A REAL-TIME DEBRIS PREDICTION MODEL (USCDPM) INCORPORATING WILDFIRE AND SUBSEQUENT STORM EVENTS

by

Jang Hyuk Pak

A Dissertation Presented to the
FACULTY OF THE GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
DOCTOR OF PHILOSOPHY
(CIVIL ENGINEERING)

May 2005

UMI Number: 3180320

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI®

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

ACKNOWLEDGEMENTS

I would first like to express my deepest gratitude to my advisor, Professor Jiin-Jen Lee who offered the valuable guidance and supervision and supported me in many ways during this study. In addition, I would like to express my appreciation to my committee members, Professors Landon C. Wellford, Douglas Robert, Hung L. Wong, and Dr. Iraj Nasseri, for their continuous support.

I am also grateful to Kerry Casey, Gregory Peacock, and Dr. James Chieh of the Hydrology and Hydraulic Branch of the U.S. Army Corps of Engineers, Los Angeles District for their helpful comments, for their interest in me and in my work, and for supporting me in many ways. Dr. Youn Sim, Loreto Soriano, Adam Walden, and John Burton of the Water Resources Division at the Department of Public Works of the Los Angeles County have provided useful data and helpful comments. As result, I am truly grateful for their help.

Finally, I would like to acknowledge the support I have received from my family, especially my parents, two people I respect and truly admire the most in this world. Most importantly, I want to thank my wife, In Young Choi, and my son, Louis Pak, for their constant support and companionship throughout this endeavor. Without these instrumental people in my life, this accomplishment would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Alluvial fans are continuously being developed for residential, industrial, commercial, and agricultural purposes in southern California. Development of these areas must consider the generation of mud and debris flows from burned mountain watersheds. Accurate prediction of debris yield is essential for the design, operation, and maintenance of debris basins. This study develops a model for the prediction of debris yield resulting from a combination of wildfire and subsequent storm events.

The watersheds used in this analysis are located in the San Gabriel Mountains. A multiple regression analysis is first utilized to establish a fundamental mathematical relationship using 46 years of data (1938-1983). Following the multiple regression analysis, a method (USCDPM) for debris yield prediction is developed and calibrated based on 17 years of debris yield, fire, and precipitation data (1984-2000).

A debris routing method is developed to predict the temporal and spatial variations of a debris flow as it moves through watershed channel reaches for the large watershed. The William Fire (September 22, 2002) in the Azusa to Claremont area is used to calibrate the routing method of USCDPM applied to large watersheds.

After calibration with debris routing method, this model is applied to provide real-time prediction of the debris yields from the 2001-2003 fire events based on the Radio Telemetry Gage information.

The model results have been found to agree well with the field data. The proposed method for debris yield prediction can be a useful tool for watershed management in the arid Southwest region.

CHAPTER 1

1 Introduction

1.1 Background

In the semi-arid regions, the rainfall is the main source of moisture in a watershed. The moisture seeps into the soil and the increased pore water pressure helps to activate the unconsolidated soil and debris. Thus, debris flows in a semi-arid region are much more prevalent when the rainfall exceed some critical value.

The U.S. Army Corps of Engineers (USACE), Los Angeles District has designed and built numerous debris control dams and storage structures in the San Gabriel Mountain watersheds since the 1930s. The Los Angeles County Department of Public Works (LACDPW) and the San Bernardino County Flood Control District (SBCFCD) maintain debris dams constructed by USACE. The combined total maximum capacity of all debris basins within Los Angeles County is approximately 5,948,925 cubic meters (7,780,900 cubic yards). Normally, debris basins are excavated immediately after a big storm event to restore the storage capacity before the occurrence of the subsequent storm events. Because most of the existing debris structures were designed to intercept debris from a single large storm event, most of them are incapable of controlling multiple debris flows.

There have been several historical debris flow disasters in the present study area. In 1934, shortly after midnight on the New Year's Eve, debris flow occurred in the La Canada Valley located near Los Angeles, California. As a result of this flood, over 458,733 m^3 of debris was moved from the mountain area to the foothill region and the valley floor, devastating buildings, citrus groves, vineyards, villages, and highway. The reported property damage exceeded $5,000,000, and more than 40 lives were lost. Prior to this event, about 1,942 hectare (ha) of mountain area tributary to the La Canada Valley was burned by a fire in November 1933. This burned area produced most of the debris in the La Crescenta-Montrose District (Troxell H.C. and Peterson J.Q. 1937). Thus, the accurate prediction of debris yield from floods is necessary to minimize loss of life and property. Accurate prediction requires considering the prior fire events in the watershed.

1.2 Review of Prior Studies

Various methods have been reported with regard to the prediction of debris yield to protect the property and loss of life in the downstream areas. In 1959, William R. Ferrel of the Los Angeles County Flood Control District conducted a pioneering study on the debris yield for all watersheds adjacent to the coastal plain. He also developed a comprehensive debris control plan for hazardous areas. Twelve debris basins with records covering a 20-year period (1935-1955) were selected. An empirical equation was originally derived from the available data as shown below.

$$\textbf{Debris Production Rate in cu.yds./sq.mi.} = \frac{35{,}600Q^{1.67}Rr^{0.72}}{(5+V.I.)^{2.67}} \qquad (1.2.1)$$

where Q = Peak Runoff expressed in ft^3/second/mi^2 resulting from the maximum 24-

hr rainfall of a given storm.

Rr = Relief Ratio (the relative steepness of a watershed) - the ratio of the total vertical dimension (from point of study to the highest point in the watershed) to the horizontal distance parallel to the main channel (from point of study to the drainage divide).

$V.I.$ = Vegetation Index: Σ ((Index Point of Vegetation × Percent of Total Area of Vegetation) + (Index Point of Percent Cover × Percent of Total Area of Percent Cover))/100, where Index Point of Vegetation: Sage(1), Sage-Chamise(2), Chamise(3), Chamise-Chaparral(5), Chaparral(8), Chaparrl-Woodland(6), and Woodland(5), and Index Point of Percent Cover: 20%(3), 40%(9), 60%(15), 80%(18), and 100%(20).

In 1963, Fred Tatum of the Los Angeles District of the Corps of Engineers introduced a method for estimating debris storage capacities for debris basins. In the ensuing 23 years, numerous debris basins have been planned, designed, and constructed using the Tatum method (Amar et al. 1992).

In 1992 the Los Angeles District of the Corps of Engineers developed a new method with new data selected from 80 debris basins for traditional hydrologic procedures and design concepts. Debris yield equations for ranges of contributing drainage areas were developed.

The selected regression equation for the watershed area ranging from 0.1 to 3.0 mi^2 areas has the following form:

$$\log D_y = 0.65(\log P) + 0.62(\log RR) + 0.18(\log A) + 0.12(FF) \qquad (1.2.2)$$

where D_y = Unit Debris Yield (yd^3/mi^2)

P = Maximum 1-hr Precipitation (inches, taken to two places after the decimal point, times 100)

RR = Relief Ratio (ft/mi) – the difference in the elevation between the highest point in the watershed and the lowest point and dividing the difference between these two by the maximum stream length as measured along the longest stream.

A = Drainage Area (acres) – the contribution area of the watershed upstream of the chosen debris collection site.

FF = Non-Dimensional Fire Factor – using the correlation between measured debris yield and computed values by means of a single fire curve.

In 1996, Richard H. McCuen and T.V. Hromadka II conducted a comprehensive study of arid hydrology methods and storm flow estimation procedures used in the southwest of the United States of America to provide a valuable compendium of information on the estimation of debris volumes. The prediction equation developed in this study has the form:

$$\hat{Y} = b_0 A^{b1} D^{b2} H^{b3} T^{b4} B^{b5} \qquad (1.2.3)$$

where $\hat{Y}$ = Predicted Debris Yield (yd^3)

A = Drainage Area (mi^2) – the contribution area of the watershed upstream of the chosen debris collection site.

D = Drainage Density (mi/mi^2) – the ratio of the total length of the concentrated flow paths to the total drainage area in square miles.

H = Hypsometric Index – value of $\Delta e/\Delta E$ from the standardized hypsometric curve, which is the cumulative relation between elevation and area within elevation intervals, corresponding a value a/A of 0.5. The value of a is the area above elevation e.

> ΔE = the total elevation difference between the high and low elevation on the watershed.
>
> Δe = the elevation difference between a contour line and the low point.

T = Total Stream Length (mi)

B = Mean Bifurcation Ratio – average of the ratio of the number of streams of any order to the number of streams of the next lower order for all ordered pairs.

b_i (i = 0, 1, 2, 3, 4, 5) = Regression Coefficients.

Previous studies mentioned above resulted in empirical equations based on the regression analysis for a unit debris yield induced by a single precipitation event. However, the present study, which resulted in the development of USC Debris Prediction Model (USCDPM), can be used to predict the accumulated debris yield due to several subsequent storms following prior fire events. Three major physical processes are incorporated in the model developed.

1. The critical condition for entrainment of debris
2. The sufficient energy to move debris to the concentration point
3. The antecedent precipitation events followed by subsequent rainfalls

1.3 Objective and Scope

Alluvial fans are rapidly being urbanized in arid and semiarid regions such as southern California because of their relatively mild terrain and aesthetic views. The mountain areas upslope from the alluvial fans are susceptible to wildfires, and this can increase the debris transported downstream during subsequent storms. Development of these fan areas must consider the possibility of increasing mud and debris flows from mountain watersheds due to the effect of wildfire events.

The major objective of this research is to develop a model to predict the accumulated debris yields resulting from the wildfire and subsequent storm events and to mitigate the damage to property and life. Existing methods (Ferrell 1959; Tatum 1963; Amar et al. 1992; Gindi et al. 1993; McCuen et al. 1996; Gatwood et al. 2000) for the debris yield focused on a single design storm event for estimating the possible debris production. The author felt the need for a new model to predict the accumulated debris yields related to several subsequent rainfall events within one storm season after wildfire for the maintenance and management of debris basins during emergency situations. This new methodology incorporates the effective rainfall events for debris yields and the critical or threshold conditions to entrain the sediment and to transport the sediment to the concentration point. The watersheds used in this research are located in the San Gabriel Mountains within Los Angeles County and San Bernardino County as shown in Fig. 1.1.

The USCDPM can be used to predict the accumulated debris yields with greater consistency and reliability for coastal southern California small watersheds in the range of 25-400 ha. Using the debris routing method, the USCDPM can be extended to predict the accumulated debris yields for large watersheds having a watershed in range of 400-3000 ha.

Finally, the USCDPM can be used to provide a real-time prediction of accumulated debris yield incorporating the effect of wildfire and subsequent storm events from small and large watersheds in terms of the debris basin.

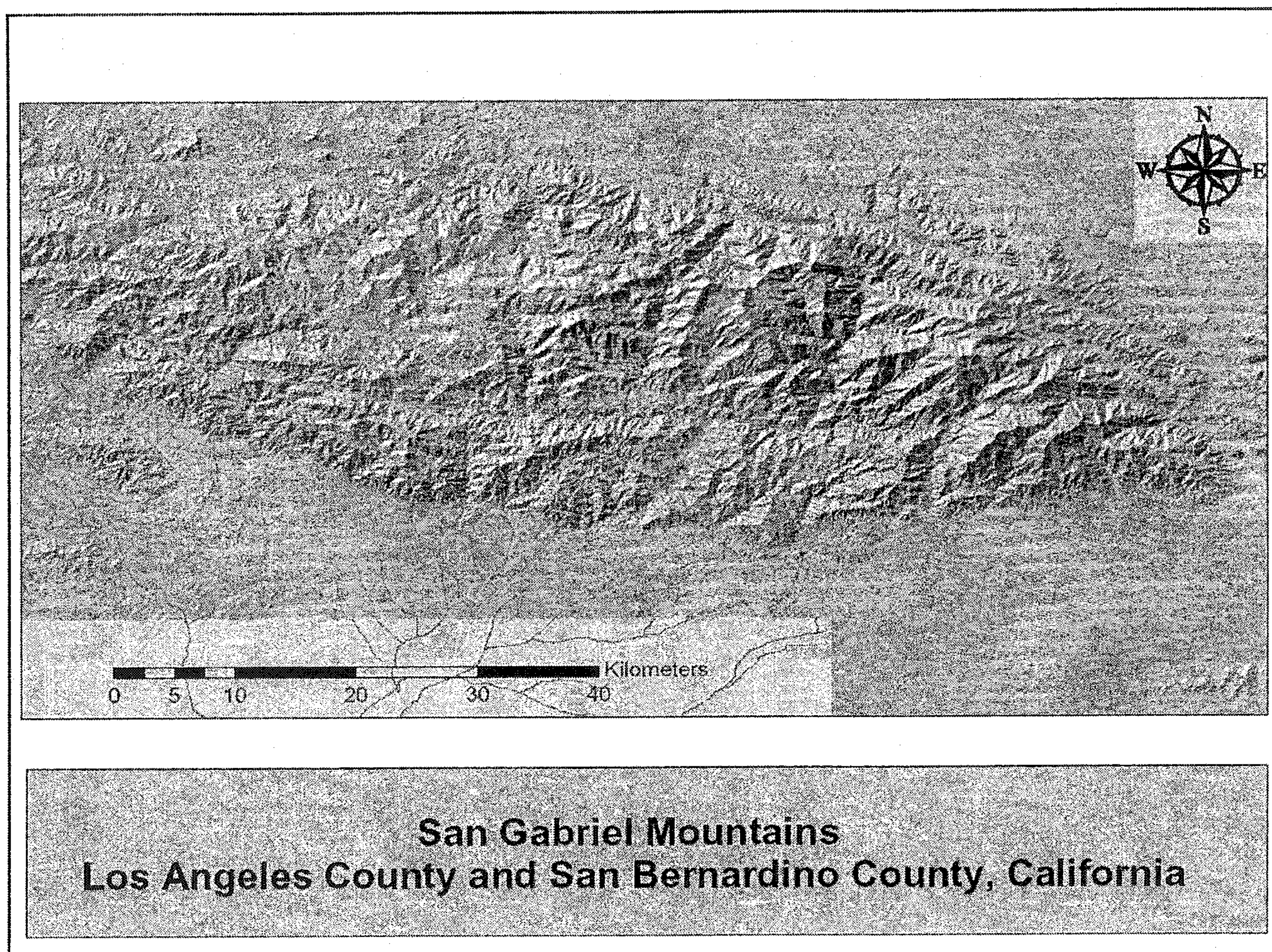

FIG. 1.1 Study Area of USCDPM

CHAPTER 2

2 Methods of Data Analysis

In this chapter, methods used for data analysis will be presented. A multiple linear regression equation is first obtained. The equation is further calibrated using the available field data. Finally, a rational equation called the USC Debris Production Model (USCDPM) is developed.

