 15.83 BD(g/cm**3): 1.56

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.5	257.6	249.5	13.50	1.58
1- 2	155.1	259.2	250.8	14.00	1.59
2- 1	154.5	257.0	248.7	13.83	1.57
2- 2	155.6	252.8	244.2	14.33	1.48
3- 1	156.4	260.4	251.3	15.17	1.58
3- 2	154.8	259.3	250.1	15.33	1.59
4- 1	156.4	260.0	250.7	15.50	1.57
4- 2	155.3	262.1	252.6	15.83	1.62
5- 1	154.8	260.4	250.7	16.17	1.60
5- 2	156.3	261.0	253.0	13.33	1.61

Ov(%): 14.70 Std: 1.02 BD(g/cm**3): 1.58 Std: .04

Remarks : NONE

PPN4BD 5 JULY 1989

RESIDUE READING : -1

Crop Residue (%): ?
Depth to layer B : 10.0 inch

GROSSMAN COMPLIANT CAVITY METHOD READING:

SET	INIV	FINALV1	FINALV2	CON	WETS+CON	DRYS+CON	<2MM	Ov	BD
1	610.00	628.00	705.00	13.80	1131.00	1058.60	-1.00	10.01	1.45
2	480.00	605.00	550.00	13.80	1034.30	983.50	-1.00	7.53	1.44

Total Sample
Ov(%): 8.77 BD(g/cm**3): 1.44

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	237.0	233.9	5.17	1.32
1- 2	156.6	236.8	234.3	4.17	1.29
2- 1	156.3	239.7	235.8	6.50	1.33
2- 2	156.0	242.5	239.0	5.83	1.38
3- 1	154.8	239.2	235.8	5.67	1.35
3- 2	155.2	237.1	234.3	4.67	1.32
4- 1	156.4	241.9	237.7	7.00	1.36
4- 2	154.7	236.5	232.1	7.33	1.29
5- 1	156.3	248.9	244.3	7.67	1.47
5- 2	156.0	242.4	238.9	5.83	1.38

APPENDIX 8 (cont'd)

Ov(%): 5.98 Std: 1.15 BD(g/cm**3): 1.35 Std: .05

Remarks : CENTER RIDGE REMOVED

PPN2BD 19 JULY 1989

Crop Residue (%): .00

Depth to layer B : 10.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	157.0	238.9	232.4	10.83	1.26
1- 2	155.7	237.0	230.8	10.33	1.25
2- 1	155.7	238.7	232.8	9.83	1.29
2- 2	156.6	243.7	237.3	10.67	1.34
3- 1	156.5	243.3	236.3	11.67	1.33
3- 2	155.6	239.9	233.2	11.17	1.29
4- 1	155.6	239.4	232.3	11.83	1.28
4- 2	155.2	240.9	234.3	11.00	1.32
5- 1	155.4	238.4	231.8	11.00	1.27
5- 2	156.4	237.3	230.8	10.83	1.24

Ov(%): 10.92 Std: .58 BD(g/cm**3): 1.29 Std: .03

Remarks : NO CURST ON SURFACE

PPW6BD 14 JULY 1989

Crop Residue (%): .00

Depth to layer B : 10.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.8	260.8	252.8	13.33	1.60
1- 2	155.5	260.3	252.6	12.83	1.62
2- 1	156.6	262.9	254.5	14.00	1.63
2- 2	156.5	261.5	253.5	13.33	1.62
3- 1	155.4	255.9	248.7	12.00	1.56
3- 2	155.2	262.0	253.3	14.50	1.64
4- 1	156.4	259.4	250.5	14.83	1.57
4- 2	156.3	257.0	247.9	15.17	1.53
5- 1	155.4	260.3	250.7	16.00	1.59
5- 2	156.4	255.8	246.4	15.67	1.50

Ov(%): 14.17 Std: 1.29 BD(g/cm**3): 1.58 Std: .05

Remarks : NONE

PPN1BD 26 JULY 1989

Crop Residue (%): 33.33

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.6	238.6	235.0	6.00	1.32
1- 2	155.1	237.9	234.5	5.67	1.32

