OVERLAND FLOW TIME OF CONCENTRATION ON FLAT TERRAINS

A Thesis

by

PARAMJIT CHIBBER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2004

Major Subject: Civil Engineering

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ABSTRACT

Overland Flow Time of Concentration on Flat Terrains. (August 2004)

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Time of concentration parameter is defined very loosely in literature and it is calculated rather subjectively in practice (Akan 1986). The situation becomes adverse as the terrain slope approaches zero; because the slope generally appears in the denominator of any formula for time of concentration, this time goes to infinity as the slope goes to zero. The variables affecting this time parameter on flat terrains have been studied through plot scale field experiments. It has been found that the antecedent moisture and rainfall rate control this parameter. Some of the existing time of concentration methods have been compared, and it is found that all the empirical models compared under predict this time parameter. This under prediction can be attributed first to the differing concepts of time of concentration previous researchers have modeled, secondly to the absence of any accounting for the initial moisture content in their respective equations and thirdly to the watersheds where these models have been calibrated. At lower time of concentrations, Izzard-based model predictions show some results close to the observed values. A methodology to determine the plot scale surface undulations has been developed to estimate the depression storage. Regression equations have been derived based upon the experiments to determine the overland flow times on a flat plot of 30 feet length with uniform rainfall intensity. The application of these equations on other lengths cannot be ascertained. Equations for the hydrograph slope on flat terrains have been determined for bare clay and grass plots.

DEDICATION

This work is dedicated to my father, mother, wife, and my daughter.

ACKNOWLEDGMENTS

I am grateful so many people for providing all the support all along the project. My sincere thanks start with Dr. Anthony Cahill for providing me with an opportunity to work under him on this project and for the encouragement and guidance all along the work. I am also thankful to Dr. Ming Han Li, for providing me with all possible support and guidance at all times. I am also grateful to Dr. Harlow C. Landphair and Dr. Francisco Olivera for their valuable guidance.

I am indebted to all the staff and students at the HSECL, Riverside Campus, Texas A&M University in performing all the tests. These include Doug Artz, Rodney Jackson, Alex Ferraras, Qiang Li, and Benjamin Brown.

I am also thankful to my friends for their moral support. These include Gaurav Garg, Srikanth Koka and Ashish Agrawal.

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1 INTRODUCTION

1.1 Statement of the Problem

Flooding near the inlet of a storm water sewer or storm water gushing out from a manhole is a common observation in most urban areas. Many times these occurrences are the consequence of wrong estimation of the peak discharges. The design of storm drainage structures requires determination of the peak discharge for a given return period. Discharge is influenced by rainfall (intensity and duration), flow length, contributing area, slope, surface type/roughness, and microtopography/depressions. Accurate peak discharge estimates are important when sizing highway culverts to prevent possible flood damages and to ensure economic design (Hotchkiss and McCallum1995). Peak flow estimates are also required for storm water management plans, reservoir operation and management, flood plain mapping besides most civil structure designs.

The rational method is one of the widely used overland flow design methods to estimate the peak discharge. “The rational equation is

$$Q_p = CiA \tag{1}$$

This thesis follows the style and format of *Journal of Hydrologic Engineering.*

where Q_p is the peak flow rate (cfs), C is dimensionless coefficient, i is intensity of rainfall with a time duration equal to the time of concentration(iph) and A is drainage area in acres" (Haan et al. 1994). "The coefficient C is called the runoff coefficient and is the most difficult factor to accurately determine. C must reflect factors such as interception, infiltration, surface detention and antecedent conditions.". (Haan et al. 1994).

The importance of the time of concentration is generally accepted throughout the hydrologic literature. Time of concentration is a primary basin parameter which represents response time of a rainfall runoff system (Akan 1986). The accuracy of estimation of peak discharge or flood hydrograph is sensitive to the accuracy of the estimated time of concentration (McCuen et al. 1984). Inlet concentration time is an important parameter, especially in the selection of design rainfalls, for urban storm drainage structures (Akan 1984). However, the time of concentration parameter is defined very loosely in the literature and it is calculated rather subjectively in practice (Akan 1986). The different definitions (Section 2.3) have led to ambiguous numerical results; based on the modeling approach, values for time of concentration can vary, not just because of different model parameters, but also because the models are modeling different conceptual definitions of time of concentration. Moreover it should be noted that in the time of concentration equations, surface slope S appears in the denominator, so that as surface slope goes to zero, the time of concentration becomes goes to infinity, which contradicts common observations. In nature, we have surfaces where the average slope is quite close to zero e.g. flat terrains of Texas, yet an infinite time of concentration is not observed. This is the fundamental problem associated with past work in this area.

1.2 Thesis Objectives

This thesis addresses the above described problem, i.e. the time of concentration of overland flow in flat terrains. The plan involved conducting several field experiments at appropriate slopes on five commonly encountered surfaces, i.e., bare-clay, lawn, pasture, concrete, and asphalt. The aims of these experiments were:

- To identify the variables that strongly affect the time of concentration on low slope areas.
- To measure runoff at different time intervals and different initial conditions, e.g., antecedent moisture content, temperature.
- To develop a regression equation for the time of concentration based upon the experimental data.
- To determine the effect of surface microtopography on runoff generation.
- To evaluate/compare commonly used time of concentration models with the observed experimental results for their applicability on flat terrains.

1.3 Assumptions

Papadakis and Kazan (1987) reviewed a number of time of concentration methods and found that these equations share the general format.

$$t_c = kL^a n^b S^{-y} i^{-z} \tag{2}$$

where t_c is time of concentration in minutes, L is the length of flow path in feet, n is the roughness coefficient, i is the intensity of excess rainfall in in./hr., S is the slope, k is constant and a, b, y, z are exponents. During the experiments the behavior of these controlling variables (length, roughness, rain intensity, and slope) observed by Papadakis and Kazan (1997) was observed. Besides these variables the effect of antecedent moisture content, soil/surface characteristic properties and microtopography was also observed.

1.4 Limitations

The small-plot studies were designed to yield information on the important characteristics and processes affecting time of concentration. However, we need to be aware of the limitations of these experiments. Parsons and Abrahams (1993) stated following problems associated with the plot/field scale studies. “Small plots are incapable of capturing either across slope variation or down slope changes in overland flow. Firstly they fail to identify the full range of infiltration changes, secondly they do not sample the range of overland flow depth, thirdly they fail to capture systematic down slope changes in flow concentration and its distribution between rill and inter-rill flow”. Additionally, our plot scale studies also encounter boundary problems e.g. infiltration across the boundary or outside the field plot area. Our rainfall simulator at the Riverside Campus, Texas A&M University could certainly generate rainfall for quite long time spans but the rainfall distribution was not uniform and average drop size was also less than natural rainfall. For all calculations in this thesis rainfall has been assumed to be unoform. Moreover there could be some loss of water due to wind. The results and observations are obtained from tests on a length of 30 feet flat surfaces therefore applicability on other flat surface with different lengths cannot be ascertained.

2 LITERATURE REVIEW

2.1 Overland Flow

Overland flow is generated by two mechanisms: infiltration excess and saturation excess. In infiltration excess, the rainfall rate exceeds infiltration capacity and this excess rainfall moves overland depending upon the topography. This type of overland flow usually occurs at places where water table is deep. Saturation excess overland excess flow occurs at a place where there is a shallow water table. In this type of overland flow, the cumulative infiltration depth exceeds the soil storage capacity, and the resulting excess saturation spills onto the surface as overland flow. Overland flow depends upon slope, flow length, soil characteristics, shape of the watershed, surface roughness, depth of water table and depression storage capacity of the watershed and rainfall intensity. Overland flow/runoff from here onwards refers to infiltration excess.

During any rainfall runoff event, in the early stages because of high infiltrability of unsaturated soil, the whole rainfall will infiltrate (Akan 1986). With continuous rainfall soil infiltration capacity continues to decrease and then comes a stage when rainfall rate exceeds the soil infiltration capacity and this difference in rainfall and infiltration rates is available for surface runoff. Surface topography then guides this available water towards the watershed outlet. With continuous rainfall the whole watershed starts to contribute towards the runoff at the outlet; at time of concentration, the discharge is the peak discharge.

2.2 Overland Flow - Peak Discharge Estimation

Methods to calculate surface runoff can broadly be classified in two ways: Infiltration models and Rainfall excess models. Infiltration excess models calculate infiltration and whatever cannot infiltrates is estimated as runoff. Some of these methods include Green Ampt, Horton, and Holton method. Rainfall excess models directly calculate runoff, e. g., SCS Curve Number Method. As peak discharge is generally required in most design analysis, there are some methods which directly calculate the peak discharge e.g. Rational Method and Graphical Peak Discharge Method.

2.3 Time of Concentration of Overland Flow

During any rainfall event, rainfall excess, i.e. rainfall minus infiltration and interception, first fills the depression storage then flows over land surface, then into shallow ill-defined rivulets, then shallow concentrated flow before entering a water course. Following the water course, the discharge the reaches the outlet. Time of concentration is thus sensitive to all the above mentioned flow types. Time of concentration (t_c) has been defined in the literature as:

- The travel time of a wave to move from the hydrological most distant point in the catchment to the outlet. (Bedient and Huber 1988).

- The time to equilibrium of the catchment under a steady rainfall excess (i.e. when the outflow from the catchment equals the rainfall excess onto the catchment) (Bedient and Huber 1988).
- USDA-NRCS (1986) defines time of concentration as sum total of travel times for sheet flow, shallow concentrated flow and channel flow.
- Time from the end of a burst of precipitation excess to the point of inflection on the falling limb of the direct runoff hydrograph (ASCE 1997).
- The duration required for runoff at the point of concentration to become a maximum under uniform and constant rainfall intensity (Hromadka et al. 1987).

Time of concentration estimation models/methods has been classified in two ways: hydraulic and empirical estimations. Hydraulic estimation considers uniform flow theory and basic wave mechanics. Some of the models in this category can be tabulated as in Table 1.

Table 1 Hydraulic Estimation Models of the Time of Concentration

S.no.	Hydraulic Model/Method	Time of concentration (minutes)	Remarks
1	Velocity Method	$\text{tc} = 1/60 \sum_{i=1}^{N} \text{Li/Vi}$	Where V= Velocity in fps = $KS^{1/2}$ N = Number of segments, L = Flow Length in feet, S = Slope (McCuen, 1998)
3	Overton and Meadows	$t_c = \frac{0.42}{\sqrt{P_2}}\left(\frac{nL}{\sqrt{S}}\right)^{0.8}$	Where 'n' is Manning's roughness,' L' is flow length in feet, 'S' is the slope and P_2 is 2 Year, 24 hour rainfall depth (Gupta, 1989)
4	Izzard	$q = ay^{m}$	Where 'q' is unit discharge in cfs/ft of flow width, yis flow depth in feet, 'k' and 'm' are coefiecients. Experimently a = $(0.0007i + k)/S^{1/3}$, 'i' is rainfall intensity in in./hr. and 'k' is the retardance coefficient.
5	Izzard- Gupta	$t_c = (0.024 i^{1/3} + 878 k / i^{2/3}) L^{2/3} / C^{2/3} H^{1/3}$	Where 'C' is Rational Method coefficient, 'i' is rainfall intensity in mm/hr, 'H' is drop in elevation in meters (Gupta, 1989)
6	Izzard - Horton	$t_c = (2/i^{1-1/m})\left(nL/\sqrt{S}\right)^{1/m}$	where 'i' is rainfall intensity in mts./hr., 'L' is in meters.

"Empirical estimation which usually arrive from hydrograph observation and often (but not always) consider watershed as a whole, not as a sum of sequentially computed reach behaviors" (Heggen 2003). Some of the methods are tabulated as in Table 2.

Table 2 Empirical Estimation Models for the Time of Concentration

S.no.	Empirical Model/Method	Time of concentration (minutes)	Remarks
1	Kiprich (Tennessee)	$t_c = 0.0078\left(L/\sqrt{S}\right)^{0.77}$	Where'L' is the longest flow path in feet, 'S' is the avg. slope along L. (McCuen, 1998).
2	Federal Aviation Authority	$t_c = 1.8(1.1-C)L^{1/2}/S^{1/3}$	Where 'L' is in feet, 'S' is in percentage and 'C' is rational method coefficient (McCuen, 1998)
3	Espey-Winslow model	$t_c = 31\Phi\left(L/\sqrt{S}\right)^{0.29}/\mathrm{Im}\,p^{0.6}$	Where 'L' is in feet, 'S' is slope, $\boxed{\Phi}$ is the “channelization” factor which includes the amount of channel vegetation and the amount of channel improvementsand 'Imp' is percentage impervious. This model was developed for Houston area watersheds, urban and rural with area less tha 35 miles^2 (McCuen 1998,p.153).
4	SCS Model	$t_c = 0.00526\frac{L^{0.8}}{S^{0.5}}\left(\frac{1000}{CN}-9\right)$	Where 'L' is in feet, CN is the curve number (dimentionless). This method can be applied to both rural and urban watershed with area less than 2000 acres (McCuen 1998, p.153)
5	Papadakis-Kazan	$t_c = 0.66L^{0.5}n^{0.52}S^{-0.31}i^{-0.38}$	Where 'n' is maninig's coeffiecient, 'L' is in feet, 'i' is in in./hr. and Slope 'S' is in ft./ft.Papadakis-Kazan gathered datasets from 84 natural rural watersheds from 22 states, 162 simulated rainfall tests at Santa Monica Muncipal airport, 93 simulated rainfall tests at CSU, and 36 simulated rainfall tests at UI and then came out with global regression equation.
7	Kerby-Hathaway	$t_c = 0.83\left(\frac{nL}{S^{0.47}}\right)^{0.47}$	Where L is in feet, S is in ft./ft.'n' is Kirby Retardance coefficient McCuen(1998). He noted that Kirby model was calculated at watersheds of less than 10 acres.

2.4 Factors Affecting Overland Flow/Time of Concentration

2.4.1 Infiltration

The rational method is a one-parameter model, i.e., time of concentration, as abstractions are accounted for in the runoff coefficient (Singh and Cruise 1989). The runoff coefficient ‘C’ vary during the rainfall duration and therefore do not physically represent infiltration (Smith and Lee 1984).

Hjelmfelt (1978) in his mathematical model indicated the influence of infiltration on time of concentration. For overland flow generation, rainfall rate has to exceed the infiltration capacity of the surface soil, so for the same rainfall rate the time of concentration can vary significantly based on the surface infiltration capacity curve. Paintal (1974) also found that the time of concentration is governed by infiltration. Akan (1986) developed a mathematical formula based on kinematic overland flow and Green-Ampt infiltration, using Manning’s roughness coefficient for time of concentration on a rectangular plane surface

2.4.2 Rainfall Intensity/Duration

After comparing 11 time of concentration methods using data collected from 48 urban watersheds, McCuen et al. (1984) found rainfall intensity is the most important input parameter. As can be seen in Tables 1 and 2, time of concentration is inversely related to this parameter. Singh (1976) stressed that rainfall duration has a definite influence on the time of concentration.

2.4.3 Surface Slope

Runoff moves from higher to lower elevations. Slope controls overland flow velocities and hence overland travel times. Surface slope controls flow velocity (Manning's Equation). Darboux et al. (2002) investigated the overland flow triggering on numerically generated surfaces and found that the ratio of slope to random roughness is an important variable. In most time of concentration models (Tables 1 and 2), the slope term appears in the denominator if it appears at all, and any value of slope close to zero would give exceptionally high values for the time of concentration or exceptionally low values for the flow velocity, which contradicts common observations. If all the variables affecting the peak discharge are kept the same but slope, time of concentration can vary significantly. In nature there commonly exist surfaces where average slope is quite close to zero, especially in Texas.

2.4.4 Roughness Coefficient/Flow Regime

The flow regime (laminar or turbulent) has also been found to affect the estimation of time of concentration, through its effect on the momentum transfer to the surface, and hence the value of the roughness coefficient. "For an overland flow with rainfall as the lateral inflow, the flow regime is complicated by the varying flow depth and velocity along the plane. The flow regime thus becomes variable. For a plane that is sufficiently long, from the upstream to the downstream end of the plane, the flow regime may change from laminar through transitional to turbulent" (Wong and Chen 1997). Butler (1977) distinguished laminar overland flow to be flow with Reynolds's number less than 1000 and turbulent otherwise. "Laminar overland flow with uniform width when analyzed as turbulent, the computed travel time is in error by

$$t_{laminar,\ true} = (Kq^{4/15})t_{turbulent,\ false} \tag{3}$$

where, the rate of discharge per unit width is q, K is a factor which varies with temperature, roughness and slope"(Butler 1982). Wong (2003) compared celerity and velocity based time of concentration of overland plane and time of travel in channel with upstream inflow. He found that average velocity time of concentration is β_o (ranges from 3.0 (laminar) to 1.5 (turbulent)) times longer than the average velocity base time of concentration for four flows (laminar to turbulent). Considering the above it can be concluded that time of concentration is sensitive to the flow regime, also there is nothing like a constant hydraulic resistance i.e. as hydraulic resistance changes with time and length of flow.

Sellin et al. (2003) concluded that for vegetated flood plain a single Manning's 'n' is inappropriate, it depends upon flow depth, velocity, vegetation type, density, dimensions, and flexibility which in turn depend upon age and season. So in the end it becomes necessary to choose an optimum/appropriate value for the roughness coefficient (Manning's 'n' or Darcy-Wiesbach 'f').

Manning's $$n = \frac{R^{2/3} S^{1/2}}{v} \tag{4}$$

Darcy-Wiesbach $$f = \frac{8gdS}{v^2} \tag{5}$$

where, acceleration due to gravity is g , S is the slope, v is the mean flow speed, d is mean depth, and R is hydraulic radius.

Sellin et al. (2003) reported that Darcy-Wiesbach friction factor recognizes different flow types based upon the Reynolds's number, so should be preferred for smooth turbulent or laminar flows and for fully turbulent, i.e., high Reynolds's number flows Manning's 'n' is preferable. Dunkerley (2002) stated that Darcy-Wiesbach 'f' can be used for both laminar and turbulent flows. Sheet flow is characterized by slow velocity and shallow depth; the flow may not be turbulent (Wong and Chen 1997).Gilley and Finkner (1991) empirically related Random Roughness (RR) and Reynold's number $\mathrm{R_e}$ to Darcy-Wiesbach ' f ' and Manning's 'n'.

$$f = \frac{6.3RR^{1.75}}{\mathrm{R_e}^{0.661}} \tag{6}$$

$$n = \frac{0.172RR^{0.742}}{\mathrm{R_e}^{0.282}} \tag{7}$$

Mwendera and Feyen (1992) suggested the following regression equation:

$$n = 5.6 * 10^{-3} \exp(1.361RR) \tag{8}$$

Manning’s ‘n’ is generally assumed to be independent of flow parameters and published values based on type of tillage, degree of crusting, presence of vegetation are usually taken. Wong (1996) developed a time of concentration formula for overland flow over a series of plane in terms of their Manning’s ‘n’, that is applicable to near turbulent and turbulent flow.

$$t_c = \sum_{j=1}^{N} 7L_j \left(\frac{n_j}{\sqrt{S_j}}\right)^{0.6} \left(\frac{\left[\sum_{r=1}^{j}\left(i_r L_r\right)\right]^{0.6} - \left[\sum_{r=1}^{j-1}\left(i_r L_r\right)\right]^{0.6}}{\left[\sum_{r=1}^{j}\left(i_r L_r\right)\right] - \left[\sum_{r=1}^{j-1}\left(i_r L_r\right)\right]} \right) \tag{9}$$

where, t_c is time of concentration in minutes, N is number of planes, L is length in m, S is slope in m m^{-1}, i is uniform net rainfall excess for jth plane in mm h^{-1}, n is Manning’s roughness coefficient of jth plane. Since net rainfall intensity is used, this formula accounts for different infiltration rates for different planes. He also developed an equation to estimate the peak discharge per unit width q_p (m^{2}.s^{-1}) for a series of planes with design rainfall intensity i_d (mm.h^{-1}) under full area contribution.

$$q_p = \frac{i_d \sum_{j=1}^{N} L_j}{3.6 * 10^{6}} \tag{10}$$

Akan (1984) equated instantaneous friction slope of a free surface flow to the bed slope and derived a physically based nomogram to determine inlet time of concentration. The inputs to the nomogram include physical properties of basin and rainfall intensity duration relationship.

Wong (2002) on the basis of rainfall simulation experiments on concrete and artificial grass surfaces, for a net uniform rainfall and a single plane coupled the Darcy-Wiesbach friction formula with the kinematic wave time of concentration formula to get Kinematic-Darcy-Wiesbach time of concentration formula. Darcy-Wiesbach coefficient f_L related to Reynolds's number R_L at the end of the plane at equilibrium are defined to be related as

$$f_L = \frac{C}{R_L^k} \tag{11}$$

$$R_L = \frac{iL}{3.6*10^6 \nu} \tag{12}$$

where, C and k are constant, experimentally for concrete $C = 4$, and $k = 0.5$ and for grass $C = 5000$, and $k = 1.0$, ν is the kinematic viscosity (m^2s^{-1}) and i is rainfall intensity (mm h^{-1}). Based upon the above two equations and substituting them in (Chen and Wong 1993; Wong, 1994; Wong and Chen, 1997).

$$t_c = \left(\frac{0.21(3.6*10^6)^k \nu C L^{2-k})}{S i^{1+k}} \right)^{1/3} \tag{13}$$

where, S is slope in m/m.

$$t_c = \left[\frac{0.21 L^2 f_L}{Si} \right]^{1/3} \tag{14}$$

From the above equations it can be seen that for time of concentration calculations, Darcy-Wiesbach resistance coefficient is not constant but depends (inversely) upon the net rainfall intensity.

2.4.5 Depression Storage

Paintal (1974) reported time of concentration to be affected by depression storage. During any rainfall event, whenever the rainfall intensity exceeds the infiltration capacity of the soil, depressions on the surface begins to fill. A part of the rainfall thus stays on surface which ultimately either evaporates back into the atmosphere and/or infiltrates. A lot of studies have been done to investigate the effect of this hydrological process on overland flow generation. Contrary to the belief that runoff begins after all depressions are filled; Hansen (2000) found that runoff starts before all the depression storage is filled. He also found that location of depressions also have a decisive influence on the precipitation excess required to all depressions.

Hansen (2000) observed that there are several roughness indices which define the surface depression storage capacity. Of all of them Random Roughness (RR) is most often cited. Allmaras et al. (1966) defined Random Roughness as a random occurrence of surface peaks and depressions or standard deviation among heights. Hansen et al. (1999) described Allmaras et al. (1966) procedure as follows:

1. All elevation data are transformed to natural logarithms.

2. Contributions from Oriented Roughness (Roughness due to ridges and occurring between rows of lister and ridge planting, undulations in surface relief such as plow furrow slices cultivator furrows (Allmaras et al., 1966)) and slope are then eliminated by correcting each elevation height of its row and column and the mean elevation height of all elevation points.
3. The 10% upper and lower extreme values are subsequently excluded from the dataset.
4. The Random Roughness is then obtained as the product of the standard deviation of the remaining logarithmic transformed data and overall arithmetic mean.

Darboux et al (2002) investigated the overland flow triggering on numerically generated surfaces and found that a ratio of slope to random roughness is an important parameter. The amount of precipitation excess needed to fill the depressions decreases with increasing slope steepness and decreasing random roughness (Onstad 1984). Depression storage Capacity (DSC) estimation from Random Roughness (cm) with slope ‘ S ‘(percentage) are as follows:

Mwendera and Feyen (1992) $$DSC = 0.294RR + 0.036RR^2 - 0.012RRS \qquad (15)$$

Onstad (1984) $$DSC = 0.112RR + 0.031RR^2 - 0.012RRS \qquad (16)$$

Planchon and Darboux (2001) made a computer model to calculate depression storage. The model inundates the surface with a thick layer of water and then removes the excess water.

2.4.6 Antecedent Moisture Content

“Surface soil moisture content is a state variable, that is either simulated or required as input for many hydrologic models” (Hawley et al. 1983). The effect of this state variable was studied by Jacobs et al. (2003) on Little Washita watershed. They found the runoff measurement error (by SCS method) was reduced when they used remotely sensed soil moisture data on an 800 m grid as compared to 28 km grid. Merz and Plate (1997) investigated the effects of initial soil moisture and its spatial variability on rainfall runoff process and found that organization in spatial patterns of soil moisture and soil properties may influence the catchment runoff. Flat terrains are more amenable to variable source area and retain ground surface inundation for longer periods of time (Hernandez et al. 2003). In the light of above findings, the effect of this state variable on overland flow time of concentration, on surfaces with negligible slopes, should be given appropriate importance.

Asch et al. (2001) also mentioned the importance of temporal and spatial distribution of soil moisture in top soil (0-5 cm.), that it affects runoff. Meyles et al. (2003) though experiments on Southeast Dartmoor, UK found that catchment response was relatively small (10% of the area) for initially dry state (low soil moisture and hence minimal lateral hydraulic conductivity) and large (65% of the area) for initially wet state (volumetric soil moisture content greater than 0.6 and rainfall events larger than 20mm).He also found that antecedent moisture content influences the shape of a resulting hydrographs from a storm event. During wet conditions runoff mainly depends upon topography (Beldring et al. 2000).

Akan (1986) combined the kinematic overland flow and Green-Ampt equations for a rectangular plot to develop a time of concentration chart for an infiltrating surface. It determines two time parameters, first the time when the surface runoff commences and the time to equilibrium (concentration). As Green-Ampt equation is used, effects of soil properties and antecedent soil moisture can be observed. He stated “the other factors remaining the same, the time of concentration increases with decreasing antecedent moisture content”.

In light of the knowledge gained in the literature review, we developed our experimental approach to consider those variables most likely to affect the time of concentration. We outline our experimental methods next.

2.5 Stepwise Regression

Stepwise regression uses an F-Test or partial F-test as its criteria to so as to whether an explanatory variable should be added to the regression equation. The steps of the algorithm as outlined in section 15.2, Draper and Smith (1998) are as follows:

1. First calculate the F-values of all the independent variables X regressed individually against the dependent variable Y. Choose the one with the highest F-value.
    a. Check if this F-value is statistically significant.
        i. If no, quit. No regression is going to be statistically significant.
        ii. If yes, proceed to 2.

2. Examine the partial F-values for all explanatory variables not included in the regression.
3. Choose the variable with the highest partial F-value, and include it in the regression.
4. Check if any variable need to be removed. Calculate the partial F-values of all the variables included in the regression.
    a. Check if the lowest partial F-value is les than the critical F-value for statistical significance.
        i. If yes, remove this variable from the set of regressors.
        ii. If not, continue with this set.
5. Continue from 2. until
    a. All variables are included.
    b. No more variables can be included because the partial F-values af all are statistically insignificant
    c. A lop is entered in which the same variable is entered and then removed in a single loop of 2.-4.

3 METHODOLOGY

The experimental setups were designed to conduct varying rainfall, microtopography measurements, infiltration measurements and drop size distribution. Plots were exposed to simulated rainfall under different environmental conditions. The setups were designed for small scale runoff measurements, rather than full scale simulation. The setups provide a comparative evaluation of runoff generation, hydrograph time parameters under controlled and documented conditions.

3.1 Experimental Rainfall Setup and Runoff Collection Procedure

3.1.1 Rainfall Simulator

From literature review, one of the key parameter/variable for the time of concentration was the rainfall intensity and uniformity. Initially it was planned that rainfall simulators available with the Hydraulics, Sediment and Erosion Control Laboratory (HSCEL), Riverside Campus, Texas A&M University, College Station shall be used. After running two test experiments with those simulators, two shortcomings were noted. Firstly there was no way to compact the soil (clay) at some standard compaction; secondly, the depth of the test beds (9 inches) was not deep enough to allow the system to reach the long term infiltration rate. It was decided, therefore, to carry out the tests on field plots.

To carry out rainfall simulations in the field, work began on the design and fabrication of a rainfall simulator. Key design criteria's involved were as follows:

1. Portability: The simulator should be portable so that it could be transported to different test plots around the riverside campus.
2. Rainfall variation: Designed simulator should be able to achieved storm intensities in the range from 1 to 3.5 inches/hour.

Continuous supply of water was needed as an input for the designed simulator. A hydro-mulcher available with the HSCEL was selected for this purpose. Key benefits of using a hydro-mulcher include variable rate of outflow (water) and large storage capacity (500 Gallons).Rainfall Simulator consisted of the following:

1. Frame.
2. Plastic Pipes and Nozzles.
3. Hydro-Mulcher.
4. Control Device.
5. Wind Shield.

3.1.1.1 Frame

Two frames 6'x 20'x 2' made of steel pipes (square cross-section 1") were joined together with C-clamp to hold plastic pipes. Two extra legs (columns of plastic pipes) were added to each frame to prevent sagging. These frames could be easily dissembled and joined to transport it to other test plots.

3.1.1.2 Plastic Pipes and Nozzles

Two plastic pipes 40 feet in length were placed/ fixed on the frame edges. The inlet of these pipes was the outlet of the control device. Two pressure gages were installed at both ends of the pipe. TORO 5H nozzles were attached to the pipes @2.5 ft. center to center spacing. A TORO 5H nozzle cover/sprays a half circle of 5 feet. The first two nozzles from both ends of the pipes was TORO 5Q. A TORO 5Q covers/sprays quarter circle of 5 feet diameter. These end nozzles were necessary as TORO 5H spread would have crossed the plot area otherwise.

3.1.1.3 Hydro-Mulcher

A hydro-mulcher was used as a continuous water supply source. The main advantages of using a hydro-mulcher include portability, large storage capacity and varying discharge capability.

3.1.1.4 Control Device

This is the most important component of the rainfall simulator. It consisted of a T- junction, Gallon-Meter, Reducer, Control Valve, and Outlet.

The T-Junction takes discharge from the mulcher. It then distributes it among pipes and mulcher. As the mulcher has a large discharge even at low RPM’s, so T-Junction returns the excess discharge (Mulcher outflow – Pipes input) back into the mulcher. A gallon-meter to measure the volume (in gallons) that goes to the pipes was installed between the control valve and outlet of the control device. The least count of the gallon-meter was 1 gallon. Outlet is a 1” plastic pipe that joined the reducer and inlet of the pipes. Control device was an assembly that converts 2” inflow from the T-Junction to a 1” supply source for the pipes. Control valve controled the flow to the pipe was placed between the reducer and the inlet to the pipes.

3.1.1.5 Wind Shield

Two wind shields 20ft. by 6ft. were constructed to block wind effects on rain drops. Wind shields were placed in a direction perpendicular to the wind direction. Figure 1 shows the rainfall simulator.

Figure 1 Rainfall Simulator

3.1.2 Experiment Plot Selection

As already stated, five different types of surfaces were needed to conduct experiments. Field reconnaissance was done in areas around the Hydraulics, Sediment and Erosion Control Laboratory (HSCEL) to locate specified plots.