2.1 Stepwise Multiple Linear Regression Analysis

The multiple linear regression analysis is selected to establish a fundamental mathematical relation between the dependent variable (Unit Debris Yield) and the independent variables (Fire Factor, Relief Ratio, Watershed Area, and Maximum 1-hr Rainfall Intensity). In addition, a stepwise regression analysis is used to avoid the irrational coefficients, which cause major problems within multiple linear regression analysis.

2.1.1 Structure of Multiple Linear Regression Analysis

The extension of the least squares technique for several predictor variables is referred to as the multiple regression technique. In the case of n predictor variables, x_i (i = 1,2,…,n) with criterion variable y and a set of m observations of y, and x_i (i = 1,2,…,n), the line to be fitted is:

$$y' = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \qquad (2.1.1)$$

in which x_i (i = 1,2,…,n) are measured values and y' is an estimated value of y.

As with the n-variable case, values of the intercept α and slopes β_1, β_2, ..., and β_n are sought such that y' is the best estimate of y. For this purpose, the sum of the squares of the differences between y and y' are minimized.

$$\sum(y-y')^2 = \sum[y-(\alpha+\beta_1 x_1+\beta_2 x_2+...+\beta_n x_n)]^2 \qquad (2.1.2)$$

Setting the partial derivatives with respect to α, β_1, β_2, ..., and β_n equal to zero leads to the normal equations.

$$\sum y - m\alpha - \beta_1\sum x_1 - \beta_2\sum x_2 - ... - \beta_n\sum x_n = 0 \qquad (2.1.3)$$

$$\sum yx_1 - \alpha\sum x_1 - \beta_1\sum x_1{}^2 - \beta_2\sum x_2x_1 - ... - \beta_n\sum x_nx_1 = 0 \qquad (2.1.4)$$

$$\sum yx_2 - \alpha\sum x_2 - \beta_1\sum x_1x_2 - \beta_2\sum x_2x_2 - ... - \beta_n\sum x_nx_2 = 0 \qquad (2.1.5)$$

•

•

•

$$\sum yx_n - \alpha\sum x_n - \beta_1\sum x_1x_n - \beta_2\sum x_2x_n - ... - \beta_n\sum x_n{}^2 = 0 \qquad (2.1.6)$$

By solving Eqs. 2.1.3 to 2.1.6 simultaneously, α, β_1, β_2, ..., and β_n are defined. Values of intercept α, β_1, β_2, ..., and β_n can also be used to fit equations of the type:

$$y = ax_1^{b_1}x_2^{b_2}...x_n^{b_n} \qquad (2.1.7)$$

First, this equation is linearized by taking the logarithms:

$$\log y = \log a + b_1 \log x_1 + b_2 \log x_2 + ... + b_n \log x_n \qquad (2.1.8)$$

As with the four-variable case, $u = \log x_1$, $v = \log x_2$, $w = \log x_3$, $x = \log x_4$, $z = \log y$, this equation is $z = \log a + bu + cv + dw + ex$. The variables u, v, w, x, and z are used in Eqs. 2.1.3 to 2.1.6 instead of x_1, x_2, x_3, x_4, and y respectively. Then $\alpha = \log a$, $\beta_1 = b_1$, $\beta_2 = b_2$, $\beta_3 = b_3$, $\beta_4 = b_4$ and regression equation is

$$y = 10^{\alpha} x_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_3} x_4^{\beta_4} \tag{2.1.9}$$

The multiple regression analysis involving more than two predictor variables is based on the same least squares principle as in the cases shown here. Computer programs are usually available to perform the computations. In this study, the Statistical Package for the Social Sciences (SPSS) program is used for regression calculations to improve the efficiency.

2.1.2 Package Program for Multiple Regression Analysis

The study utilized the SPSS 11.5 computer program for multiple linear regression analysis. This program is a powerful data analysis tool. The analysis used the stepwise method to enter variables into the regression equation. Some variables that qualified to enter the analysis lose predictive validity when other variables are introduced. If this takes place, the stepwise method removed the "weakened" variable. The stepwise method is probably the most frequently used regression methods (Darren George and Paul Mallery, 1999).

2.2 Trial and Error Method for Calibration of USCDPM

The rational method is the most widely used method for the analysis of runoff response from small catchments. In this study, a rational model is developed to predict the debris yield. It is used to predict the realistic debris yield from several storm events after a big fire event. In this model, three additional parameters are introduced to apply the physical phenomena of debris flow: (1) the antecedent precipitation concept is used together with the subsequent storm events, since the more recent rainfall has the greater effect on debris yields, (2) the Threshold Maximum 1-hr Rainfall Intensity (TMRI), (mm/hr), is introduced to determine the critical condition for entrainment of sediments, and (3) the Total Minimum Rainfall Amount (TMRA), (mm) is incorporated to account for the runoff volume required to move sediments to the concentration point. The TMRI is correlated to the relief ratio and TMRA. These relationships are utilized in the model for predicting the debris yield. As a result, all the major hydrologic processes and parameters responsible for debris yield are included in the USCDPM.

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of each debris basin are determined through a trial and error method by minimizing the difference between the measured debris yield and the estimated debris yield predicted by the USCDPM.

CHAPTER 3

3 Evaluation and Selection of Hydrologic Variables for Debris Prediction Model

Hydrologic variables are evaluated by simple correlation analysis and selected based on the level of correlation with debris yields in this chapter. Finally, four-variables (Maximum 1-hr Rainfall Intensity, Relief Ratio, Drainage Area, and Fire Factor) are chosen to develop the USCDPM based on the correlation analysis in the USACE Los Angeles District Method (Amar et al. 1992; Gatwood et al. 2000). The correlation coefficients (R) of four parameters are presented in Table 3.1.

TABLE 3.1 Simple Correlation Coefficients (R) for Parameters

Parameter	Coefficient	Parameter	Coefficient
Max. 1-hr Rainfall Intensity	0.980*	Drainage Area	0.952*
Relief Ratio	0.989*	Fire Factor	0.959

*-Each value log transformed (base 10) to liberalize the relationship

3.1 Maximum 1-hr Rainfall Intensity

The maximum 1-hr rainfall intensity is collected from 1-hr rainfall records of raingages. The raingages are selected to collect the precipitation data from both the LACDPW and the USACE Los Angeles District raingage network systems. Although a comprehensive raingage network system exists, it is not always easy to get reliable rainfall data since the raingages do not exist within watersheds where debris yields are measured and predicted. Reliability of prediction depends on the accuracy of rainfall data. Efforts were made to gather reliable and constant rainfall data.

3.2 Relief Ratio (Watershed Slope)

The relief ratio (*S*) is defined as the difference in elevation between the highest point and the lowest point in the watershed divided by the longest stream length in the watershed (Amar et al. 1992; Gatwood et al. 2000).

3.3 Drainage Area

The drainage area is the watershed area upstream of the debris basin concentration point. A drainage area is selected as one of the variables for the final regression analysis because of its high correlation with debris yields in prior studies, as well as in the current study.

3.4 Fire Factor

Wildfire events play a very important role in the generation of debris in mountain watersheds. Rowe et al. (1949 and 1954) estimated that a 100% burned watershed produces 35 times more debris yield than a normal or unburned watershed. Previous studies show that wildfire had a considerable influence on the erosion of southern California mountain watersheds (Troxell et al. 1937; Cannon et al. 2003 & 2004; Middleton J. 2004).

F.E. Tatum (1963) applied the relationship established by Rowe et al. (1949 and 1954), to correlate measured debris yields and computed debris yields by means of a single fire curve. The new Fire Factor (*F*) in Eq. (3.4.1) is generated using the Fire Factor Curves from USACE Los Angeles District Debris Method (Amar et al. 1992; Gatwood et al. 2000) as guides.

$$\boldsymbol{F = 6.5 \times (B_p \times B_y^{-0.29} + (1 - B_p) \times (20 - B_y)^{-0.29})} \quad (3.4.1)$$

where: B_p = % of Burn/100, ($0 \le B_p \le 1$)

B_y = Number of Year since Burn, ($1 \le B_y \le 10yr$)

The Reduction Fire Factor (*RFF*) is introduced to consider antecedent precipitation effects from subsequent storm events, since the fire impacts are gradually reduced with subsequent storms.

$$\boldsymbol{RFF = (2 - e^{(A_p/200)})} \quad (3.4.2)$$

for $RFF > 0$

where A_p = Number of Antecedent Effective Precipitation Events

The Reduction Fire Factor is reduced approximately 0.5% following each rainfall event based on *RFF*, Eq. (3.4.2), until around 10 antecedent precipitation events. Therefore, the final Fire Factor is obtained by combining Eqs. (3.4.1) and (3.4.2) as follows:

$$\boldsymbol{F = 6.5 \times (B_p \times B_y^{-0.29} + (1 - B_p) \times (20 - B_y)^{-0.29}) \times (2 - e^{(A_p/200)})} \quad (3.4.3)$$

for $1yr \le B_y \le 10yr$, and $3.0 \le F \le 6.5$

Several trials are tested before arriving at the final fire factor equation. Each trial is adjusted in a manner that minimizes the residuals between the measured values and estimated values. The final Fire Factor equation curves are presented in Fig. 3.1. These curves present a 100%-burn condition with the Reduction Fire Factor.

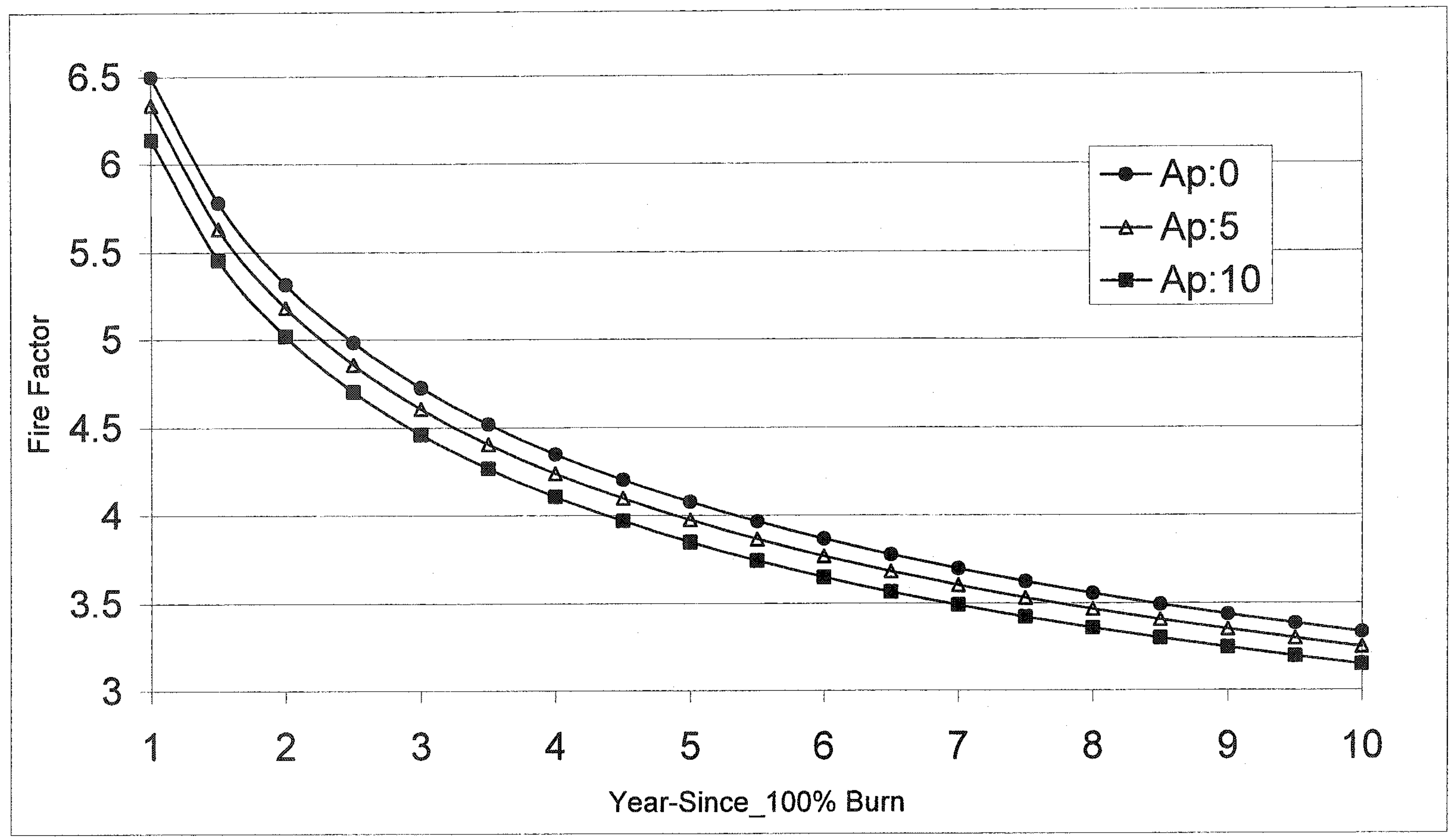

FIG. 3.1 Fire Factor Curves for Number of Antecedent Precipitation Events

CHAPTER 4

4 Development of USC Debris Prediction Model (USCDPM)

In this chapter, the procedures used for the development of the USCDPM will be presented from the data collection to the model development.

Debris cleanout data from 1938 to 1983 are obtained for 80 debris basins from the LACDPW. A multiple regression analysis is first utilized using the data from 1938 to 1983, and an equation based on precipitation, drainage area, relief ratio, and a non-dimensional fire factor is developed. The regression equation is then expanded to include threshold precipitation factors. The USCDPM is developed based on three main physical processes: the critical condition to entrain debris, the required energy to move debris to the concentration point, and the antecedent precipitation events followed by subsequent rainfalls. As a result, the USC Debris Prediction Model (USCDPM), is developed with the new design criteria and analysis of debris structures, incorporating storm events subsequent to wildfires.