APPENDIX 8 (cont'd)

2- 1	156.8	240.2	236.4	6.33	1.33
2- 2	155.1	237.0	233.1	6.50	1.30
3- 1	155.3	241.2	236.7	7.50	1.36
3- 2	155.2	241.5	237.8	6.17	1.38
4- 1	156.9	246.2	242.4	6.33	1.42
4- 2	156.9	238.8	235.3	5.83	1.31
5- 1	156.0	237.4	233.2	7.00	1.29
5- 2	155.7	242.3	237.5	8.00	1.36

Ov(%): 6.53 Std: .75 BD(g/cm**3): 1.34 Std: .04

Remarks : Residue generated by this year's crop

PMN5BD 26 JULY 1989

Crop Residue (%): 20.00

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	243.1	240.6	4.17	1.43
1- 2	156.6	236.6	234.0	4.33	1.29
2- 1	156.3	238.3	235.3	5.00	1.32
2- 2	156.0	234.6	231.6	5.00	1.26
3- 1	154.8	237.4	233.6	6.33	1.31
3- 2	155.2	238.0	234.1	6.50	1.32
4- 1	156.4	239.9	236.2	6.17	1.33
4- 2	154.7	234.7	231.2	5.83	1.27
5- 1	156.3	239.3	234.7	7.67	1.31
5- 2	156.0	240.6	235.8	8.00	1.33

Ov(%): 5.90 Std: 1.30 BD(g/cm**3): 1.32 Std: .05

Remarks : Residue generated by current crop

pmw6bd 26 July 1989

Crop Residue (%): 56.67

Depth to layer B : 9.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	258.5	252.4	10.17	1.63
1- 2	154.5	258.1	251.7	10.67	1.62
2- 1	153.9	259.2	252.8	10.67	1.65
2- 2	153.9	257.2	250.8	10.67	1.62
3- 1	153.7	255.9	249.1	11.33	1.59
3- 2	154.9	257.9	250.7	12.00	1.60
4- 1	154.6	251.2	245.3	9.83	1.51
4- 2	153.7	255.2	247.4	13.00	1.56
5- 1	155.1	258.1	252.1	10.00	1.62
5- 2	154.4	255.3	249.3	10.00	1.58

Ov(%): 10.83 Std: 1.01 BD(g/cm**3): 1.60 Std: .04

Remarks : none

ppw1bd 26 July 1989

APPENDIX 8 (cont'd)

Crop Residue (%): 25.00

Depth to layer B : 9.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.3	246.7	243.1	6.00	1.46
1- 2	156.2	252.5	248.5	6.67	1.54
2- 1	155.4	247.7	244.5	5.33	1.49
2- 2	156.6	249.7	245.4	7.17	1.48
3- 1	155.3	257.4	253.3	6.83	1.63
3- 2	156.5	257.8	253.2	7.67	1.61
4- 1	155.3	253.2	249.2	6.67	1.56
4- 2	155.7	253.3	249.4	6.50	1.56
5- 1	156.3	259.5	254.5	8.33	1.64
5- 2	155.3	258.1	252.9	8.67	1.63

Ov(%): 6.98 Std: 1.02 BD(g/cm**3): 1.56 Std: .07

Remarks : So compacted that we could not press cupholders into soil.

PPWSBD 1 AUG 1989

Crop Residue (%): 10.00

Depth to layer B : 15.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.1	265.1	254.9	17.00	1.66
1- 2	155.1	264.6	254.5	16.83	1.66
2- 1	154.4	265.4	256.4	15.00	1.70
2- 2	153.9	262.0	251.5	17.50	1.63
3- 1	153.8	267.9	257.3	17.67	1.72
3- 2	154.3	266.2	255.9	17.17	1.69
4- 1	154.5	257.5	248.0	15.83	1.56
4- 2	155.2	260.5	250.5	16.67	1.59
5- 1	155.2	263.2	252.6	17.67	1.62
5- 2	155.3	261.3	250.2	18.50	1.58