3.1.2.1 Bare Clay Plots

After reconnaissance, detailed survey was done with a level. The process began by taking reduced levels longitudinally every 5ft. spacing on already marked lines on our selected area and selecting a 30 feet length which closely relates to our requirement, i.e., slope less than 0.5%. Three such plots were selected with their four corners marked with wooden pegs. These four corners were adjusted so that the plots resemble more of a rectangle than a parallelogram. Metal strips 4” in height were inserted along the three edges (two long edges (30ft.) and one short edge (the one with higher elevation)) with metal pegs. All joints between metal strips were sealed with clayey soil. To the fourth edge a runoff collection system was installed. This runoff collection system was fabricated from a 4ft. by 10 ft. galvanized iron sheet. The system collects runoff from the edges of the plot, 6 ft. in width and tapers to 6 inches at the other end. By doing so it became easier to observe, collect and measure runoff. A big ditch near the outlet of the collection system was made. The purpose of this ditch was to smooth line the process of runoff measurement.

3.1.2.2 Grass/Pasture Plots

Out of the three bare clay plots, on two plots seeds of Bermuda grass were planted. To enhance grass growth fertilization and mulch was sprayed. After one month, when no substantial vegetation showed up, Bermuda grass soding was done.

3.1.2.3 Concrete/Asphalt Plot

After reconnaissance, detailed survey was done with a level. The process began by taking level measurements on concrete runway around the HSCEL As plot selection required a construction of a ditch at the end of the plot, our selection process was limited to only concrete pavements along the edges of the runway. After extensive survey session, one plot which met our slope requirements was selected. The four corners were marked with a spray paint. Aluminum angle 2”x2” was used in place of metal sheets. Caulk was used as a sealant between the concrete and aluminum angle, and a runoff collection system was installed.

3.1.3 Rainfall Test Procedure

As the experiments were carried on field plots, it was observed that significant amounts of the artificial rainfall was blow away from the plots by the wind, and lost from our experimental system, so we closely monitored weather forecasts for wind and planned accordingly. Early mornings were the best; with the full sun, the top wind speed/gusts increased significantly. Low wind speed effects on rain drops could be reduced significantly with wind shields and long trees (along the south end of the plot). With the above precautions for bare clay, grass and pasture plots we could substantially do our experiments under controlled conditions. On concrete and asphalt plots, which were on the runway, absence of long trees, control was not that good.

3.1.3.1 Steps Involved on Bare Clay, Grass, and Pasture Plots

As the hydro-mulcher was also used by HSCEL for testing different mulches for their effect in preventing soil erosion, it was thoroughly cleaned with jet stream of water to remove all mulch. The experimental procedure for these plots was as follows:

1. Hydro-mulcher was filled with water and transported to the test plot site.
2. All nozzles were cleaned.
3. Initial gallon-meter reading (I_{gmr}), temperature and humidity values were recorded. Wind shields were placed in appropriate direction.
4. To measure initial moisture content, a core soil sample was taken from the plot and its initial weight is recorded immediately. Mulcher engine was started and its RPM and valve on control assembly adjusted keeping a watch on the pressure meter. Stop watch was started. Time when runoff appears on the runoff collection system was recorded as the Time of Beginning.
5. Runoff measurements were taken every minute. These measurements during the early tests were carried out by measuring the weight of water. The weight scale had a least count of 0.5lb. After that to improve the measurements, two graduated mugs with 1 liter capacity (least count of 100ml) and a graduated cylinder with a least count of 10 ml were used.
6. Once more than 6 readings were the same (steady-state runoff-plateau) (+-50ml), the hydro-mulcher was shut down.
7. Runoff measurements in the mean time continued till there is almost no runoff.

8. Final gallon-meter reading was taken (F_{gmr}). Figure 2 shows the rainfall simulation test on a pasture plot.

Figure 2 Simulated Rainfall Test

3.1.3.2 Steps Involved on Concrete/Asphalt Plots

As the quantity of runoff from concrete/asphalt plots was considerably higher than from the clay/grass/bare plots, the time was kept as a variable instead of discharge. Steps 1 to 8 were the same as mentioned in 3.1.3.1 with the replacement of steps 5 and 6 as:

5. An initial 2-liter container was filled, the time was noted, and immediately a second container was used to collect the water.
6. Subsequent time measurements were recorded. After running the experiments for more than 20 minutes, the mulcher was shut down.

3.2 Microtopography Measurement Description and Methodology

Microtopography measurements were taken to assess its affect on overland flow time of concentration on flat terrains. For this Dick Zimmer, Senior Research specialist, Proving Ground Support, TTI designed and fabricated a portable device that automatically records elevation measurements, for a grid spacing of 6”x7” in C drive of a computer. The instrument ran on DC power, and hence was fully portable. In honor of its inventor, we christened the device the “Zimmometer”.

3.2.1 Description of Zimmometer

This instrument records X, Y and Z ordinates of a grid node. X and Y values would be multiples of 6 and 7 respectively. For Z value it records a number that lies from +3.78” to -3.78” with a least count of 0.01”. It consisted of three parts a base fame, a movable trolley and a computer.

3.2.1.1 Base Frame

The Base Frame consisted of two parts, Side support Beams and Overhanging Beams. Two Side Support Beams (channel cross-section 3”x1.25”) 8 feet in length provided support to Overhanging beams with their columns fixed to the surface soil with staples. Each column had a jack attached to adjust its height. Two Overhanging Beams (channel cross-section 3”x1.25”), each 20 ft. in length, resting on Side Support Beams would provide a track for the Moving Trolley. Both overhanging beams had a supporting column in the centre with jacks attached onto it to adjust the elevation. One of the Overhanging beams had sensors attached to it. The center to center spacing of the sensors was six inches.

3.2.1.2 Movable Trolley

The movable trolley consisted of a Z-Bar, three sensors, four small rubber tires, a recording knob, a fixed and a movable plate. The adjustable Z-bar, attached to the movable plate was calibrated to record the Z-value of a grid node. The movable plate could be fixed in three defined positions on the fixed plate with a centre to centre spacing of 7 inches. The fixed plate carries three sensors at these defined positions to record Y-value of grid node. The movable plate had a small knob on it, pressing which records a set of X, Y and Z values. The recording knob, when pushed with all correct readings stored in the computer, generated a characteristic small beep. A long beep characterized something wrong in the connections and/or faulty sensor alignments. To the fixed plate was attached a port, through which recorded data was transmitted to the computer.

In summary sensors attached to an Overhanging Beam recorded X- value, sensors attached to the fixed plate recorded Y-value and sensor attached on adjustable bar recorded Z-value. Figure 3 shows the basic Zimmometer set up.

Figure 3 Microtopography Measurement System: Zimmometer

3.2.1.3 Computer Program

Dick Zimmer developed a computer program “soilplt3” to store the measured values on a desktop PC’s C-drive. This microtopography measurement system can take measurements on 15 feet by14 inches strip of soil surface.

3.2.2 Microtopography Data Collection Basic Set Up

The following steps completed the execution of the microtopography measurements on 30 feet by 6 feet plot.

3.2.2.1 Base Frame Leveling

The idea behind his step is to take all Z-values from a fixed reference reduced level. Two side support beams (KL and MN) were fixed to the soil surface using steel staples (6”x1”) inserted into the base plates of their columns. The positions of these beams were:

A. KL:-1 foot away from a shorter edge (AB), outside the plot area.
B. MN:-16 feet from the same edge (AB), towards the opposite edge of the plot.
C. Two overhanging beams (PQ and RS) were placed on the side support beams (21inches center to center) parallel to the longer edges of the plot (AC and BD).
D. With a leveling machine all four corners (J1, J2, J3, and J4) of the side support beams were adjusted to a constant level (say = RL). This was done using jacks attached to the columns of the side support beams. The idea here is if the corners are at the same level, the supporting beams would be at the same level.

3.2.2.2 Overhanging Beams Alignment and Leveling

The purpose of this step was to align the overhanging beams parallel to the longer edges (AC and BD) of the plot. Steps involved were as follows:

A. Two overhanging beams were moved together with trolley on it in such a way that the Z-bar is right on a corner (A) of the plot.

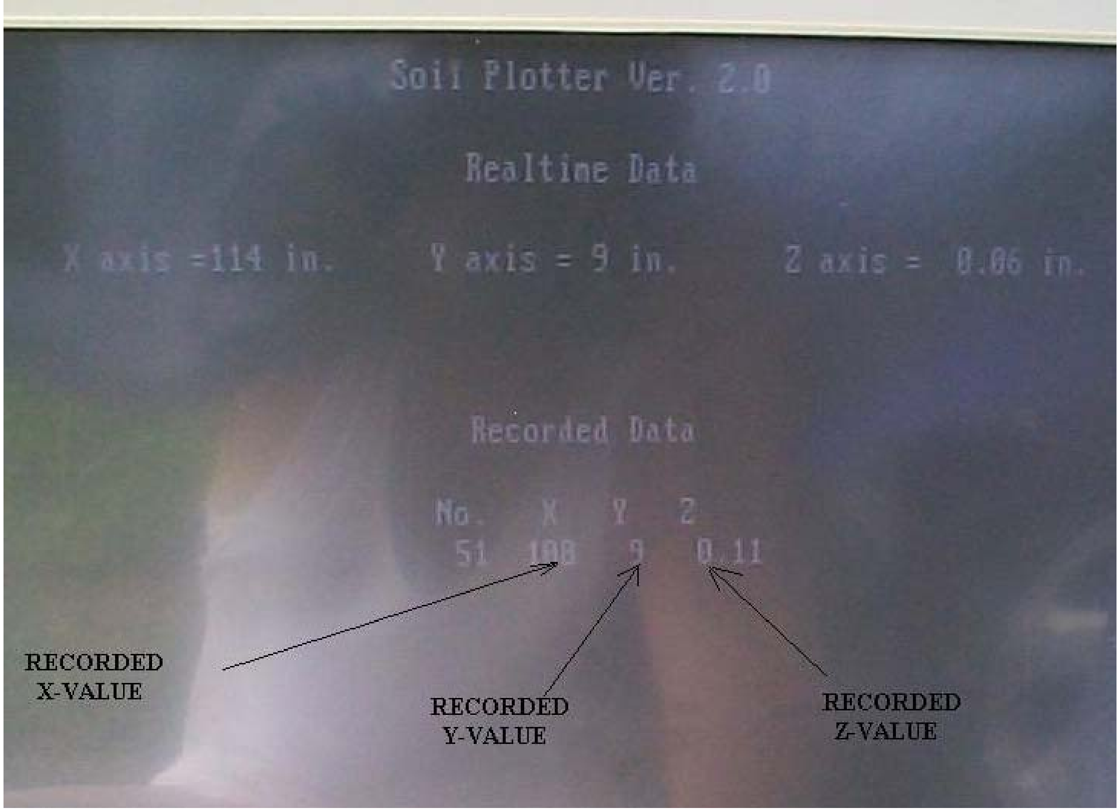
B. The trolley was than moved, with Z-bar almost touching the soil surface, all along the length (AE) to check for the alignment of the overhanging beams with the plot edge. The Z-bar should always be close to the edge (AC) and inside the plot. This completes the alignment part.

C. Overhanging beams were fixed to the side support beams using C-clamps at X1, X2, X3, and X4. Levels at X1, X2, X3 and X4 were taken. These values should be same (RL+ height of the channel i.e. 1.25”=RL1). In case these levels are not the same, levels at J1, J2, J3, and J4 are checked and corrected. Jacks on columns of overhanging beams at Y1 and Y2 are adjusted to get a level equal to RL1. By the end of this step two overhanging beams are at same level.

3.2.2.3 Microtopography Data Collection Procedure

To record measurements, a ‘file name’ and ‘run number’ was given to the ‘SOILPLT3’ program.

A. Z-bar was released to just touch the soil surface. The knob on top of the moving trolley was then pressed to record the first value at A (X=0, Y=2). As already stated a short beep should sound. Figure 4 shows the recorded values for a node.



```
Soil Plotter Ver. 2.0

Realtime Data

X axis =114 in.     Y axis = 9 in.     Z axis =  0.06 in.


Recorded Data

No.  X   Y  Z
 51  108  9  0.11
```

Figure 4 Microtopography: Data Storage

B. The moving trolley was then moved to the next location i.e. X=6, Y=2 and step ‘3.2.2.3.A’ repeated. This process continues till X=180.

C. The movable plate was then moved to its next position on the fixed plate and the trolley was moved back to X=0. The new location of the Z-bar is X=0, Y=9.

D. Steps ‘3.2.2.3.A, 3.2.2.3.B’ were then repeated.
E. Steps ‘3.2.2.3.C, 3.2.2.3.A, 3.2.2.3.B’ were then repeated.
F. Overhanging beams OP and QR were then moved each by 21” toward the plot edge BD. Levels at new Y1 and Y2 were corrected to equal RL1. and steps ‘3.2.2.3.A to E’ repeated.
G. Step ‘3.2.2.3.F’ was repeated once more.
H. Overhanging beams OP and QR were then moved each by 21” toward the plot edge BD and steps ‘3.2.2.3.A and 3.2.2.3.B’ were repeated.
I. Overhanging beams OP and QR were then moved each by 9” toward the plot edge BD and steps ‘3.2.2.3.A and 3.2.2.3.B’ were repeated.

By the end of step ‘3.2.2.3.I’, microtopography measurements of half of the plot were completed. The second half was completed by shifting the base frame (15ft) towards the other shorter edge of the plot and repeating steps 3.2.2.1, 3.2.2.2 and 3.2.2.3 considering A as E and B as F. The level set was never disturbed all throughout the process. The idea behind this was to keep level at new J1, J2, J3, and J4 same as RL. By doing so, the combined measurements of the whole plot are from the same level (RL1). Figure 5 shows the points on the plot as mentioned above.

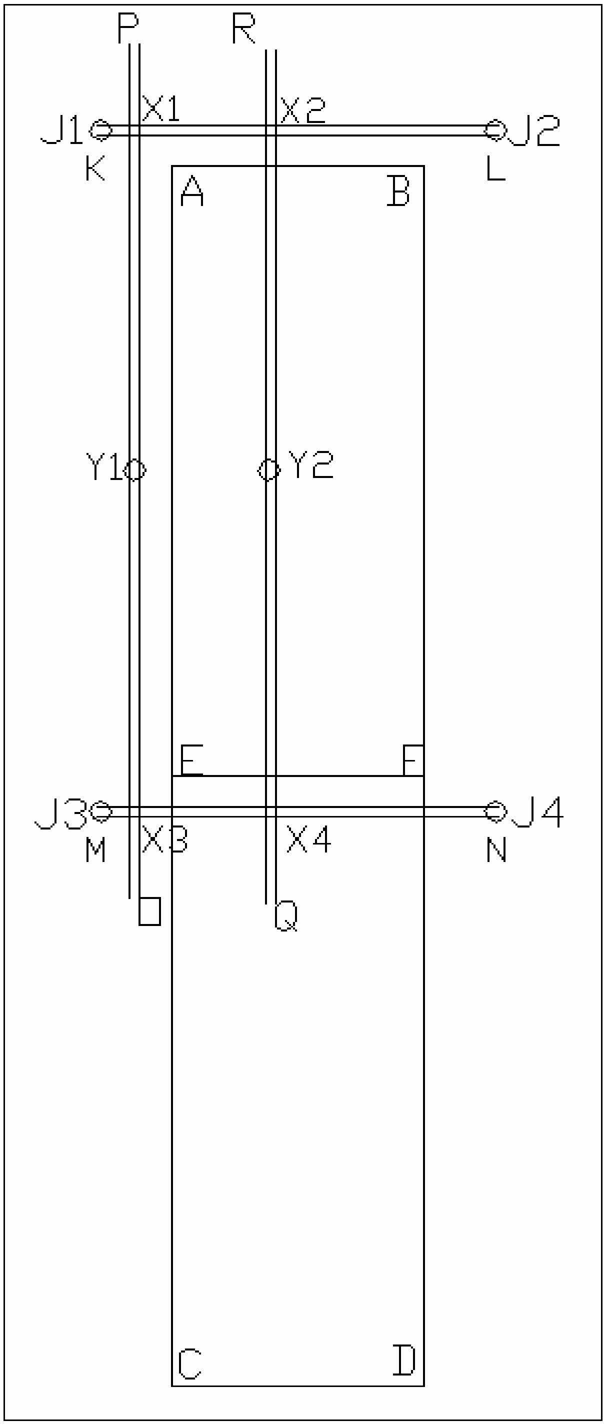


Figure 5 Microtopography Basic Set Up

3.3 Tension Infiltration Test

Tension infiltrometers are designed to measure hydraulic conductivities at different heads. Steps involved in measuring saturated hydraulic conductivity follows as:

1. A small portion of soil surface inside the plot area was cleaned and leveled (using fine sand).
2. A soil sample to measure initial soil moisture was taken close to the clean/leveled area.
3. A metal ring was inserted into this selected site.
4. Water was added into the tension disc (24 cm. diameter), by inserting it in a bucket of water and carefully removing the entrapped air.
5. Water was filled in the water tower (5 cm diameter) with the valve at the bottom of the tower closed. With disc in the bucket, blocking the loss of water from the water tower the valve was opened and joined to the disc. The valve was then closed immediately.
6. The system will generally still have some air it. This air can be removed using a suction pump.
7. The disc was placed on the cleaned/leveled surface, inside the metal disc.
8. By adjusting (raising/lowering) the tube in the bubble tower, a position of zero head was set.

9. Initial reading was then recorded from the scale on the water tower. The valve at the bottom of the water tower was opened and 'START' knob on the stop watch was pressed.
10. Water level readings on the water tower were taken every minute initially, followed by 5, 10 and 15 min interval.
11. In the end a soil sample was taken for final moisture content. Figure 6 shows basic Disc Infiltrometer test.

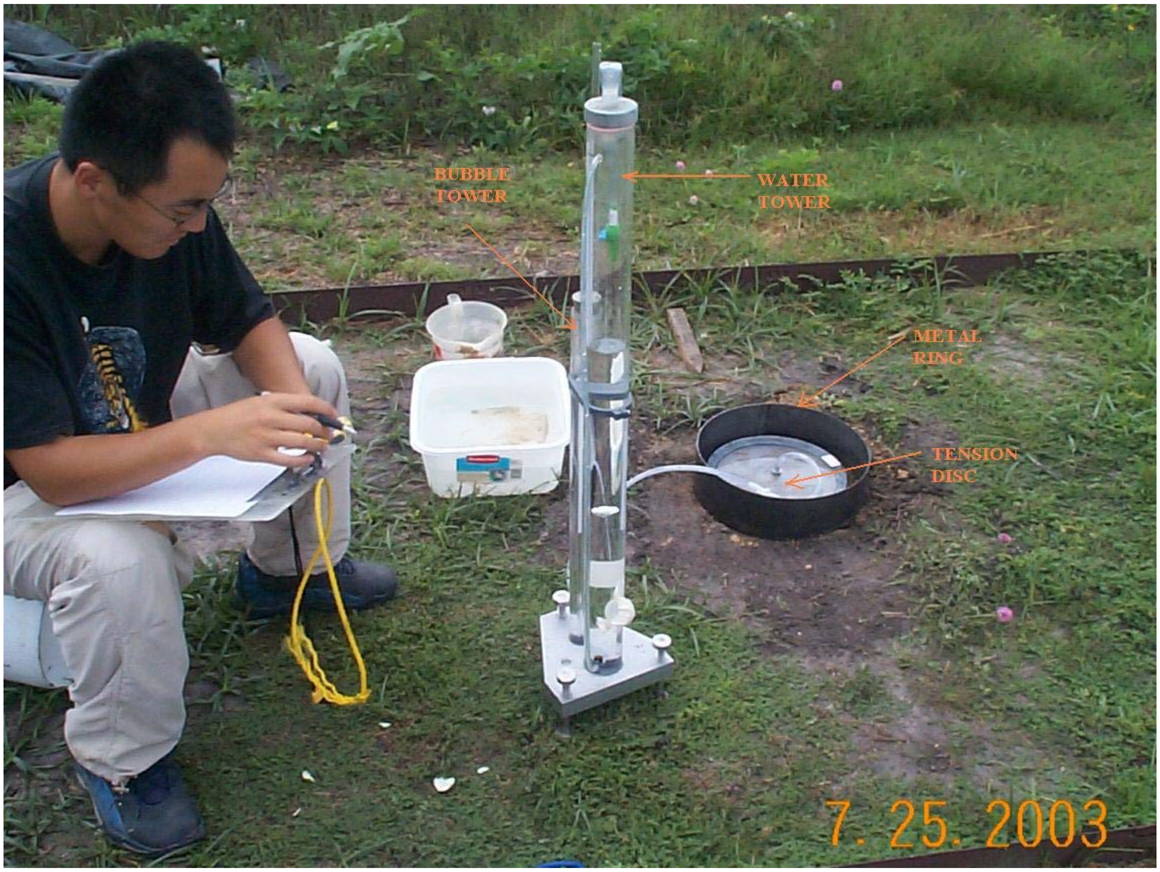


Figure 6 Set up Details: Disc Infiltrometer Test

3.4 Drop Size

To get rain drop size a method as described in Erosion Control Technology Council Test Method 2 section A1.2 , “Determination of rolled erosion control product (RECP) performance in protecting soil from rain splash” was used. The section A1.2 has been described as:

1. Fill four pie pans with sifted flour and strike off with a ruler to produce a smooth uncompacted surface.
2. Place the pie pans in a holding container and cover with a water proof lid or canopy.
3. Turn on the rainfall simulator and allow it to reach a steady rate of rainfall. Remove the water proof cover briefly to let drops impinge on the flour to form pallets.
4. Replace the cover after only a few seconds before pallets start to touch each other.
5. Air dry the flour filled pans for a minimum of 12 hours.
6. Screen the semi-dry pallets by emptying the entire contents of the pans onto a 70 mesh sieve in order to carefully remove as much loose flour as possible.
7. Transfer the remaining pallets to evaporating dishes and heat in an oven at 110^{o}F for 2 hours.
8. Weigh the total mass of the hard flour pellets.
9. Pour the pellets through standard soil sieves and shake for 2 minutes. Foreign matter and any double pallets are culled from each sieve and total weight of size is recorded.

3.5 Particle Size Distribution

This test determines percentages of different particle sizes in a soil sample. Particle size distribution was composed of two sets Sieve Analysis and Hydrometer Test.

3.5.1 Sieve Analysis

This test determines distribution of particle sizes larger than 0.0075mm. As dry sieve analysis of clayey soil was impossible, so to remove the effects of clogging, wet sieving was preferred. The steps involved are as follows:

1. Sieve Numbers 4, 10, 40, 100, and 200 were cleaned and dried thoroughly.
2. Testing soil was dried in a microwave and a sample weighing 200.00 grams was taken.
3. Sieves were assembled with smallest sieve number at the top to the largest sieve number at the bottom to obtain a sieve set. This sieve set was placed on top of a 5 gallon bucket.
4. Testing dried soil was mixed with water in 2000ml jug. The soil solution thus obtained was thoroughly stirred.
5. The soil solution was then poured on the sieve set with intermittent vibrations applied to the sieve set with a wooden/ metallic stick. These small vibrations helped in preventing clogging of the sieves. More water was poured to jar to mix the

remaining soil in the jar and poured again on the sieve set. This process continued till there was no soil left in the jar.

6. The top sieve i.e. number 4 was removed from the set. With this sieve above the remaining sieve set, clean water was added while breaking all lumps. This process and small vibrations continued till there is a clean discharge from this removed sieve to the remainder sieve set. This allows all particles smaller than sieve 4 mesh opening onto the sieve 10.
7. Step ‘6’ continued for the remaining sieves i.e. sieve numbers 10, 40, 100 and 200.
8. Soil retained all sieves was then weighed after drying them under shade for at least 24 hours.
9. The solution in 5 gallon bucket was kept aside for natural sedimentation.

3.5.2 Hydrometer Test

This test determines distribution of particle sizes smaller than 0.075mm. This uses sedimentation rate of different particles sizes to determine the particle size distribution. Steps involved are as follows:

1. Clean water at the top of 5 gallon bucket, obtained from 3.5.1.9, was poured out and remaining soil solution was taken out in a dish container and dried in microwave.
2. 50 grams of this dried soil was mixed with a solution of 125 ml solution of dispersing agent (120ml of distilled water and 5 grams of Sodium Hexametaphosphate) and kept as it for at least 16 hours.
3. After 16 hours, this solution was added to a sedimentation cylinder and more distilled water was added to reach 1000ml mark on the sedimentation cylinder.
4. Covering the top of the sedimentation cylinder with a stopper, the resulting solution was mixed thoroughly.
5. Room temperature was recorded. The sedimentation cylinder was placed down and ‘START’ knob of the stop watch pushed.
6. Hydrometer readings were taken at the following times 1, 2, 5, 15, 60, 250, and 1440 minutes. To take a hydrometer reading the hydrometer was very slowly and carefully placed in the sedimentation cylinder. Once there was no vertical movement of the hydrometer and then note down the reading from the graduations on the hydrometer.

3.6 Soil Moisture

This test determines the gravimetric moisture content of a soil sample. The steps involved are as follows:

1. Take initial weight of the pan.
2. Add soil sample into the pan and weigh it.
3. Place the pan in a microwave and dry it for 10 minutes. Let the sample cool down and weigh it again.
4. Repeat step ‘3’ for time equal to one minute until there is no change in the measured dried weight.

4 PRELIMINARY DATA ANALYSIS

4.1 Rainfall Test

From soil sample gravimetric moisture content ‘ θ ‘was measured as described in 3.6.

4.1.1 Rainfall Intensity

Rainfall intensity (i) was obtained by dividing the difference between final (F_{gmr}) and initial gallon-meter reading (I_{gmr}) by the product of mulcher stop time (T_s) and the area of the plot. Although the rain distribution was non-uniform, for all calculations it has been assumed uniform, and was derived using:

$$i(iph) = \frac{F_{gmr} - I_{gmr}}{T_s}\left(\frac{3.78*1000*60}{30*6*12*12*2.54}\right) \tag{17}$$

4.1.2 Discharge

Discharge ‘ Q ’ measurements were computed as follows:

1. If the runoff ‘ R ’ was measured in pounds per minute

$$Q\left(cm^3/\min\right) = R*453.6 \tag{18}$$

$$Q\left(gpm\right) = R*0.119828 \tag{19}$$

2. If the runoff ‘ R ’ was measured in milliliter per minute

$$Q\left(gpm\right) = \frac{R}{3780} \tag{20}$$

$$Q\left(cm^3/\min\right) = R \tag{21}$$

3. If the runoff ‘ R ’ was measured as the time (in minutes) to fill a 2 liter mug (t_{diff}).

$$Q\left(cm^3/\min\right) = \frac{2000}{60*t_{diff}} \tag{22}$$

4.1.3 Time to Peak/ Time of Concentration

Time to peak was obtained from the resulting hydrographs as follows:

1. For bare clay, lawn and pasture plots, the time to peak is the first observed time after which the discharge remains more or less constant. An amount equals to +-100ml. was taken as standard.

2. For concrete and asphalt surfaces, time steps to fill a 2 liter container (t_{diff}) were noted. The time measurements were difficult to take, and a relatively small error of 1 second cause large deviations in the measured discharge. After a certain time t_{diff} showed undulations, resulting in an undulated hydrograph. Time to peak was

then inferred as the time when the observed hydrograph first reaches a value close to the average discharge (This value was obtained as the average of discharge measurements from the time when the hydrographs showed undulation and the time when the mulcher was stopped.)

4.2 Microtopography

The microtopography measurements were recorded for the test plots were edited in Microsoft-Excel. The following stepwise procedure generated wire frame surface plots as:

1. The Zimmometer gave X values from 0 to180 inches at an interval of 6 inches for both halves of the plot. So for the second half all X values were increased by 180.

2. The Zimmometer gave Y values as 2, 9, and 16 inches which is the default program setting for those predefined positions on the fixed plate. As we needed it from origin, so these values were changed to 0, 7, 14, 21, 28, 35, 42, 49, 56, 63 and 72 inches as per the grid node location as described in section 3.2.2.3.

3. The Zimmometer gave Z values from -3.78 to +3.78 inches. An offset of 100 was added to all the Z values, so that they would all be positive for analysis and plotting purposes.

4. These X, Y and Z values were added in the SURFER 8.0 to generate wire frames of the surface plots.

4.3 Infiltration Test

From initial and final soil samples, initial and final gravimetric moisture content was determined as described in section 3.6. Infiltration rate ‘ I ’(cm/hr) was calculated as follows:

$$I\left(cm/hr\right)=\frac{\mathrm{I}_{measured}*5*5*60}{24*24*T_{step}} \tag{23}$$

Where $\mathrm{I}_{measured}$ =Measured infiltration (cm of water tower drop); 5 = diameter of water tower cylinder; 24 = Diameter of the tension disc and T_{step} is the time step in minutes.

4.4 Particle Size

4.4.1 Sieve Analysis

1. Weight of soil retained on each sieve was measured (W_i).
2. Percentage of soil retained (R_i) on each sieve was determined as:

$$R_i\left(\%\right)=\frac{W_i}{W}100 \tag{24}$$

3. Percentage of soil that passes each sieve (P_i) was calculated as:

$$P_i(\%) = 100 - \sum_{k=1}^{i} R_i \tag{25}$$

4. The amount of soil that passes Sieve number 200 (W_{200})was calculated as:

$$W_{200} = W - \sum W_i \tag{26}$$

4.4.2 Hydrometer Analysis

1. Hydrometer readings (R_h) were corrected for meniscus and dispersion. Specific gravity was assumed to be 2.65. Diameter of soil particles (D) was determined by

$$D = K\sqrt{\frac{L}{T}} \tag{27}$$

Where K is constant which depends upon temperature and specific gravity; L is the effective depth taken for hydrometer 152H from ASTM D422.

2. Percentage of soil remaining in suspension (P) was calculated as

$$P = \frac{Rh * \alpha * 100}{W} \tag{28}$$

Where α is the correction factor and W is the weight of dry soil (50grams).

5 RESULTS

5.1 Variation in the Runoff Coefficient

There has been a good deal of variation noted in the values of the runoff coefficients for different surfaces (Table 3). The average runoff coefficients arranged in descending order follows as Asphalt, Concrete, Bare clay, Pasture and Grass. Even for the flat terrains the runoff coefficients lie in the ranges as reported in the literature. The difference in the observed and reported runoff coefficients for asphalt and concrete can be attributed to some losses from the rainfall due to wind. Also the time scale required to measure small rate of change of discharge for these non infiltrating surfaces could not be feasible with our experimental procedure.