4.1 Step 1: Data Collection

Fire history is collected for the San Bernardino and San Gabriel Mountain areas. Debris yield data are collected from debris basins within the study area. Precipitation data are collected from the precipitation gages located in or near the watersheds for all debris basins.

4.2 Step 2: Data Evaluation and Selection

The evaluation and selection of data are time-consuming processes because the field data are not always consistent or complete. At the start of data analysis, all debris basins, having burned upstream watersheds, are selected and rainfall data at several precipitation gages are chosen. The reliable data are selected through data screening for application with the USCDPM. The precipitation data selection is very important in this study because the model is sensitive to the data.

4.3 Step 3: Development of Regression Equation

The relief ratio (S), drainage area (A), maximum 1-hr rainfall intensity (I_m), and fire factor (F) were selected statistically for the multiple linear regression analysis (Amar et al. 1992; Gatwood et al. 2000). In total, 349 debris yield data sets are collected from 80 debris basins to generate the regression equation. The regression equation is statistically depicted as the best fit based on empirical data (1938-1983) as shown in Appendix A:

$$\mathbf{\log D_y = 0.691(\log I_m) + 0.716(\log S) + 0.216(\log A) + 0.129(F)} \qquad (4.3.1)$$

where: D_y = Unit Debris Yield (m^3/km^2)

I_m = Maximum 1-hr Rainfall Intensity, (mm/hr)

S = Relief Ratio (m/km)

A = Drainage Area (hectare (ha))

F = Non-dimensional Fire Factor

The multiple correlation (R) between the dependent variable (D_y) and the four variables in the regression equation is 0.992. The value of R^2 identifying the portion of the variance accounted for by the independent variables is 0.983. This implies that approximately 98% of the variance in D_y is accounted for by I_m, S, A, and F.

4.4 Step 4: Development of Watershed Correlation Factor (*C*)

The watershed correlation factor (C) of each debris basin is developed by a single regression analysis to generate additional correlation between the measured debris yield and the estimated debris yield.

$$D_y^M = C \times D_y^E \tag{4.4.1}$$

where: C = Watershed Correlation Factor

D_y^M = Measured Debris Yield

D_y^E = Estimated Debris Yield by Eq. (4.3.1)

The watershed correlation factor is intended to increase the accuracy of the USCDPM by providing the specific correlation for each debris basin. If enough data are provided, a reliable watershed correlation factor can be determined through regression analysis. The watershed correlation factors used in this case study are presented in Table 4.1.

TABLE 4.1 Watershed Correlation Factors (C) for Watersheds Studied

DEBRIS BASIN	NUMBER OF RECORDS	WATERSHED CORRELATION FACTOR	DEBRIS BASIN	NUMBER OF RECORDS	WATERSHED CORRELATION FACTOR
Lannan	4	0.937	Carriage House	2	1.079
Kinneloa East	1	1.000*	Auburn	11	0.987
Kinneloa West	9	1.007	Fairoaks	4	1.157
Rubio	6	0.991	West Ravine	5	1.092
Bailey	12	0.961	Big Briar	2	0.972
Sunnyside	1	1.000*	Hay	8	0.991

*- 1 is assumed as a correlation factor until more events became available.

4.5 Step 5: USC Debris Prediction Model (USCDPM)

4.5.1 Core Principle of USCDPM

The USCDPM takes into account several hydrologic characteristics and processes: rainfall intensity, rainfall duration, total rainfall amount, watershed area, relief ratio, and burn effect. In general, the USCDPM allows the user to determine the debris yield that is based on the total rainfall amount, maximum 1-hr rainfall intensity, threshold maximum 1-hr rainfall intensity (TMRI), total minimum rainfall amount (TMRA), relief ratio (S), drainage area (A), antecedent precipitation events, and fire condition.

It should be noted that the basic model of USCDPM does not consider the spatial variation of effective rainfall within the watershed. Thus, the basic model of USCDPM is applicable primarily for small watersheds. The accuracy will be decreased for large watersheds. Therefore, a debris routing process is introduced in chapter 7 to predict the temporal and spatial variations of a debris flow as it moves through a channel reach for large watershed analysis.

4.5.2 Threshold Maximum 1-hr Rainfall Intensity (TMRI)

The TMRI is related to the critical condition for entrainment of sediment. When the hydrodynamic force acting on a particle of sediment has reached a critical or threshold condition, sediment particles are entrained into the flows as shown in Fig. 4.1. Not all of the rainfall events can generate debris yields because some minimum energy is needed to entrain sediment particles. Therefore, rainfall events are screened to select the effective rainfall that can exceed the critical value to entrain sediment particles. Eventually the critical maximum 1-hr rainfall intensity for entrainment of sediment is determined as the TMRI (I_c) for each watershed by case studies, which defined the critical condition used in USCDPM. Eq. (4.5.1) is developed to screen the maximum 1-hr rainfall intensity for the effective rainfall intensity that is greater than the TMRI.

$$\frac{1}{2}\left(1+\frac{|I_m - I_c|}{(I_m - I_c)}\right) \tag{4.5.1}$$

where, $I_m \neq I_c$

I_m = Maximum 1-hr Rainfall Intensity, (mm/hr)

I_c = Threshold Maximum 1-hr Rainfall Intensity (TMRI), (mm/hr)

It is noted that Eq. (4.5.1) equals one if $I_m > I_c$, and equals zero when $I_m < I_c$.

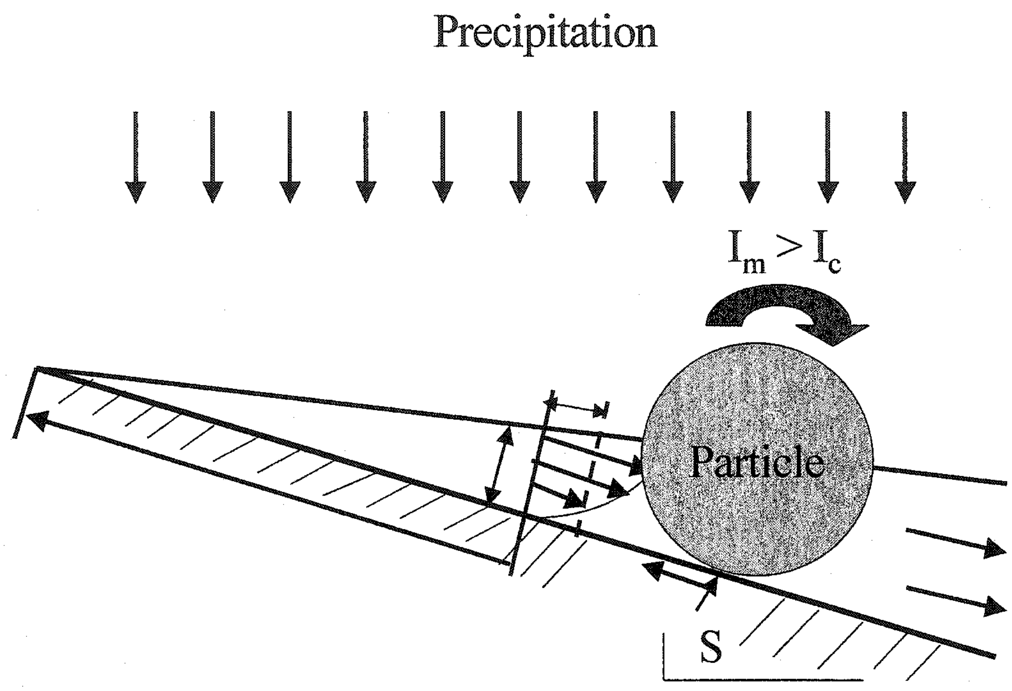

FIG. 4.1 Threshold Condition for Entrainment of Sediment

4.5.3 Total Minimum Rainfall Amount (TMRA)

The TMRA is related to the transport capacity to move the sediment to the concentration point. Not all rainfall events can generate debris yields because once sediment has become entrained; a certain amount of additional energy is needed to move the sediment particles to the concentration point as shown in Fig. 4.2. Therefore rainfall events are screened again to select the effective rainfall events that can provide the required energy. The critical total rainfall amount is determined as TMRA (P_c) for each debris basin by case studies. The total rainfall amount (P) is compared with the TMRA (P_c) to provide another trigger for the debris generation.

Eq. (4.5.2) is developed to screen the total rainfall amount as the effective total rainfall that is greater than the TMRA.

$$\frac{1}{2}\left(1+\frac{|P-P_c|}{(P-P_c)}\right) \tag{4.5.2}$$

where, $P \neq P_c$

P = Total Rainfall Amount, (mm)

P_c = Total Minimum Rainfall Amount (TMRA), (mm)

It is seen that Eq. (4.5.2) equals one if $P > P_c$ and equals zero if $P < P_c$.

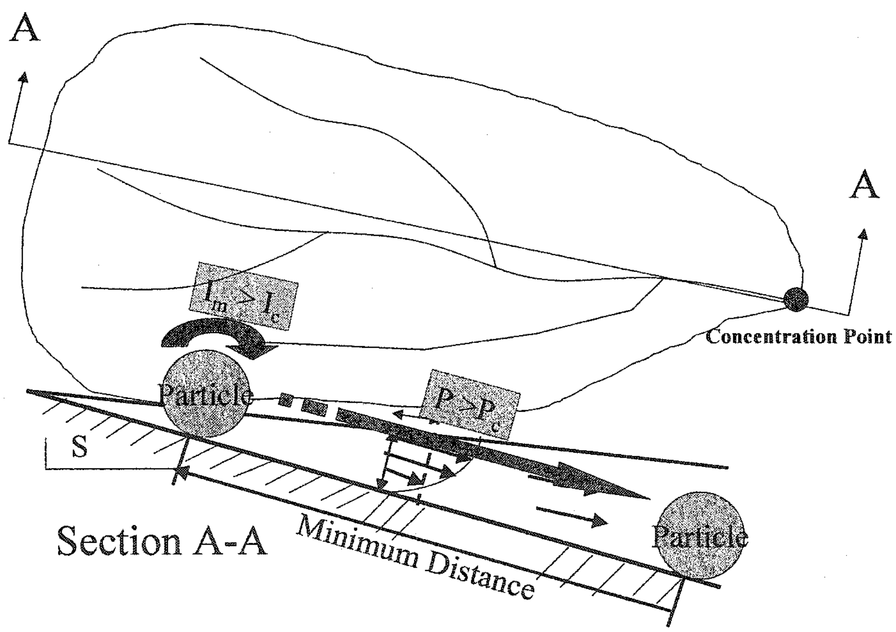

FIG. 4.2 Travel Capacity to Move Debris at Concentration Point

4.5.4 Antecedent Precipitation

The antecedent precipitation effect is related to the reduction fire factor according to subsequent storm events since rainfall effects are gradually reduced by the reduction fire factor according to subsequent rainfall events. The antecedent precipitation is considered as the Reduction Fire Factor (RFF) described in section 3.4.

4.5.5 Formula of USCDPM

Finally, Eq. (4.5.3) is developed based upon the hydrologic processes described above as the USCDPM:

$$\sum_{i=1}^{N}(D_y)_i = 2.5\times10^{-3}C\sum_{i=1}^{N}\left(1+\frac{|(I_m)_i-I_c|}{((I_m)_i-I_c)}\right)\left(1+\frac{|(P)_i-P_c|}{((P)_i-P_c)}\right)(I_m)_i^{0.691}S^{0.716}A^{1.216}e^{0.297F} \quad (4.5.3)$$

where $P \neq P_c$ and $I_m \neq I_c$

N = No. of Effective Rainfall Events

D_y= Debris Yield, (m^3)

C = Watershed Correlation Factor

I_m = Maximum 1-hr Rainfall Intensity per Event, (mm/hr)

I_c = Threshold Maximum 1-hr Rainfall Intensity (TMRI), (mm/hr)

P = Total Rainfall Amount per Event, (mm)

P_c = Total Minimum Rainfall Amount (TMRA), (mm)

S = Relief Ratio, (m/km)

$$= \frac{h_2 - h_1}{L}$$

h_2 = Highest Point in the watershed, (m)

h_1 = Lowest Point in the watershed, (m)

L = Maximum stream length, (km), as measured along the longest stream

A = Size of Drainage Area, (ha)

F = Fire Factor (dimensionless) depicted in Fig. 3.1 and as shown in Eq. (3.4.3)

CHAPTER 5

5 Calibration of USCDPM by Case Studies

In this chapter, USCDPM calibrated by field data for 1984 to 2000 will be shown. The Threshold Maximum 1-hr Rainfall Intensity (TMRI, I_c) and Total Minimum Rainfall Amount (TMRA, P_c) of each debris basin are determined via the model calibration based on the debris yield data generated by three fire events that occurred from 1984 to 2000.

5.1 Santa Anita II Fire

The Santa Anita II Fire (Fig. 5.1) of December 27-31, 1999 burned 299 ha (566 acres) about the 80 percent of watershed. The Lannan Debris Basin, which captures debris from the burned portion of watershed, is chosen due to its data availability and quality for the present study. Table 5.1 indicates the burn conditions and watershed characteristics of the Lannan watershed.

TABLE 5.1 Characteristics of Watershed burned by Santa Anita II Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Lannan	63.9	80	405	0.937

5.1.1 Precipitation Data

The precipitation data are collected from four precipitation gages (Sierra Madre, Santa Fe Dam, Santa Anita Dam (Gage No. 63C), and Henniger Flats (Gage No. 253C)) located in the vicinity of the Santa Anita II Fire area. Three raingage stations, (Sierra Madre station, Santa Fe Dam station, and Santa Anita Dam) are automatic raingages and one raingage station (Henniger) is a standard raingage station. The Santa Anita Dam precipitation gage is finally selected for the data analysis among the four precipitation gages because its data are more reliable for the analysis of Lannan Debris Basin.