Ov(%): 16.98 Std: 1.00 BD(g/cm**3): 1.64 Std: .06

Remarks : NONE

PPN5BD 1 AUG 1989

Crop Residue (%): 15.00

Depth to layer B : 11.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	-1.0	-1.0	-1.0	.00	.00
1- 2	155.1	243.1	232.5	17.67	1.29
2- 1	156.8	-1.0	-1.0	.00	.00
2- 2	155.1	242.9	232.4	17.50	1.29
3- 1	155.3	241.0	231.7	15.50	1.27
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	156.9	239.1	230.8	13.83	1.23
4- 2	-1.0	-1.0	-1.0	.00	.00
5- 1	-1.0	-1.0	-1.0	.00	.00
5- 2	155.7	245.7	236.2	15.83	1.34

Ov(%): 16.07 Std: 1.58 BD(g/cm**3): 1.28 Std: .04

APPENDIX 8 (cont'd)

Remarks : HALF OF MADERA SOIL SAMPLE BEEN OUT ACCIDENTLY

PMN2BD 1 AUG 1989

Crop Residue (%): 6.67

Depth to layer B : 14.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	-1.0	-1.0	-1.0	.00	.00
1- 2	155.1	237.8	230.1	12.83	1.25
2- 1	-1.0	-1.0	-1.0	.00	.00
2- 2	155.6	242.4	233.8	14.33	1.30
3- 1	156.4	245.3	236.4	14.83	1.33
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	156.4	238.1	229.9	13.67	1.23
4- 2	-1.0	-1.0	-1.0	.00	.00
5- 1	-1.0	-1.0	-1.0	.00	.00
5- 2	156.3	247.7	238.4	15.50	1.37

Ov(%): 14.23 Std: 1.03 BD(g/cm**3): 1.30 Std: .06

Remarks : HALF OF MADERA SOIL SAMPLES BEEN OUT ACCIDENTLY

PMW4BD 1 AUG 1989

Crop Residue (%): 5.00

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.3	262.6	254.5	13.50	1.64
1- 2	156.1	259.1	251.4	12.83	1.59
2- 1	155.2	259.3	252.0	12.17	1.61
2- 2	155.2	257.0	249.5	12.50	1.57
3- 1	154.7	254.3	247.1	12.00	1.54
3- 2	155.9	256.4	249.6	11.33	1.56
4- 1	-1.0	-1.0	-1.0	.00	.00
4- 2	-1.0	-1.0	-1.0	.00	.00
5- 1	154.8	255.5	248.9	11.00	1.57
5- 2	155.9	255.8	249.6	10.33	1.56

Ov(%): 11.96 Std: 1.03 BD(g/cm**3): 1.58 Std: .03

Remarks : NONE

PMN3BD 7 AUG 1989

Crop Residue (%): 6.67

Depth to layer B : 13.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	155.4	240.7	232.5	13.67	1.29
1- 2	156.4	244.1	235.3	14.67	1.32
2- 1	156.0	243.2	234.4	14.67	1.31
2- 2	155.2	237.9	229.2	14.50	1.23
3- 1	156.6	246.4	236.9	15.83	1.34

APPENDIX 8 (cont'd)

3- 2	156.8	242.3	233.8	14.17	1.28
4- 1	155.6	246.3	237.5	14.67	1.36
4- 2	156.9	246.7	238.1	14.33	1.35
5- 1	156.7	245.6	237.4	13.67	1.34
5- 2	155.1	241.4	233.8	12.67	1.31

Ov(%): 14.28 Std: .84 BD(g/cm**3): 1.31 Std: .04

Remarks : NONE

PMW2BD 7 AUG 1989

Crop Residue (%): 6.67

Depth to layer B : 12.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.8	261.5	251.8	16.17	1.58
1- 2	155.5	259.6	250.7	14.83	1.59
2- 1	156.6	258.3	249.1	15.33	1.54
2- 2	156.5	263.5	253.3	17.00	1.61
3- 1	155.4	257.5	248.7	14.67	1.56
3- 2	155.2	260.0	249.5	17.50	1.57
4- 1	156.4	262.4	253.3	15.17	1.62
4- 2	156.3	262.7	253.3	15.67	1.62
5- 1	155.4	265.2	255.1	16.83	1.66
5- 2	156.4	262.7	252.9	16.33	1.61