Table 3 Observed and Reported Runoff Coefficients

Surface Type	Descripition	Runoff Coefficient		Runoff Coefficient		Runoff Coefficient (Chow et. al. 1988) for 2-500 year Return Period.	
		Average	Range	Average	Range	Average	Range
Bare Clay	Bareclay02	0.29	0.23-0.32	0.47	0.23-0.62		
	Bareclay03	0.53	0.52-0.62 , 0.24				
Grass	Grass-Left	0.27	0.22-0.36	0.25	0.17-0.36	0.35	0.21-0.49
	Grass-Right	0.22	0.17-0.29				
Pasture	Pasture-Left	0.42	0.32-0.47	0.42	0.29-0.6	0.39	0.25-0.53
	Pasture-Right	0.41	0.29-0.49				
Concrete with expantion/contraction joints				0.67	0.61-0.80	0.875	0.75-1.0
Concrete without expantion/contraction joints				0.58	0.52-0.70	0.875	0.75-1.0
Asphalt				0.69	0.63-0.79	0.865	0.73-1.0

Bare clay, lawn and pasture plots were all on the same type of soil. It was observed that the grass roots tend to increase infiltration and/or detention. This can be ascertained from the observed runoff coefficients. Contrary to the logic that lesser the grass height the greater the runoff coefficient should be, pasture plots (height 8”-12”) generated more runoff coefficients than grass (height 2”-6”). The other difference between the two grassy surfaces was in their growth stage. The Grass/Lawn plots were tested when grass was in dormant stage, i.e., no evapotranspiration whereas the pasture surfaces were tested in their growing season, i.e., evapotranspiring.

Effects of surface undulations on runoff coefficient can be seen from the bare clay plots, for bareclay02 (more undulating, Random Roughness =0.536 cm.) runoff coefficient varied from 0.23 to 0.32 whereas for bareclay03 (Random Roughness = 0.434 cm.) the runoff coefficient varied from 0.52 to 0.62 with one exception when it came out to be 0.24 with an antecedent moisture content of 8.62%. The bareclay02 plot also had some reverse slope on to it towards the end. In general all infiltrating surfaces showed variations with respect to antecedent moisture content (Figure 7) and rainfall intensity (Figure 8).

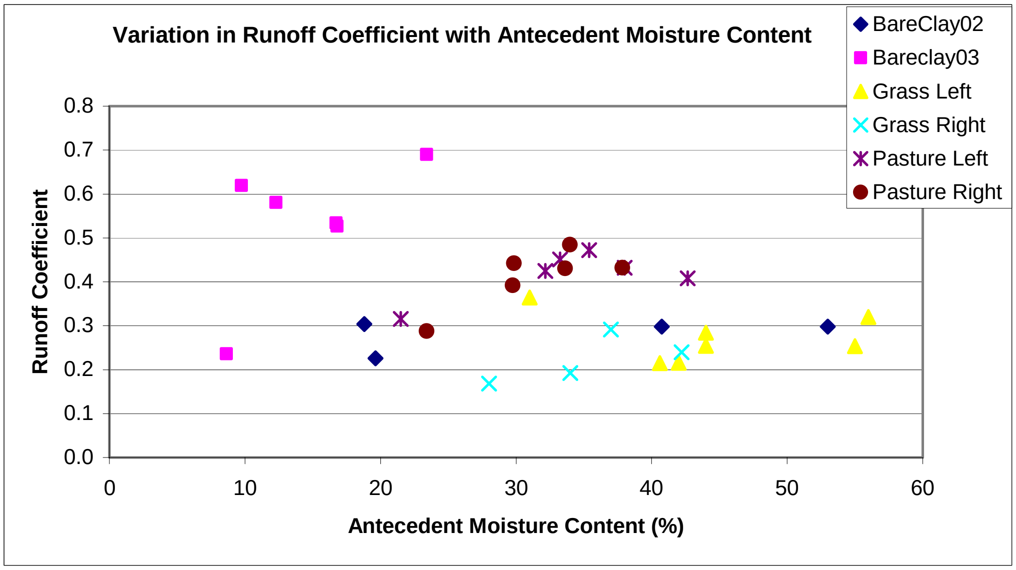


Figure 7 Variation of the Runoff Coefficient with Antecedent Moisture

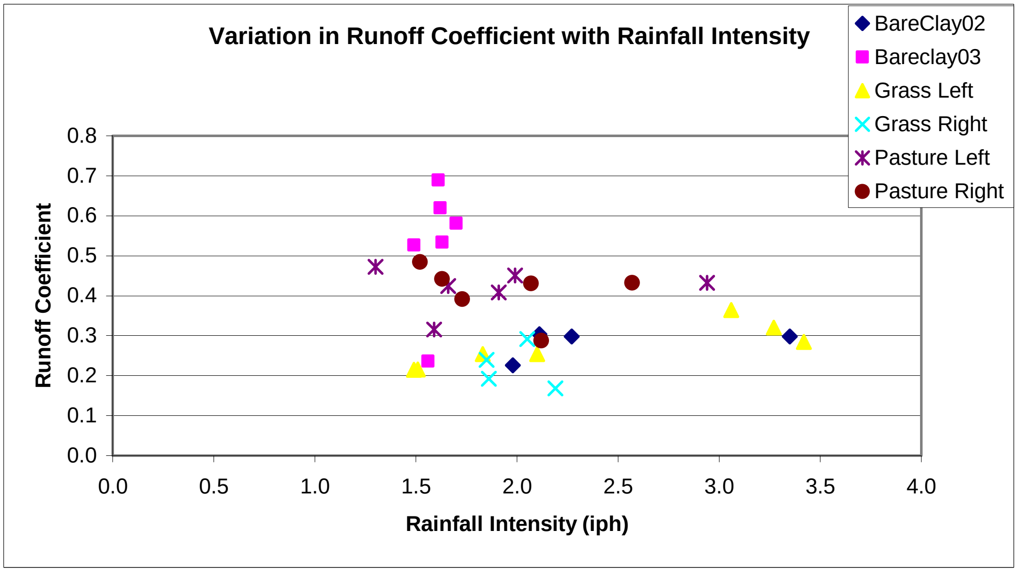


Figure 8 Variation of the Runoff Coefficient with Rainfall Intensity

5.2 Factors Affecting Time of Concentration

5.2.1 Bare Clay Plots

A direct relation between the time of concentration (TOC) and rainfall intensity as well as time of concentration and antecedent moisture content was observed for both the plots (Figure 9, Figure 10). The time of beginning (TOB) of runoff was found to influence the time of concentration more than the time from the beginning of the runoff to time when the discharge reaches equilibrium (TOB to TOC). TOB was observed to be more affected by the antecedent moisture than the rainfall rates. Once the runoff shows up combined affect of both these parameters affect the time to reach the peak, e.g., For almost the same rainfall intensity (1.61 iph) on the same plot, i.e., Bareclay03 with different antecedent moisture contents 8.64%, 9.74%, 16.74% and 23.4%, the time of concentration was observed to be 71, 61, 36 and 34 minutes and TOB was observed as 38, 26.66, 15 and 9.67 minutes. The TOB to TOC for these tests were 33, 34, 19 and 26 minutes.

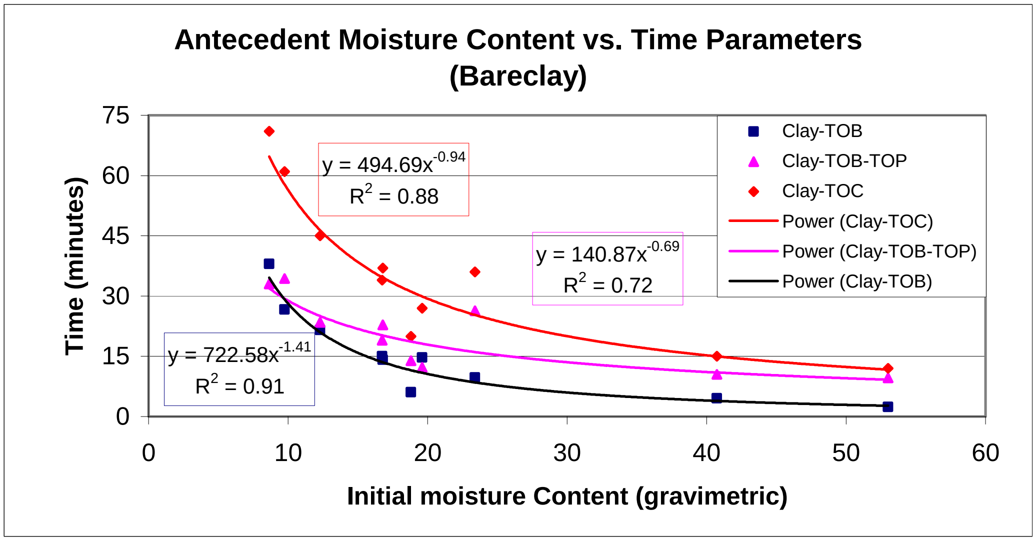


Figure 9 Variation in the Time Parameters with Antecedent Moisture Content for the Bare Clay Plots

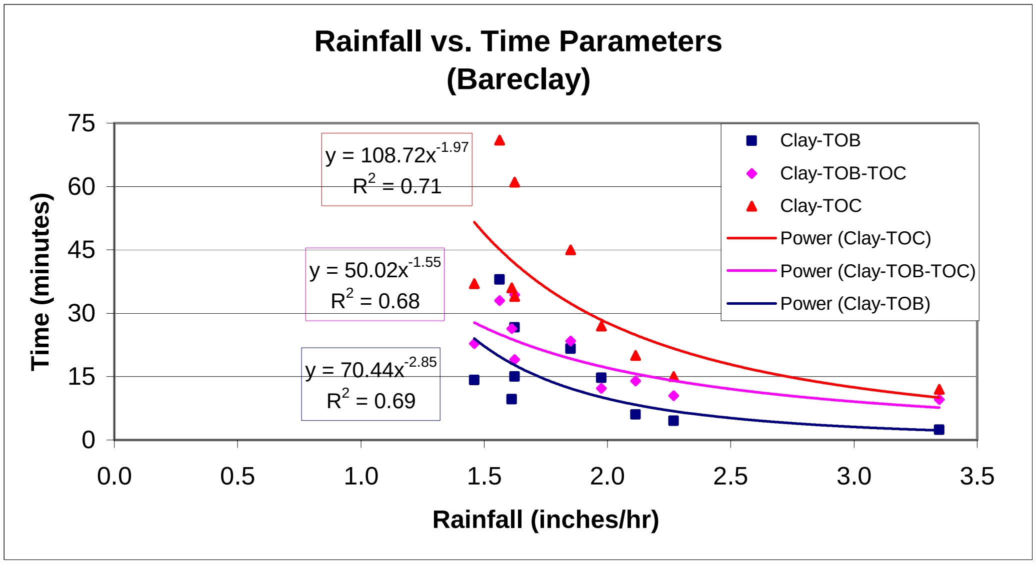


Figure 10 Variation in the Time Parameters with Rainfall Intensity for the Bare Clay Plots

5.2.2 Grass/Lawn Plots

Because grass plots were tested with higher antecedent moisture contents and high rainfall rates, little variation had been noted for the TOB (Figure 11). Time of concentration had been found to be directly proportional to the combined effect of antecedent moisture and rainfall intensity (Figure 11, Figure 12). Surface retention, infiltration and friction have been found to influence the time (TOB to TOC). This is evident from the tests (Grass left test-7, AMC = 56% and Rain intensity= 3.27iph vs. Bareclay02 Test-5, AMC= 53% and Rain intensity = 1.87iph). After the runoff showed up the grass plot took 17 minutes and the bareclay02 plot took just 9.6 minutes to reach the equilibrium.

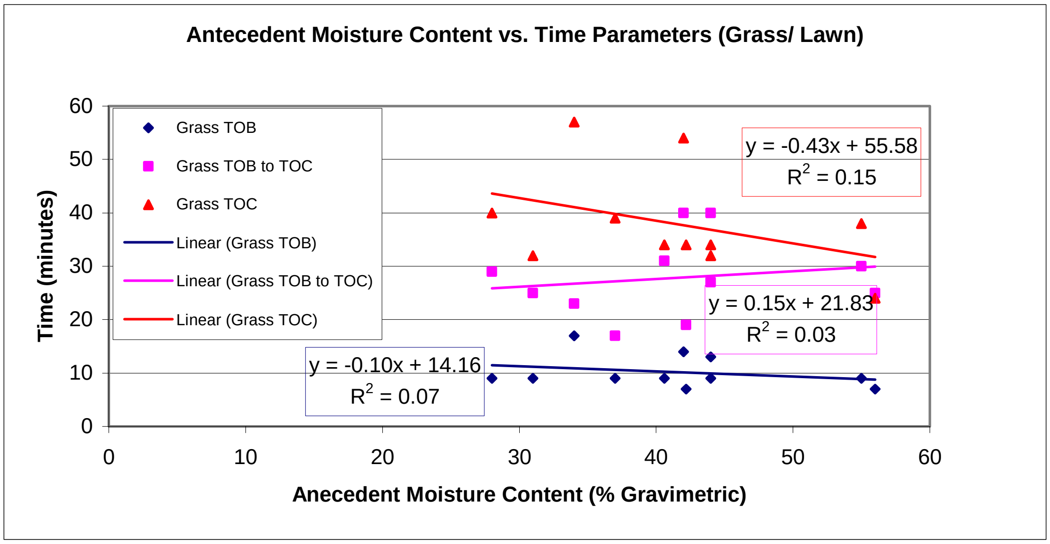


Figure 11 Variation in the Time Parameters with Antecedent Moisture Content for the Grass/Lawn Plots

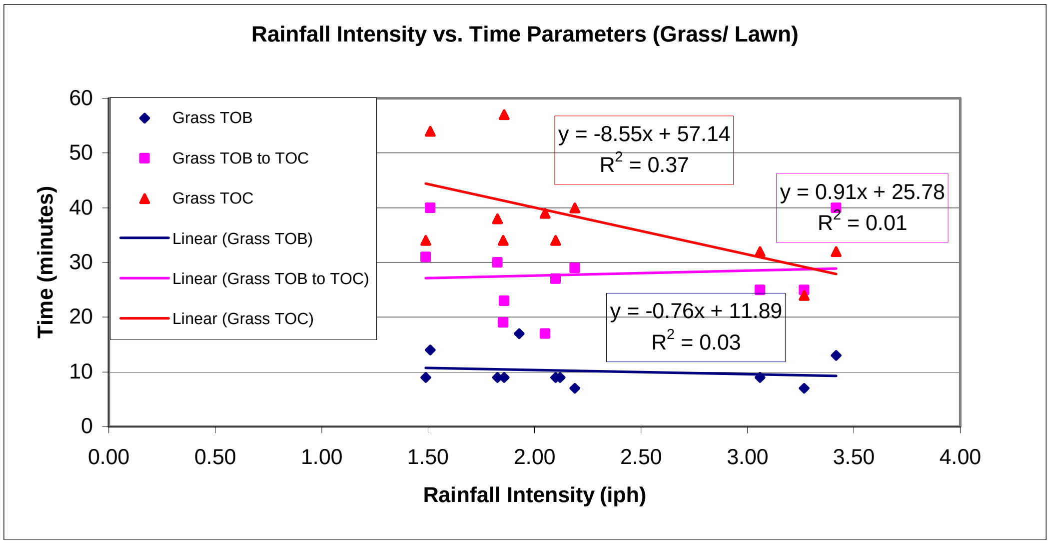


Figure 12 Variation in the Time Parameters with Rainfall Intensity for the Grass/Lawn Plots

5.2.3 Pasture Plots

Because pastures plots were also tested with middle to higher antecedent moisture contents, large TOB values were observed, which confirms the large surface retention and/or high infiltration rates of pasture plots. Even on mid-range antecedent soil moisture contents, large TOB values suggest the importance of interception, surface roughness and infiltration on runoff generation. TOB to TOC has been observed to be sensitive to both antecedent moisture content and rainfall intensity (Figure 13, Figure 14).

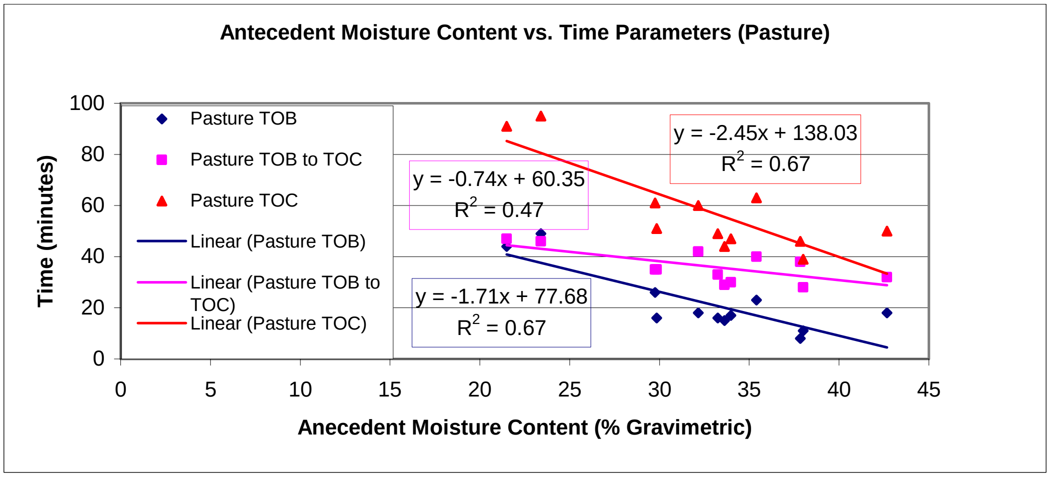


Figure 13 Variation in the Time Parameters with Antecedent Moisture for Pasture Plots

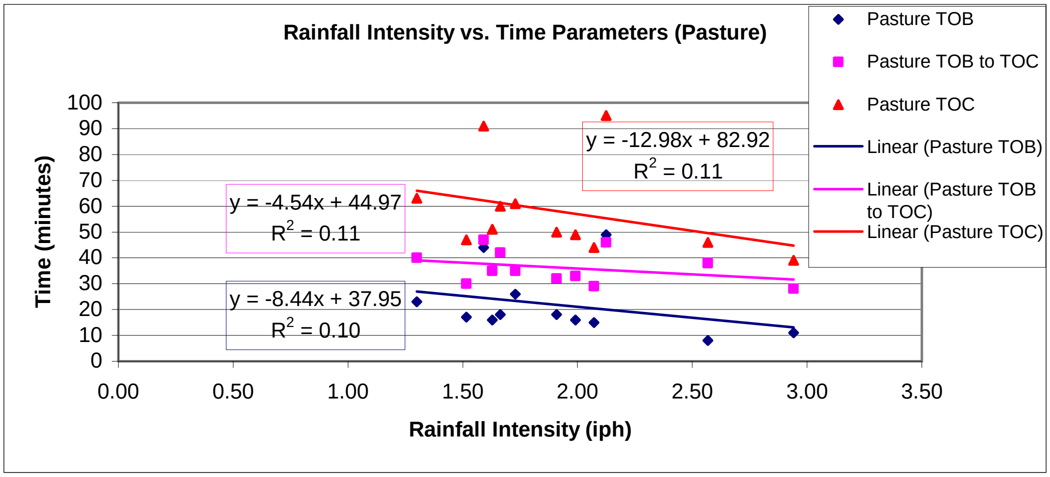


Figure 14 Variation in the Time Parameters with Rainfall Intensity for Pasture Plots

5.3 Comparison of Time Parameters for Different Surfaces

5.3.1 Time of Beginning (TOB)

The effect of AMC and rainfall intensity on TOB for all the infiltrating surfaces tested was found to be significant (Figure 15). From figure 17 it can be seen that for almost the same initial conditions and almost the same rainfall rates this parameter for bare clay, pasture and concrete was 9.67, 44 and 2.92 minutes. In general for the same initial conditions, TOB can be arranged in ascending order as bare clay, grass, and pasture. For bare clay surfaces equation 29 describes TOB’s sensitivity to the Antecedent Moisture Content (AMC) ‘θ’ in percentage value. Clear relationship between TOB and AMC is missing for the grassy surfaces. The relation might be missing because of the moisture ranges in which the tests were conducted. With respect to rainfall intensity, inverse trends can be observed for the bare clay and pasture plots for the time of beginning (Figure 16).

For bare clay plots: $$TOB = 722.58\theta^{-1.41}, (R^2 = 0.91) \qquad (29)$$

For pasture plots: $$TOB = 30409\theta^{-2.1255}, (R^2 = 0.66) \qquad (30)$$

This time parameter has been found to show large variability with respect to the initial conditions for the bare clay and pasture surfaces to induce larger variability in the time of concentration. Also as bare clay surfaces shrink and swell depending upon the soil moisture, cracks are common observations. Such cracks were tested by adding water onto them; it has been seen that these cracks act as a sink and take up a lot of water without showing any substantial water at the top.

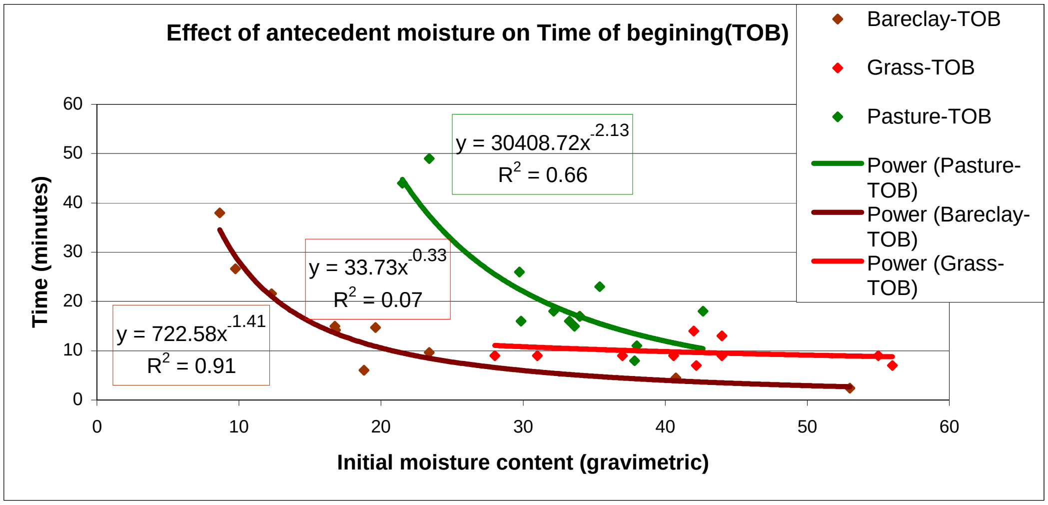


Figure 15 Variation of the Time of Beginning with Antecedent Moisture Content

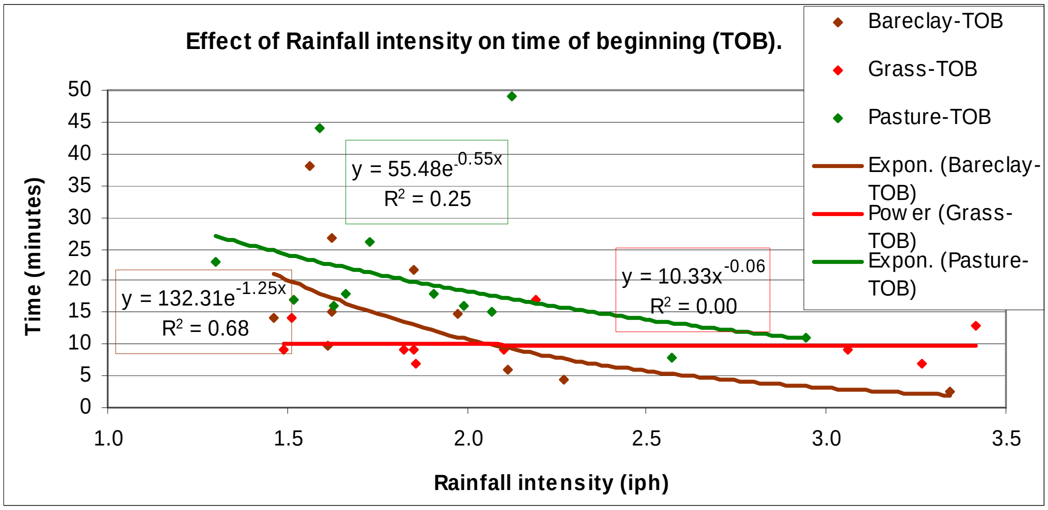


Figure 16 Variation of the Time of Beginning with Rainfall Intensity

TOB values for the different infiltrating surfaces can be tabulated as shown in Table 4.

Table 4 Comparative Tabulation of the Time of Beginning

Surface Type	Rainfall Intensity (iph)	AMC (%)	TOB (minutes)
Bare Clay	1.49-3.35	8.6-53.0	2.4-----38
Grass	1.49-3.42	28-56	7-----17
Pasture	1.3-2.94	21.5-42.7	8-----46

5.3.2 Time of Beginning to Time of Concentration (TOB to TOC)

In spite of the fact that the two grassy surfaces were tested on medium to high antecedent moisture contents, TOB to TOC for these surfaces (Pasture-29-47 minutes, Grass 17-40 minutes) were still quite high. The rate of increase of discharge per unit time could be arranged in ascending order as concrete/asphalt, bare clay and pasture. This can be seen from the Figure 17.

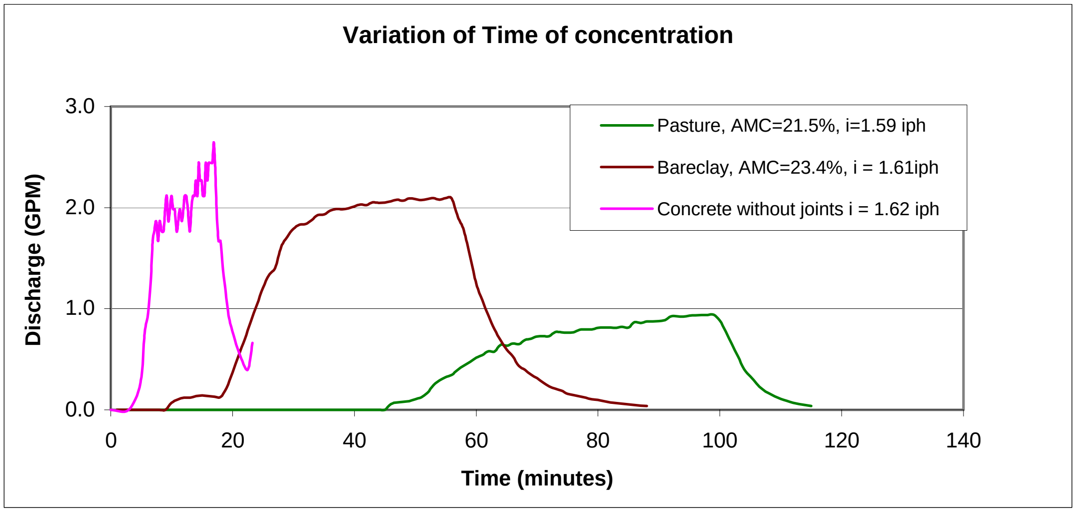


Figure 17 Typical Hydrographs for Concrete, Bare Clay and Pasture

5.3.2.1 Hydrograph Slope

All surfaces generated different shapes for their hydrographs. If the time of beginning is known, assuming a linear hydrograph and slope of the hydrograph in degree as:

$$Slope = \tan^{-1}\left(\frac{Q(gpm)}{(TOBtoTOC)(\min)}\right)*180/\pi \tag{31}$$

A linear relationship between the slope of the hydrograph and the rainfall rate (iph) has been observed. The $Slope$ can be determined given the rainfall rate 'i'as:

For Barclay $$Slope = 4.298i - 3.3829, (R^2 = 0.834) \tag{32}$$

For Grass/Lawn $$Slope = 2.807i - 3.5882, (R^2 = 0.90) \tag{33}$$

For Pasture $$Slope = 1.6949i - 0.3356, (R^2 = .604) \tag{34}$$

Figures 18, 19 and 20 shows the variation in the hydrograph slope with rainfall intensity for bare clay, grass and pasture plots respectively.