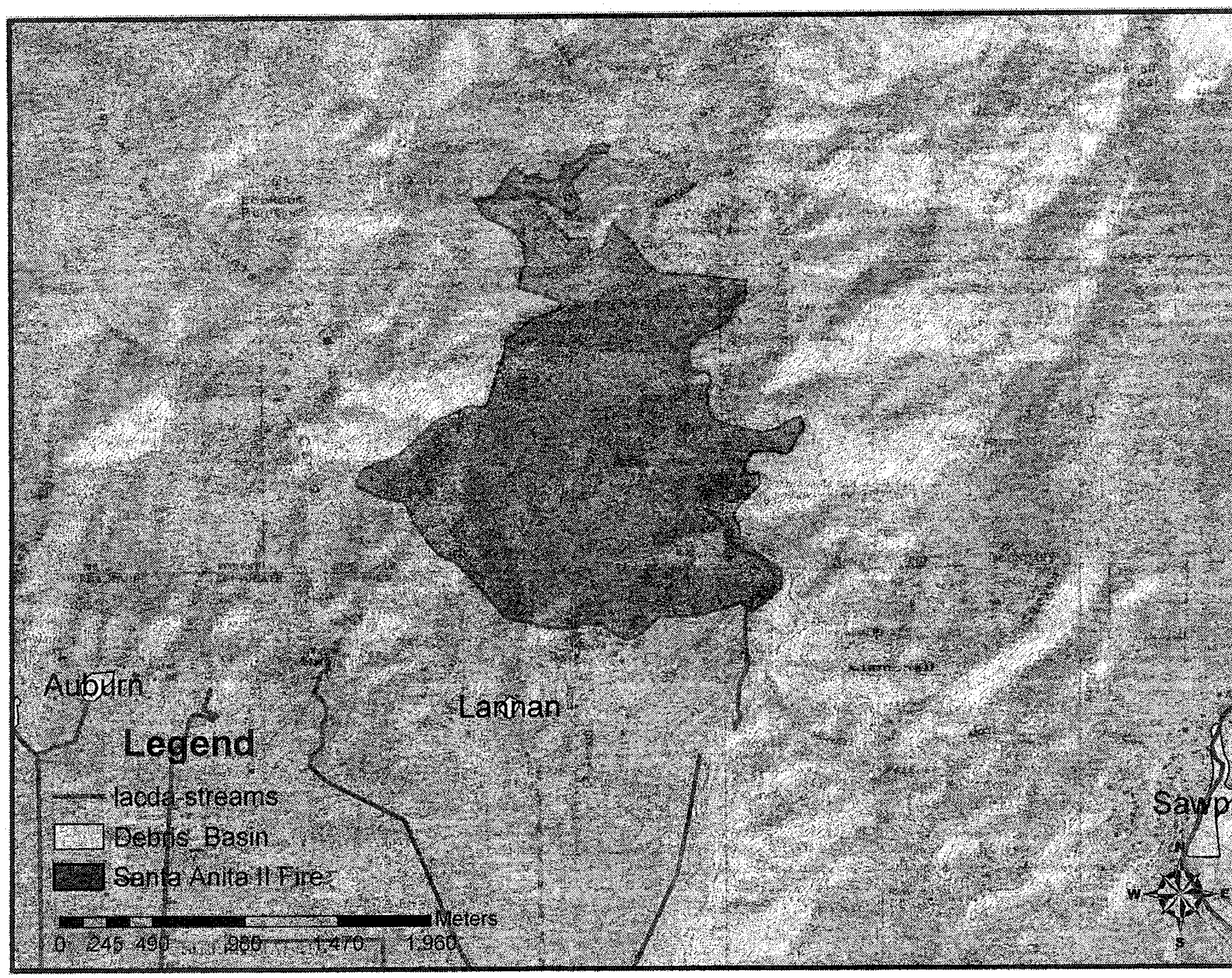

FIG. 5.1 Fire Map of Santa Anita II Fire

5.1.2 Lannan Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Lannan Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season following the Santa Anita II Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Lannan Debris Basin to be used for the future debris prediction. For this case, the two sequent debris basin maintenance data sets are used to analyze the data. For the first case, the measured debris yield is 13,577m^3 between April 1999 and March 2, 2000, while the estimated debris yield by the USCDPM is 13,492 m^3. The difference of the two values is –85 m^3. For the second case, the measured debris yield is 5,047 m^3 between March 3, 2000 and April 24, 2000, while the estimated debris yield by the USCDPM is 5,645 m^3. The difference of the two values is 598 m^3. Finally, 5.817 mm/hr and 17.755 mm are selected for the TMRI and TMRA, respectively, for the Lannan Debris Basin. The summary of the analysis is indicated in Table 5.2.

TABLE 5.2 Summary of Analysis for Lannan Debris Basin

Event	TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
1	5.817	17.755	13,577	13,492	-85	-0.6
2	5.817	17.755	5,047	5,645	598	11.9

The precipitation data are obtained from the Santa Anita Dam Raingage Station (Station 63). The more detailed procedures of calculation are delineated in Tables 5.3 and 5.4, and Fig. 5.2.

TABLE 5.3 Calculation Sheet for Lannan Debris Basin Case I

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
12/31/1999	0	0	4.064	6.096	5.8166	17.7546	0.8	1		
1/2/2000	0	0	0.762	0.762	5.8166	17.7546	0.8	1		
1/19/2000	0	0	1.016	1.016	5.8166	17.7546	0.8	1		
1/25/2000	0	0	4.064	25.146	5.8166	17.7546	0.8	1		
1/31/2000	0	0	2.032	9.906	5.8166	17.7546	0.8	1		
2/10/2000	2,093	2,093	6.096	27.94	5.8166	17.7546	0.8	1	0	5.75
2/12/2000	2,746	4,839	9.144	27.178	5.8166	17.7546	0.8	1	1	5.72
2/14/2000	0	4,839	2.032	12.954	5.8166	17.7546	0.8	1		
2/16/2000	2,455	7,294	7.874	34.036	5.8166	17.7546	0.8	1	2	5.70
2/20/2000	2,434	9,728	7.874	48.006	5.8166	17.7546	0.8	1	3	5.67
2/21/2000	3,764	13,492	14.986	35.052	5.8166	17.7546	0.8	1	4	5.64
Total	13,492 m^3									

TABLE 5.4 Calculation Sheet for Lannan Debris Basin Case II

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
3/3/2000	0	0	2.794	6.858	5.8166	17.7546	0.8	1		
3/4/2000	0	0	2.032	3.048	5.8166	17.7546	0.8	1		
3/5/2000	1,946	1,946	5.842	42.164	5.8166	17.7546	0.8	1	5	5.61
3/8/2000	0	1,946	3.048	17.018	5.8166	17.7546	0.8	1		
4/17/2000	3,699	5,645	14.986	54.102	5.8166	17.7546	0.8	1	6	5.58
4/18/2000	0	5,645	4.064	14.986	5.8166	17.7546	0.8	1		
4/23/2000	0	5,645	3.048	3.048	5.8166	17.7546	0.8	1		
Total	5,645 m^3									

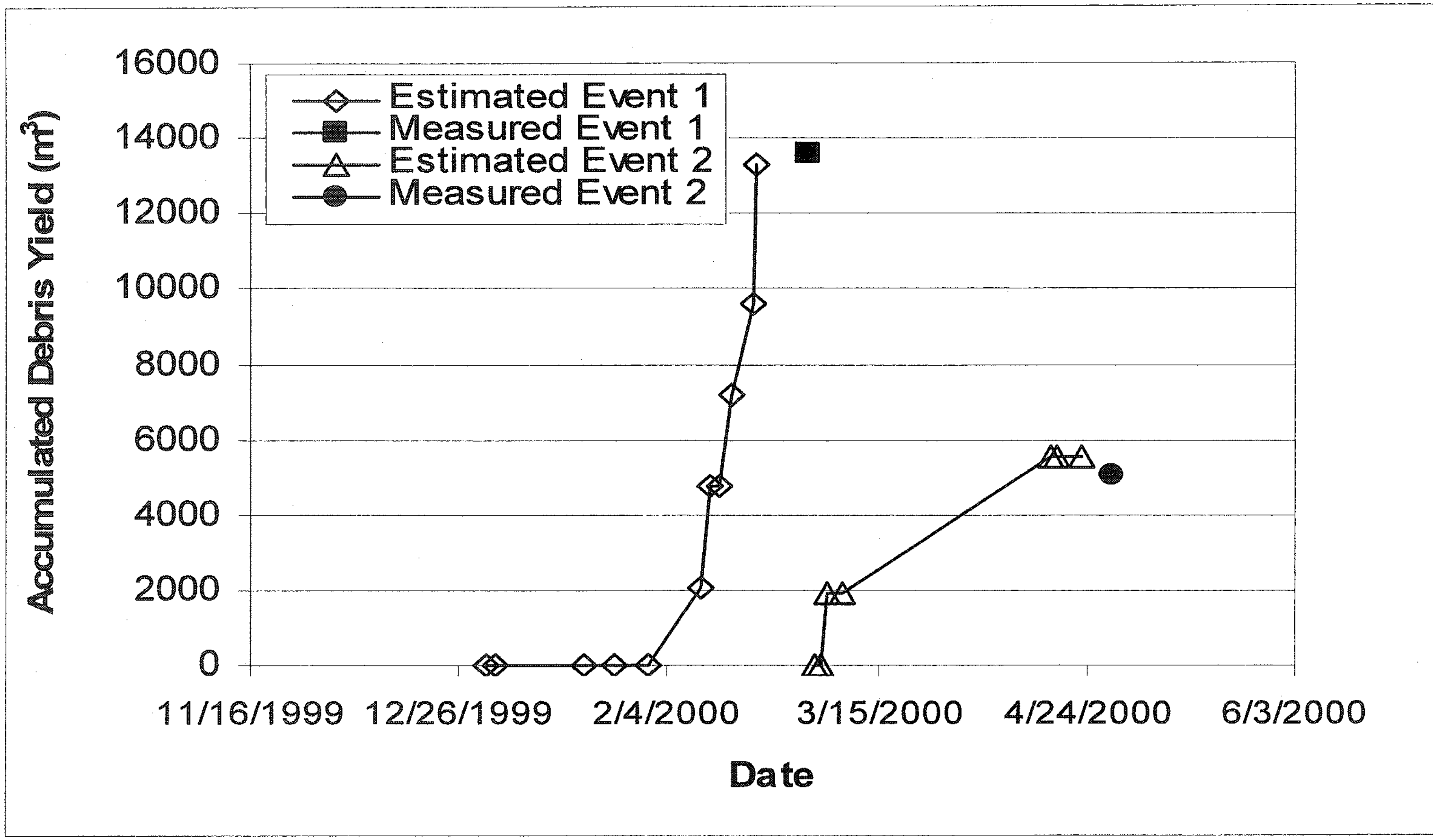

FIG. 5.2 Comparison with Estimated D_y and Measured D_y for Lannan Debris Basin (DB)

5.2 Kinneloa Fire

On October 27, 1993, the Kinneloa Fire (Fig. 5.3) in Altadena caused a huge amount of damage to the surrounding area and destroyed 121 homes in the foothills of the San Gabriel Mountains. Watersheds of thirteen debris basins were burned ranging from 20% to 100%. However, data from nine debris basins are collected due to data availability and quality. Table 5.5 indicates the burn conditions and watershed characteristics of nine watersheds.

TABLE 5.5 Characteristics of Watersheds burned by Kinneloa Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Kinneloa East	51.8	100	444.033	1.000*
Kinneloa West	52.2	100	475.838	1.007
Rubio	329.0	92	280.060	0.991
Bailey	153.8	95	337.072	0.961
Sunnyside	135.2	100	475.802	1.000*
Carriage House	7.7	90	433.993	1.079
Auburn	41.3	78	521.712	0.987
Fair Oaks	54.7	41	60.013	1.157
West Ravine	63.9	69	286.761	1.092

*- 1 is assumed as a coefficient because available record is just 1.

5.2.1 Precipitation Data

The precipitation data are obtained from four precipitation gages located in the vicinity of the Kinneloa fire area. The Sierra Madre gage is finally chosen for the data analysis among the other four precipitation gages because its data appear to be the most consistent for the nine debris basins burned by the Kinneloa fire.

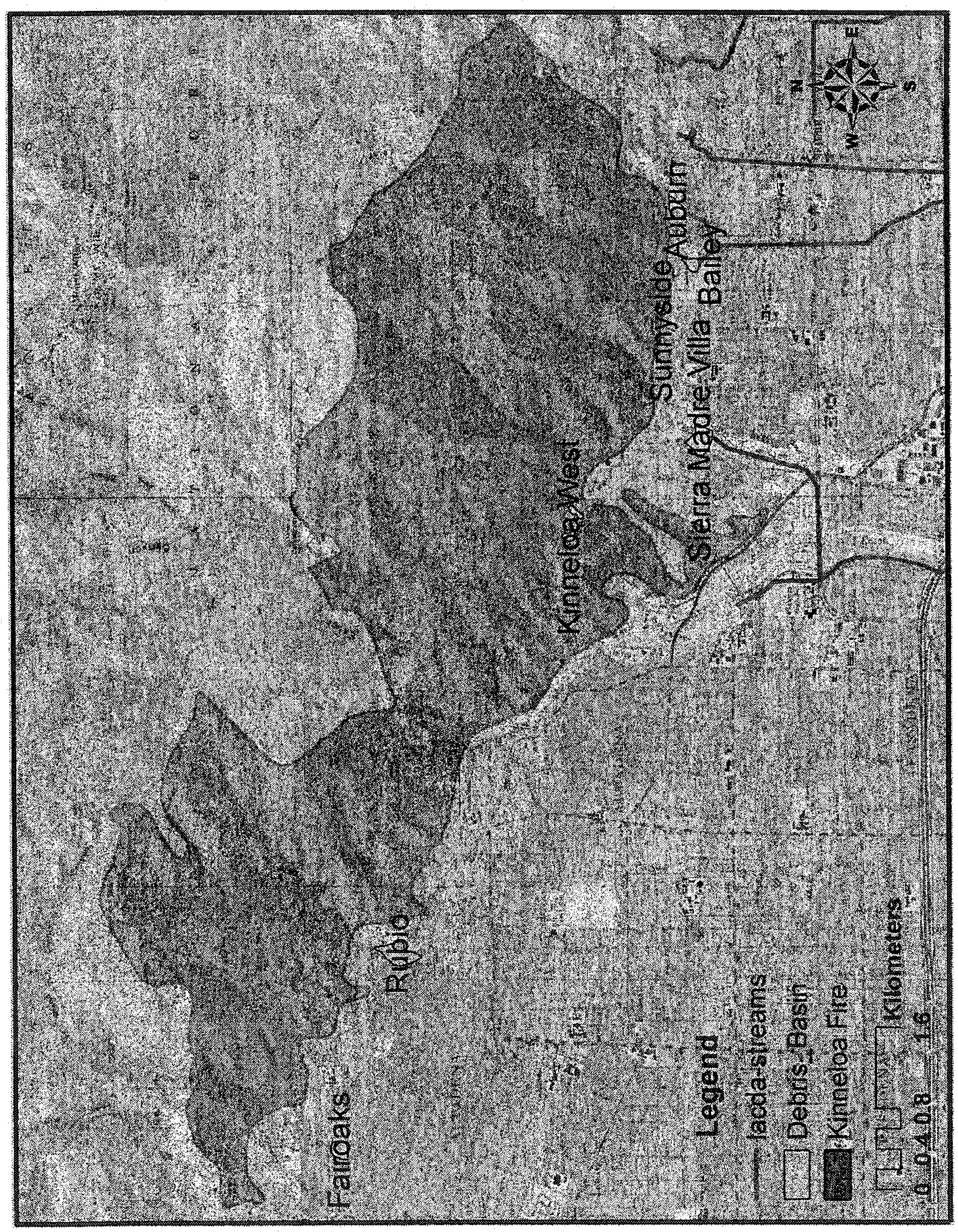

FIG. 5.3 Fire Map of Kinneloa Fire

5.2.2 Kinneloa East Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Kinneloa East Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 100% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Kinneloa East Debris Basin to be used for the future debris prediction. The measured debris yield is 23,627 m^3 between September 16, 1993 and June 8, 1994, while the estimated debris yield by the USCDPM is 24,651 m^3. The difference of the two values is 1,024 m^3. Finally, 5.817 mm/hr and 18.771 mm are selected for the TMRI and TMRA, respectively, for the Kinneloa East Debris Basin. The summary of the analysis is indicated in Table 5.6.