Ov(%): 15.95 Std: .97 BD(g/cm**3): 1.60 Std: .03

Remarks : NONE

PPW2BD 7 AUG 1989

Crop Residue (%): 16.67

Depth to layer B : 12.0 inch

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	156.3	263.9	255.3	14.33	1.65
1- 2	156.1	259.3	251.9	12.33	1.60
2- 1	155.2	260.9	253.2	12.83	1.63
2- 2	155.2	257.9	249.9	13.33	1.58
3- 1	154.7	259.6	251.9	12.83	1.62
3- 2	155.9	263.8	256.0	13.00	1.67
4- 1	155.0	256.2	250.1	10.17	1.59
4- 2	155.9	257.9	250.9	11.67	1.58
5- 1	154.8	252.4	246.0	10.67	1.52
5- 2	155.9	261.6	254.9	11.17	1.65

Ov(%): 12.23 Std: 1.30 BD(g/cm**3): 1.61 Std: .04

Remarks : NONE

PPN3BD 7 AUG 1989

Crop Residue (%): 5.00

Depth to layer B : 13.0 inch

APPENDIX 8 (cont'd)

MADERA METHOD READING AND INDIVIDUAL OUTPUT:

SET	CON	WETS+CON	DRYS+CON	Ov	BD
1- 1	154.6	237.2	229.5	12.83	1.25
1- 2	154.5	237.7	229.6	13.50	1.25
2- 1	153.9	241.1	232.1	15.00	1.30
2- 2	153.9	247.5	238.3	15.33	1.41
3- 1	153.7	243.8	234.5	15.50	1.35
3- 2	-1.0	-1.0	-1.0	.00	.00
4- 1	154.6	245.2	236.4	14.67	1.36
4- 2	153.7	244.0	235.4	14.33	1.36
5- 1	155.1	247.1	238.2	14.83	1.38
5- 2	154.4	245.1	236.3	14.67	1.37

Ov(%): 14.52 Std: .86 BD(g/cm**3): 1.34 Std: .06

Remarks : NONE

APPENDIX 9

Field measured ponding time and water applied depth at ponding for sprinkling infiltrometer experiment

APPENDIX 9. Field measured ponding time and water applied depth at ponding for sprinkling infiltrometer experiment.

PMW5 30 JUNE 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.2171	7.25	30.9137	.1471	3.7354	1
.9132	8.50	23.1942	.1294	3.2859	2
1.1775	8.50	29.9084	.1668	4.2370	3
1.3348	4.00	33.9045	.0890	2.2603	4
1.1202	11.50	28.4527	.2147	5.4534	5
2.4709	1.75	62.7609	.0721	1.8305	6

PMN4 30 JUNE 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7998	15.50	20.3139	.2066	5.2478	1
1.0584	13.25	26.8831	.2337	5.9367	2
1.0048	13.25	25.5231	.2219	5.6363	3
1.4324	5.00	36.3831	.1194	3.0319	4
3.6705	3.00	93.2318	.1835	4.6616	5
3.1647	1.50	80.3840	.0791	2.0096	6

PPW4 5 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7990	17.50	20.2950	.2330	5.9194	1
1.2032	7.25	30.5618	.1454	3.6929	2
1.0184	5.50	25.8661	.0933	2.3711	3
1.6185	5.25	41.1090	.1416	3.5970	4
1.1280	3.25	28.6517	.0611	1.5520	5
2.8075	1.50	71.3109	.0702	1.7828	6

PPN4IN 5 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.2032	11.50	30.5618	.2306	5.8577	1
1.3991	9.50	35.5370	.2215	5.6267	2
1.1996	10.50	30.4709	.2099	5.3324	3
1.4762	6.50	37.4948	.1599	4.0619	4
1.0938	10.75	27.7835	.1960	4.9779	5
2.3366	3.00	59.3500	.1168	2.9675	6

PMW1IN 13 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6870	18.50	17.4490	.2118	5.3801	1
.7938	13.00	20.1623	.1720	4.3685	2
.7438	10.25	18.8935	.1271	3.2276	3
1.6450	5.00	41.7837	.1371	3.4820	4
1.3966	3.75	35.4735	.0873	2.2171	5
3.4781	1.50	88.3428	.0870	2.2086	6