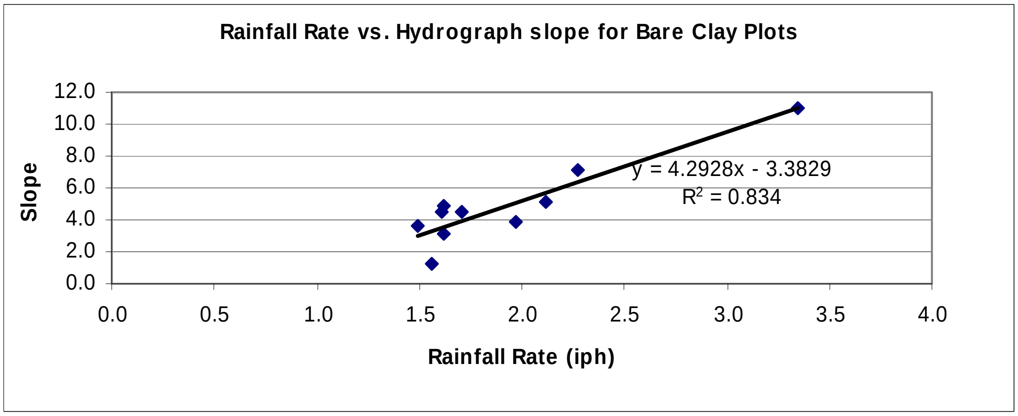


Figure 18 Variation in the Hydrograph Slope with Rainfall Intensity for Bare Clay Plots

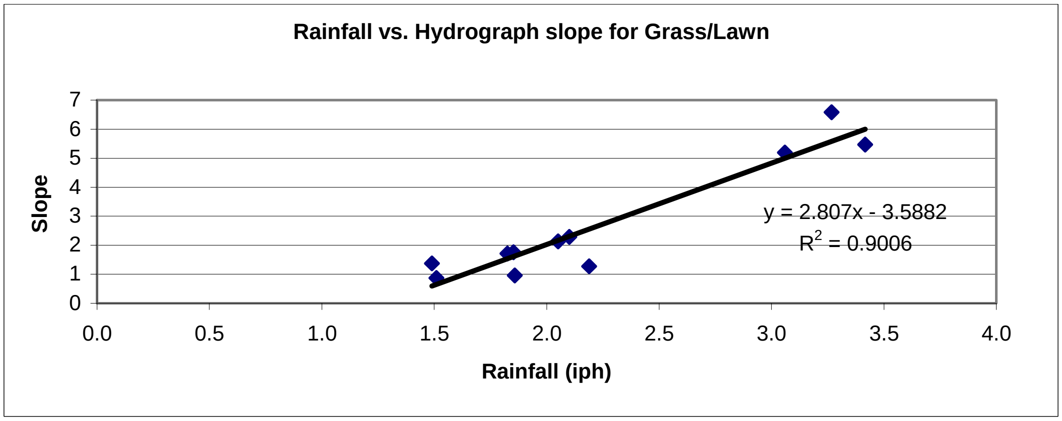


Figure 19 Variation in the Hydrograph Slope with Rainfall Intensity for Grass Plots

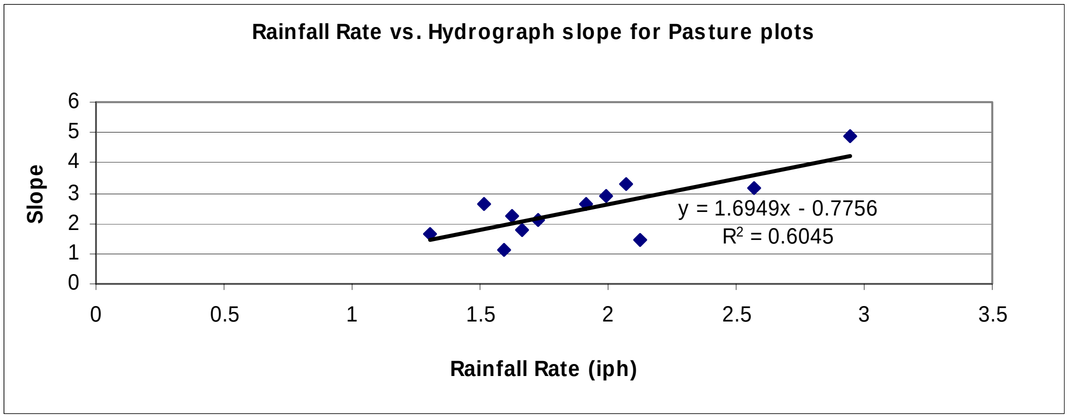


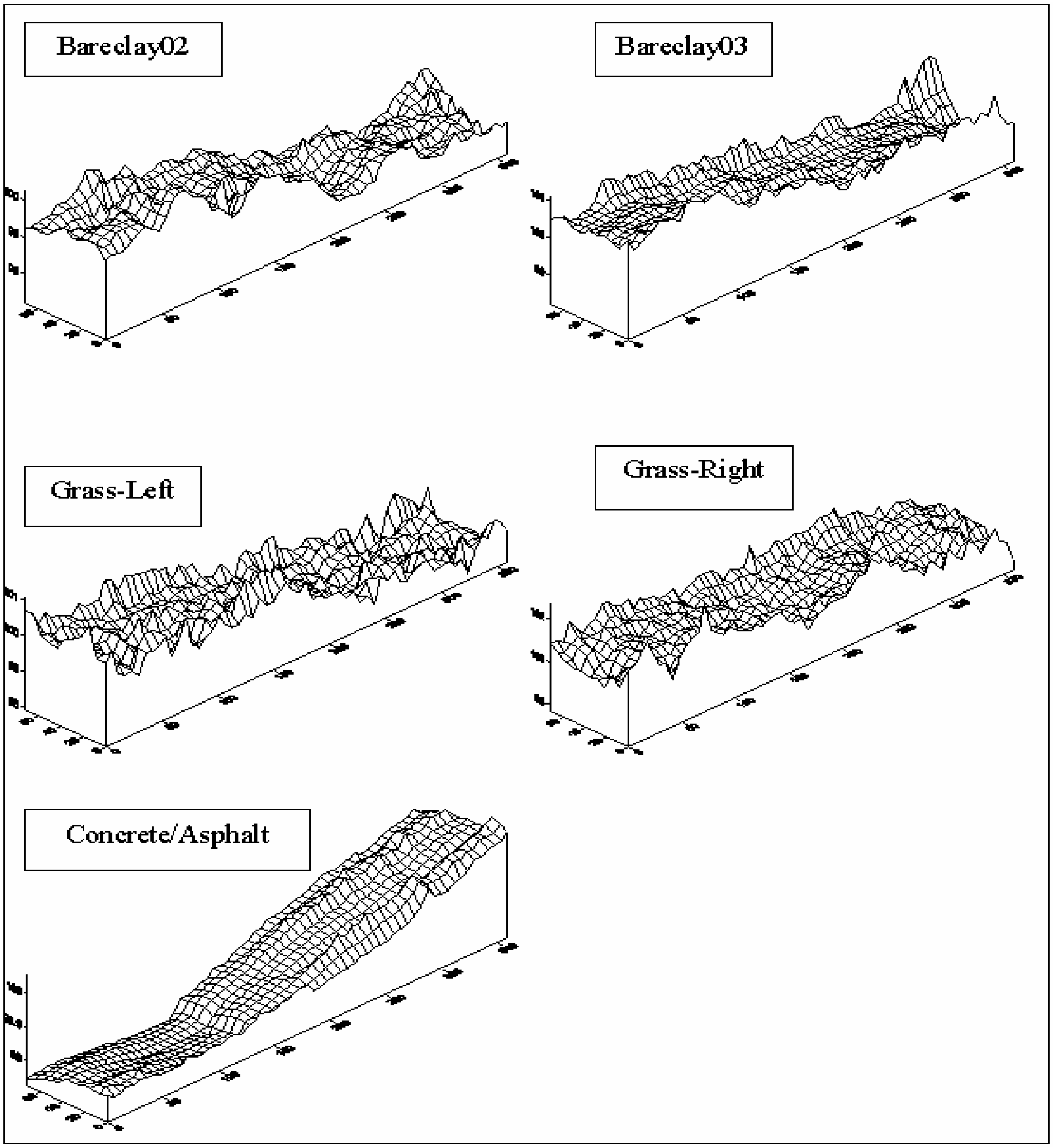
Figure 20 Variation in the Hydrograph Slope with Rainfall Intensity for Pasture

5.3.3 TOC to Zero

The falling limb of the hydrographs for showed substantial variation. This parameter was found to be highest for pasture (21-47 minutes), followed by grass (21-45 minutes) and bare clay (7-18 minutes).

5.4 Effect of Microtopography

Microtopography controls the time of concentration to an extent for the infiltrating plots. This can be seen from the time of concentration regression model for infiltrating surfaces. Exact estimation of the depression storage in order to understand its effect on the time parameters requires smaller grid cell size. As with our measurement system the grid size varied from 6 to 9 inches, which is very large to measure the exact random roughness and thus the depressions. Never the less this system is good enough to compare the undulation patterns of two or more plots. Figure 21 shows the wire frame structures of the plots generated with Surfer 8.0.



Bareclay02

Bareclay03

Grass-Left

Grass-Right

Concrete/Asphalt

Figure 21 Microtopography Generated with SURFER 8.0

5.4.1 Depression Storage of the Plots

Depression storage of the plots was calculated following Onstad (1984). Random Roughness was calculated as per Allamaras et al (1966), including the extreme 10% of the data points. The slope of the plots has been taken as the difference of the average level at X= 354inches and X=6 inches divided by 29. No measurements have been taken for the pasture plots. As grass on the lawn plots had been let grow to reach a height greater than 6” to treat those plots as Pasture. Thus values calculated for the grass plots have also been used for the pasture plots. The calculated depression storage can be tabulated as in Table 5.

Table 5 Random Roughness and Depression Storage Values for the Plots

Calculation Of Depression Storage from Microtopography data.		
Surface Type	**Random Roughness (cms)**	**Depression Storage (cms)**
Bareclay02	0.566	0.070
Bareclay03	0.434	0.052
Grass-left / Pasture-Left	0.561	0.069
Grass-Right / Pasture-Right	0.706	0.092
Concrete	0.181	0.021

5.5 Green Ampt Parameter Calibration

Using the ‘Solver’ tool of the Microsoft Excel Green Ampt parameters were calibrated for the bare clay and pasture surfaces. The L.P. formulation was defined as:

Minimize $$\sum (f_o - f_p)^2 \tag{35}$$

Subject to:

$$0.001 \leq K_{sat} \leq 0.1 \tag{36}$$

$$f_p > 0.001 \tag{37}$$

$$\psi >= 10 \tag{38}$$

For Bare Clay $$\partial\theta \leq 0.3 \tag{39}$$

For Pasture $$0.05 \leq \partial\theta \leq 0.15 \tag{40}$$

$$t_p = \frac{F_t - \psi\partial\theta\left(1 + \left(\dfrac{F_t}{\psi\partial\theta}\right)\right)}{K_{sat}} = t_{obs} \tag{41}$$

Where F_t = Cumulative infiltration at time‘t’; ψ =Wetting front suction head (cm); $\partial\theta$ = Residual moisture content; t_p =Predicted time (hrs); t_{obs} = Observed time (hrs); f_p = Predicted infiltration rate (cm/hr); f_o = Observed infiltration rate (cm/hr). The objective function came out to be 0.068 for bare clay and 56.93 for the pasture surface. This explains the non suitability of the Green Ampt for the grass surfaces. From the infiltration curve for the pasture plot it can be seen that there are large infiltration rates for the first 20 minutes even with an initial moisture content of 32.5% (gravimetric).

These large infiltration rates could be because of the grass roots effects. Only a few infiltration tests were conducted, and the best test was used for calibration, limiting the confidence level of our results. These results will vary depending upon the number of good test datasets we have. Figure 22 and 23 shows the observed and predicted infiltration rates for bare clay and pasture plots.

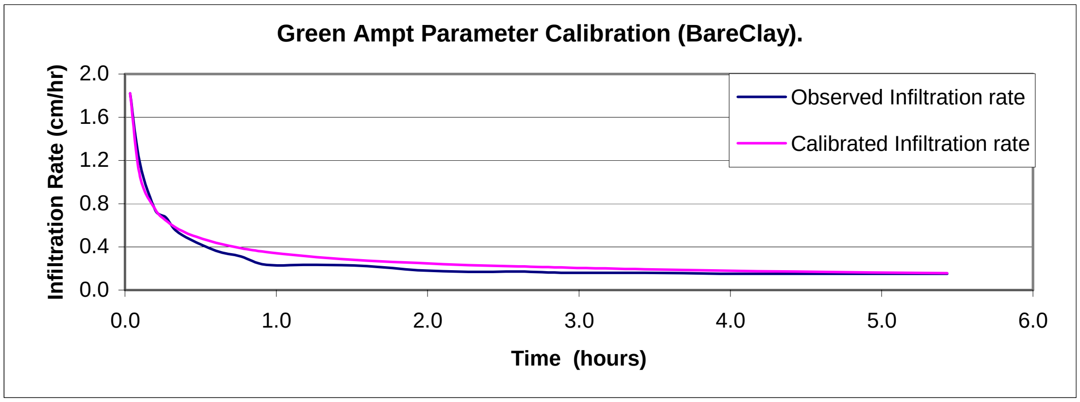


Figure 22 Green Ampt Calibration for Bare Clay

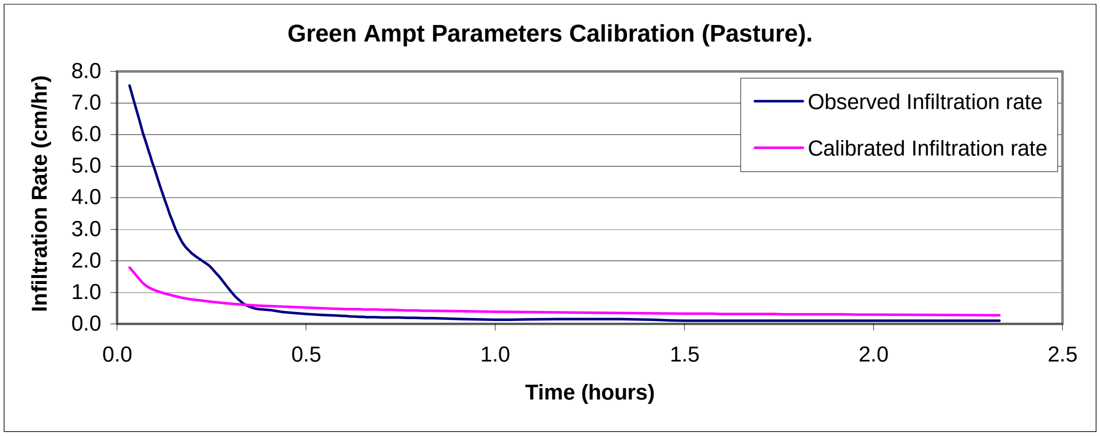


Figure 23 Green Ampt Calibration for Pasture

The resulting parameters for the two soil surfaces were as:

Bare Clay: - $Ksat = 0.0218 cm/hr.; \psi = 34.99 cm.; \theta s = 0.49 gm/gm$.

Pasture: - $Ksat = 0.1 cm/hr.; \psi = 13.19 cm.; \theta s = 0.475 gm/gm$.

5.6 Comparison of Different Time of Concentration Models

Some of the commonly used time of concentration models have been compared with the observed datasets (Figure 24 to Figure 31). Following are the observations:

1. There has been substantial variation in the predicted time of concentration by different methods. This variation can be firstly due to the fact that different models have been calibrated on different watersheds, as an example Kiprich (1940) calibration came out with different exponents/constants for Pennsylvania and Tennessee watersheds and secondly these existing models are based on different definitions.
2. Most of the empirical models under predict the time of concentration, which limits their application on flat terrains.
3. The sensitivity of the initial moisture content towards the time of concentration is missing in the models compared.
4. Models based on Izzard model showed good results for lower time of concentration values.

5.6.1 Bare Clay

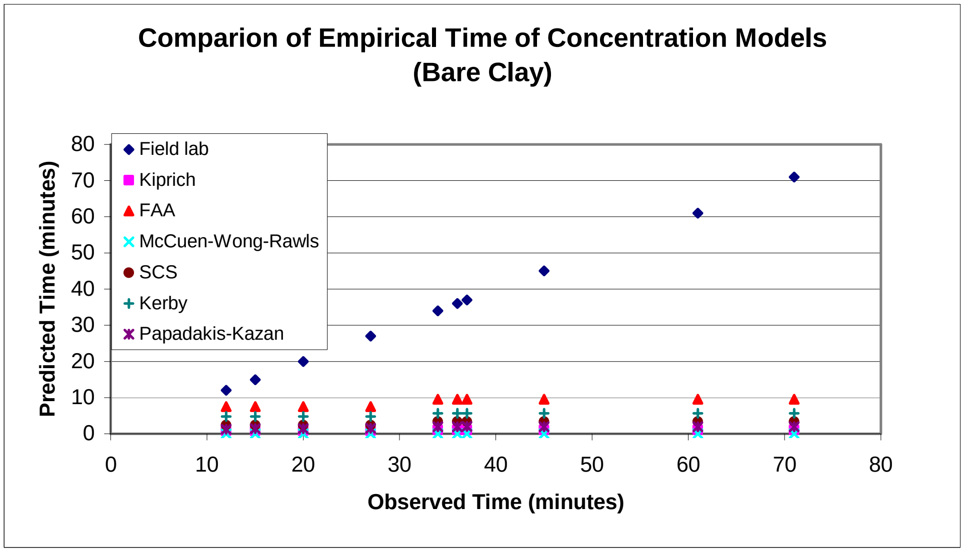


Figure 24 Comparison of the Empirical Time of Concentration Models for Bare Clay

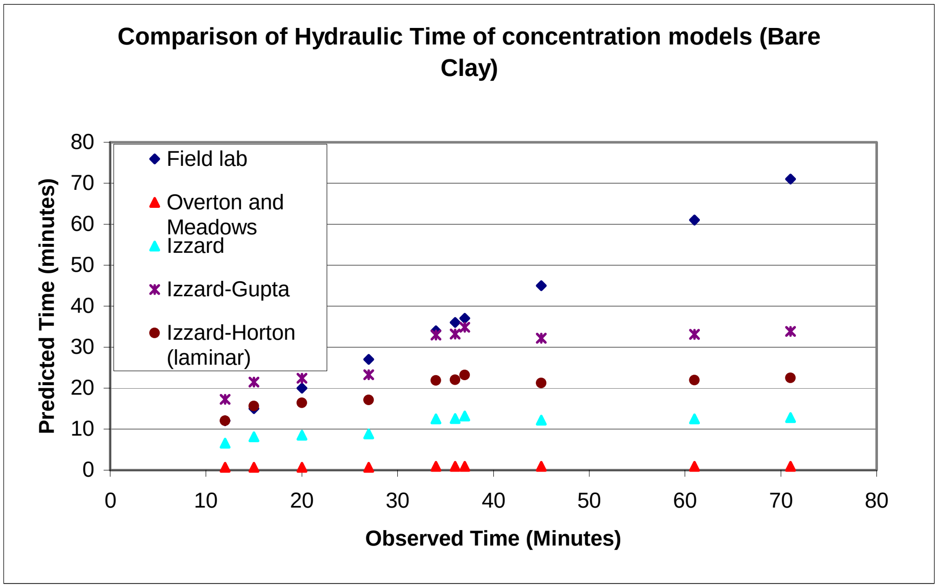


Figure 25 Comparison of the Hydraulic Time of Concentration Models for Bare Clay

5.6.2 Grass/Lawn

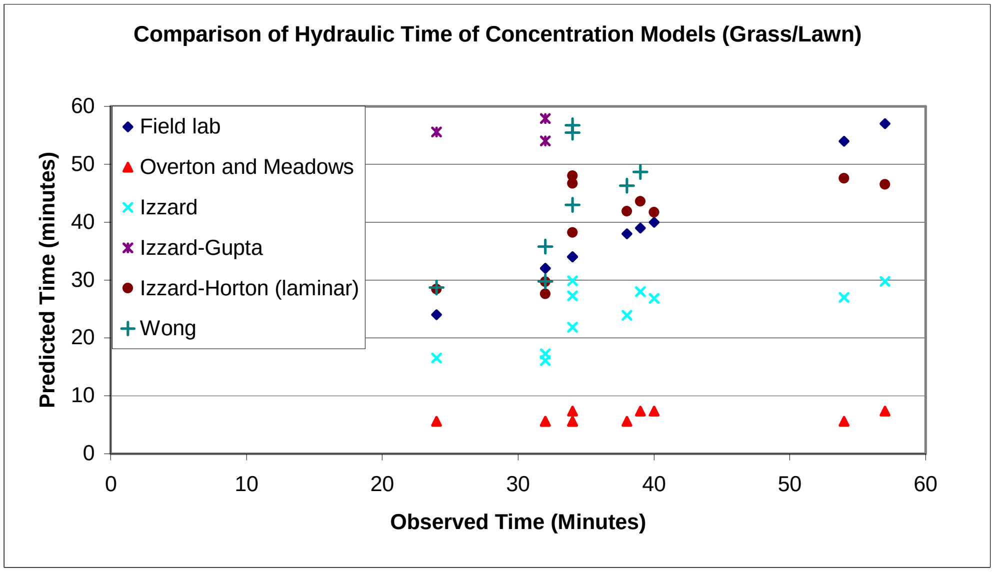


Figure 26 Comparison of the Empirical Time of Concentration Models for Grass

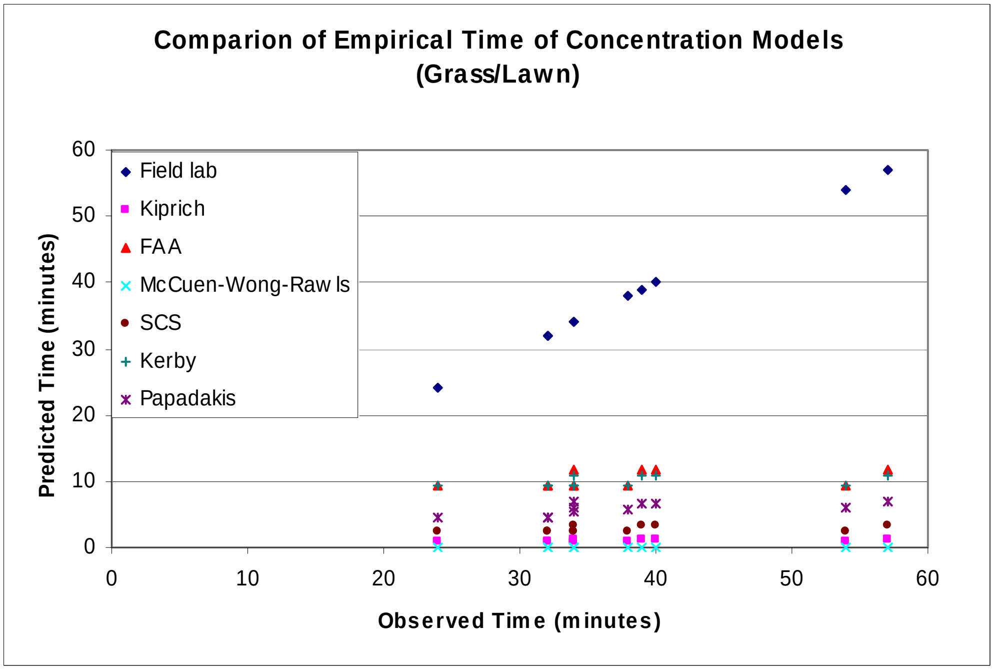


Figure 27 Comparison of the Hydraulic Time of Concentration Models for Grass

5.6.3 Pasture

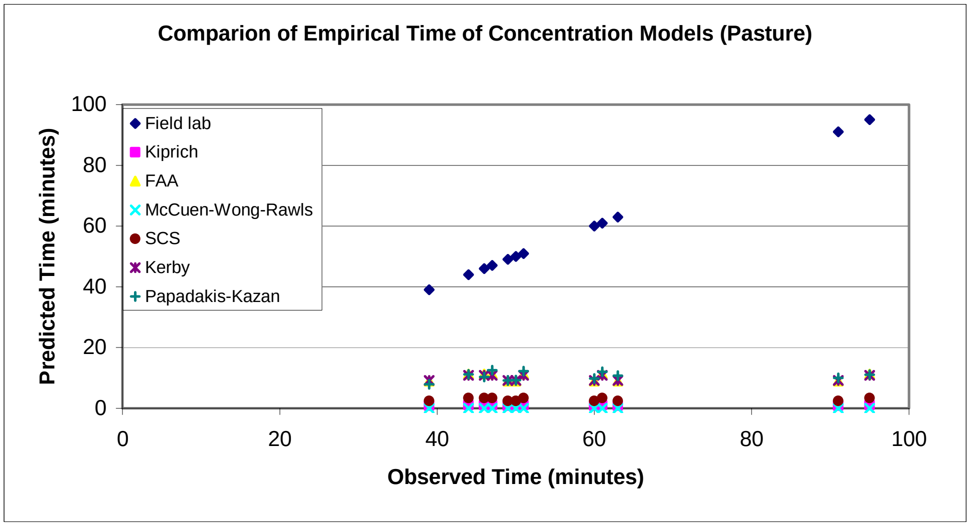


Figure 28 Comparison of the Empirical Time of Concentration Models for Pasture

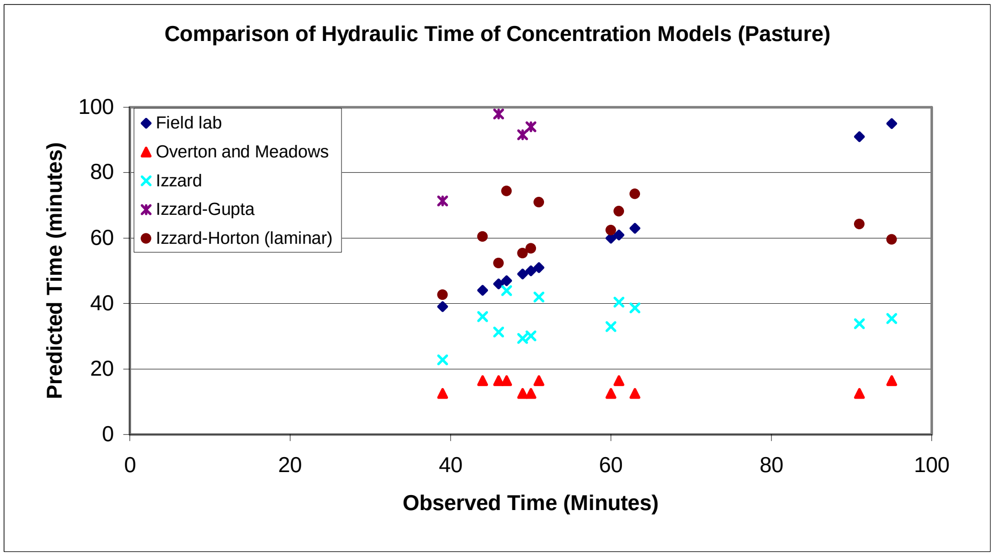


Figure 29 Comparison of the Hydraulic Time of Concentration Models for Pasture

5.6.4 Concrete/Asphalt

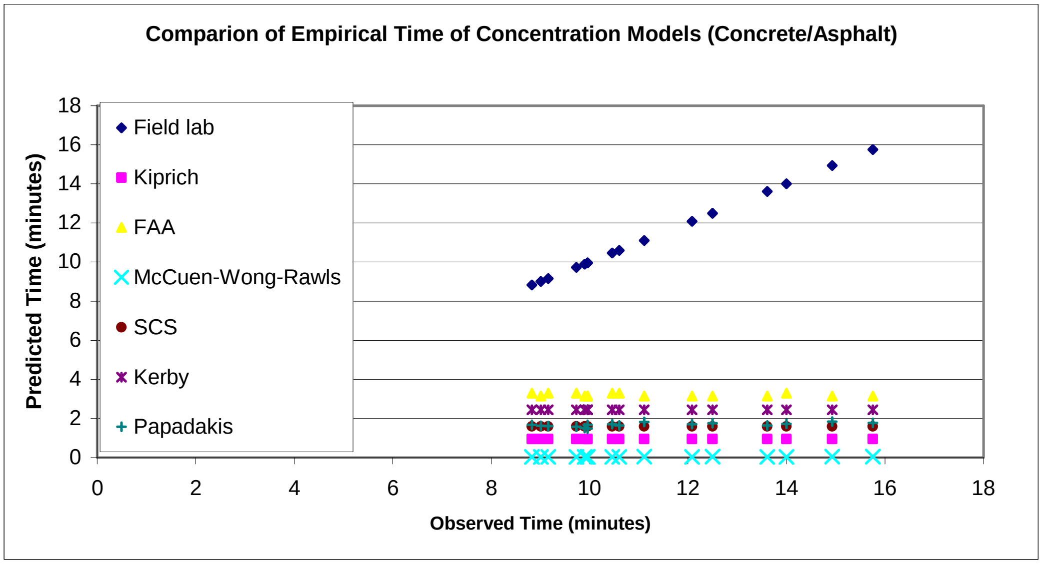


Figure 30 Comparison of the Empirical Time of Concentration Models for Concrete and Asphalt

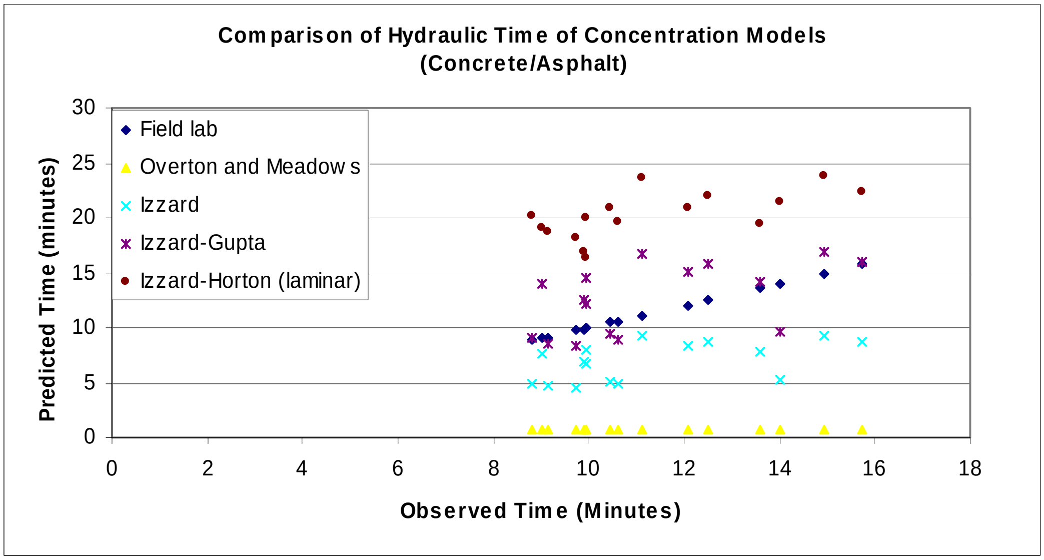


Figure 31 Comparison of the Hydraulic Time of Concentration Models for Concrete and Asphalt

5.7 Regression Model

Stepwise forward regression as described in Section 15.2 Draper and Smith (1998) was chosen to derive the influence of measured independent variables on the dependent variables, i.e., Time Parameters (Table 6). A general regression equation can be written as:

$$t_c = kL^a i^b S^c \theta^x f_L^y dsc^z \tag{42}$$

Where t_c is the time of concentration in minutes; L is overland flow length in meters; θ is the antecedent moisture content (gravimetric) in gm/gm; i is the rainfall intensity in inches per hour; S is the overland plane slope in feet per feet; f_L is the Darcy-Wiesbach friction factor calculated as per Wong 2002 equation-14, assuming kinematic viscosity of the water as 10^{-6} m^2s^{-1} ; dsc is the depression storage capacity calculated as per Onstad 1984 . An interception of 0.1 inches has been added to the dsc value for the grass surfaces.' a ' has been assumed to be 0.5 as per Papadakis-Kazan (1987). For non infiltrating surfaces, for the time of concentration regression model Izzard retardance coefficients have been chosen in place of the Darcy-Wiesbach coefficient.

Table 6 Regression Analysis Coefficients for Different Surfaces and Time Parameters

Surface	Time Parameter	Dependent Variable Coefficients					
		k	**b**	**c**	**x**	**y**	**z**
All	TOC	0.2294	-0.3997	-0.1751	-0.3878	0.2033	0.077
	TOB	0.3698			-0.9997		0.3563
IS	TOC	0.7179	-0.3887		-0.5652	0.1741	0.2185
	TOB	-0.4245			-0.8599	0.2759	
NIS	TOC	1.6077	-0.8234			0.4192	
Bare Clay	TOC	-1.3923			-0.67		-1.568
	TOB	-0.4415			-1.4098		
Grass	TOC	-80.375	-0.3566	-11.26	-0.3113	0.2644	-111.43
	TOB	-0.527			-1.1956	0.2622	
Note							
ALL - All tested surfaces							
IS - All infiltrating surfaces.							
NIS - All non infiltrating surfaces.							