TABLE 5.6 Summary of Analysis for Kinneloa East Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
5.817	18.771	23,627	24,651	1,024	4.3

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.7 and Fig. 5.4.

TABLE 5.7 Calculation Sheet for Kinneloa East Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
6/5/1993	1,749	1,749	18.288	38.608	5.8166	18.7706	0	1	0	3.00
10/11/1993	0	1,749	1.016	2.54	5.8166	18.7706	1	1		
11/11/1993	0	1,749	5.08	10.922	5.8166	18.7706	1	1		
11/29/1993	0	1,749	10.414	16.256	5.8166	18.7706	1	1		
12/11/1993	3,206	4,955	9.906	18.796	5.8166	18.7706	1	1	1	6.47
12/14/1993	0	4,955	12.192	18.542	5.8166	18.7706	1	1		
12/17/1993	0	4,955	0.762	0.762	5.8166	18.7706	1	1		
1/24/1994	0	4,955	14.224	17.272	5.8166	18.7706	1	1		
1/25/1994	0	4,955	3.048	5.334	5.8166	18.7706	1	1		
2/4/1994	0	4,955	5.08	22.86	5.8166	18.7706	1	1		
2/6/1994	0	4,955	0.762	0.762	5.8166	18.7706	1	1		
2/7/1994	2,270	7,225	6.096	20.574	5.8166	18.7706	1	1	2	6.43
2/8/1994	0	7,225	10.16	13.462	5.8166	18.7706	1	1		
2/17/1994	0	7,225	8.128	18.034	5.8166	18.7706	1	1		
2/20/1994	3,418	10,643	11.176	32.004	5.8166	18.7706	1	1	3	6.40
3/6/1994	0	10,643	2.032	6.604	5.8166	18.7706	1	1		
3/7/1994	0	10,643	1.016	2.794	5.8166	18.7706	1	1		
3/11/1994	0	10,643	0.254	0.254	5.8166	18.7706	1	1		
3/19/1994	2,476	13,119	7.112	30.988	5.8166	18.7706	1	1	4	6.37
3/24/1994	3,137	16,256	10.16	35.306	5.8166	18.7706	1	1	5	6.34
4/9/1994	0	16,256	2.032	2.794	5.8166	18.7706	1	1		
4/25/1994	0	16,256	3.302	6.35	5.8166	18.7706	1	1		
4/26/1994	4,707	20,964	18.542	22.86	5.8166	18.7706	1	1	6	6.30
4/27/1994	3,687	24,651	13.208	23.114	5.8166	18.7706	1	1	7	6.27
4/28/1994	0	24,651	0.508	0.762	5.8166	18.7706	1	1		
5/6/1994	0	24,651	6.604	13.462	5.8166	18.7706	1	1		
5/7/1994	0	24,651	0.254	0.254	5.8166	18.7706	1	1		
5/8/1994	0	24,651	1.016	1.524	5.8166	18.7706	1	1		
5/17/1994	0	24,651	11.176	13.462	5.8166	18.7706	1	1		
5/25/1994	0	24,651	1.016	4.572	5.8166	18.7706	1	1		
Total	24,651 m^3									

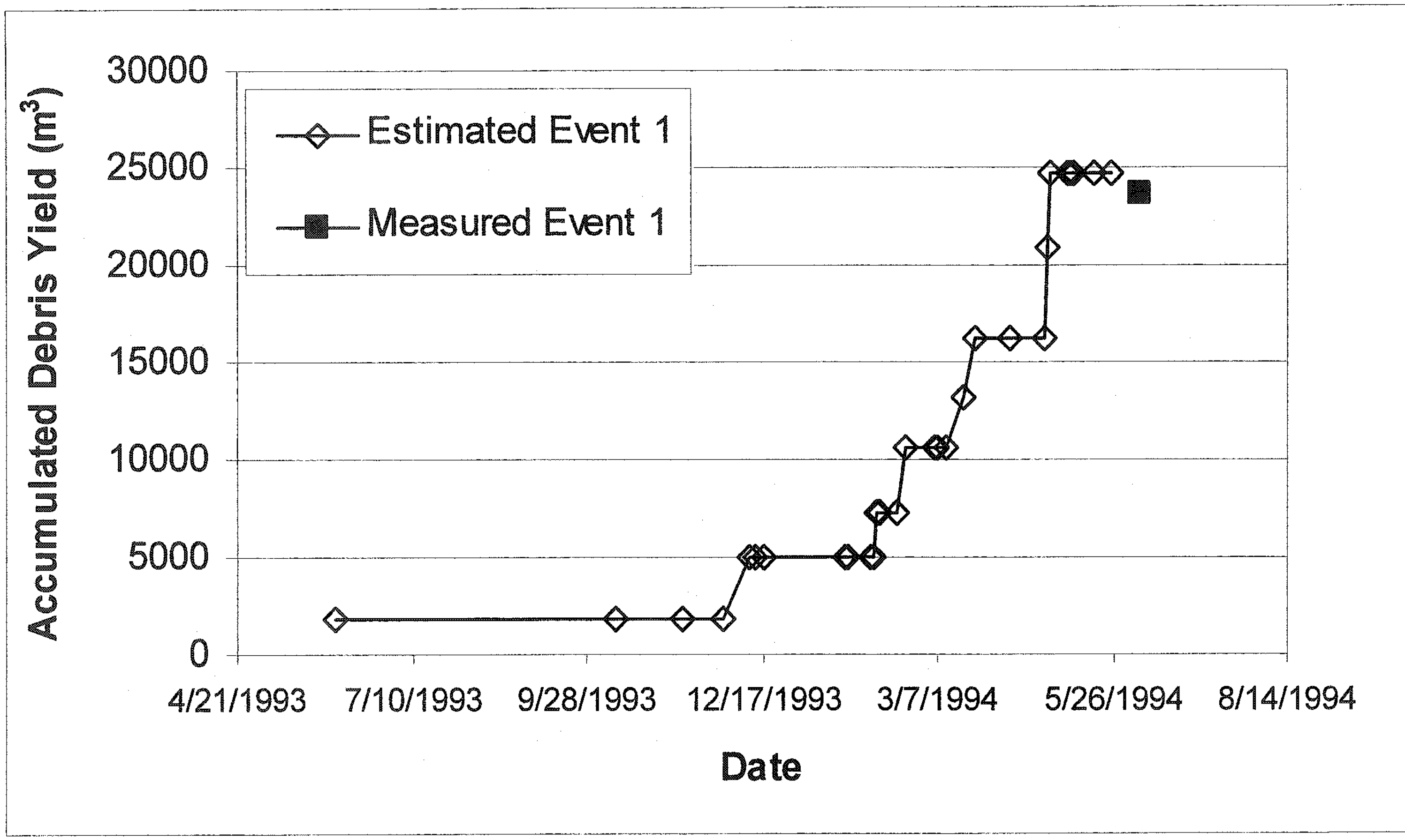

FIG. 5.4 Comparison with Estimated D_y and Measured D_y for Kinneloa East DB

5.2.3 Kinneloa West Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Kinneloa West Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 100% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Kinneloa West Debris Basin to be used for the future debris prediction The measured debris yield is 33,261 m^3 between April 14, 1993 and May 16, 1994, while the estimated debris yield by the USCDPM is 34,725 m^3. The difference of the two values is 1,464 m^3. Finally, 5.309 mm/hr and 17.247 mm are selected for the TMRI and TMRA, respectively, for the Kinneloa West Debris Basin. The summary of the analysis is indicated in Table 5.8.

TABLE 5.8 Summary of Analysis for Kinneloa West Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
5.309	17.247	33,261	34,725	1,464	4.4

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.9 and Fig. 5.5.

TABLE 5.9 Calculation Sheet for Kinneloa West Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
6/5/1993	1,761	1,761	18.288	38.608	5.3086	17.2466	1	1	0	3.00
10/11/1993	0	1,761	1.016	2.54	5.3086	17.2466	1	1		
11/11/1993	0	1,761	5.08	10.922	5.3086	17.2466	1	1		
11/29/1993	0	1,761	10.414	16.256	5.3086	17.2466	1	1		
12/11/1993	3,229	4,990	9.906	18.796	5.3086	17.2466	1	1	1	6.47
12/14/1993	3,691	8,680	12.192	18.542	5.3086	17.2466	1	1	2	6.43
12/17/1993	0	8,680	0.762	0.762	5.3086	17.2466	1	1		
1/24/1994	4,066	12,746	14.224	17.272	5.3086	17.2466	1	1	3	6.40
1/25/1994	0	12,746	3.048	5.334	5.3086	17.2466	1	1		
2/4/1994	0	12,746	5.08	22.86	5.3086	17.2466	1	1		
2/6/1994	0	12,746	0.762	0.762	5.3086	17.2466	1	1		
2/7/1994	2,242	14,987	6.096	20.574	5.3086	17.2466	1	1	4	6.37
2/8/1994	0	14,987	10.16	13.462	5.3086	17.2466	1	1		
2/17/1994	2,708	17,695	8.128	18.034	5.3086	17.2466	1	1	5	6.34
2/20/1994	3,341	21,036	11.176	32.004	5.3086	17.2466	1	1	6	6.30
3/6/1994	0	21,036	2.032	6.604	5.3086	17.2466	1	1		
3/7/1994	0	21,036	1.016	2.794	5.3086	17.2466	1	1		
3/11/1994	0	21,036	0.254	0.254	5.3086	17.2466	1	1		
3/19/1994	2,421	23,457	7.112	30.988	5.3086	17.2466	1	1	7	6.27
3/24/1994	3,066	26,523	10.16	35.306	5.3086	17.2466	1	1	8	6.23
4/9/1994	0	26,523	2.032	2.794	5.3086	17.2466	1	1		
4/25/1994	0	26,523	3.302	6.35	5.3086	17.2466	1	1		
4/26/1994	4,600	31,123	18.542	22.86	5.3086	17.2466	1	1	9	6.20
4/27/1994	3,602	34,725	13.208	23.114	5.3086	17.2466	1	1	10	6.17
4/28/1994	0	34,725	0.508	0.762	5.3086	17.2466	1	1		
5/6/1994	0	34,725	6.604	13.462	5.3086	17.2466	1	1		
5/7/1994	0	34,725	0.254	0.254	5.3086	17.2466	1	1		
5/8/1994	0	34,725	1.016	1.524	5.3086	17.2466	1	1		
5/17/1994	0	34,725	11.176	13.462	5.3086	17.2466	1	1		
5/25/1994	0	34,725	1.016	4.572	5.3086	17.2466	1	1		
Total	34,725 m^3									