PPN2IN 14 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.6215	5.17	41.1868	.1396	3.5466	1

APPENDIX 9 (cont'd)

1.7284	4.17	43.9018	.1200	3.0487	2
1.2972	3.83	32.9495	.0829	2.1051	3
1.8012	2.83	45.7503	.0851	2.1604	4
1.5096	5.50	38.3427	.1384	3.5148	5
2.7395	1.17	69.5827	.0533	1.3530	6

PPW6IN 14 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6368	30.67	16.1744	.3255	8.2669	1
.8569	8.33	21.7643	.1190	3.0228	2
1.1809	4.00	29.9948	.0787	1.9997	3
1.6091	3.50	40.8708	.0939	2.3841	4
1.4453	4.83	36.7100	.1164	2.9572	5
2.7260	1.33	69.2416	.0606	1.5387	6

ppn1in 26 July 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6247	41.83	15.8669	.4355	11.0627	1
.9816	17.00	24.9325	.2781	7.0642	2
.8996	26.83	22.8511	.4023	10.2195	3
1.9740	5.50	50.1405	.1810	4.5962	4
1.9281	6.83	48.9744	.2196	5.5776	5
3.8353	1.83	97.4158	.1172	2.9766	6

pmn5in 26 July 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.0046	21.17	25.5179	.3544	9.0022	2
1.9289	8.00	48.9944	.2572	6.5326	4
1.7133	8.50	43.5182	.2427	6.1651	5
3.2149	3.00	81.6574	.1607	4.0829	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7190	29.42	18.2624	.3525	8.9537	1
.8532	29.42	21.6714	.4183	10.6250	3

pmw6in 26 July 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.9097	20.33	23.1062	.3083	7.8304	2
.6677	14.00	16.9605	.1558	3.9574	3
1.4555	4.83	36.9699	.1172	2.9781	4
1.3536	5.50	34.3821	.1241	3.1517	5
2.8201	2.17	71.6293	.1018	2.5866	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5512	58.67	14.0003	.5389	13.6891	1

ppw1in 26 July 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.0521	17.17	26.7232	.3010	7.6458	2
.8108	12.50	20.5934	.1689	4.2903	3
2.4064	4.33	61.1236	.1738	4.4145	4

APPENDIX 9 (cont'd)

1.7775	5.00	45.1482	.1481	3.7623	5
3.6849	2.17	93.5956	.1331	3.3798	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6294	57.50	15.9868	.6032	15.3207	1

PPW5IN 1 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.4745	8.67	12.0523	.0685	1.7409	1
.8831	10.50	22.4304	.1545	3.9253	2
.8356	6.67	21.2235	.0928	2.3582	3
2.0868	3.50	53.0057	.1217	3.0920	4
1.2062	5.00	30.6366	.1005	2.5531	5
2.6814	1.50	68.1065	.0670	1.7027	6

PPN5IN 1 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6363	12.67	16.1625	.1343	3.4121	1
1.0887	6.83	27.6522	.1240	3.1493	2
.9505	6.83	24.1417	.1082	2.7495	3
2.4440	3.00	62.0787	.1222	3.1039	4
1.5980	3.83	40.5899	.1021	2.5932	5
3.2901	1.33	83.5675	.0731	1.8571	6

NON-PONDED SECONDARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6517	7.50	16.5543	.0815	2.0693	5

PMN2IN 1 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6939	21.02	17.6249	.2431	6.1736	1
.6970	17.53	17.7046	.2037	5.1737	2
.8154	13.50	20.7121	.1835	4.6602	3
1.8019	3.65	45.7695	.1096	2.7843	4
1.1496	7.60	29.1992	.1456	3.6986	5
2.7305	1.82	69.3553	.0827	2.0999	6