5.7.1 Regression Results

Table 7 Regression Analysis Summary Table for TOC and TOB

Surface	Time Parameter	Regression Anaysis Summary			
		R Square	**Standard Error**	**F**	**Significance F**
All	TOC	0.97	0.0525	328.13	4.47643E-33
	TOB	0.83	0.1984	115.61	1.14396E-18
IS	TOC	0.69	0.1208	15.83	6.94621E-07
	TOB	0.71	0.1534	36.35	9.62182E-09
NIS	TOC	0.74	0.0480	18.74	0.000148011
Bare Clay	TOC	0.97	0.0526	66.35	5.41919E-05
	TOB	0.92	0.1179	40.53	0.000141654
Grass	TOC	0.93	0.0414	48.04	1.9564E-09
	TOB	0.60	0.1513	15.16	9.81854E-05
Note					
ALL - All tested surfaces					
IS - All infiltrating surfaces.					
NIS - All non infiltrating surfaces.					

From the regression analysis, i.e., Table 6 and Table 7 it can be seen that:

1. Surface slope has low exponent value.
2. Initial moisture content controls the time of beginning.
3. Rainfall intensity (within the range tested) affects (inversely) the time of concentration but no good significance of this variable had been found on the time of beginning.

Figures 32 to 40 shows the observed and predicted times through regression equations for different surfaces as listed in Table 7.

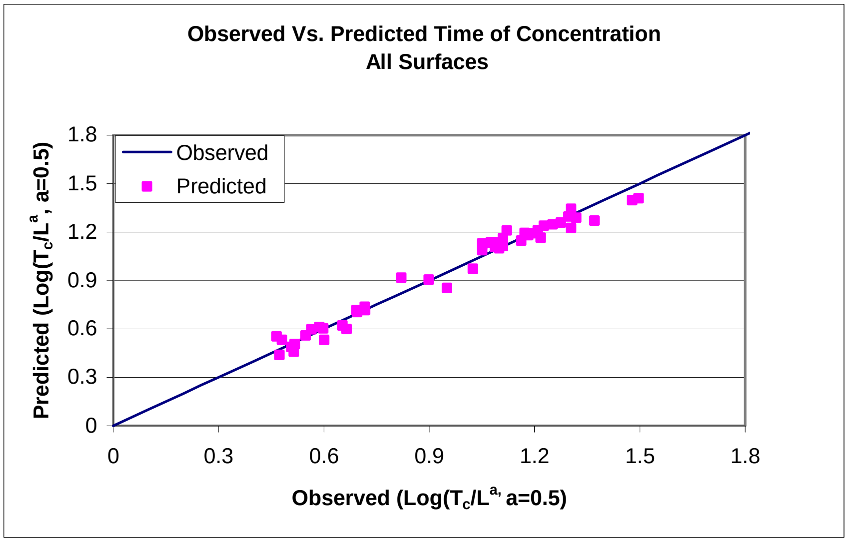


Figure 32 Observed vs. Predicted Time of Concentration for All Surfaces

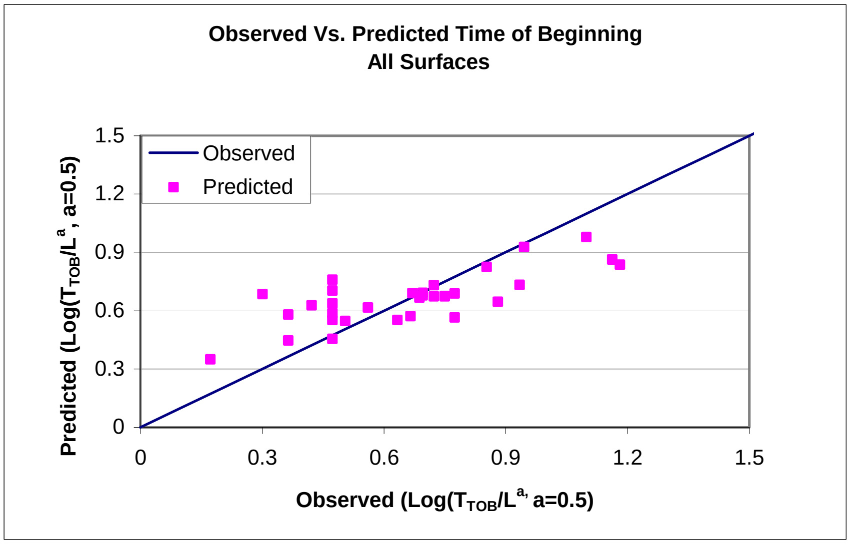


Figure 33 Observed vs. Predicted Time of Beginning for All Surfaces

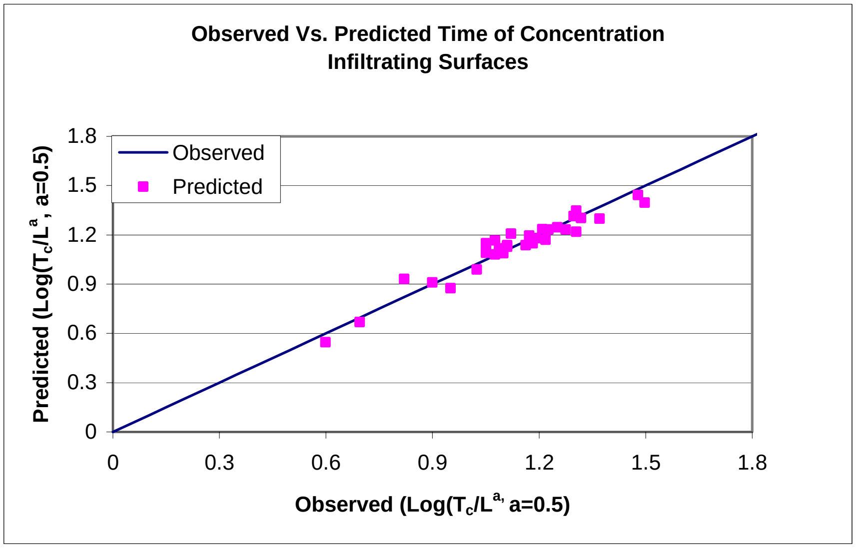


Figure 34 Observed vs. Predicted Time of Concentration for Infiltrating Surfaces

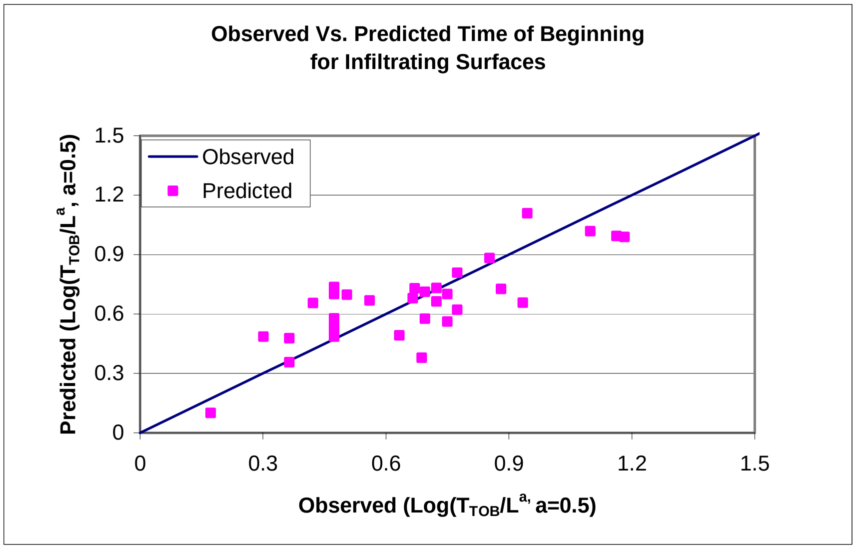


Figure 35 Observed vs. Predicted Time of Beginning for Infiltrating Surfaces

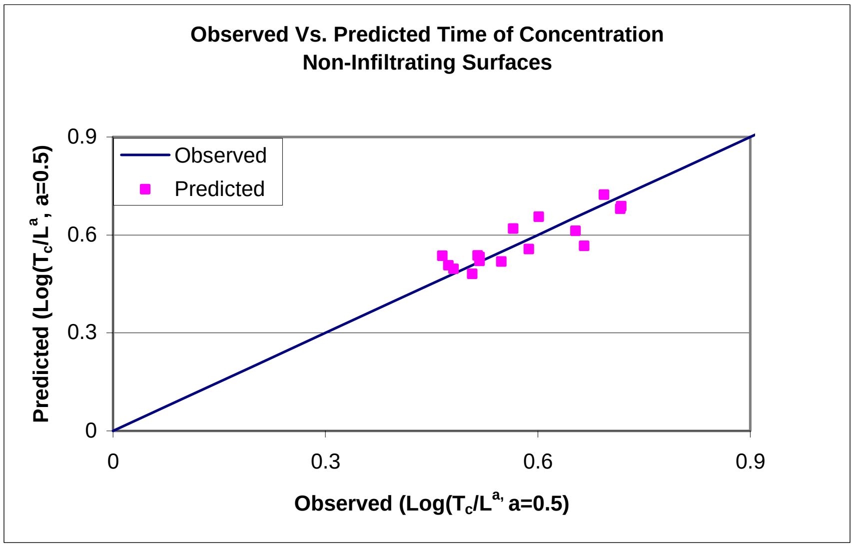


Figure 36 Observed vs. Predicted Time of Concentration for Non-Infiltrating Surfaces

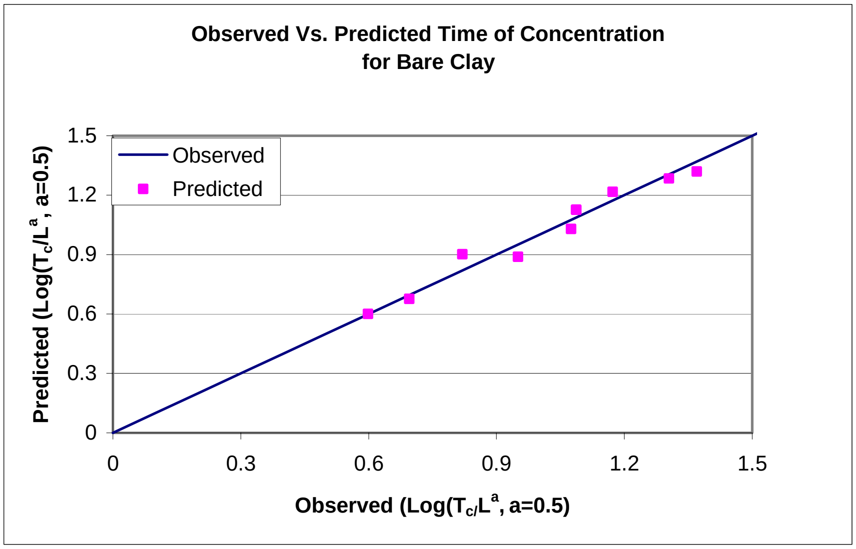


Figure 37 Observed vs. Predicted Time of Concentration for Bare-Clay

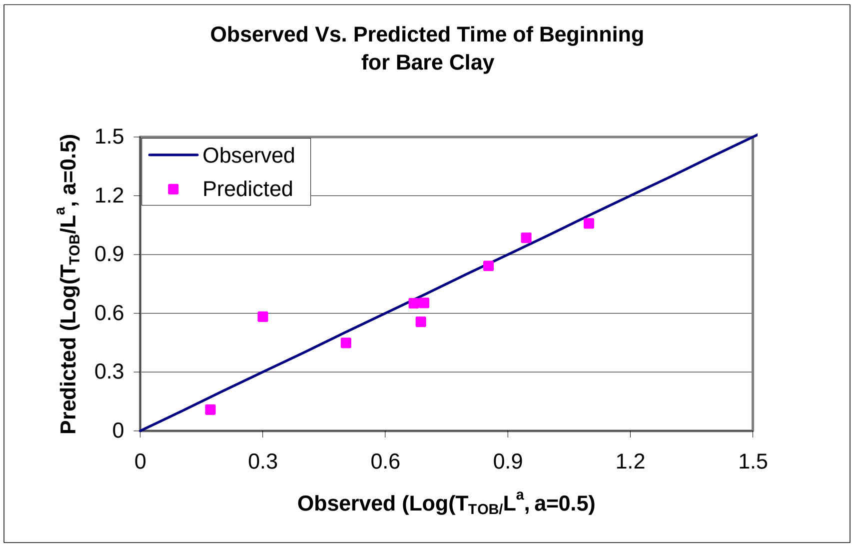


Figure 38 Observed vs. Predicted Time of Beginning for Bare-Clay

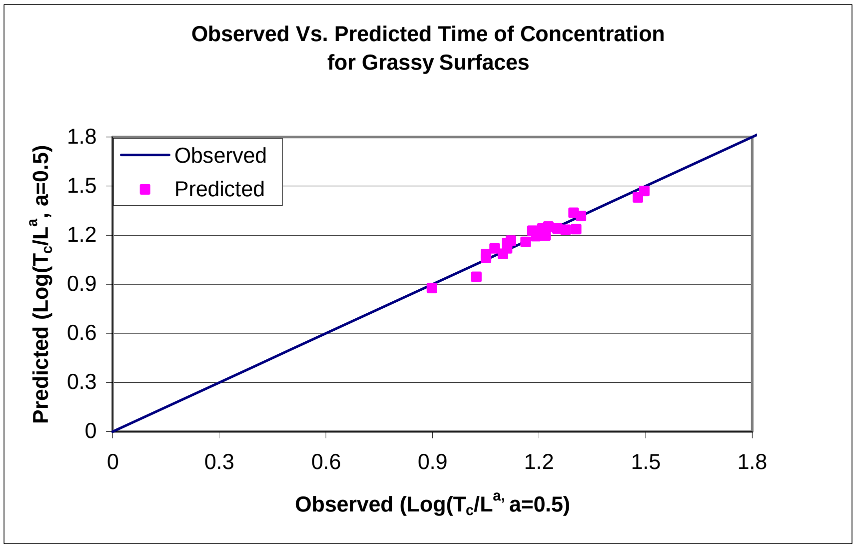


Figure 39 Observed vs. Predicted Time of Concentration for Grassy Surfaces

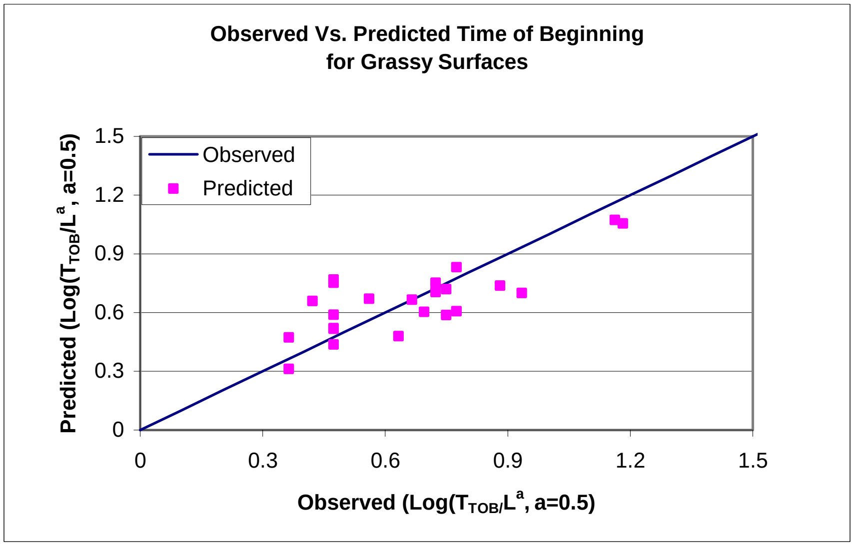


Figure 40 Observed vs. Predicted Time of Beginning for Grassy Surfaces

5.8 Particle Size Distribution

From the Sieve Analysis and Hydrometer Tests the soil was found to consist of the following as in Table 8.

Table 8 Soil Textural Results

Sand -	**21.13%**
Silt -	**31.95%**
Clay/colloids -	**47.92%**

5.9 Drop Size Analysis

The rain drop size distribution can be tabulated as in Table 9.

Table 9 Result of the Rain Drop-Size Test

Sieve number	Sieve size (mm)	Number of drops	Avg. weight (grams)
8	2.38	0	0
10	2	2	0.0137
16	1.18	109	0.1713
20	0.84	235	0.1214
30	0.59	703	0.1231
50	0.3	15335	0.6257

6 CONCLUSIONS

On the basis of the field tests, the results strongly indicate the importance of the hydrological processes (rainfall intensity, depression storage), surface characteristics (slope, roughness) and the antecedent conditions on the time of concentration parameter. It can be concluded that:

- There exist a variety of definitions for the time of concentration. In the absence of a clear definition of which “time” is desired or used in a specific application, experimental results may be difficult to compare to theory.
- Most of the empirical models found in the literature which were compared in this study under predict the time of concentration parameter.
- The influence of the time of beginning on the time of concentration parameter has provided us with a fact that we cannot overlook the initial conditions.
- Large values for the time to zero on the grassy surfaces confirm the large surface detention for these surfaces.
- Results show some correlation between the depression storage and the runoff coefficient.
- A cost effective system “Zimmometer” to measure the random roughness worked well for this study. This system can certainly be modified for a smaller grid cell size.

6.1 Future Work

In light of the results found in this study, we can recommend some directions for future work and improvements on the methods used in this study. Obviously our regression results are handicapped by the fact that we were unable to vary the size of the plot over which we rained. This meant that the area variable could not be used in the time of concentration regressions. More tests on the plots with varying area/length would help achieve greater insight into the effects of area and plot shape.

Additional improvements that would make the results from a study of this sort more valid include:

- Uniform Rainfall Application. Although we endeavored to apply the rainfall in a uniform manner, there was some spatial variation, which led to the instigation of flow in some spots on the plot before others.
- Windshields. Better windshield so that the tests can be carried out in a controlled way. As mentioned, there was some loss of rain water volume due to wind blowing it away from the plot. A better windshield setup would preserve the mass of water applied, removing some of the noise in the intensity variable in the regression.
- Overland Flow Velocity/Depth. Some means of measuring overland flow velocity/depth. By measuring overland flow velocity/depth, we would be able to validate runoff/time of concentration models better, giving our results greater utility.

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APPENDIX A

RUNOFF MEASUREMENTS FOR BARECLAY02 (BC02) AND BARECLAY03 (BC03)

Surface	BC02	BC02	BC02	BC02	BC03	BC03	BC03	BC03	BC03	BC03
Date	10/17/02	10/18/02	10/30/02	11/01/02	05/01/03	05/20/03	05/22/03	05/23/03	05/29/03	06/03/03
Temp ('C)	31.6	18.3	32.3	15.3	25.5	24	20.7	24	27.8	30.85
Humidity (%)	31	86	86	76	88	91	88	76	49	69
Initial Moisture (%)	19.62	18.8	53	40.74	12.3	16.8	16.74	23.4	8.64	9.74
Initial Reading, I_{gmr}	357295	357407	357525	357619	365397	365560	365674	365809	365939	366183
Final Reading, F_{gmr}	357406	357506	357619	357704	365560	365686	365808	365936	366179	366390
Input (GPM/iph)	3.7/1.97	3.96/2.11	6.267/3.34	4.25/2.26	3.19/1.70	2.8/1.49	3.04/1.62	3.02/1.61	2.926/1.56	3.04/1.62
Test No.	4	5	6	7	1	2	3	4	5	6
Time (minutes)	**Incremental Runoff in Gallons**									
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	1.57	0.01	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	1.69	0.05	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.15	1.75	0.30	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.34	1.75	0.72	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.53	1.75	0.97	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.60	1.75	1.03	0.00	0.00	0.00	0.02	0.00	0.00
11	0.00	0.90	1.81	1.15	0.00	0.00	0.00	0.12	0.00	0.00
12	0.00	1.02	1.87	1.21	0.00	0.00	0.00	0.87	0.00	0.00
13	0.00	1.08	1.87	1.21	0.00	0.00	0.00	1.12	0.00	0.00
14	0.00	1.14	1.87	1.21	0.00	0.00	0.00	1.32	0.00	0.00
15	0.03	1.14	1.87	1.27	0.00	0.02	0.00	1.39	0.00	0.00
16	0.27	1.14	1.39	1.27	0.00	0.03	0.03	1.48	0.00	0.00
17	0.33	1.14	0.78	1.27	0.00	0.03	0.04	1.52	0.00	0.00
18	0.36	1.26	0.66	1.27	0.00	0.03	0.05	1.59	0.00	0.00
19	0.42	1.26	0.36	1.33	0.00	0.07	0.06	1.61	0.00	0.00
20	0.42	1.20	0.24	1.33	0.00	0.66	0.56	1.61	0.00	0.00
21	0.54	1.20	0.18	1.21	0.00	0.82	0.83	1.76	0.00	0.00
22	0.60	1.20	0.18	0.85	0.10	0.85	0.93	1.77	0.00	0.00
23	0.66	1.20	0.18	0.54	0.53	0.99	0.99	1.80	0.00	0.00
24	0.78	1.20	0.12	0.42	0.69	1.08	1.06	1.81	0.00	0.00
25	0.78	1.20	0.06	0.29	0.79	1.11	1.11	1.85	0.00	0.00
26	0.78	1.14	XXX	0.17	0.87	1.11	1.19	1.77	0.00	0.00

Continued										
Surface	BC02	BC02	BC02	BC02	BC03	BC03	BC03	BC03	BC03	BC03
Test No.	4	5	6	7	1	2	3	4	5	6
27	0.84	0.60	XXX	0.12	0.95	1.12	1.28	1.85	0.00	0.03
28	0.84	0.60	XXX	0.60	1.03	1.24	1.36	1.96	0.00	0.06
29	0.84	0.42	XXX	0.10	1.11	1.31	1.38	1.93	0.00	0.07
30	0.84	0.31	XXX	0.03	1.14	1.30	1.40	1.94	0.00	0.40
31	0.66	0.28	XXX	0.02	1.38	1.35	1.48	2.00	0.00	0.78
32	0.60	0.20	XXX	XXX	1.38	1.35	1.48	2.05	0.00	0.93
33	0.30	0.17	XXX	XXX	1.36	1.36	1.51	2.02	0.00	1.01
34	0.18	0.16	XXX	XXX	1.46	1.43	1.59	2.02	0.00	1.07
35	0.16	0.12	XXX	XXX	1.46	1.44	1.59	2.06	0.00	1.18
36	0.09	0.09	XXX	XXX	1.43	1.43	1.61	2.08	0.00	1.24
37	0.04	0.07	XXX	XXX	1.48	1.46	1.63	2.06	0.00	1.26
38	XXX	0.06	XXX	XXX	1.64	1.47	1.61	2.06	0.00	1.24
39	XXX	0.05	XXX	XXX	1.59	1.47	1.60	2.08	0.00	1.34
40	XXX	0.03	XXX	XXX	1.61	1.47	1.61	2.09	0.01	1.36
40	XXX	0.03	XXX	XXX	1.61	1.47	1.61	2.09	0.01	1.36
41	XXX	0.03	XXX	XXX	1.61	1.46	1.63	2.08	0.11	1.38
42	XXX	0.02	XXX	XXX	1.61	1.46	1.63	2.08	0.25	1.39
43	XXX	0.02	XXX	XXX	1.64	1.47	1.61	1.69	0.30	1.48
44	XXX	XXX	XXX	XXX	1.72	1.47	1.61	1.06	0.33	1.48
45	XXX	XXX	XXX	XXX	1.85	1.46	1.46	0.61	0.38	1.49
46	XXX	XXX	XXX	XXX	1.85	1.32	0.93	0.36	0.40	1.48
47	XXX	XXX	XXX	XXX	1.83	0.82	0.53	0.22	0.43	1.53
48	XXX	XXX	XXX	XXX	1.85	0.49	0.29	0.16	0.43	1.57
49	XXX	XXX	XXX	XXX	1.88	0.25	0.17	0.11	0.44	1.53
50	XXX	XXX	XXX	XXX	1.88	0.15	0.11	0.08	0.47	1.61
51	XXX	XXX	XXX	XXX	1.90	0.10	0.07	0.05	0.50	1.77
52	XXX	XXX	XXX	XXX	1.64	0.06	0.04	0.04	0.50	1.79
53	XXX	XXX	XXX	XXX	0.87	0.04	XXX	XXX	0.53	1.75
54	XXX	XXX	XXX	XXX	0.44	XXX	XXX	XXX	0.55	1.75
55	XXX	XXX	XXX	XXX	0.22	XXX	XXX	XXX	0.56	1.77
56	XXX	XXX	XXX	XXX	0.13	XXX	XXX	XXX	0.56	1.77
57	XXX	XXX	XXX	XXX	0.07	XXX	XXX	XXX	0.56	1.79
58	XXX	XXX	XXX	XXX	0.03	XXX	XXX	XXX	0.56	1.83
59	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.59	1.84
60	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.61	1.83
61	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.63	1.88

Continued

Surface	BC02	BC02	BC02	BC02	BC03	BC03	BC03	BC03	BC03	BC03
Test No.	4	5	6	7	1	2	3	4	5	6
62	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.63	1.88
63	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.63	1.85
64	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.64	1.85
65	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.65	1.87
66	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.65	1.88
67	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.65	1.88
68	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.66	1.87
69	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.66	1.59
70	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.66	0.86
71	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.67	0.44
72	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.66	0.24
73	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.67	0.13
74	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.67	0.07
75	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.67	0.04
76	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.71	0.02
77	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
78	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
79	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
80	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
81	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
82	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.69	XXX
83	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.58	XXX
84	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.36	XXX
85	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.21	XXX
86	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.11	XXX
87	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.07	XXX
88	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.04	XXX
89	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	0.02	XXX
Runoff Begins (mins)	14.73	6.05	2.40	4.50	21.57	14.17	15.00	9.67	38.00	26.66
Peak Runoff (gpm)	0.84	1.26	1.87	1.32	1.85	1.46	1.61	2.08	0.69	1.88
Runoff Coefficient	0.23	0.32	0.30	0.31	0.58	0.52	0.53	0.69	0.24	0.62
Time to Peak (mins)	27.00	20.00	12.00	15.00	45.00	37.00	34.00	36.00	71.00	61.00
Time to zero (mins)	7.00	18.00	10.00	11.00	7.00	8.00	8.00	10.00	7.00	8.00

APPENDIX B

RUNOFF MEASUREMENTS FOR GRASS-LEFT (G-LEFT) AND GRASS-RIGHT (G-RIGHT) PLOTS

Surface	G-left	G-left	G-left	G-left	G-left	G-left	G-left	G-Right	G-Right	G-Right	G-Right
Date	11/23/02	11/30/02	12/06/02	12/18/02	12/20/02	01/06/03	01/08/03	02/01/03	02/03/03	02/10/03	02/12/03
Temp ('C)	16.2	14.5	5.9	19.1	10.5	16.9	24.9	17.8	12	8.3	14
Humidity (%)	47	62	69	93	43	52	29	53	40	40	92
Initial Moisture (%)	40.6	42	44	55	31	44	56	28	34	42.2	37
Initial Reading, I_{gmr}	357972	358095	358278	358600	358767	359047	259336	360089	360290	360523	360684
Final Reading, F_{gmr}	358092	358276	358455	358761	359048	359335	359593	360290	360520	360683	360903
Input (GPM/iph)	2.79/1.49	2.83/1.51	3.93/2.1	3.42/1.82	5.73/3.06	6.4/3.42	6.12/3.27	4.1/2.19	3.48/1.86	3.47/1.85	3.84/2.05
Test No.	2	3	4	6	7	8	9	3	4	5	6
Time (mins)	**Incremental Runoff in Gallons**										
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.03	0.00
9	0.03	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.04	0.00
10	0.04	0.00	0.05	0.03	0.03	0.00	0.10	0.03	0.00	0.05	0.02
11	0.06	0.00	0.04	0.04	0.03	0.00	0.10	0.06	0.00	0.07	0.04
12	0.07	0.00	0.07	0.05	0.04	0.00	0.12	0.07	0.00	0.08	0.05
13	0.07	0.00	0.06	0.06	0.13	0.00	0.24	0.07	0.00	0.10	0.07
14	0.07	0.01	0.08	0.06	0.31	0.03	0.41	0.07	0.00	0.12	0.10
15	0.07	0.03	0.03	0.06	0.63	0.12	0.46	0.10	0.00	0.15	0.14
16	0.07	0.03	0.14	0.06	0.71	0.29	1.04	0.12	0.00	0.19	0.19
17	0.08	0.03	0.17	0.06	0.76	0.53	1.27	0.16	0.00	0.22	0.25
18	0.10	0.03	0.20	0.08	1.01	0.81	1.49	0.19	0.02	0.28	0.30
19	0.11	0.04	0.26	0.12	1.28	1.06	1.61	0.19	0.03	0.32	0.37

Continued										
Surface	G-left	G-left	G-left	G-left	G-left	G-left	G-left	G-Right	G-Right	G-Right	G-Right
Test No.	2	3	4	6	7	8	9	3	4	5	6
20	0.11	0.05	0.35	0.12	1.27	1.16	1.72	0.19	0.06	0.38	0.45
21	0.13	0.06	0.40	0.16	1.59	1.30	1.79	0.19	0.11	0.47	0.53
22	0.17	0.07	0.48	0.20	1.61	1.39	1.85	0.20	0.15	0.50	0.59
23	0.20	0.07	0.59	0.25	1.72	1.47	1.92	0.21	0.17	0.54	0.73
24	0.27	0.08	0.65	0.34	1.63	1.57	1.97	0.25	0.19	0.59	0.74
25	0.31	0.10	0.71	0.41	1.82	1.61	1.96	0.30	0.22	0.62	0.78
26	0.37	0.11	0.74	0.49	2.06	1.66	1.94	0.30	0.25	0.65	0.85
27	0.43	0.15	0.81	0.59	2.04	1.67	1.94	0.29	0.27	0.69	0.87
28	0.47	0.19	0.89	0.63	2.04	1.67	1.95	0.29	0.29	0.72	0.90
29	0.51	0.26	0.87	0.70	2.06	1.68	1.95	0.30	0.31	0.74	0.93
30	0.53	0.27	0.89	0.73	2.07	1.72	1.95	0.33	0.34	0.76	0.96
31	0.56	0.32	0.90	0.76	2.08	1.75	1.95	0.33	0.37	0.78	0.97
32	0.61	0.37	0.95	0.79	2.16	1.80	1.96	0.33	0.39	0.79	1.01
33	0.63	0.38	0.98	0.81		1.81	1.96	0.33	0.42	0.81	1.04
34	0.66	0.40	1.01	0.84	2.06	1.81	1.96	0.35	0.45	0.83	1.05
35	0.66	0.44	1.01	0.86	2.06	1.81	1.96	0.36	0.47	0.84	1.06
36	0.66	0.47	1.01	0.87	2.07	1.81	1.96	0.42	0.49	0.83	1.06
37	0.66	0.50	1.01	0.87	2.07	1.81	1.96	0.54	0.52	0.83	1.07
38	0.66	0.52	1.01	0.87	2.07	1.82	1.96	0.60	0.55	0.83	1.10
39	0.67	0.53	1.01	0.87	2.07	1.82	1.96	0.65	0.56	0.83	1.11
40	0.67	0.53	1.01	0.87	2.08	1.83	1.97	0.71	0.58	0.84	1.10
41	0.67	0.53	1.01	0.87	2.10	1.83	1.96	0.70	0.59	0.83	1.11
42	0.63	0.53	1.00	0.87	2.10	1.83	1.96	0.67	0.59	0.84	1.11
43	0.56	0.56	1.00	0.87	2.10	1.82	1.57	0.69	0.59	0.83	1.12
44	0.52	0.56	1.01	0.87	2.10	1.83	1.19	0.69	0.61	0.84	1.12
45	0.48	0.56	1.00	0.87	2.10	1.83	0.94	0.69	0.61	0.83	1.12
46	0.42	0.56	0.89	0.87	2.10	1.77	0.78	0.69	0.61	0.84	1.12
47	0.37	0.56	0.83	0.87	2.10	1.61	0.66	0.69	0.62	0.73	1.12
48	0.31	0.56	0.71	0.84	2.10	1.36	0.54	0.69	0.61	0.68	1.12
49	0.30	0.56	0.63	0.79	2.10	1.10	0.47	0.69	0.61	0.57	1.12
50	0.27	0.56	0.56	0.68	1.97	1.03	0.40	0.63	0.62	0.50	1.12
51	0.24	0.59	0.50	0.60	1.41	0.57	0.33	0.57	0.62	0.38	1.13
52	0.22	0.59	0.43	0.51	1.34	0.51	0.29	0.52	0.63	0.33	1.12
53	0.19	0.59	0.40	0.46	1.13	0.45	0.25	0.45	0.64	0.29	1.13
54	0.18	0.61	0.37	0.41	0.94	0.36	0.22	0.37	0.64	0.25	1.13
55	0.17	0.61	0.32	0.38	0.82	0.33	0.20	0.28	0.64	0.21	1.13
56	0.16	0.61	0.30	0.33	0.70	0.29	0.18	0.23	0.65	0.18	1.14
57	0.13	0.61	0.27	0.29	0.61	0.24	0.16	0.21	0.66	0.15	1.13
58	0.11	0.61	0.25	0.27	0.52	0.22	0.15	0.19	0.67	0.12	1.10