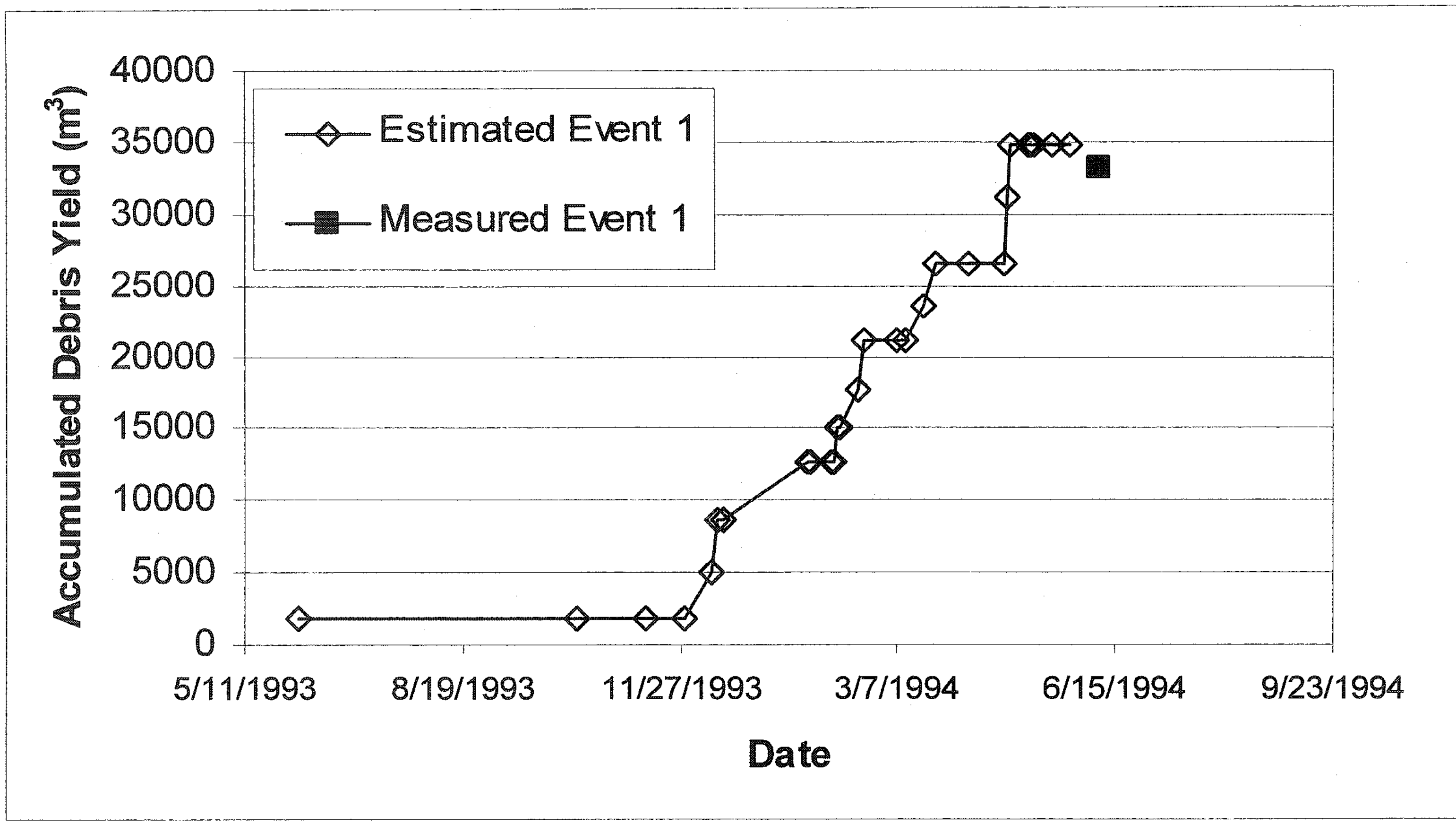

FIG. 5.5 Comparison with Estimated D_y and Measured D_y for Kinneloa West DB

5.2.4 Rubio Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Rubio Debris Basin are determined through the trial and error method by minimizing difference between the measured debris yield caused by the first storm season after 92% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Rubio Debris Basin to be used for the future debris prediction. The measured debris yield is 17,001 m^3 between December 11, 1993 and March 18, 1994, while the estimated debris yield by the USCDPM is 21,555 m^3. The difference of the two values is 4,554 m^3. Finally, 7.849 mm/hr and 22.835 mm are selected for the TMRI and TMRA, respectively, for the Rubio Debris Basin. The summary of the analysis is indicated in Table 5.10.

TABLE 5.10 Summary of Analysis for Rubio Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
7.849	22.835	17,001	21,555	4,554	26.8

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.11 and Fig. 5.6.

TABLE 5.11 Calculation Sheet for Rubio Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
12/11/1993	0	0	9.906	18.796	7.8486	22.8346	0.92	1		
12/14/1993	0	0	12.192	18.542	7.8486	22.8346	0.92	1		
12/17/1993	0	0	0.762	0.762	7.8486	22.8346	0.92	1		
1/24/1994	0	0	14.224	17.272	7.8486	22.8346	0.92	1		
1/25/1994	0	0	3.048	5.334	7.8486	22.8346	0.92	1		
2/4/1994	0	0	5.08	22.86	7.8486	22.8346	0.92	1		
2/6/1994	0	0	0.762	0.762	7.8486	22.8346	0.92	1		
2/7/1994	0	0	6.096	20.574	7.8486	22.8346	0.92	1		
2/8/1994	0	0	10.16	13.462	7.8486	22.8346	0.92	1		
2/17/1994	0	0	8.128	18.034	7.8486	22.8346	0.92	1		
2/20/1994	21,555	21,555	11.176	32.004	7.8486	22.8346	0.92	1	0	6.20
3/6/1994	0	21,555	2.032	6.604	7.8486	22.8346	0.92	1		
3/7/1994	0	21,555	1.016	2.794	7.8486	22.8346	0.92	1		
3/11/1994	0	21,555	0.254	0.254	7.8486	22.8346	0.92	1		
Total	21,555 m^3									

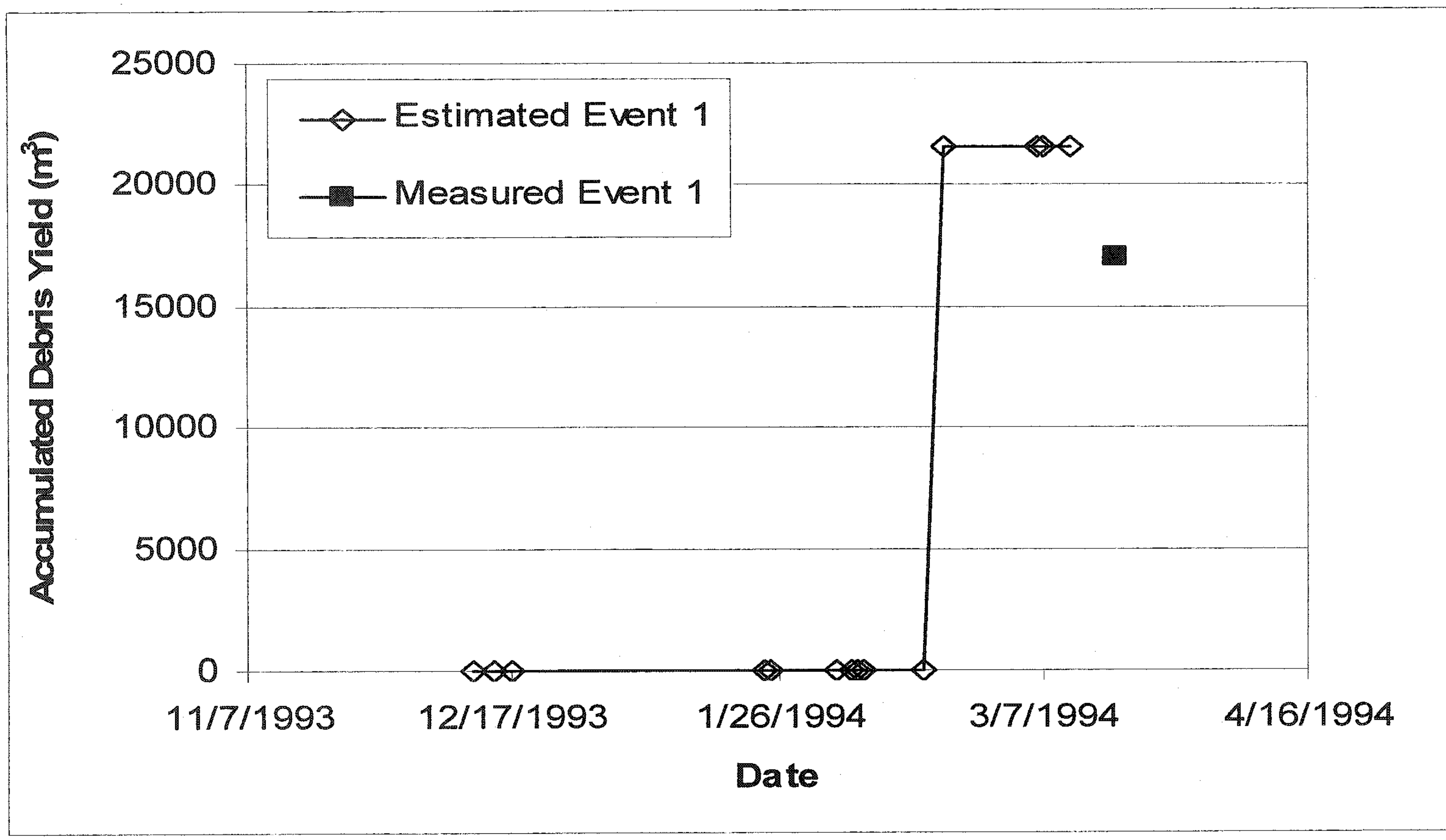

FIG. 5.6 Comparison with Estimated D_y and Measured D_y for Rubio DB

5.2.5 Bailey Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Bailey Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 95% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Bailey Debris Basin to be used for the future debris prediction. The measured debris yield is 22,948 m^3 between November 15, 1993 and March 23, 1994, while the estimated debris yield by the USCDPM is 25,873 m^3. The difference of the two values is 2,925 m^3. Finally, 7.087 mm/hr and 21.565 mm are selected for the TMRI and TMRA, respectively, for the Bailey Debris Basin. The summary of the analysis is indicated in Table 5.12.

TABLE 5.12 Summary of Analysis for Bailey Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
7.087	21.565	22,948	25,873	2,925	12.7

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.13 and Fig. 5.7.

TABLE 5.13 Calculation Sheet for Bailey Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
11/29/1993	0	0	10.414	16.256	7.0866	21.5646	1	1		
12/11/1993	0	0	9.906	18.796	7.0866	21.5646	0.95	1		
12/14/1993	0	0	12.192	18.542	7.0866	21.5646	0.95	1		
12/17/1993	0	0	0.762	0.762	7.0866	21.5646	0.95	1		
1/24/1994	0	0	14.224	17.272	7.0866	21.5646	0.95	1		
1/25/1994	0	0	3.048	5.334	7.0866	21.5646	0.95	1		
2/4/1994	0	0	5.08	22.86	7.0866	21.5646	0.95	1		
2/6/1994	0	0	0.762	0.762	7.0866	21.5646	0.95	1		
2/7/1994	0	0	6.096	20.574	7.0866	21.5646	0.95	1		
2/8/1994	0	0	10.16	13.462	7.0866	21.5646	0.95	1		
2/17/1994	0	0	8.128	18.034	7.0866	21.5646	0.95	1		
2/20/1994	9,787	9,787	11.176	32.004	7.0866	21.5646	0.95	1	0	6.31
3/6/1994	0	9,787	2.032	6.604	7.0866	21.5646	0.95	1		
3/7/1994	0	9,787	1.016	2.794	7.0866	21.5646	0.95	1		
3/11/1994	0	9,787	0.254	0.254	7.0866	21.5646	0.95	1		
3/19/1994	7,094	16,881	7.112	30.988	7.0866	21.5646	0.95	1	1	6.28
3/24/1994	8,992	25,873	10.16	35.306	7.0866	21.5646	0.95	1	2	6.25
Total	25,873 m^3									

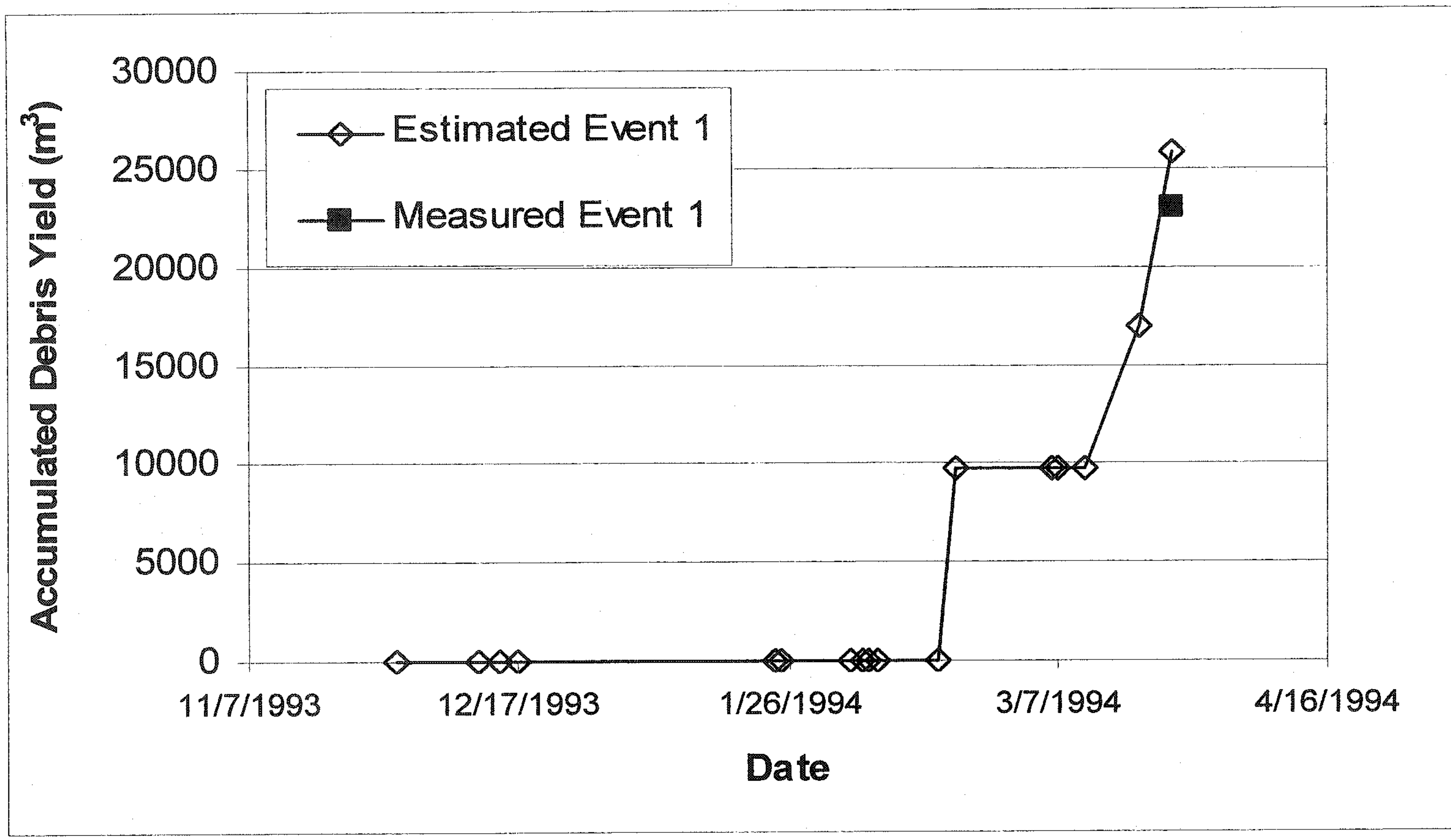

FIG. 5.7 Comparison with Estimated D_y and Measured D_y for Bailey DB

5.2.6 Sunnyside Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Sunnyside Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 100% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Sunnyside Debris Basin to be used for the future debris prediction. The measured debris yield is 1,239 m^3 during the storm season between 1993 and 1994, while the estimated debris yield by the USCDPM is 1,259 m^3. The difference of the two values is 19 m^3. Finally, 6.325 mm/hr and 20.295 mm are selected for the TMRI and TMRA, respectively, for the Sunnyside Debris Basin. The summary of the analysis is indicated in Table 5.14.