PMW4IN 1 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7395	19.25	18.7841	.2373	6.0266	2
1.5824	5.08	40.1920	.1341	3.4052	4
1.1482	8.83	29.1633	.1690	4.2935	5
2.5783	2.63	65.4896	.1132	2.8743	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5774	56.33	14.6649	.5421	13.7687	1
.7058	56.33	17.9285	.6627	16.8329	3

PMN3IN 7 AUG 1989

PONDED PRIMARY

APPENDIX 9 (cont'd)

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5089	22.00	12.9256	.1866	4.7394	1
.9099	12.20	23.1124	.1850	4.6995	2
.8502	11.00	21.5957	.1559	3.9592	3
1.7383	4.83	44.1518	.1400	3.5567	4
1.7672	4.83	44.8877	.1424	3.6160	5
2.9006	2.00	73.6758	.0967	2.4559	6

PMW2IN 7 AUG 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5582	23.75	14.1782	.2210	5.6122	1
.9380	7.50	23.8262	.1173	2.9783	2
.9991	5.17	25.3772	.0860	2.1853	3
1.2918	4.25	32.8108	.0915	2.3241	4
1.5687	2.92	39.8438	.0763	1.9369	5
2.4440	1.17	62.0787	.0475	1.2071	6

PPW2IN 7 AUG 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.4929	30.75	12.5207	.2526	6.4169	1
.7104	17.17	18.0451	.2033	5.1629	2
.8278	9.50	21.0267	.1311	3.3292	3
1.4698	4.00	37.3340	.0980	2.4889	4
1.5980	4.50	40.5899	.1199	3.0442	5
3.0551	1.75	77.5984	.0891	2.2633	6

PPN3IN 7 AUG 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5098	43.00	12.9484	.3653	9.2797	1
.9125	12.75	23.1769	.1939	4.9251	2
.9605	8.17	24.3965	.1307	3.3206	3
1.7296	4.17	43.9326	.1201	3.0509	4
1.8988	2.83	48.2304	.0897	2.2775	5
3.4311	1.33	87.1489	.0762	1.9366	6

CMW3IN 25 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.0716	4.33	27.2191	.0774	1.9658	1
1.3016	8.17	33.0597	.1772	4.4998	2
1.0636	5.33	27.0145	.0945	2.4013	3
2.7655	2.17	70.2429	.0999	2.5365	4
1.8988	2.50	48.2304	.0791	2.0096	5
4.6531	1.33	118.1883	.1034	2.6264	6

CMN3IN 25 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7435	10.67	18.8841	.1322	3.3572	1
1.4582	5.17	37.0376	.1256	3.1893	2
1.1012	4.83	27.9695	.0887	2.2531	3
3.0833	2.00	78.3147	.1028	2.6105	4
2.6164	2.00	66.4560	.0872	2.2152	5
4.6061	1.33	116.9945	.1024	2.5999	6

CDW3IN 25 JULY 1989

RATE(in/hr)	TP(min)	PONDED PRIMARY RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#

APPENDIX 9 (cont'd)

1.0064	8.33	25.5618	.1398	3.5503	1
1.6744	3.83	42.5299	.1070	2.7172	2
1.0399	5.00	26.4133	.0867	2.2011	3
2.9963	2.00	76.1061	.0999	2.5369	4
2.3688	1.00	60.1686	.0395	1.0028	5
4.7001	1.17	119.3821	.0914	2.3213	6

CNW5IN 27 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
2.0798	2.50	52.8266	.0867	2.2011	2
2.1679	2.50	55.0650	.0903	2.2944	4
3.9951	1.67	101.4748	.1110	2.8187	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.2240	23.50	31.0902	.4794	12.1770	1

CNN1IN 27 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.7048	6.83	43.3032	.1942	4.9317	4

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
4.5886	19.67	116.5493	1.5040	38.2023	1
1.8559	44.17	47.1402	1.3662	34.7004	2
1.8558	31.00	47.1367	.9588	24.3540	3
1.7422	52.50	44.2510	1.5244	38.7196	5
3.4085	42.33	86.5755	2.4049	61.0839	6

CDN6IN 28 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6517	7.33	16.5543	.0797	2.0233	1
1.3282	2.33	33.7351	.0517	1.3119	2
.8997	5.33	22.8531	.0800	2.0314	3
2.4744	1.17	62.8489	.0481	1.2221	4
1.9467	2.17	49.4473	.0703	1.7856	5
4.2301	.67	107.4439	.0470	1.1938	6