Continued										
Surface	G-left	G-left	G-left	G-left	G-left	G-left	G-left	G-Right	G-Right	G-Right	G-Right
Test No.	2	3	4	6	7	8	9	3	4	5	6
59	0.11	0.61	0.23	0.25	0.46	0.20	0.13	0.17	0.69	0.11	1.01
60	0.10	0.61	0.21	0.22	0.41	0.17	0.12	0.16	0.68	0.09	0.85
61	0.10	0.61	0.20	0.20	0.38	0.16	0.11	0.13	0.67	0.09	0.70
62	0.09	0.61	0.19	0.19	0.32	0.14	0.11	0.13	0.68	0.07	0.60
64	0.09	0.61	0.16	0.16	0.26	0.12	0.09	0.11	0.68	0.06	0.44
65	0.08	0.59	0.16	0.15	0.24	0.11	0.08	0.10	0.68	0.05	0.38
66	0.08	0.58	0.14	0.12	0.21	0.10	0.08	0.09	0.68	0.05	0.32
67	0.08	0.54	0.13	0.12	0.19	0.09	0.07	0.08	0.63	0.04	0.27
68	0.07	0.48	0.13	0.12	0.17	0.08	0.07	0.08	0.56	XXX	0.24
69	0.06	0.43	0.12	0.11	0.16	0.08	0.06	0.07	0.47	XXX	0.21
70	0.05	0.37	0.11	0.10	0.15	0.07	0.06	0.07	0.39	XXX	0.18
71	0.04	0.34	0.10	0.10	0.11	0.07	0.06	0.06	0.33	XXX	0.16
72	0.04	0.29	0.10	0.09	0.11	0.07	0.05	0.06	0.27	XXX	0.14
73	0.03	0.27	0.10	0.09	0.11	0.06	0.05	0.06	0.24	XXX	0.13
74	0.03	0.24	0.10	0.08	0.11	0.05	0.04	XXX	0.20	XXX	0.11
75	0.03	0.21	0.09	0.08	0.10	0.05	0.04	XXX	0.16	XXX	0.10
76	XXX	0.20	0.08	0.07	0.09	0.04	XXX	XXX	0.14	XXX	0.09
77	XXX	0.19	0.08	0.07	0.08	XXX	XXX	XXX	0.13	XXX	0.08
78	XXX	0.16	0.07	0.07	0.08	XXX	XXX	XXX	0.12	XXX	0.07
79	XXX	0.15	0.07	0.06	0.07	XXX	XXX	XXX	0.10	XXX	0.07
80	XXX	0.14	0.07	0.06	0.07	XXX	XXX	XXX	0.09	XXX	0.06
81	XXX	0.13	0.07	0.06	0.06	XXX	XXX	XXX	0.08	XXX	0.06
82	XXX	0.12	0.07	0.05	0.05	XXX	XXX	XXX	0.08	XXX	0.06
83	XXX	0.11	0.07	0.05	0.05	XXX	XXX	XXX	0.07	XXX	0.05
84	XXX	0.10	0.06	0.05	XXX	XXX	XXX	XXX	0.06	XXX	0.05
85	XXX	0.10	0.06	0.05	XXX	XXX	XXX	XXX	0.06	XXX	XXX
86	XXX	0.10	0.05	XXX	XXX	XXX	XXX	XXX	0.05	XXX	XXX
87	XXX	0.08	0.05	XXX	XXX	XXX	XXX	XXX	0.05	XXX	XXX
88	XXX	0.07	0.04	XXX	XXX	XXX	XXX	XXX	0.04	XXX	XXX
89	XXX	0.07	0.05	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
90	XXX	0.05	0.04	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
91	XXX	0.05	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
92	XXX	0.04	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
93	XXX	0.03	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Runoff Begins (minutes)	9.00	14.00	9.00	9.00	9.00	13.00	7.00	9.00	17.00	7.00	9.00
Peak Runoff (GPM)	0.60	0.61	1.00	0.87	2.09	1.82	1.96	0.69	0.67	0.83	1.12
Runoff Coefficient	0.22	0.22	0.25	0.25	0.36	0.28	0.32	0.17	0.19	0.24	0.29
Time-to-Peak (minutes)	34.00	54.00	34.00	38.00	32.00	32.00	24.00	40.00	57.00	34.00	39.00
Time to zero (minutes)	32.00	29.00	45.00	38.00	34.00	31.00	33.00	23.00	22.00	21.00	27.00

APPENDIX C

RUNOFF MEASUREMENTS FOR PASTURE-LEFT (P-LEFT) AND PASTURE-RIGHT (P-RIGHT) PLOTS

Surface	P-Left	P-Left	P-Left	P-Left	P-Left	P-Left	P-Right	P-Right	P-Right	P-Right	P-Right	P-Right
Date	06/17/03	06/18/03	06/19/03	06/20/03	06/26/03	06/26/03	06/28/03	07/01/03	07/02/03	07/03/03	07/08/03	07/09/03
Temp ('C)	23.2	23	24.3	26.3	24.9	26.8	XXX	26	23.5	25.5	25.5	25.9
Humidity	94	98	92	87	83	88	XXX	89	94	85	94	95
AMC (%)	42.67	35.4	38	33.25	21.5	32.16	23.4	37.84	33.62	29.85	29.75	33.97
Initial Reading, I_{gmr}	366803	367016	367189	367471	367686	367989	368525	369174	369438	369643	369825	370058
Final Reading, F_{gmr}	367014	367189	367470	367684	367978	368201	368927	369434	369644	369823	370055	370217
Input (GPM/iph)	3.58/1.91	2.44/1.3	5.51/2.94	3.73/1.99	2.98/1.59	3.12/1.66	3.98/2.12	4.81/2.57	3.88/2.07	3.05/1.63	3.239/1.73	2.84/1.52
Test No.	2	3	4	5	6	7	1	4	5	6	8	9
Time (mins)	**Incremental Runoff in gallons**											
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00
12	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00
13	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00
15	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00
16	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.13	0.06	0.00	0.00	0.00
17	0.00	0.00	0.56	0.08	0.00	0.00	0.00	0.13	0.08	0.05	0.00	0.00
18	0.00	0.00	0.93	0.09	0.00	0.00	0.00	0.22	0.08	0.06	0.00	0.06
19	0.07	0.00	1.19	0.11	0.00	0.07	0.00	0.37	0.08	0.07	0.00	0.07
20	0.08	0.00	1.34	0.16	0.00	0.07	0.00	0.54	0.08	0.07	0.00	0.08
21	0.10	0.00	1.51	0.23	0.00	0.08	0.00	0.70	0.18	0.08	0.00	0.13
22	0.16	0.00	1.61	0.43	0.00	0.09	0.00	0.87	0.29	0.08	0.00	0.16
23	0.27	0.00	1.67	0.65	0.00	0.10	0.00	1.04	0.42	0.06	0.00	0.21

Continued

Surface	P-Left	P-Left	P-Left	P-Left	P-Left	P-Left	P-Right	P-Right	P-Right	P-Right	P-Right	P-Right
Test No.	2	3	4	5	6	7	1	4	5	6	8	9
24	0.49	0.06	1.73	0.82	0.00	0.12	0.00	1.21	0.52	0.08	0.00	0.26
25	0.66	0.11	1.80	0.95	0.00	0.15	0.00	1.33	0.70	0.10	0.00	0.32
26	0.79	0.16	1.85	1.06	0.00	0.26	0.00	1.40	0.75	0.16	0.00	0.38
27	0.87	0.26	1.89	1.12	0.00	0.45	0.00	1.61	0.85	0.21	0.05	0.43
28	0.94	0.43	1.88	1.15	0.00	0.54	0.00	1.71	0.95	0.26	0.05	0.52
29	1.01	0.53	2.00	1.22	0.00	0.65	0.00	1.79	1.11	0.35	0.09	0.63
30	1.06	0.59	2.06	1.26	0.00	0.73	0.00	1.83	1.18	0.44	0.16	0.71
31	1.10	0.67	2.12	1.32	0.00	0.79	0.00	1.84	1.22	0.50	0.24	0.80
32	1.11	0.70	2.14	1.36	0.00	0.84	0.00	1.88	1.30	0.60	0.30	0.83
33	1.15	0.77	2.14	1.38	0.00	0.85	0.00	1.93	1.38	0.70	0.35	0.92
34	1.17	0.79	2.20	1.40	0.00	0.92	0.00	1.93	1.41	0.79	0.44	1.01
35	1.18	0.81	2.21	1.39	0.00	0.95	0.00	1.97	1.46	0.83	0.48	1.06
36	1.22	0.83	2.26	1.40	0.00	0.95	0.00	1.99	1.51	0.93	0.56	1.09
37	1.23	0.82	2.30	1.42	0.00	1.01	0.00	1.98	1.52	1.02	0.62	1.15
38	1.24	0.85	2.30	1.44	0.00	1.06	0.00	1.99	1.53	1.07	0.69	1.19
39	1.24	0.89	2.34	1.47	0.00	1.08	0.00	2.01	1.59	1.11	0.74	1.22
40	1.25	0.92	2.33	1.48	0.00	1.07	0.00	2.03	1.60	1.16	0.81	1.23
41	1.27	0.90	2.33	1.51	0.00	1.12	0.00	2.02	1.61	1.17	0.85	1.24
42	1.29	0.93	2.31	1.53	0.00	1.14	0.00	2.05	1.61	1.19	0.91	1.28
43	1.29	0.93	2.32	1.59	0.00	1.15	0.00	2.05	1.64	1.23	0.95	1.30
44	1.30	0.93	2.35	1.60	0.00	1.18	0.00	2.05	1.66	1.25	0.96	1.31
45	1.34	0.95	2.34	1.60	0.06	1.20	0.00	2.06	1.65	1.28	1.01	1.33
46	1.38	0.97	2.33	1.61	0.07	1.21	0.00	2.08	1.65	1.26	1.05	1.35
47	1.38	0.98	2.35	1.65	0.08	1.20	0.00	2.07	1.67	1.27	1.08	1.38
48	1.40	0.98	2.37	1.64	0.08	1.21	0.00	2.09	1.66	1.30	1.11	1.38
49	1.41	1.02	2.38	1.67	0.10	1.21	0.00	2.08	1.67	1.31	1.12	1.37
50	1.44	1.01	2.37	1.66	0.12	1.21	0.07	2.07	1.68	1.33	1.11	1.38
51	1.43	1.02	2.38	1.65	0.17	1.21	0.08	2.08	1.67	1.34	1.16	1.38
52	1.46	1.03	2.30	1.67	0.24	1.22	0.08	2.09	1.68	1.33	1.17	1.39
53	1.46	1.08	1.90	1.68	0.29	1.28	0.09	2.08	1.68	1.35	1.18	1.37
54	1.44	1.07	1.72	1.65	0.32	1.25	0.13	2.10	1.59	1.34	1.17	1.38
55	1.45	1.07	1.39	1.68	0.34	1.26	0.15	2.09	1.43	1.33	1.22	1.39
56	1.42	1.07	1.06	1.68	0.40	1.29	0.16	1.91	1.26	1.35	1.22	1.39
57	1.43	1.08	0.97	1.69	0.44	1.28	0.18	1.78	1.07	1.35	1.21	1.35
58	1.46	1.10	0.74	1.60	0.48	1.30	0.21	1.51	0.90	1.35	1.23	1.25
59	1.46	1.10	0.61	1.46	0.52	1.31	0.23	1.25	0.78	1.36	1.24	1.14
60	1.35	1.12	0.53	1.23	0.54	1.32	0.26	1.08	0.66	1.30	1.24	1.00
61	1.19	1.12	0.46	1.06	0.58	1.31	0.30	0.93	0.60	1.19	1.25	0.79

Continued												
Surface	P-Left	P-Left	P-Left	P-Left	P-Left	P-Left	P-Right	P-Right	P-Right	P-Right	P-Right	P-Right
Test No.	2	3	4	5	6	7	1	4	5	6	8	9
62	0.99	1.13	0.38	0.89	0.58	1.32	0.32	0.79	0.53	1.03	1.25	0.71
63	0.85	1.14	0.33	0.66	0.64	1.34	0.34	0.69	0.43	0.90	1.25	0.62
64	0.68	1.14	0.26	0.61	0.63	1.32	0.37	0.60	0.40	0.77	1.25	0.54
65	0.56	1.14	0.24	0.50	0.66	1.33	0.41	0.53	0.29	0.67	1.26	0.48
66	0.45	1.15	0.19	0.40	0.65	1.32	0.42	0.43	0.28	0.58	1.26	0.41
67	0.39	1.15	0.17	0.34	0.69	1.31	0.46	0.40	0.25	0.53	1.27	0.35
68	0.29	1.13	0.14	0.28	0.70	1.33	0.50	0.35	0.23	0.45	1.26	0.32
69	0.26	1.12	0.12	0.26	0.72	1.23	0.53	0.31	0.21	0.39	1.26	0.26
70	0.20	1.14	0.11	0.21	0.73	1.10	0.56	0.27	0.19	0.35	1.27	0.24
71	0.18	1.13	0.09	0.19	0.73	0.85	0.57	0.23	0.17	0.30	1.27	0.21
72	0.15	1.07	0.07	0.16	0.77	0.79	0.58	0.21	0.15	0.26	1.22	0.19
73	0.12	1.04	0.06	0.14	0.77	0.57	0.61	0.19	0.13	0.24	1.17	0.17
74	0.11	0.92	0.05	0.12	0.76	0.46	0.67	0.16	0.11	0.21	1.04	0.16
75	0.08	0.79	0.05	0.10	0.77	0.37	0.70	0.15	0.10	0.19	0.87	0.13
76	0.07	0.60	0.04	0.09	0.79	0.32	0.74	0.13	0.09	0.17	0.76	0.12
77	0.06	0.47	XXX	0.08	0.79	0.24	0.78	0.12	0.08	0.15	0.65	0.11
78	0.05	0.40	XXX	0.07	0.79	0.20	0.79	0.11	0.08	0.13	0.56	0.10
79	0.04	0.33	XXX	0.06	0.81	0.16	0.81	0.10	0.07	0.12	0.53	0.09
80	XXX	0.28	XXX	0.05	0.81	0.14	0.82	0.08	0.06	0.11	0.44	0.08
81	XXX	0.26	XXX	0.04	0.81	0.11	0.85	0.07	0.06	0.10	0.37	0.07
82	XXX	0.19	XXX	XXX	0.81	0.09	0.88	0.07	0.05	0.08	0.30	0.06
83	XXX	0.15	XXX	XXX	0.82	0.08	0.89	0.06	0.04	0.08	0.26	0.06
84	XXX	0.13	XXX	XXX	0.81	0.07	0.93	0.05	0.04	0.07	0.23	0.05
85	XXX	0.12	XXX	XXX	0.87	0.06	0.99	0.05	XXX	0.06	0.19	0.05
86	XXX	0.09	XXX	XXX	0.86	0.05	1.01	0.04	XXX	0.06	0.17	0.04
87	XXX	0.07	XXX	XXX	0.87	0.04	1.00	0.04	XXX	0.05	0.15	XXX
88	XXX	0.06	XXX	XXX	0.87	XXX	1.02	XXX	XXX	0.04	0.13	XXX
89	XXX	0.05	XXX	XXX	0.88	XXX	1.03	XXX	XXX	XXX	0.11	XXX
90	XXX	0.04	XXX	XXX	0.89	XXX	1.06	XXX	XXX	XXX	0.09	XXX
91	XXX	XXX	XXX	XXX	0.93	XXX	1.06	XXX	XXX	XXX	0.08	XXX
92	XXX	XXX	XXX	XXX	0.93	XXX	1.07	XXX	XXX	XXX	0.07	XXX
93	XXX	XXX	XXX	XXX	0.92	XXX	1.08	XXX	XXX	XXX	0.06	XXX
94	XXX	XXX	XXX	XXX	0.93	XXX	1.11	XXX	XXX	XXX	0.05	XXX
95	XXX	XXX	XXX	XXX	0.93	XXX	1.12	XXX	XXX	XXX	0.04	XXX
96	XXX	XXX	XXX	XXX	0.94	XXX	1.12	XXX	XXX	XXX	0.04	XXX

Continued

Surface	P-Left	P-Left	P-Left	P-Left	P-Left	P-Left	P-Right	P-Right	P-Right	P-Right	P-Right	P-Right
Test No.	2	3	4	5	6	7	1	4	5	6	8	9
97	XXX	XXX	XXX	XXX	0.94	XXX	1.12	XXX	XXX	XXX	XXX	XXX
98	XXX	XXX	XXX	XXX	0.94	XXX	1.14	XXX	XXX	XXX	XXX	XXX
99	XXX	XXX	XXX	XXX	0.88	XXX	1.15	XXX	XXX	XXX	XXX	XXX
100	XXX	XXX	XXX	XXX	0.77	XXX	1.15	XXX	XXX	XXX	XXX	XXX
101	XXX	XXX	XXX	XXX	0.65	XXX	1.13	XXX	XXX	XXX	XXX	XXX
102	XXX	XXX	XXX	XXX	0.53	XXX	1.01	XXX	XXX	XXX	XXX	XXX
103	XXX	XXX	XXX	XXX	0.40	XXX	0.93	XXX	XXX	XXX	XXX	XXX
104	XXX	XXX	XXX	XXX	0.33	XXX	0.75	XXX	XXX	XXX	XXX	XXX
105	XXX	XXX	XXX	XXX	0.26	XXX	0.68	XXX	XXX	XXX	XXX	XXX
106	XXX	XXX	XXX	XXX	0.20	XXX	0.60	XXX	XXX	XXX	XXX	XXX
107	XXX	XXX	XXX	XXX	0.16	XXX	0.50	XXX	XXX	XXX	XXX	XXX
108	XXX	XXX	XXX	XXX	0.13	XXX	0.42	XXX	XXX	XXX	XXX	XXX
109	XXX	XXX	XXX	XXX	0.11	XXX	0.39	XXX	XXX	XXX	XXX	XXX
110	XXX	XXX	XXX	XXX	0.09	XXX	0.33	XXX	XXX	XXX	XXX	XXX
111	XXX	XXX	XXX	XXX	0.07	XXX	0.27	XXX	XXX	XXX	XXX	XXX
112	XXX	XXX	XXX	XXX	0.06	XXX	0.25	XXX	XXX	XXX	XXX	XXX
113	XXX	XXX	XXX	XXX	0.05	XXX	0.21	XXX	XXX	XXX	XXX	XXX
114	XXX	XXX	XXX	XXX	0.04	XXX	0.18	XXX	XXX	XXX	XXX	XXX
115	XXX	XXX	XXX	XXX	XXX	XXX	0.14	XXX	XXX	XXX	XXX	XXX
116	XXX	XXX	XXX	XXX	XXX	XXX	0.12	XXX	XXX	XXX	XXX	XXX
117	XXX	XXX	XXX	XXX	XXX	XXX	0.11	XXX	XXX	XXX	XXX	XXX
118	XXX	XXX	XXX	XXX	XXX	XXX	0.10	XXX	XXX	XXX	XXX	XXX
119	XXX	XXX	XXX	XXX	XXX	XXX	0.07	XXX	XXX	XXX	XXX	XXX
120	XXX	XXX	XXX	XXX	XXX	XXX	0.07	XXX	XXX	XXX	XXX	XXX
121	XXX	XXX	XXX	XXX	XXX	XXX	0.05	XXX	XXX	XXX	XXX	XXX
122	XXX	XXX	XXX	XXX	XXX	XXX	0.04	XXX	XXX	XXX	XXX	XXX
Runoff Begins (minutes)	18.00	23.00	11.00	16.00	44.00	18.00	49.00	8.00	15.00	16.00	26.00	17.00
Peak Runoff (GPM)	1.46	1.14	2.38	1.68	0.94	1.32	1.15	2.08	1.67	1.35	1.27	1.38
Runoff Coefficient	0.41	0.47	0.43	0.45	0.32	0.42	0.29	0.43	0.43	0.44	0.39	0.49
Time to Peak (minutes)	50.00	63.00	39.00	49.00	91.00	60.00	95.00	46.00	44.00	51.00	61.00	47.00
Time to zero (minutes)	20.00	19.00	25.00	24.00	47.00	19.00	21.00	33.00	31.00	29.00	25.00	30.00

APPENDIX D

RUNOFF MEASUREMENTS FOR CONCRETE WITH EXPANSION/CONTRACTION JOINTS (CwJ) AND WITHOUT EXPANSION/CONTRACTION JOINTS (Cw/oJ)

Surface	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	Cw/oJ	Cw/oJ	Cw/oJ
Date	2/29/03	02/28/03	3/4/2003	3/6/2003	3/6/2003	3/7/2003	04/07/03	04/07/03	04/07/03
Temp ('C)	24	13	17.3	19.2	14.9	21.8	21.2		23.1
Humidity (%)	64	52	32	35	57	44	94		94
Initial Reading,I_{gmr}	361034	361118	361222	361299	361352	361420	362268	362320	362320
Final Reading, F_{gmr}	361117	361202	361281	361350	361420	361488	362320	362368	362368
Input (GPM/iph)	2.83/1.51	2.87/1.53	2.35/1.254	2.64/1.41	3.84/1.88	4.12/2.2	3.03/1.62	3.28/1.74	2.39/1.27
Test No.	1	2	3	4	5	6	1	2	3
Bucket No.	**Incremental Time steps' t_{diff} ' to collect 2 liters of Runoff after TOB (Minutes)**								
1	2.84	5.33	4.55	5.23	2.40	2.90	1.97	3.53	4.68
2	0.57	0.55	0.82	0.68	0.50	0.52	0.70	0.57	0.93
3	0.53	0.45	0.65	0.52	0.38	0.32	0.55	0.45	0.67
4	0.42	0.42	0.57	0.45	0.32	0.38	0.42	0.47	0.50
5	0.42	0.37	0.37	0.42	0.32	0.33	0.32	0.40	0.53
6	0.37	0.35	0.50	0.40	0.28	0.33	0.30	0.35	0.53
7	0.35	0.32	0.55	0.37	0.30	0.28	0.28	0.35	0.48
8	0.33	0.33	0.43	0.35	0.27	0.30	0.32	0.38	0.48
9	0.33	0.32	0.43	0.32	0.27	0.25	0.28	0.30	0.45
10	0.33	0.32	0.43	0.28	0.25	0.27	0.30	0.32	0.43
11	0.33	0.32	0.43	0.32	0.23	0.23	0.30	0.32	0.40
12	0.33	0.30	0.30	0.33	0.23	0.25	0.27	0.30	0.43
13	0.32	0.35	0.43	0.30	0.23	0.23	0.25	0.33	0.45
14	0.28	0.32	0.37	0.33	0.23	0.23	0.28	0.35	0.45
15	0.28	0.32	0.40	0.28	0.23	0.25	0.27	0.32	0.38
16	0.32	0.28	0.35	0.30	0.22	0.27	0.25	0.32	0.40
17	0.32	0.28	0.30	0.27	0.22	0.23	0.27	0.30	0.45
18	0.28	0.30	0.27	0.30	0.22	0.23	0.27	0.32	0.47
19	0.30	0.28	0.33	0.30	0.22	0.22	0.30	0.30	0.45
20	0.30	0.33	0.33	0.32	0.22	0.22	0.28	0.32	0.47
21	0.32	0.32	0.28	0.30	0.23	0.20	0.27	0.28	0.43
22	0.32	0.30	0.27	0.35	0.22	0.20	0.28	0.32	0.38
23	0.28	0.30	0.25	0.28	0.20	0.22	0.27	0.32	0.40
24	0.32	0.30	0.27	0.30	0.23	0.20	0.25	0.32	0.43
25	0.32	0.30	0.33	0.33	0.22	0.20	0.25	0.32	0.43
26	0.27	0.30	0.32	0.27	0.20	0.20	0.27	0.30	0.42
27	0.30	0.28	0.32	0.25	0.22	0.22	0.30	0.30	0.43
28	0.28	0.33	0.30	0.22	0.20	0.20	0.27	0.43	0.45

Continued									
Surface	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	Cw/oJ	Cw/oJ	Cw/oJ
Test No.	1	2	3	4	5	6	1	2	3
29	0.30	0.32	0.35	0.22	0.22	0.20	0.25	0.45	0.38
30	0.30	0.28	0.30	0.22	0.20	0.22	0.25	0.58	0.43
31	0.27	0.30	0.28	0.23	0.23	0.18	0.23	0.80	0.45
32	0.30	0.28	0.27	0.23	0.20	0.20	0.25	1.17	0.60
33	0.28	0.27	0.32	0.27	0.23	0.20	0.22	2.77	0.73
34	0.28	0.25	0.33	0.28	0.20	0.22	0.23	XXX	0.93
35	0.30	0.23	0.32	0.28	0.22	0.23	0.23	XXX	1.40
36	0.30	0.23	0.30	0.23	0.20	0.23	0.25	XXX	2.25
37	0.28	0.23	0.28	0.32	0.22	0.23	0.25	XXX	XXX
38	0.30	0.27	0.27	0.27	0.20	0.22	0.22	XXX	XXX
39	0.27	0.25	0.27	0.27	0.20	0.22	0.23	XXX	XXX
40	0.30	0.28	0.25	0.25	0.20	0.22	0.22	XXX	XXX
41	0.33	0.30	0.32	0.27	0.22	0.22	0.22	XXX	XXX
42	0.28	0.27	0.32	0.37	0.20	0.20	0.22	XXX	XXX
43	0.28	0.23	0.35	0.40	0.22	0.20	0.22	XXX	XXX
44	0.30	0.25	0.33	0.50	0.23	0.22	0.20	XXX	XXX
45	0.33	0.27	0.32	0.57	0.23	0.22	0.22	XXX	XXX
46	0.27	0.25	0.27	0.55	0.25	0.20	0.27	XXX	XXX
47	0.28	0.27	0.30	0.80	0.23	0.20	0.32	XXX	XXX
48	0.28	0.27	0.28	0.98	0.23	0.20	0.32	XXX	XXX
49	0.28	0.27	0.35	1.62	0.22	0.23	0.38	XXX	XXX
50	0.32	0.27	0.33	2.35	0.22	0.23	0.45	XXX	XXX
51	0.27	0.25	0.32	3.95	0.25	0.25	0.58	XXX	XXX
52	0.32	0.27	0.38	XXX	0.22	0.27	0.72	XXX	XXX
53	0.27	0.27	0.35	XXX	0.27	0.25	0.95	XXX	XXX
54	0.28	0.27	0.33	XXX	0.32	0.33	1.33	XXX	XXX
55	0.30	0.30	0.32	XXX	0.37	0.35	0.80	XXX	XXX
56	0.30	0.28	0.33	XXX	0.38	0.43	XXX	XXX	XXX
57	0.28	0.27	0.32	XXX	0.47	0.55	XXX	XXX	XXX
58	0.30	0.27	0.40	XXX	0.57	0.67	XXX	XXX	XXX
59	0.30	0.27	0.43	XXX	0.72	0.92	XXX	XXX	XXX
60	0.30	0.25	0.53	XXX	0.98	1.35	XXX	XXX	XXX
61	0.28	0.28	0.60	XXX	1.45	2.25	XXX	XXX	XXX
62	0.32	0.28	0.73	XXX	2.23	5.25	XXX	XXX	XXX
63	0.28	0.27	0.85	XXX	4.58	XXX	XXX	XXX	XXX
64	0.32	0.22	0.97	XXX	XXX	XXX	XXX	XXX	XXX
65	0.30	0.23	0.92	XXX	XXX	XXX	XXX	XXX	XXX
66	0.33	0.23	1.83	XXX	XXX	XXX	XXX	XXX	XXX
67	0.30	0.23	2.38	XXX	XXX	XXX	XXX	XXX	XXX