TABLE 5.14 Summary of Analysis for Sunnyside Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
6.325	20.295	1,239	1,259	19	1.5

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.15 and Fig. 5.8.

TABLE 5.15 Calculation Sheet for Sunnyside Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
6/5/1993	112	112	18.288	38.608	6.3246	20.2946	0	0	0	3.00
10/11/1993	0	112	1.016	2.54	6.3246	20.2946	1	1		
11/11/1993	0	112	5.08	10.922	6.3246	20.2946	1	1		
11/29/1993	0	112	10.414	16.256	6.3246	20.2946	1	1		
12/11/1993	0	112	9.906	18.796	6.3246	20.2946	1	1		
12/14/1993	0	112	12.192	18.542	6.3246	20.2946	1	1		
12/17/1993	0	112	0.762	0.762	6.3246	20.2946	1	1		
1/24/1994	0	112	14.224	17.272	6.3246	20.2946	1	1		
1/25/1994	0	112	3.048	5.334	6.3246	20.2946	1	1		
2/4/1994	0	112	5.08	22.86	6.3246	20.2946	1	1		
2/6/1994	0	112	0.762	0.762	6.3246	20.2946	1	1		
2/7/1994	0	112	6.096	20.574	6.3246	20.2946	1	1		
2/8/1994	0	112	10.16	13.462	6.3246	20.2946	1	1		
2/17/1994	0	112	8.128	18.034	6.3246	20.2946	1	1		
2/20/1994	225	337	11.176	32.004	6.3246	20.2946	1	1	0	6.50
3/6/1994	0	337	2.032	6.604	6.3246	20.2946	1	1		
3/7/1994	0	337	1.016	2.794	6.3246	20.2946	1	1		
3/11/1994	0	337	0.254	0.254	6.3246	20.2946	1	1		
3/19/1994	163	500	7.112	30.988	6.3246	20.2946	1	1	1	6.47
3/24/1994	206	706	10.16	35.306	6.3246	20.2946	1	1	2	6.43
4/9/1994	0	706	2.032	2.794	6.3246	20.2946	1	1		
4/25/1994	0	706	3.302	6.35	6.3246	20.2946	1	1		
4/26/1994	310	1,016	18.542	22.86	6.3246	20.2946	1	1	3	6.40
4/27/1994	243	1,259	13.208	23.114	6.3246	20.2946	1	1	4	6.37
4/28/1994	0	1,259	0.508	0.762	6.3246	20.2946	1	1		
5/6/1994	0	1,259	6.604	13.462	6.3246	20.2946	1	1		
5/7/1994	0	1,259	0.254	0.254	6.3246	20.2946	1	1		
5/8/1994	0	1,259	1.016	1.524	6.3246	20.2946	1	1		
5/17/1994	0	1,259	11.176	13.462	6.3246	20.2946	1	1		
5/25/1994	0	1,259	1.016	4.572	6.3246	20.2946	1	1		
10/4/1994	0	1,259	1.27	4.826	6.3246	20.2946	1	1		
10/5/1994	0	1,259	5.842	10.668	6.3246	20.2946	1	1		
10/15/1994	0	1,259	1.27	2.032	6.3246	20.2946	1	1		
11/10/1994	0	1,259	7.62	15.748	6.3246	20.2946	1	1		
11/26/1994	0	1,259	1.778	3.81	6.3246	20.2946	1	1		
Total	1,259 m^3									

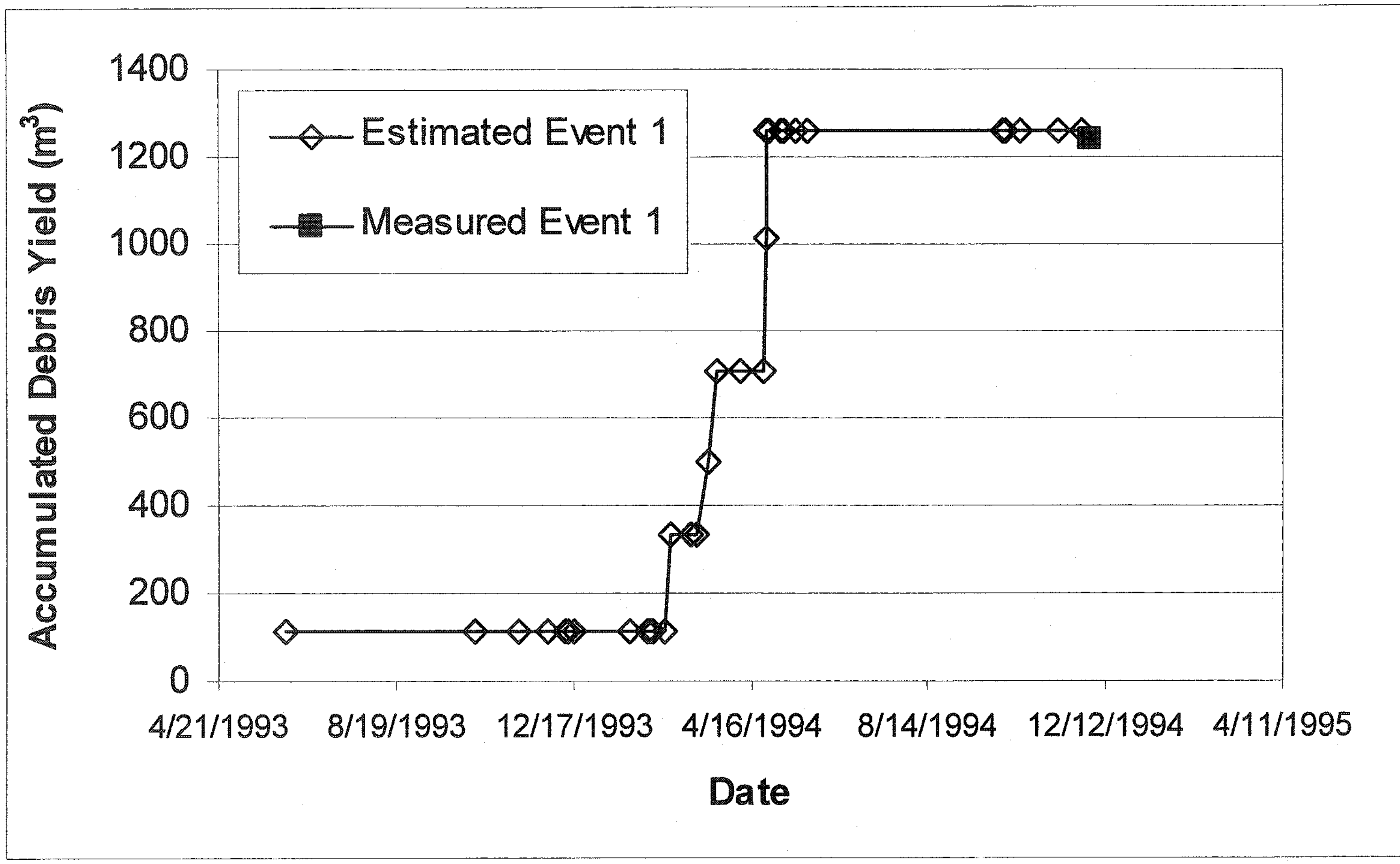

FIG. 5.8 Comparison with Estimated D_y and Measured D_y for Sunnyside DB

5.2.7 Carriage House Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Carriage House Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 90% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Carriage House Debris Basin to be used for the future debris prediction The measured debris yield is 1,710 m^3 between April 15, 1993 and November 29, 1994, while the estimated debris yield by the USCDPM is 1,853 m^3. The difference of the two values is 143 m^3. Finally, 6.579 mm/hr and 20.041 mm are selected for the TMRI and TMRA, respectively, for the Carriage House Debris Basin. The summary of the analysis is indicated in Table 5.16.

TABLE 5.16 Summary of Analysis for Carriage House Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
6.579	20.041	1,710	1,853	143	8.4

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.17 and Fig. 5.9.

TABLE 5.17 Calculation Sheet for Carriage House Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
6/5/1993	182	182	18.288	38.608	6.5786	20.0406	0	0	0	3.00
10/11/1993	0	182	1.016	2.54	6.5786	20.0406	0.9	1		
11/11/1993	0	182	5.08	10.922	6.5786	20.0406	0.9	1		
11/29/1993	0	182	10.414	16.256	6.5786	20.0406	0.9	1		
12/11/1993	0	182	9.906	18.796	6.5786	20.0406	0.9	1		
12/14/1993	0	182	12.192	18.542	6.5786	20.0406	0.9	1		
12/17/1993	0	182	0.762	0.762	6.5786	20.0406	0.9	1		
1/24/1994	0	182	14.224	17.272	6.5786	20.0406	0.9	1		
1/25/1994	0	182	3.048	5.334	6.5786	20.0406	0.9	1		
2/4/1994	0	182	5.08	22.86	6.5786	20.0406	0.9	1		
2/6/1994	0	182	0.762	0.762	6.5786	20.0406	0.9	1		
2/7/1994	0	182	6.096	20.574	6.5786	20.0406	0.9	1		
2/8/1994	0	182	10.16	13.462	6.5786	20.0406	0.9	1		
2/17/1994	0	182	8.128	18.034	6.5786	20.0406	0.9	1		
2/20/1994	327	509	11.176	32.004	6.5786	20.0406	0.9	1	0	6.13
3/6/1994	0	509	2.032	6.604	6.5786	20.0406	0.9	1		
3/7/1994	0	509	1.016	2.794	6.5786	20.0406	0.9	1		
3/11/1994	0	509	0.254	0.254	6.5786	20.0406	0.9	1		
3/19/1994	237	746	7.112	30.988	6.5786	20.0406	0.9	1	1	6.10
3/24/1994	301	1,047	10.16	35.306	6.5786	20.0406	0.9	1	2	6.07
4/9/1994	0	1,047	2.032	2.794	6.5786	20.0406	0.9	1		
4/25/1994	0	1,047	3.302	6.35	6.5786	20.0406	0.9	1		
4/26/1994	452	1,499	18.542	22.86	6.5786	20.0406	0.9	1	3	6.03
4/27/1994	354	1,853	13.208	23.114	6.5786	20.0406	0.9	1	4	6.00
4/28/1994	0	1,853	0.508	0.762	6.5786	20.0406	0.9	1		
5/6/1994	0	1,853	6.604	13.462	6.5786	20.0406	0.9	1		
5/7/1994	0	1,853	0.254	0.254	6.5786	20.0406	0.9	1		
5/8/1994	0	1,853	1.016	1.524	6.5786	20.0406	0.9	1		
5/17/1994	0	1,853	11.176	13.462	6.5786	20.0406	0.9	1		
5/25/1994	0	1,853	1.016	4.572	6.5786	20.0406	0.9	1		
10/4/1994	0	1,853	1.27	4.826	6.5786	20.0406	0.9	1		
10/5/1994	0	1,853	5.842	10.668	6.5786	20.0406	0.9	1		
10/15/1994	0	1,853	1.27	2.032	6.5786	20.0406	0.9	1		
11/10/1994	0	1,853	7.62	15.748	6.5786	20.0406	0.9	1		
11/26/1994	0	1,853	1.778	3.81	6.5786	20.0406	0.9	1		
Total	1,853 m^3									

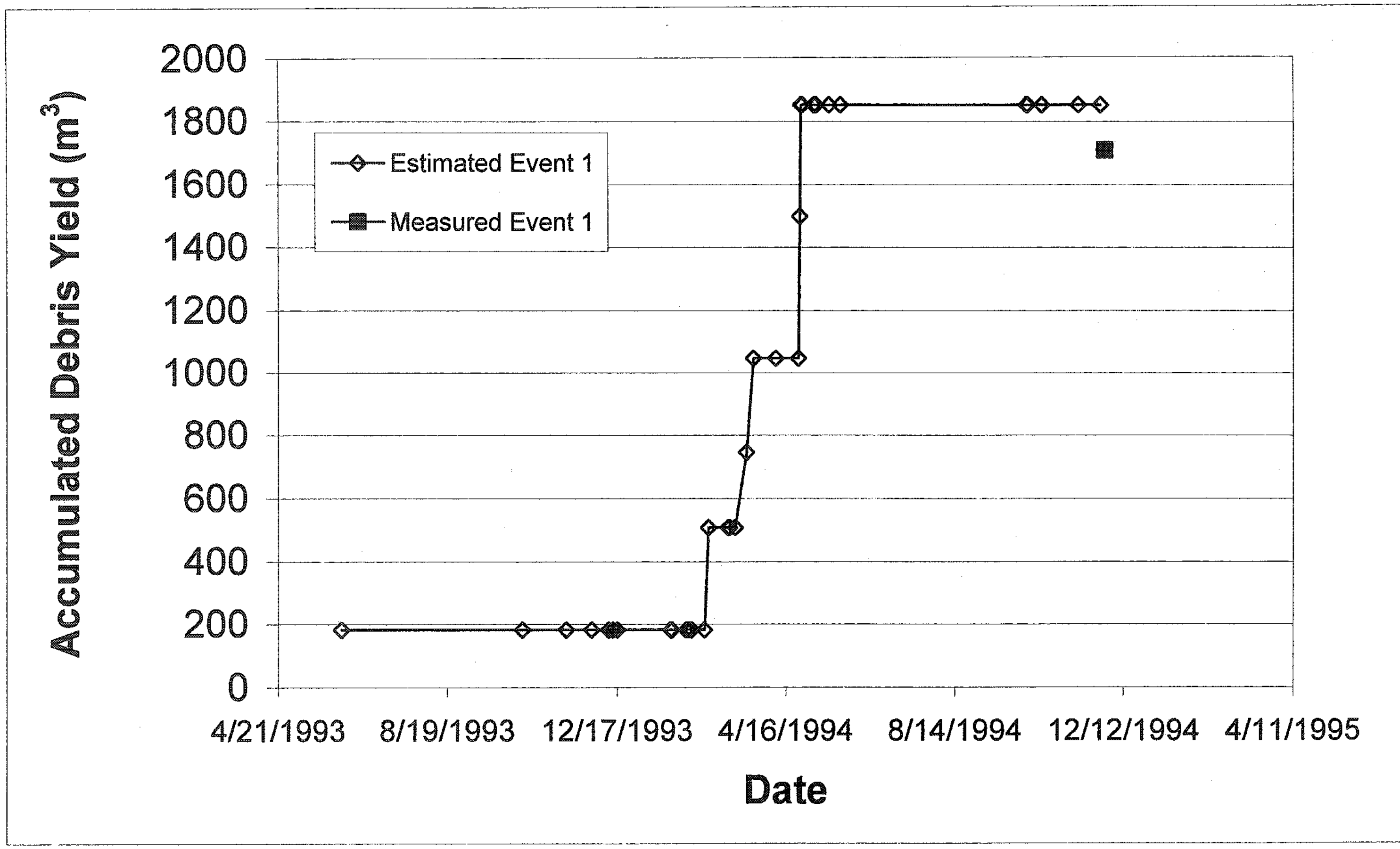

FIG. 5.9 Comparison with Estimated D_y and Measured D_y for Carriage House DB

5.2.8 Auburn Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Auburn Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 78% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Auburn Debris Basin to be used for the future debris prediction. The measured debris yield is 8,364 m^3 between September 1993 and March 15, 1994, while the estimated debris yield by the USCDPM is 10,084 m^3. The difference of the two values is 1,721 m^3. Finally, 6.071 mm/hr and 18.009 mm are selected for the TMRI and TMRA, respectively, for the Auburn Debris Basin. The summary of the analysis is indicated in Table 5.18.