CDW6IN 28 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.9464	7.17	24.0383	.1130	2.8712	1
1.0545	7.33	26.7831	.1289	3.2735	2
.7410	8.17	18.8202	.1009	2.5616	3
2.2184	3.00	56.3484	.1109	2.8174	4
1.1205	4.67	28.4620	.0872	2.2137	5
3.1430	1.33	79.8311	.0698	1.7740	6

CMW2IN 3 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6647	9.17	16.8840	.1016	2.5795	1
1.0916	4.92	27.7275	.0895	2.2721	2
1.4644	3.50	37.1970	.0854	2.1698	3
1.7830	3.00	45.2882	.0891	2.2644	4
2.4816	1.83	63.0338	.0758	1.9260	5
3.6765	.92	93.3833	.0562	1.4267	6

APPENDIX 9 (cont'd)

CMW1IN 31 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.5724	22.33	14.5381	.2130	5.4114	1
.7130	8.50	18.1100	.1010	2.5656	2
.8376	7.67	21.2760	.1070	2.7186	3
2.0304	5.00	51.5731	.1692	4.2978	4
1.2287	6.50	31.2078	.1331	3.3808	5
.5099	2.00	12.9521	.0170	.4317	6

CMN4IN 31 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7064	16.50	17.9421	.1943	4.9341	1
1.1050	7.33	28.0670	.1351	3.4304	2
1.1040	7.50	28.0421	.1380	3.5053	3
2.6199	4.00	66.5459	.1747	4.4364	4
1.6257	4.83	41.2922	.1310	3.3263	5
4.8411	1.00	122.9636	.0807	2.0494	6

CNN5IN 2 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
3.9481	4.33	100.2810	.2851	7.2425	2
2.5102	5.67	63.7601	.2371	6.0218	3
2.7109	4.67	68.8565	.2108	5.3555	4
1.1689	15.83	29.6909	.3085	7.8351	5
4.4181	1.50	112.2192	.1105	2.8055	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.4782	46.17	37.5472	1.1374	28.8905	1

CNW3IN 2 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.5581	12.83	39.5752	.3333	8.4647	1
4.4584	6.67	113.2425	.4954	12.5825	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
3.5079	35.67	89.1015	2.0853	52.9659	2
1.7592	46.17	44.6843	1.3536	34.3821	3
1.9616	49.17	49.8248	1.6074	40.8287	4
1.5123	49.17	38.4127	1.2393	31.4771	5

CDN1IN 2 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7296	9.50	18.5310	.1155	2.9341	1
1.2032	2.67	30.5618	.0535	1.3583	2
.6255	8.20	15.8867	.0855	2.1712	3
2.2184	2.58	56.3484	.0955	2.4261	4
2.1081	1.72	53.5458	.0603	1.5320	5
3.8804	.83	98.5619	.0539	1.3689	6

CMN5IN 3 AUG 1989

PONDED PRIMARY

APPENDIX 9 (cont'd)

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6212	30.08	15.7781	.3115	7.9109	1
1.0887	6.17	27.6522	.1119	2.8420	2
.6858	19.98	17.4185	.2284	5.8013	3
2.1022	2.25	53.3964	.0788	2.0024	4
2.2748	3.00	57.7809	.1137	2.8890	5
3.8071	.83	96.6995	.0529	1.3430	6

CDW1IN 3 AUG 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7381	6.50	18.7474	.0800	2.0310	1
1.2944	4.88	32.8790	.1054	2.6760	2
.9772	5.37	24.8199	.0874	2.2200	3
2.1636	2.50	54.9549	.0901	2.2898	4
2.5192	1.33	63.9888	.0560	1.4220	5
4.7941	1.00	121.7698	.0799	2.0295	6

CMN6 26 June 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.4305	32.50	10.9358	.2332	5.9235	1
.9068	8.25	23.0337	.1247	3.1671	2
1.0340	6.25	26.2641	.1077	2.7358	3
1.6486	5.25	41.8756	.1443	3.6641	4
1.7234	5.25	43.7734	.1508	3.8302	5
4.6296	1.50	117.5914	.1157	2.9398	6