Continued

Surface	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	Cw/oJ	Cw/oJ	Cw/oJ
Test No.	1	2	3	4	5	6	1	2	3
68	0.30	0.23	XXX	XXX	XXX	XXX	XXX	XXX	XXX
69	0.32	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
70	0.30	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
71	0.30	0.25	XXX	XXX	XXX	XXX	XXX	XXX	XXX
72	0.28	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
73	0.33	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
74	0.25	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
75	0.32	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
76	0.43	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
77	0.45	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
78	0.53	0.32	XXX	XXX	XXX	XXX	XXX	XXX	XXX
79	0.62	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
80	0.75	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
81	1.07	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
82	1.38	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
83	2.20	0.27	XXX	XXX	XXX	XXX	XXX	XXX	XXX
84	3.43	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
85	8.50	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
86	XXX	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
87	XXX	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
88	XXX	0.30	XXX	XXX	XXX	XXX	XXX	XXX	XXX
89	XXX	0.32	XXX	XXX	XXX	XXX	XXX	XXX	XXX
90	XXX	0.28	XXX	XXX	XXX	XXX	XXX	XXX	XXX
91	XXX	0.33	XXX	XXX	XXX	XXX	XXX	XXX	XXX
92	XXX	0.38	XXX	XXX	XXX	XXX	XXX	XXX	XXX
93	XXX	0.47	XXX	XXX	XXX	XXX	XXX	XXX	XXX
94	XXX	0.52	XXX	XXX	XXX	XXX	XXX	XXX	XXX
95	XXX	0.63	XXX	XXX	XXX	XXX	XXX	XXX	XXX
96	XXX	0.73	XXX	XXX	XXX	XXX	XXX	XXX	XXX
97	XXX	1.03	XXX	XXX	XXX	XXX	XXX	XXX	XXX
98	XXX	1.00	XXX	XXX	XXX	XXX	XXX	XXX	XXX

Continued									
Surface	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	Cw/oJ	Cw/oJ	Cw/oJ
Test No.	1	2	3	4	5	6	1	2	3
98	XXX	1.00	XXX	XXX	XXX	XXX	XXX	XXX	XXX
99	XXX	1.58	XXX	XXX	XXX	XXX	XXX	XXX	XXX
100	XXX	2.00	XXX	XXX	XXX	XXX	XXX	XXX	XXX
101	XXX	2.92	XXX	XXX	XXX	XXX	XXX	XXX	XXX
102	XXX	7.02	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Runoff Begins (minutes)	4.33	1.87	1.57	1.60	3.23	1.93	2.91	2.21	1.02
Peak Runoff (gpm)	1.87	1.78	1.73	2.11	2.45	2.52	2.14	1.70	1.24
Runoff Coefficient	0.63	0.70	0.74	0.80	0.64	0.61	0.71	0.52	0.52
Time to Peak (mins)	12.08	12.50	14.93	15.75	9.90	9.96	9.96	9.01	11.11

APPENDIX E

RUNOFF MEASUREMENTS FOR ASPHALT PLOTS

Surface	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
Date	04/12/03	04/12/03	04/14/03	04/21/03	04/28/03	04/28/03
Temp ('C)	24.7	26.9	20.8	20.3	19.2	19.2
Humidity (%)	47	43	82	48	86	90
Initial Reading I_{gmr}	362419	362462	362502	362563	362675	362718
Final Reading F_{gmr}	362461	362500	362560	362614	362718	362766
Input (GPM/iph)	2.82/1.5	2.55/1.36	2.55/1.47	3.35/1.788	3.14/1.676	3.45/1.87
Test No.	1	2	3	4	6	7
Time (minutes)	**Incremental Time steps ' t_{diff} ' to collect 2 liters of Runoff after TOB (Minutes)**					
0	4.5667	4.23	2.25	2.87	2.8333	2.40
1	0.8333	0.83	0.68	0.70	1.1167	0.63
2	0.5333	0.58	0.58	0.57	0.6333	0.50
3	0.4833	0.45	0.50	0.42	0.4667	0.42
4	0.4667	0.37	0.45	0.37	0.4333	0.37
5	0.3833	0.32	0.43	0.37	0.3833	0.30
6	0.3833	0.33	0.33	0.35	0.4000	0.30
7	0.3333	0.33	0.32	0.28	0.3333	0.25
8	0.3167	0.30	0.35	0.28	0.3167	0.28
9	0.3000	0.27	0.30	0.28	0.2833	0.25
10	0.3000	0.23	0.38	0.28	0.2667	0.30
11	0.2833	0.23	0.40	0.27	0.2667	0.27
12	0.3333	0.23	0.32	0.25	0.2667	0.30
13	0.3167	0.27	0.33	0.28	0.2667	0.27
14	0.3000	0.30	0.28	0.27	0.2667	0.23
15	0.2833	0.30	0.33	0.25	0.2667	0.27
16	0.3000	0.23	0.35	0.23	0.2333	0.23
17	0.3000	0.28	0.30	0.23	0.2167	0.22
18	0.2833	0.28	0.32	0.25	0.2167	0.22
19	0.2667	0.28	0.33	0.27	0.2167	0.27
20	0.2833	0.27	0.25	0.22	0.2333	0.27
21	0.3000	0.25	0.25	0.23	0.2167	0.23
22	0.2833	0.27	0.30	0.22	0.2333	0.23

Surface	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
Test No.	1	2	3	4	6	7
23	0.2667	0.27	0.28	0.22	0.2333	0.25
24	0.3000	0.27	0.28	0.20	0.2333	0.27
25	0.3000	0.25	0.28	0.23	0.2167	0.20
26	0.3000	0.28	0.28	0.23	0.2167	0.27
27	0.3167	0.27	0.28	0.27	0.2167	0.25
28	0.3000	0.25	0.28	0.27	0.2500	0.25
29	0.3667	0.25	0.28	0.22	0.2333	0.25
30	0.3667	0.25	0.35	0.27	0.2333	0.22
31	0.4667	0.25	0.32	0.27	0.2667	0.30
32	0.5000	0.27	0.28	0.27	0.2500	0.28
33	0.6667	0.28	0.30	0.30	0.2333	0.28
34	0.8000	0.30	0.27	0.25	0.3333	0.33
35	1.1167	0.32	0.28	0.22	0.3500	0.37
36	1.4000	0.37	0.28	0.23	0.3667	0.43
37	1.7833	0.42	0.25	0.25	0.4500	0.50
38	XXX	0.48	0.30	0.23	0.5667	0.65
39	XXX	0.60	0.28	0.23	0.6500	0.78
40	XXX	0.72	0.27	0.23	0.8167	0.88
40	XXX	0.92	0.28	0.42	0.9833	1.03
41	XXX	1.13	0.25	0.37	1.2667	1.22
42	XXX	1.57	0.27	0.47	1.6833	1.57
43	XXX	1.97	0.30	0.43	2.4167	XXX
44	XXX	2.87	0.27	0.58	3.6833	XXX
45	XXX	XXX	0.35	0.72	XXX	XXX
46	XXX	XXX	0.27	0.97	XXX	XXX
47	XXX	XXX	0.30	1.18	XXX	XXX
48	XXX	XXX	0.33	1.50	XXX	XXX
49	XXX	XXX	0.38	3.10	XXX	XXX
50	XXX	XXX	0.42	2.40	XXX	XXX
51	XXX	XXX	0.52	3.93	XXX	XXX
52	XXX	XXX	0.67	4.32	XXX	XXX
53	XXX	XXX	0.77	4.62	XXX	XXX
54	XXX	XXX	1.08	XXX	XXX	XXX
55	XXX	XXX	1.42	XXX	XXX	XXX
56	XXX	XXX	1.90	XXX	XXX	XXX
Runoff Begins(minutes)	1.28	0.63	4.20	1.08	1.47	2.67
Peak Runoff (gpm)	1.80	2.01	1.89	2.21	2.34	2.20
Runoff Coefficient	0.64	0.79	0.69	0.66	0.75	0.63
Time to Peak (mins)	10.46	8.83	14.00	9.16	11.60	9.73

APPENDIX F

COMPARISON OF DIFFERENT TIME OF CONCENTRATION METHODS WITH THE OBSERVED RESULTS FOR BARE CLAY PLOTS

Surface	BC02	BC02	BC02	BC02	BC03	BC03	BC03	BC03	BC03	BC03
Run	4	5	6	7	1	2	3	4	5	6
Length (ft)	30	30	30	30	30	30	30	30	30	30
Slope (ft./ft.)	0.0048	0.0048	0.0048	0.0048	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
Tatal fall (ft)	0.144	0.144	0.144	0.144	0.072	0.072	0.072	0.072	0.072	0.072
Rainfall intensity (iph)	1.98	2.11	3.35	2.27	1.7	1.49	1.63	1.61	1.56	1.62
Manning's 'n', (McCuen 1998)	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
(inches)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
CN (SCS)	89	89	89	89	89	89	89	89	89	89
I (imp fraction)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
slope %	0.48	0.48	0.48	0.48	0.24	0.24	0.24	0.24	0.24	0.24
Izzard's k (for tar and gravel)	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
D (min)	50	50	50	50	50	50	50	50	50	50
Kirby's n (Debo and Reese 2003)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Runoff Coeff.(Chow 1964)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S=1000/CN-10	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Model	**Time of Concentraion (minutes)**									
Hydraulic Estimates										
Overton and Meadows	0.74	0.74	0.74	0.74	0.98	0.98	0.98	0.98	0.98	0.98
Izzard	8.81	8.49	6.53	8.13	12.15	13.16	12.47	12.56	12.80	12.51
Izzard - Gupta	23.30	22.44	17.26	21.50	32.15	34.82	32.98	33.22	33.87	33.10
Izzard - Horton (laminar)	17.11	16.40	12.05	15.62	21.27	23.22	21.87	22.05	22.52	21.96
Empirical Estimates										
Kiprich	0.84	0.84	0.84	0.84	1.09	1.09	1.09	1.09	1.09	1.09
FAA	7.55	7.55	7.55	7.55	9.52	9.52	9.52	9.52	9.52	9.52
McCuen, Wong and Rawls	0.03	0.03	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04
SCS	2.38	2.38	2.38	2.38	3.37	3.37	3.37	3.37	3.37	3.37
Kerby	4.81	4.81	4.81	4.81	5.66	5.66	5.66	5.66	5.66	5.66
Papadakis-Kazan	1.46	1.43	1.20	1.39	1.92	2.02	1.95	1.96	1.99	1.96
Observed										
Field	27	20	12	15	45	37	34	36	71	61

APPENDIX G

COMPARISON OF DIFFERENT TIME OF CONCENTRATION METHODS WITH THE OBSERVED RESULTS FOR GRASS/LAWN PLOTS

Surface	G-left	G-left	G-left	G-left	G-left	G-left	G-left	G-Right	G-Right	G-Right	G-Right
Run	1	2	3	4	5	6	7	5	6	7	8
Length (ft)	30	30	30	30	30	30	30	30	30	30	30
Slope (ft./ft.)	0.0048	0.005	0.005	0.0048	0.0048	0.0048	0.0048	0.0024	0.0024	0.0024	0.0024
Tatal fall (ft)	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.072	0.072	0.072	0.072
Rainfall intensity (iph)	1.49	1.51	2.1	1.83	3.06	3.42	3.27	2.19	1.86	1.85	2.05
Manning's 'n' (McCuen 1998)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
2Yr. 24 hr. rainfall	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
CN (SCS)	89	89	89	89	89	89	89	89	89	89	89
I (imp fraction)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
slope %	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.24	0.24	0.24	0.24
Izzard's k 'sod' (Chow 1964)	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
D (min)	50	50	50	50	50	50	50	50	50	50	50
Kirby's n (Debo and Reese 2003)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Runoff coeff.(Chow et al. 1988)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
S=1000/CN-10	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Model	**Time of Concentration (minutes)**										
Hydraulic Estimates											
Overton and Meadows	5.58	5.58	5.58	5.58	5.58	5.58	5.58	7.36	7.36	7.36	7.36
Izzard	27.24	27.01	21.87	23.87	17.26	16.11	16.56	26.83	29.77	29.87	27.98
Izzard - Gupta	91.44	90.66	73.39	80.13	57.91	54.05	55.57	90.04	99.91	100.26	93.90
Izzard - Horton (laminar)	48.01	47.58	38.19	41.86	29.71	27.59	28.43	41.69	46.48	46.65	43.56
Empirical Estimates											
Kiprich	0.84	0.84	0.84	0.84	0.84	0.84	0.84	1.09	1.09	1.09	1.09
FAA	9.44	9.44	9.44	9.44	9.44	9.44	9.44	11.90	11.90	11.90	11.90
McCuen, Wong and Rawls	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.03
SCS	2.38	2.38	2.38	2.38	2.38	2.38	2.38	3.37	3.37	3.37	3.37
Kerby	9.20	9.20	9.20	9.20	9.20	9.20	9.20	10.82	10.82	10.82	10.82
Papadakis-Kazan	6.06	6.03	5.32	5.61	4.61	4.42	4.50	6.49	6.91	6.92	6.66
Other											
Wong	56.74	61.22	42.96	46.26	29.77	35.78	28.68	63.80	72.88	55.45	48.67
Field	34.00	54.00	34.00	38.00	32.00	32.00	24.00	40.00	57.00	34.00	39.00

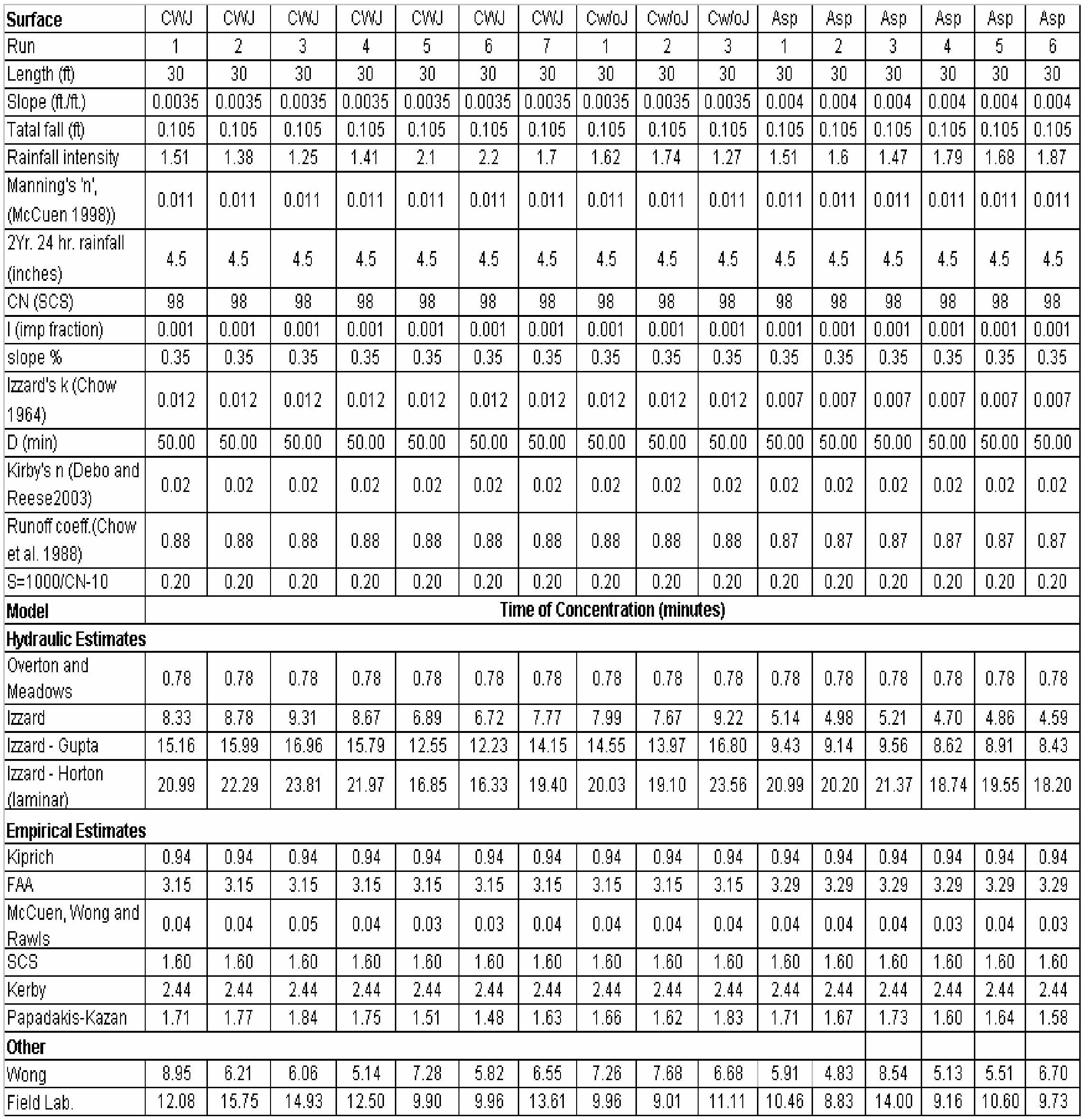
APPENDIX H

COMPARISON OF DIFFERENT TIME OF CONCENTRATION METHODS WITH THE OBSERVED RESULTS FOR PASTURE PLOTS

Surface	P-Left	P-Left	P-Left	P-Left	P-Left	P-Left	P-Right	P-Right	P-Right	P-Right	P-Right	P-Right
Run	2	3	4	5	6	7	1	4	5	56	7	8
Length (ft)	30	30	30	30	30	30	30	30	30	30	30	30
Slope (ft./ft.)	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
Tatal fall (ft)	0.14	0.14	0.14	0.14	0.14	0.14	0.07	0.07	0.07	0.07	0.07	0.07
Rainfall intensity	1.91	1.30	2.94	1.99	1.59	1.66	2.12	2.57	2.07	1.63	1.73	1.52
Manning's 'n' (McCuen 1998)	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
2Yr. 24 hr. rainfall	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
CN (SCS)	89	89	89	89	89	89	89	89	89	89	89	89
I (imp fraction)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
slope %	0.48	0.48	0.48	0.48	0.48	0.48	0.24	0.24	0.24	0.24	0.24	0.24
Izzard's k (Chow, VT 1964)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
D (min)	50	50	50	50	50	50	50	50	50	50	50	50
Kirby's n (Debo and Reese 2003)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Runoff coeff.(Chow et al. 1988)	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
S=1000/CN-10	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Model	**Time of Concentration (minutes)**											
Hydraulic												
Overton and Meadows	12.48	12.48	12.48	12.48	12.48	12.48	16.46	16.46	16.46	16.46	16.46	16.46
Izzard	30.10	38.63	22.84	29.32	33.89	32.96	35.46	31.35	36.01	42.02	40.43	43.96
Izzard - Gupta	94.00	120.65	71.33	91.55	105.84	102.92	110.74	97.90	112.45	131.22	126.25	137.30
Izzard - Horton (laminar)	56.88	73.51	42.67	55.35	64.28	62.46	59.56	52.39	60.51	70.97	68.20	74.35
Empirical Estimates												
Kiprich	0.84	0.84	0.84	0.84	0.84	0.84	1.09	1.09	1.09	1.09	1.09	1.09
FAA	8.94	8.94	8.94	8.94	8.94	8.94	11.26	11.26	11.26	11.26	11.26	11.26
McCuen, Wong and Rawls	0.03	0.04	0.02	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.04
SCS	2.38	2.38	2.38	2.38	2.38	2.38	3.37	3.37	3.37	3.37	3.37	3.37
Putnam (lag time)	22.58	22.58	22.58	22.58	22.58	22.58	31.93	31.93	31.93	31.93	31.93	31.93
Kerby	9.20	9.20	9.20	9.20	9.20	9.20	10.82	10.82	10.82	10.82	10.82	10.82
Papadakis-Kazan	9.31	10.77	7.90	9.16	9.98	9.82	11.09	10.31	11.19	12.25	11.98	12.58
Observed												
Field Lab.	50.00	63.00	39.00	49.00	91.00	60.00	95.00	46.00	44.00	51.00	61.00	47.00

APPENDIX I

COMPARISON OF DIFFERENT TIME OF CONCENTRATION METHODS WITH THE OBSERVED RESULTS FOR CONCRETE AND ASPHALT PLOTS



Surface	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	CWJ	Cw/oJ	Cw/oJ	Cw/oJ	Asp	Asp	Asp	Asp	Asp	Asp
Run	1	2	3	4	5	6	7	1	2	3	1	2	3	4	5	6
Length (ft)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Slope (ft./ft.)	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.004	0.004	0.004	0.004	0.004	0.004
Tatal fall (ft)	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
Rainfall intensity	1.51	1.38	1.25	1.41	2.1	2.2	1.7	1.62	1.74	1.27	1.51	1.6	1.47	1.79	1.68	1.87
Manning's 'n', (McCuen 1998))	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
2Yr. 24 hr. rainfall (inches)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
CN (SCS)	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
I (imp fraction)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
slope %	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Izzard's k (Chow 1964)	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.007	0.007	0.007	0.007	0.007	0.007
D (min)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Kirby's n (Debo and Reese2003)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Runoff coeff.(Chow et al. 1988)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.87	0.87	0.87	0.87	0.87	0.87
S=1000/CN-10	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Model	**Time of Concentration (minutes)**															
Hydraulic Estimates																
Overton and Meadows	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Izzard	8.33	8.78	9.31	8.67	6.89	6.72	7.77	7.99	7.67	9.22	5.14	4.98	5.21	4.70	4.86	4.59
Izzard - Gupta	15.16	15.99	16.96	15.79	12.55	12.23	14.15	14.55	13.97	16.80	9.43	9.14	9.56	8.62	8.91	8.43
Izzard - Horton (laminar)	20.99	22.29	23.81	21.97	16.85	16.33	19.40	20.03	19.10	23.56	20.99	20.20	21.37	18.74	19.55	18.20
Empirical Estimates																
Kiprich	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
FAA	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.29	3.29	3.29	3.29	3.29	3.29
McCuen, Wong and Rawls	0.04	0.04	0.05	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.03
SCS	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
Kerby	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Papadakis-Kazan	1.71	1.77	1.84	1.75	1.51	1.48	1.63	1.66	1.62	1.83	1.71	1.67	1.73	1.60	1.64	1.58
Other																
Wong	8.95	6.21	6.06	5.14	7.28	5.82	6.55	7.26	7.68	6.68	5.91	4.83	8.54	5.13	5.51	6.70
Field Lab.	12.08	15.75	14.93	12.50	9.90	9.96	13.61	9.96	9.01	11.11	10.46	8.83	14.00	9.16	10.60	9.73

APPENDIX J

CALIBRATION OF THE OBSERVED INFILTRATION FOR BARE CLAY SURFACE

Date	7/30/2003	Green Ampt Parameters	
Surface	Bareclay	Variables -	Values
Initial Moisture-	21.1%	K_{sat} (cm/hr)	0.0219
Final Moisture-	26.97%	Si (cm)	35.00
Diameter of the Water Tower	5 cm.	delta Theta (%)	0.2810
Diameter of the Tension Disc	24 cm.		

Time	Reading	Time	Observed Infiltration rate	Pred. Infiltration rate	Predicted comulative infiltration F(t)	Predicted Time	Square Difference
Minutes	cm	Hrs.	cm\hr.	cm\hr.	cm	Hrs.	
0	17.5	0.000					
2	18.9	0.033	1.823	1.822	0.119	0.033	0.000
6	20.7	0.100	1.172	1.048	0.210	0.101	0.015
12	22.4	0.200	0.738	0.748	0.296	0.200	0.000
16	23.3	0.267	0.677	0.650	0.342	0.266	0.001
20	24.1	0.333	0.553	0.582	0.384	0.334	0.001
26	25.1	0.433	0.469	0.512	0.438	0.434	0.002
36	26.5	0.600	0.365	0.438	0.516	0.599	0.005
46	27.7	0.767	0.313	0.389	0.586	0.767	0.006
56	28.6	0.933	0.234	0.354	0.648	0.934	0.014
76	30.4	1.267	0.234	0.306	0.757	1.267	0.005
96	32.1	1.600	0.221	0.274	0.853	1.600	0.003
116	33.5	1.933	0.182	0.251	0.940	1.934	0.005
136	34.8	2.267	0.169	0.233	1.021	2.267	0.004
156	36.1	2.600	0.171	0.218	1.096	2.600	0.002
176	37.4	2.933	0.161	0.206	1.167	2.933	0.002
206	39.2	3.433	0.161	0.192	1.266	3.433	0.001
236	41.0	3.933	0.152	0.180	1.359	3.933	0.001
266	42.7	4.433	0.152	0.171	1.446	4.433	0.000
296	44.4	4.933	0.152	0.162	1.530	4.933	0.000
326	46.2	5.433	0.152	0.156	1.609	5.433	0.000
Sum of the Square difference of observed and predicted infiltration rates. =							0.068

APPENDIX K

CALIBRATION OF THE OBSERVED INFILTRATION FOR PASTURE PLOT

Date				7/30/2003	Green Ampt Parameters		
Surface				Pasture	Variables -	Optimized Value	
Initial Moisture-				32.5%	K_{sat} (cm/hr)	0.100	
Final Moisture-				34.15%	Si (cm)	13.196	
Diameter of the Water Tower				5 cm.	delta Theta (%)	0.150	
Diameter of the Tension Disc				24 cm.			
Time	Reading	Time	Observed Infiltration rate	Pred. Infiltration rate	Predicted comulative infiltration F(t)	Predicted Time	Square Difference
Minutes	cm	Hrs.	cm\hr.	cm\hr.	cm	Hrs.	
1	5.9	0.017					
2	8.8	0.033	7.552	1.790	0.117	0.033	33.199
5	15.1	0.083	5.469	1.157	0.187	0.083	18.589
10	20.3	0.167	2.708	0.838	0.268	0.167	3.497
15	21.9	0.250	1.771	0.697	0.331	0.250	1.153
20	22.8	0.333	0.651	0.613	0.386	0.333	0.001
25	23.5	0.417	0.417	0.556	0.434	0.417	0.019
30	24.1	0.500	0.313	0.513	0.479	0.500	0.040
35	24.6	0.583	0.260	0.481	0.520	0.583	0.048
40	25	0.667	0.208	0.454	0.559	0.667	0.060
50	25.7	0.833	0.182	0.414	0.631	0.833	0.053
60	26.2	1.000	0.130	0.384	0.698	1.000	0.064
70	26.8	1.167	0.156	0.361	0.760	1.167	0.042
80	27.4	1.333	0.156	0.342	0.818	1.333	0.034
90	27.8	1.500	0.104	0.327	0.874	1.500	0.049
100	28.2	1.667	0.104	0.314	0.927	1.667	0.044
120	29	2.000	0.104	0.293	1.028	2.000	0.035
140	29.8	2.333	0.104	0.276	1.123	2.333	0.030
Sum of the Square difference of observed and predicted infiltration rates. =							56.930

APPENDIX L

MICROTOPOGRAPHY DATASET FOR THE BARECLAY (BC02) PLOT

Microtopography Measurements for Bareclay02 Plot. (RL = 100.00 inches)											
360	99.38	99.65	99.74	99.64	99.54	99.75	99.64	99.39	99.35	99.36	99.24
354	99.42	99.52	99.52	99.56	99.47	99.53	99.43	99.55	99.1	99.23	99.18
348	99.38	99.58	99.62	99.67	99.56	99.59	99.48	99.11	99.15	99.16	99.25
342	99.41	99.78	99.71	99.77	99.54	99.48	99.22	99.1	99.14	99.28	99.27
336	99.54	99.77	99.79	99.7	99.45	99.39	99.07	99.05	99.13	99.36	99.26
330	99.71	99.78	99.77	99.81	99.49	99.35	99.23	99.03	99.22	99.42	99.47
324	99.76	99.77	99.78	99.9	99.6	99.46	99.21	99.1	99.14	99.34	99.41
318	99.61	99.61	99.67	99.75	99.68	99.87	99.1	98.83	99.23	99.34	99.51
312	99.5	99.38	99.49	99.61	99.56	99.65	99.43	98.94	98.91	99.35	99.64
306	99.76	99.8	99.79	99.75	100.1	99.86	99.69	99.06	99.46	99.37	100.03
300	100.11	100.06	99.46	100.03	99.97	99.85	99.36	99.22	98.91	99.79	99.98
294	100.3	99.84	99.78	99.66	99.82	99.59	99.67	99.01	98.96	99.42	99.9
288	100.24	99.67	99.51	99.65	99.69	99.11	99.45	98.57	99.05	99.73	99.48
282	100.01	99.6	99.79	99.85	99.85	99.61	99.35	98.93	99.41	99.55	99.5
276	99.94	99.66	99.78	99.85	99.6	99.34	99.16	98.92	99.57	99.54	99.5
270	99.8	99.6	99.71	99.77	99.84	99.43	99.28	99.03	99.01	99.51	99.69
264	99.38	99.36	99.51	99.52	99.57	99.38	99.14	99.13	99.16	99.27	99.34
258	99.34	99.29	99.4	99.26	99.18	99.12	98.94	99.15	99.07	99.25	99.06
252	99.16	99.13	98.96	99.08	99.08	98.94	98.79	98.92	98.89	99.13	99.2
246	98.96	98.85	99.12	99.05	98.93	98.91	98.82	98.96	99	99.19	99.21
240	99.02	98.85	98.2	99.16	99.05	99	98.94	99.03	99.11	99.2	99.34
234	99.43	99.26	98.54	99.56	99.19	99.07	99.13	99.15	99.08	99.15	99.28
228	99.51	98.47	98.07	98.45	99.01	99.13	99.16	99.23	99.04	99.17	99.26
222	99.72	98.97	98.5	99.01	98.54	99.07	99.14	99.13	98.98	99.23	99.1
216	99.61	98.64	98.63	98.85	98.79	99.16	99.11	99.26	99.03	99.18	99.1
210	99.57	99.42	98.81	98.95	98.18	99.01	99.04	99.26	99.18	99.19	99.27
204	99.54	99.14	98.72	98.74	99.07	98.91	98.81	99.05	98.88	99.2	99.21
198	99.22	98.67	98.9	97.9	98.58	98.65	98.68	98.78	98.86	99.07	99.01
192	99.19	98.95	98.84	98.72	98.46	98.66	98.7	98.61	98.68	98.94	98.97
186	99.07	99	98.76	98.66	98.43	98.62	98.58	98.62	98.7	98.76	98.87
180	99.02	98.94	98.9	98.85	98.48	98.36	98.37	98.43	98.65	98.91	98.69
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

Continued

Microtopography Measurements for Bareclay02 Plot. (RL = 100.00 inches)