CDN4 28 JUNE 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6381	8.00	16.2070	.0851	2.1609	1
.9400	6.50	23.8764	.1018	2.5866	2
1.1414	6.00	28.9928	.1141	2.8993	3
1.2784	3.50	32.4719	.0746	1.8942	4
1.8487	2.75	46.9570	.0847	2.1522	5
2.7072	1.25	68.7641	.0564	1.4326	2

CDW2 28 June 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.2995	14.75	7.6081	.0736	1.8703	1
.6963	6.75	17.6862	.0783	1.9897	2
.5216	7.25	13.2476	.0630	1.6007	3
1.3348	3.75	33.9045	.0834	2.1190	4
1.8048	3.50	45.8427	.1053	2.6742	5
3.1664	1.75	80.4258	.0924	2.3458	6

CMW6 26 June 1989

CNW2 29 JUNE 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.3687	6.00	34.7641	.1369	3.4764	4
4.4745	2.50	113.6518	.1864	4.7355	5

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6886	43.00	17.4909	.4935	12.5351	1
.9199	39.75	23.3659	.6094	15.4799	2

APPENDIX 9 (cont'd)

.8882	14.50	22.5591	.2146	5.4518	3

CNN3 29 JUNE 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
2.1432	4.50	54.4382	.1607	4.0829	4
4.2746	2.00	108.5749	.1425	3.6192	5
3.7959	1.75	96.4153	.1107	2.8121	6

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
1.0975	18.50	27.8773	.3384	8.5955	1
1.1900	21.25	30.2247	.4214	10.7046	2
1.4637	28.00	37.1790	.6831	17.3502	3

CMW5 6 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7332	13.75	18.6236	.1680	4.2679	2
.7322	8.25	18.5985	.1007	2.5573	2
1.3732	4.00	34.8803	.0915	2.3254	3
.7520	9.25	19.1011	.1159	2.9448	4
1.6981	7.50	43.1316	.2123	5.3915	5
3.4311	1.75	87.1489	.1001	2.5418	6

CMN2 6 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7718	9.25	19.6038	.1190	3.0223	1
.9697	9.08	24.6304	.1468	3.7288	2
2.1996	4.00	55.8708	.1466	3.7247	3
2.0868	2.50	53.0057	.0870	2.2086	4
1.9427	3.25	49.3446	.1052	2.6728	5
4.7172	1.25	119.8162	.0983	2.4962	6

CDW5IN 10 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.7438	11.25	18.8935	.1395	3.5425	1
1.0795	7.00	27.4194	.1259	3.1989	2
1.5040	3.25	38.2023	.0815	2.0693	3
2.3456	2.25	59.5774	.0880	2.2342	4
1.3944	4.75	35.4167	.1104	2.8038	5
4.0891	1.00	103.8624	.0682	1.7310	6

CDN2IN 10 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6306	12.67	16.0165	.1331	3.3813	1
1.1917	6.23	30.2680	.1238	3.1445	2
1.2943	2.67	32.8741	.0575	1.4611	3
2.3312	2.25	59.2135	.0874	2.2205	4
3.1466	1.42	79.9232	.0743	1.8871	5
2.3688	2.25	60.1686	.0888	2.2563	6

CNN6 11 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
4.5485	2.33	115.5311	.1769	4.4929	6

APPENDIX 9 (cont'd)

CNW1 11 JULY 1989

PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
2.4709	5.50	62.7609	.2265	5.7531	4

NON-PONDED PRIMARY

RATE(in/hr)	TP(min)	RATE(mm/hr)	CUM_AMT(in)	CUM_AMT(mm)	NOZZLE#
.6787	48.75	17.2400	.5515	14.0075	1
1.0076	51.50	25.5918	.8648	21.9663	2
.3802	22.50	9.6567	.1426	3.6213	3
1.8324	37.50	46.5431	1.1453	29.0894	5
1.5322	20.00	38.9186	.5107	12.9729	6

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