180	99.02	98.94	98.9	98.85	98.48	98.36	98.37	98.43	98.65	98.91	98.69
174	98.98	99.05	98.88	98.78	98.64	98.3	98.34	98.41	98.5	98.47	98.51
168	98.68	98.66	98.7	98.56	98.53	98.14	98.1	98.24	98.34	98.36	98.43
162	98.44	98.52	98.44	98.2	97.91	97.9	97.84	98.07	98.52	98.18	98.33
156	98.21	98.22	98.17	97.92	97.66	97.88	97.84	98.01	98.22	98.29	98.41
150	98.06	98.06	98.1	97.93	97.66	97.82	97.95	98.03	98.25	98.43	98.42
144	98.11	98.04	97.94	97.77	97.78	97.92	97.98	98	98.14	98.26	98.31
138	98.04	98.11	98.02	97.88	97.95	97.74	97.92	97.96	98.14	98.1	98.01
132	98	98.2	98.13	97.9	97.9	97.74	97.99	98	98.2	98.07	98.1
126	98.18	98.21	98.17	98.26	98.1	97.94	98	98.18	98.73	98.25	98.08
120	98.14	98.54	98.32	98.37	98.35	98.17	98.12	98.3	98.35	98.14	98.11
114	98.56	98.57	98.53	98.39	98.61	98.22	98.24	98.49	98.6	98.24	98.08
108	98.71	98.6	98.71	98.53	98.48	98.23	98.24	98.54	98.57	98.16	97.98
102	98.73	98.61	98.64	98.52	98.3	98.24	98.18	98.38	98.37	98.13	98.16
96	98.74	98.64	98.66	98.63	98.4	98.29	98.35	98.45	98.32	98.19	98.14
90	98.61	98.61	98.53	98.56	98.4	98.28	98.32	98.34	98.38	98.08	98.25
84	98.62	98.47	98.45	98.56	98.21	98.09	97.95	98.13	98.18	98.03	97.99
78	98.2	98.42	98.17	98.18	98.13	98	98.14	97.96	97.92	97.85	97.44
72	98.14	98.03	97.76	98.19	98.09	97.91	98.1	97.93	97.9	97.54	97.41
66	98.07	98.01	98.02	98.21	98.08	97.84	98.05	98.04	97.97	97.64	97.45
60	98.04	98.05	98.05	98.2	98.04	97.89	97.96	98.19	98.01	98.07	97.7
54	98.25	98.03	97.96	98.12	97.91	97.87	98.08	98.06	98.02	97.91	97.7
48	98.48	98.2	97.97	98.13	98.03	97.76	98.03	97.99	98.1	97.84	97.82
42	98.17	98.11	98.15	98.25	98.06	97.84	97.96	97.98	98.09	97.8	97.88
36	98.13	98.25	98.37	98.36	98.01	98.18	98.07	97.95	97.97	97.75	97.89
30	98.22	98.19	98.3	98.15	98.05	98.17	98.15	98.04	98.15	98.12	98.2
24	98.06	97.96	97.92	98.1	98.17	98.1	98.17	97.81	98.11	98.25	98.23
18	98.05	97.69	97.99	98.28	98.21	97.98	98.09	98.66	98.25	98.37	98.41
12	98.22	97.5	98.1	97.95	98.19	98.01	97.68	98.11	97.69	97.75	98.3
6	98.08	97.85	97.51	97.49	97.82	98.18	97.56	97.3	98.39	98.16	98.58
0	98.14	97.53	97.79	97.56	97.17	97.65	97.45	98.11	97.99	98.36	98.53
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

APPENDIX M

MICROTOPOGRAPHY DATASET FOR THE BARECLAY03 PLOT

Microtopography Measurements for Bareclay03 Plot. (RL = 100.00 inches)											
360	100.93	100.59	100.6	100.76	100.6	100.7	100.5	100.5	100.7	100.7	100.53
354	100.56	100.52	100.5	100.46	100.4	100.4	100.3	100.2	100.2	100.3	100.29
348	100.65	100.61	100.6	100.53	100.7	100.5	100.4	100.2	100.2	100.2	100.44
342	100.8	100.82	100.6	100.6	100.6	100.4	100.3	100.3	100.3	100.2	100.22
336	100.88	100.71	100.7	100.56	100.6	100.5	100.4	100.3	100.2	100.3	100.19
330	101.03	100.86	100.7	100.6	100.6	100.5	100.4	100.3	100.3	100.3	100.32
324	100.93	100.81	100.8	100.64	100.6	100.6	100.5	100.3	100.4	100.4	100.28
318	100.91	100.8	100.8	100.63	100.7	100.7	100.5	100.3	100.3	100.3	100.43
312	100.78	100.73	100.8	100.59	100.6	100.7	100.4	100.4	100.3	100.4	100.9
306	101.14	100.77	100.8	100.58	100.6	100.6	100.5	100.4	100.3	100.5	100.86
300	101.16	101	100.8	100.66	100.6	100.6	100.5	100.5	100.4	100.4	100.8
294	101.09	100.78	100.7	100.55	100.5	100.5	100.5	100.3	100.3	100.4	100.58
288	100.96	100.74	100.7	100.52	100.5	100.4	100.4	100.2	100.4	100.4	100.75
282	101.05	100.71	100.7	100.41	100.5	100.4	100.3	100.1	100.2	100.3	100.61
276	101.1	100.74	100.7	100.44	100.5	100.4	100.2	100.1	100.1	100.3	100.6
270	100.92	100.55	100.4	100.3	100.3	100.2	100	100.2	100.2	100.2	100.64
264	100.75	100.49	100.3	100.18	100.2	100.2	99.99	100	100.1	100.2	100.42
258	100.53	100.45	100.2	100.06	100	99.98	99.91	99.85	99.81	100.1	100.14
252	100.46	100.11	100.2	100.02	100	100	99.87	99.9	99.96	99.98	100.25
246	100.28	100.07	100	99.99	99.93	99.91	99.89	99.93	99.87	100.1	100.38
240	100.33	100.04	100.1	100.03	99.87	99.86	99.9	99.91	99.96	100.1	100.34
234	100.6	100.11	100	99.9	99.83	99.77	99.9	99.94	99.98	99.97	100.21
228	100.49	100.17	100.1	99.76	99.7	99.75	99.97	99.91	99.98	100.3	100.27
222	100.22	100.19	100.2	99.69	99.66	99.78	100.1	99.99	99.95	99.96	100.15
216	100.36	100.21	100.4	99.65	99.73	99.79	100.1	99.96	99.93	100	100.32
210	100.39	100.22	100.4	99.62	99.61	99.72	99.88	99.99	99.94	99.87	100.12
204	100.19	100.25	100.4	99.58	99.65	99.72	99.87	99.87	99.81	99.72	100.1
198	100.21	100.23	100.4	99.56	99.6	99.71	99.76	99.75	99.64	99.65	100.05
192	100.31	100.21	100.4	99.54	99.57	99.65	99.67	99.61	99.55	99.53	100.22
186	100.25	100.13	100.4	99.54	99.51	99.63	99.61	99.57	99.62	99.48	100.09
180	100	100.03	100.4	99.5	99.48	99.61	99.59	99.53	99.53	99.55	100.29
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

Continued											
Microtopography Measurements for Bareclay03 Plot. (RL = 100.00 inches)											
174	99.97	99.64	99.63	99.52	99.54	99.54	99.55	99.5	99.6	99.57	99.99
168	99.9	99.53	99.52	99.43	99.54	99.51	99.48	99.51	99.55	99.6	99.98
162	99.62	99.45	99.47	99.4	99.5	99.5	99.51	99.54	99.5	99.54	99.68
156	99.57	99.39	99.41	99.4	99.46	99.56	99.47	99.36	99.51	99.56	99.7
150	99.76	99.28	99.35	99.43	99.39	99.53	99.43	99.51	99.41	99.4	99.67
144	99.87	99.33	99.36	99.36	99.36	99.47	99.38	99.41	99.42	99.44	99.9
138	99.59	99.4	99.36	99.31	99.34	99.45	99.42	99.43	99.42	99.52	99.63
132	99.84	99.43	99.4	99.38	99.36	99.41	99.4	99.45	99.38	99.53	99.5
126	99.59	99.49	99.46	99.53	99.39	99.39	99.34	99.42	99.45	99.52	99.55
120	99.82	99.59	99.5	99.64	99.44	99.39	99.35	99.42	99.47	99.75	99.5
114	99.82	99.72	99.57	99.45	99.48	99.37	99.35	99.42	99.47	99.39	99.6
108	100	99.63	99.63	99.38	99.46	99.44	99.33	99.35	99.4	99.44	99.77
102	100.26	99.5	99.46	99.56	99.46	99.44	99.38	99.34	99.52	99.47	99.81
96	99.89	99.67	99.37	99.7	99.53	99.42	99.37	99.34	99.44	99.49	99.77
90	99.88	99.61	99.36	99.57	99.5	99.41	99.38	99.33	99.3	99.34	99.67
84	100.05	99.65	99.34	99.5	99.46	99.4	99.37	99.3	99.28	99.37	99.28
78	99.96	99.58	99.3	99.49	99.38	99.33	99.35	99.22	99.23	99.36	99.18
72	99.87	99.91	99.37	99.44	99.45	99.27	99.35	99.25	99.23	99.33	99.2
66	99.65	99.56	99.3	99.48	99.36	99.25	99.3	99.4	99.21	99.27	99.17
60	99.99	99.41	99.24	99.38	99.28	99.23	99.28	99.3	99.25	99.24	99.21
54	99.87	99.38	99.25	99.35	99.24	99.17	99.23	99.26	99.22	99.2	99.3
48	100	99.56	99.22	99.35	99.17	99.12	99.35	99.2	99.17	99.17	99.32
42	99.95	99.32	99.15	99.27	99.12	99.05	99.22	99.12	99.1	99.08	99.28
36	99.72	99.22	99.08	99.27	99.11	99.03	99.02	99.03	99.14	99.19	99.33
30	99.91	99.17	98.98	99.15	99.28	99.01	98.95	98.87	99.06	99.03	99.93
24	99.78	99.09	98.9	99.1	99.17	99.01	98.82	98.79	98.86	98.98	99.43
18	100.21	98.99	98.73	98.92	99.11	99.01	98.63	98.83	98.87	99.08	99.79
12	99.61	98.91	98.61	98.88	98.69	99.01	98.48	98.51	99.14	99.09	100.14
6	99.32	98.78	98.39	98.59	98.6	98.44	98.42	98.54	98.95	99.06	100.17
0	99.28	98.59	98.28	98.59	98.41	98.22	98.21	98.65	99	99.17	100
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

APPENDIX N

MICROTOPOGRAPHY DATASET FOR GRASS-LEFT PLOT

Microtopography Measurements for Grass-Left Plot. (RL = 100.00 inches)											
360	100.29	100.26	101.1	100.76	100.5	100.5	100.1	100.1	100.1	100.8	100.69
354	100.5	100.31	100.3	99.64	99.85	100	99.78	100.1	100.2	100	100.58
348	99.8	99.96	100	99.56	99.92	100.2	99.64	99.85	100.1	99.78	100.21
342	99.69	99.93	99.77	99.72	99.97	99.78	99.97	99.87	100.4	99.8	100.4
336	99.71	99.75	99.81	99.74	99.87	99.99	99.9	99.83	100.2	99.87	100.15
330	99.52	99.27	99.6	99.51	99.48	99.91	99.58	99.73	100	99.83	100.13
324	100.03	100.12	99.42	99.47	99.6	99.87	99.66	99.8	99.93	100	100.05
318	100.02	100.35	99.68	99.88	99.96	100	99.94	100.1	99.81	99.94	99.93
312	100.07	100.42	99.6	99.54	99.47	99.92	99.69	99.83	99.58	99.76	100.22
306	100.23	100.29	99.38	99.26	99.51	99.57	99.31	99.74	99.6	99.79	100.03
300	99.63	99.65	99.49	99.43	99.47	99.78	99.42	99.65	99.8	99.58	100.06
294	100	99.56	99.64	99.61	99.34	100.2	99.45	99.38	99.66	99.65	100.09
288	100.51	99.5	99.74	99.48	99.45	99.68	99.43	99.83	99.63	99.96	100.54
282	99.67	99.48	99.75	99.52	99.54	100.2	99.71	99.88	99.64	99.78	100.43
276	99.5	99.53	100	99.49	99.54	99.78	99.65	99.87	99.63	99.48	100.08
270	99.71	99.38	99.45	99.88	99.64	100.1	99.51	99.8	99.76	99.51	100.42
264	99.83	100.06	99.96	99.82	99.86	99.97	99.56	99.74	99.69	99.51	100.33
258	100.12	99.84	99.91	99.68	99.82	100.2	99.64	99.73	99.65	99.8	100.27
252	99.81	99.95	100	99.92	99.72	99.65	99.73	99.74	99.68	99.59	100.21
246	99.62	100.06	100.1	100.21	99.68	99.88	99.52	99.69	99.51	99.5	100.24
240	99.65	99.82	99.49	99.75	99.69	99.7	99.48	99.54	99.66	99.74	100.08
234	99.83	100.33	99.89	99.69	99.67	99.99	99.46	99.4	99.72	99.56	100.08
228	99.65	100.63	100	99.8	99.49	99.95	99.45	99.44	99.69	99.49	99.72
222	100.07	100.41	99.97	99.71	99.71	99.78	99.61	99.45	99.66	99.59	99.99
216	99.82	100.61	100.2	99.72	99.49	99.66	99.63	99.41	99.51	99.38	99.78
210	99.83	100.64	99.75	99.84	99.52	100	99.45	99.56	99.55	99.6	99.89
204	100.09	100.46	99.89	99.81	99.3	99.71	99.36	99.1	99.29	99.3	99.29
198	100.18	100.66	99.91	99.73	98.91	99.46	99.23	99.32	99.31	99.04	99.33
192	99.91	100.01	99.53	99.81	99.35	99.53	99.13	98.86	99.03	99.08	99.23
186	99.76	99.47	99.36	99.47	99.28	99.34	99.4	99.06	99.23	98.94	99.51
180	99.97	99.4	99.05	99.5	99.04	99.31	98.88	98.78	99.17	99.2	99.31
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

Continued

Microtopography Measurements for Grass-Left Plot. (RL = 100.00 inches)

180	99.97	99.4	99.05	99.5	99.04	99.31	98.88	98.78	99.17	99.2	99.31
174	99.39	99.18	99.15	98.9	99.03	99.23	98.93	98.89	98.92	99.07	98.67
168	99.42	99.06	99.24	98.94	98.76	99.04	98.97	99.18	99.33	99.27	99.46
162	99.27	99.23	99.14	98.82	98.75	98.85	98.83	99.23	99.11	99.2	99.55
156	99.29	99	98.77	98.92	98.83	99.19	98.9	99	98.97	98.9	99.36
150	99.24	98.81	99.1	98.9	98.93	98.92	98.78	98.93	99.11	98.7	99.29
144	99.01	98.81	98.89	98.57	98.86	98.86	98.94	98.67	98.94	98.81	99.58
138	99.1	98.97	98.56	98.45	98.6	98.64	98.78	98.85	99.06	98.68	99.58
132	98.72	98.86	98.99	98.35	98.66	99	98.56	98.68	99.07	98.58	99.15
126	98.79	98.67	98.7	98.61	98.64	98.63	98.69	98.67	98.79	98.87	99.1
120	98.51	99.06	98.72	98.53	98.5	98.88	98.46	98.56	98.73	98.81	98.91
114	99.15	99.01	99.5	98.54	98.53	98.88	98.73	98.93	99.04	99.13	98.98
108	98.98	99.25	99.24	98.71	98.73	98.8	98.88	98.79	99.2	98.72	99.13
102	99.16	99.27	99.4	98.92	98.91	98.71	98.96	98.91	99.16	98.96	99.04
96	98.77	98.95	99.23	98.96	98.74	98.97	98.79	99.11	98.79	98.62	98.97
90	98.67	99.08	99.05	98.79	98.53	99.13	98.75	99.04	99.16	98.44	98.72
84	98.91	98.73	98.9	98.65	98.26	98.71	98.53	98.64	98.78	98.28	98.88
78	99.01	98.7	98.46	98.38	98.71	98.46	98.42	98.26	98.58	98.15	98.92
72	99	99.13	99.04	98.57	98.77	98.23	98.2	98.29	98.5	98.02	98.86
66	98.62	98.78	98.99	98.02	98.62	98.01	98.43	98.17	98.19	97.82	98.36
60	98.68	98.79	98.46	98.31	98.28	98.26	98.15	98.61	98.25	98.09	98.63
54	98.73	98.67	98.48	98.35	98.21	98.36	98.25	98.36	98.77	98.17	99.03
48	98.51	98.85	98.85	98.06	98.58	98.36	98.08	98.55	98.48	98.3	98.42
42	98.62	98.32	98.69	98.36	98.45	98.82	98.42	98.53	98.6	98.15	98.15
36	98.12	99.1	98.32	98.12	98.14	98.8	98.37	98.34	98.73	98.23	98.86
30	98.69	98.79	98.56	98.23	98.37	98.4	98.29	98.39	98.86	98.49	99.25
24	98.99	98.63	98.61	98.02	98.22	98.5	98.62	98.63	98.73	98.42	99.06
18	98.87	98.68	98.67	98.18	98.04	98.55	98.65	98.85	99.19	98.3	98.9
12	99.27	98.99	98.62	98.21	98.46	98.47	98.6	98.59	98.58	98.41	98.76
6	99.12	98.73	98.4	98.43	98.41	98.51	98.13	98.3	98.44	98.16	98.41
0	98.85	98.52	98.41	98.07	98.34	98.39	98.28	98.35	98.24	98.1	98.99
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

APPENDIX O

MICROTOPOGRAPHY DATASET FOR GRASS RIGHT PLOT

Microtopography Measurements for Grass-Right Plot. (RL = 100.00 inches)											
360	101.25	100.35	100.8	100.02	100.3	100.1	100.3	100.2	100.3	100.6	100.89
354	101.31	100.32	99.51	99.49	99.08	99.48	99.49	99.75	100.3	100.4	100.88
348	101.74	100.23	100.3	100.05	100	99.87	99.8	100.5	100.7	100.8	100.68
342	102.24	100.44	100.3	100.42	99.84	99.54	100.1	100.7	100.7	100.9	101.49
336	101.49	100.6	100.6	100.4	100.2	100.4	100.2	100.4	100.3	100.6	101.05
330	100.87	100.43	100.8	100.5	100.6	100.7	100.5	100.7	100.6	100.7	100.68
324	100.79	100.28	100.5	100.83	100.6	100.8	100.6	100.8	101.3	100.6	100.95
318	99.87	99.93	100.1	100.65	100.6	100.4	100.8	100.6	101	100.8	101.1
312	100.62	99.91	100.1	100.25	100.4	100.8	100.5	100.6	100.8	101	101.62
306	101.12	99.91	99.82	100.12	100.4	100.5	100.1	100.4	101	101	101.57
300	101.4	100.3	100.2	100.1	100.4	100.4	100.6	100.1	100.8	100.7	101.27
294	101.58	100.83	100.2	100.35	100.4	100.3	100.3	100.4	100.9	100.5	101.13
288	102.79	100.45	100.5	100.39	100.1	100.1	100.5	100.8	100.6	100.7	101.26
282	101.33	100.54	100.4	100.13	100.4	100.2	100.5	100.5	100.6	100.8	100.74
276	101.09	100.24	100.2	100.04	100.5	100.4	100.5	100.4	100.5	100.6	101.07
270	100.89	100.33	100.2	100.22	100.5	100.3	100.4	100.5	100.6	100.7	100.85
264	101.11	100.51	100.5	100.13	99.79	100.3	100.7	100.7	100.3	100.5	100.86
258	100.77	100.18	99.99	99.83	99.74	100.1	100.3	100.6	100	100.5	100.59
252	100.64	99.97	99.6	99.48	99.62	99.76	100.2	100.2	100.5	100.5	100.66
246	100.49	100.33	99.72	100.15	99.97	99.86	100.3	100.4	100.3	100.2	100.83
240	100.67	99.69	99.93	100.24	99.75	99.65	100.2	100.4	100.1	100.1	100.23
234	100.47	99.85	99.98	99.83	100.1	99.78	100.2	100.2	100.4	100.3	100.53
228	100.68	99.87	99.97	99.94	99.85	100.4	100.1	100	100.3	100.4	100.7
222	100.76	99.87	100.2	100.21	100.3	99.99	100	99.96	100.3	100.5	100.86
216	100.67	99.82	99.84	99.87	99.74	99.69	99.8	99.73	99.78	100.1	100.79
210	100.13	99.46	99.43	99.61	99.77	99.45	99.5	99.34	99.48	100.2	100.85
204	99.87	99.32	99.28	99.34	99.68	99.8	99.75	99.6	99.76	100.1	100.54
198	99.93	99.29	99.08	99.17	99.39	99.24	99.44	99.68	99.5	100.1	100.15
192	99.35	99.07	99.43	99.02	99.27	99.26	99.63	99.67	99.47	100.2	100.45
186	99.62	99.47	99.52	99.37	99.43	99.27	99.09	99.6	99.6	100.1	100.36
180	99.85	99.46	99.09	99.53	99.56	99.31	99.65	99.74	100.2	100.1	100.24
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

Continued

Microtopography Measurements for Grass-Right Plot. (RL = 100.00 inches)

180	99.85	99.46	99.09	99.53	99.56	99.31	99.65	99.74	100.2	100.1	100.24
174	100.01	99.43	99.5	99.4	99.34	99.57	99.64	99.95	99.83	99.8	101.15
168	100.1	99.65	99.9	99.32	99.48	99.56	100.1	100.1	99.87	100.2	100.39
162	100.01	100.06	99.85	99.7	99.68	99.61	99.87	99.79	99.66	99.98	100.44
156	100.04	99.94	100	99.58	99.64	99.5	99.68	99.79	100.3	100.1	100.55
150	100.51	99.87	99.99	99.76	99.73	99.71	99.87	100.1	99.88	100.3	100.83
144	100.65	99.86	99.99	99.87	99.85	100.1	99.78	99.69	99.52	99.9	100.62
138	100.69	99.7	99.9	100.21	100.1	100	99.87	99.84	100	99.9	100.67
132	101.24	99.99	100.4	100.19	100.2	100.2	100.1	100.2	100.3	100.5	100.75
126	100.92	99.94	100.1	100.37	100.2	99.91	100.1	99.91	100.2	100.3	100.6
120	101	100.33	100.4	100.15	100	100.4	100	99.96	99.98	99.84	100.63
114	100.5	99.89	99.91	100.03	99.91	100.2	100.2	100.1	99.86	100.4	100.78
108	100.56	99.8	99.5	99.83	99.84	100.1	100.1	99.75	99.85	100.5	100.98
102	99.97	99.43	99.72	99.96	99.72	99.72	99.9	99.93	99.89	100.5	100.9
96	99.89	99.05	99.45	99.49	99.11	99.32	99.64	100.1	100	100.3	101.13
90	99.76	99.27	99.46	99.3	99.5	99.17	99.24	99.65	99.56	100.1	100.53
84	99.38	99.62	99.77	99.31	99.33	99.17	99.38	99.27	99.49	99.52	100.48
78	99.82	98.9	99.35	99.24	99.42	98.9	99.55	100.3	99.44	99.78	100.49
72	99.62	98.93	99.08	99.19	99.13	99.22	99.37	99.95	99.65	99.79	100.45
66	99.2	99.08	98.95	99.21	99.37	99.17	99.51	99.68	99.48	99.53	100.09
60	100.02	98.95	98.96	99.23	99.56	99.38	99.47	99.97	100.1	99.89	99.96
54	99.57	98.95	99.43	99.24	99.51	99.57	99.85	99.82	99.87	99.91	100.19
48	99.32	99.2	99.17	99.39	99.67	99.56	99.85	100	100.1	99.48	99.51
42	100.06	99.56	99.69	100.12	99.63	100.2	99.65	100.2	99.67	99.76	99.84
36	99.74	99.39	99.98	99.72	99.84	99.49	99.85	99.97	99.7	99.79	100.03
30	99.15	98.88	99.46	99.84	99.66	99.88	99.92	99.91	99.48	99.78	99.85
24	99.56	99.01	99.12	100.25	99.89	100.1	99.51	99.64	99.55	99.49	99.87
18	99.99	99.11	99.09	99.32	99.54	100.2	99.56	99.44	99.52	99.4	99.47
12	99.33	98.81	99.12	99.51	99.67	99.65	99.34	99.24	99.84	99.34	99.14
6	99.1	98.65	98.74	99.38	99.36	99.45	99.1	98.58	99.59	99.43	99.21
0	98.17	97.85	97.64	98.1	98.42	98.61	98.48	98.4	98.38	98.47	98.95
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

APPENDIX P

MICROTOPOGRAPHY DATASET FOR CONCRETE/ASPHALT PLOT

Microtopography Measurements for Concrete/Asphalt Plots. (RL = 100.00 inches)											
360	100.23	100.29	100.3	100.14	100.1	100.2	100.1	100.1	100.1	100.1	99.99
354	100.13	100.2	100.3	100.1	100.1	100.1	100.1	100.3	100.1	100.1	100.01
348	100.12	100.16	100.2	100.08	100.1	100.1	100.1	100.2	100.2	100.1	100.09
342	100.1	100.19	100.2	100.04	100.1	100.1	100.1	100.2	100.2	100.1	100.04
336	100.02	100.08	100.2	100	100	100.1	100.1	100.1	100.1	100	100.02
330	100.03	100.11	100.1	99.96	100.1	100.1	100	100.1	100.1	100	100
324	99.92	100.01	100.1	99.94	99.97	99.98	99.99	100	100.1	99.99	99.97
318	99.86	100.05	100	99.91	99.91	99.95	99.97	100.1	100.2	99.94	99.92
312	99.83	99.91	99.98	99.84	99.88	99.88	99.91	99.89	100.1	99.9	99.87
306	99.74	99.89	99.96	99.77	99.81	99.82	99.84	99.97	99.98	99.84	99.82
300	99.75	99.88	99.89	99.71	99.76	99.78	99.8	99.93	99.96	99.81	99.79
294	99.78	99.89	99.92	99.75	99.76	99.81	99.89	99.99	99.93	99.82	99.86
288	99.92	99.96	100	99.82	99.78	99.81	99.84	99.91	99.91	99.82	99.81
282	99.69	99.85	99.92	99.71	99.74	99.75	99.75	99.81	99.87	99.77	99.78
276	99.61	99.78	99.84	99.64	99.67	99.71	99.71	99.81	99.86	99.73	99.74
270	99.54	99.69	99.81	99.56	99.63	99.65	99.71	99.73	99.97	99.72	99.77
264	99.51	99.64	99.75	99.56	99.61	99.65	99.71	99.88	99.85	99.69	99.73
258	99.48	99.62	99.77	99.53	99.56	99.62	99.63	99.76	99.78	99.67	99.67
252	99.43	99.6	99.73	99.48	99.54	99.58	99.58	99.72	99.73	99.64	99.63
246	99.41	99.55	99.77	99.44	99.52	99.57	99.54	99.78	99.7	99.61	99.59
240	99.4	99.53	99.67	99.44	99.5	99.55	99.53	99.64	99.67	99.59	99.56
234	99.36	99.48	99.66	99.41	99.47	99.52	99.49	99.69	99.65	99.55	99.52
228	99.36	99.45	99.57	99.38	99.44	99.5	99.48	99.6	99.6	99.52	99.48
222	99.33	99.46	99.64	99.38	99.42	99.46	99.46	99.58	99.56	99.48	99.45
216	99.28	99.41	99.54	99.35	99.38	99.41	99.43	99.49	99.61	99.43	99.45
210	99.27	99.38	99.47	99.33	99.37	99.39	99.39	99.47	99.48	99.39	99.38
204	99.25	99.33	99.42	99.27	99.34	99.36	99.33	99.4	99.45	99.34	99.38
198	99.23	99.28	99.38	99.25	99.31	99.31	99.32	99.36	99.4	99.29	99.28
192	99.2	99.25	99.31	99.23	99.26	99.28	99.26	99.33	99.33	99.24	99.23
186	99.17	99.21	99.27	99.21	99.21	99.24	99.23	99.26	99.29	99.2	99.19
180	99.3	99.21	99.21	99.23	99.19	99.17	99.18	99.19	99.19	99.18	99.11
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

Continued											
Microtopography Measurements for Concrete/Asphalt Plots. (RL = 100.00 inches)											
174	99.31	99.17	99.18	99.18	99.17	99.18	99.14	99.14	99.17	99.14	99.08
168	99.29	99.14	99.15	99.15	99.15	99.14	99.08	99.11	99.15	99.1	99.08
162	99.23	99.1	99.1	99.12	99.1	99.11	99.08	99.07	99.12	99.07	99.01
156	99.23	99.07	99.07	99.07	99.06	99.03	99.03	99.04	99.08	99.02	98.97
150	99.15	99.04	99.02	99.03	99.03	99	98.99	99	99.01	98.99	98.91
144	99.18	99.03	98.99	99.01	99.01	98.96	98.91	98.96	98.98	98.94	98.88
138	99.21	98.97	98.96	98.98	98.96	98.94	98.82	98.92	98.92	98.92	98.87
132	99.13	98.85	98.79	98.79	98.75	98.77	98.72	98.75	98.75	98.74	98.7
126	99.1	98.83	98.76	98.77	98.77	98.71	98.69	98.73	98.74	98.72	98.64
120	99.03	98.82	98.77	98.77	98.76	98.73	98.67	98.71	98.72	98.69	98.64
114	99.07	98.82	98.79	98.78	98.75	98.72	98.68	98.7	98.71	98.68	98.64
108	99.06	98.83	98.79	98.78	98.74	98.72	98.68	98.69	98.7	98.69	98.63
102	99.01	98.81	98.78	98.74	98.72	98.69	98.68	98.68	98.69	98.68	98.63
96	99.04	98.8	98.8	98.74	98.72	98.69	98.69	98.68	98.71	98.67	98.63
90	99.03	98.81	98.81	98.73	98.72	98.73	98.67	98.69	98.7	98.71	98.65
84	98.99	98.85	98.86	98.76	98.72	98.76	98.69	98.7	98.72	98.72	98.69
78	99.01	98.89	98.88	98.77	98.76	98.77	98.69	98.72	98.75	98.73	98.67
72	99.06	98.9	98.91	98.79	98.78	98.78	98.71	98.74	98.76	98.75	98.71
66	98.97	98.92	98.93	98.82	98.8	98.83	98.73	98.76	98.8	98.77	98.72
60	98.98	98.95	98.95	98.83	98.84	98.84	98.76	98.78	98.81	98.78	98.71
54	98.97	98.95	98.98	98.87	98.88	98.89	98.77	98.79	98.8	98.78	98.72
48	98.98	98.97	99	98.89	98.9	98.93	98.71	98.8	98.84	98.81	98.74
42	99.03	98.99	99.03	98.92	98.91	98.94	98.8	98.83	98.85	98.81	98.75
36	99.04	99.08	99.03	98.95	98.92	98.96	98.84	98.85	98.88	98.82	98.77
30	99.06	99.01	99.04	98.95	98.96	98.98	98.88	98.92	98.9	98.81	98.78
24	99	99.03	99.03	98.97	98.98	99	98.91	98.88	98.88	98.86	98.77
18	99.03	99.01	99.04	98.98	98.98	99.01	98.9	98.88	98.89	98.84	98.78
12	99	99.05	99.04	98.99	98.97	99.01	98.91	98.86	98.86	98.82	98.75
6	98.98	99.07	99.04	99	98.97	99.01	98.89	98.86	98.85	98.82	98.74
0	99.03	99.01	99.04	99.04	98.98	99.03	98.92	98.87	98.85	98.81	98.73
Y(in)= **X(in) =**	0	7	14	21	28	35	42	49	56	63	72

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