TABLE 5.18 Summary of Analysis for Auburn Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
6.071	18.009	8,364	10,084	1,721	20.6

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.19 and Fig. 5.10.

TABLE 5.19 Calculation Sheet for Auburn Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
10/11/1993	0	0	1.016	2.54	6.0706	18.0086	0.78	1		
11/11/1993	0	0	5.08	10.922	6.0706	18.0086	0.78	1		
11/29/1993	0	0	10.414	16.256	6.0706	18.0086	0.78	1		
12/11/1993	2,124	2,124	9.906	18.796	6.0706	18.0086	0.78	1	0	5.68
12/14/1993	2,431	4,555	12.192	18.542	6.0706	18.0086	0.78	1	1	5.65
12/17/1993	0	4,555	0.762	0.762	6.0706	18.0086	0.78	1		
1/24/1994	0	4,555	14.224	17.272	6.0706	18.0086	0.78	1		
1/25/1994	0	4,555	3.048	5.334	6.0706	18.0086	0.78	1		
2/4/1994	0	4,555	5.08	22.86	6.0706	18.0086	0.78	1		
2/6/1994	0	4,555	0.762	0.762	6.0706	18.0086	0.78	1		
2/7/1994	1,493	6,047	6.096	20.574	6.0706	18.0086	0.78	1	2	5.62
2/8/1994	0	6,047	10.16	13.462	6.0706	18.0086	0.78	1		
2/17/1994	1,806	7,853	8.128	18.034	6.0706	18.0086	0.78	1	3	5.59
2/20/1994	2,231	10,084	11.176	32.004	6.0706	18.0086	0.78	1	4	5.56
3/6/1994	0	10,084	2.032	6.604	6.0706	18.0086	0.78	1		
3/7/1994	0	10,084	1.016	2.794	6.0706	18.0086	0.78	1		
3/11/1994	0	10,084	0.254	0.254	6.0706	18.0086	0.78	1		
Total	10,084 m^3									

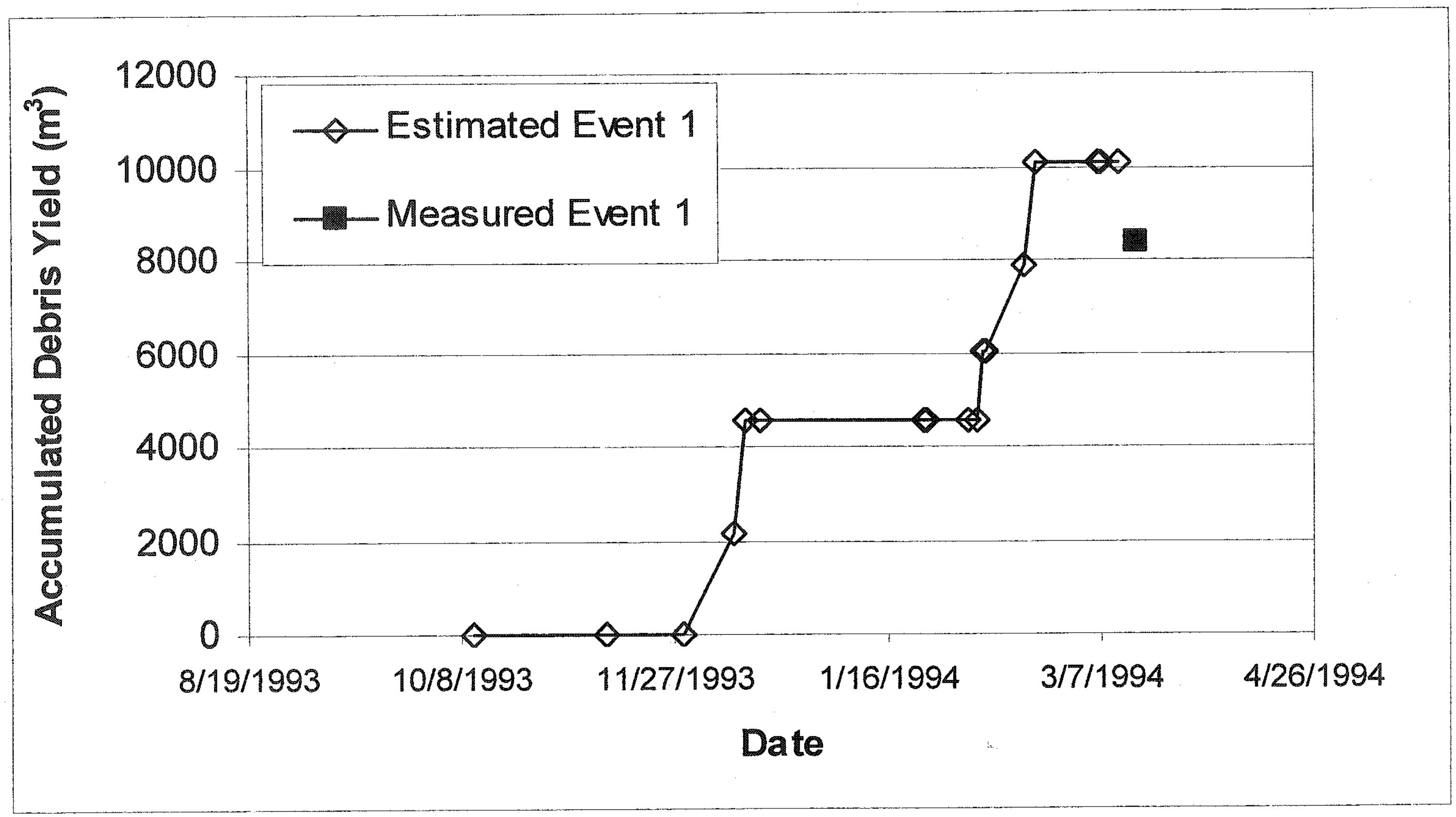

FIG. 5.10 Comparison with Estimated D_y and Measured D_y for Auburn DB

5.2.9 Fairoaks Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Fairoaks Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 41% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Fairoaks Debris Basin to be used for the future debris prediction. The measured debris yield is 1,847 m^3 between April 21, 1993 and April 1994, while the estimated debris yield by the USCDPM is 1,267 m^3. The difference of the two values is 581 m^3. Finally, 18.263 mm/hr and 38.583 mm are selected for the TMRI and TMRA, respectively, for the Fairoaks Debris Basin. The summary of the analysis is indicated in Table 5.20.

TABLE 5.20 Summary of Analysis for Fairoaks Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
18.263	38.583	1,847	1,267	-581	-31.4

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.21 and Fig. 5.11.

TABLE 5.21 Calculation Sheet for Fairoaks Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
6/5/1993	510	510	18.288	38.608	18.2626	38.5826	0	0	0	3.00
10/11/1993	0	510	1.016	2.54	18.2626	38.5826	0.41	1		
11/11/1993	0	510	5.08	10.922	18.2626	38.5826	0.41	1		
11/29/1993	0	510	10.414	16.256	18.2626	38.5826	0.41	1		
12/11/1993	0	510	9.906	18.796	18.2626	38.5826	0.41	1		
12/14/1993	0	510	12.192	18.542	18.2626	38.5826	0.41	1		
12/17/1993	0	510	0.762	0.762	18.2626	38.5826	0.41	1		
1/24/1994	0	510	14.224	17.272	18.2626	38.5826	0.41	1		
1/25/1994	0	510	3.048	5.334	18.2626	38.5826	0.41	1		
2/4/1994	0	510	5.08	22.86	18.2626	38.5826	0.41	1		
2/6/1994	0	510	0.762	0.762	18.2626	38.5826	0.41	1		
2/7/1994	0	510	6.096	20.574	18.2626	38.5826	0.41	1		
2/8/1994	0	510	10.16	13.462	18.2626	38.5826	0.41	1		
2/17/1994	0	510	8.128	18.034	18.2626	38.5826	0.41	1		
2/20/1994	0	510	11.176	32.004	18.2626	38.5826	0.41	1		
3/6/1994	0	510	2.032	6.604	18.2626	38.5826	0.41	1		
3/7/1994	0	510	1.016	2.794	18.2626	38.5826	0.41	1		
3/11/1994	0	510	0.254	0.254	18.2626	38.5826	0.41	1		
3/19/1994	0	510	7.112	30.988	18.2626	38.5826	0.41	1		
3/24/1994	0	510	10.16	35.306	18.2626	38.5826	0.41	1		
4/9/1994	0	510	2.032	2.794	18.2626	38.5826	0.41	1		
4/25/1994	0	510	3.302	6.35	18.2626	38.5826	0.41	1		
4/26/1994	757	1,267	18.542	45.974	18.2626	38.5826	0.41	1	0	4.30
4/28/1994	0	1,267	0.508	0.762	18.2626	38.5826	0.41	1		
Total	1,267 m^3									

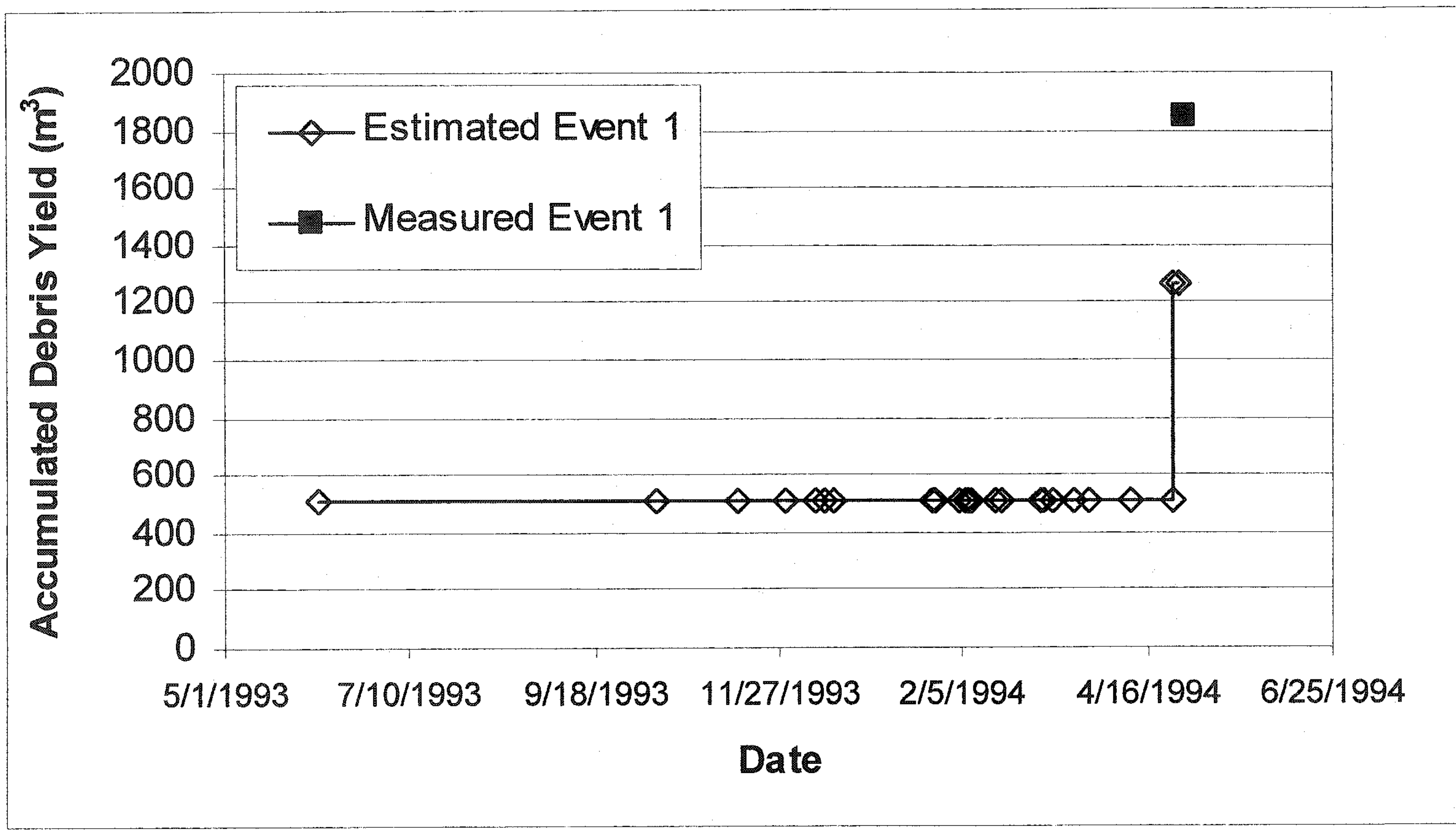

FIG. 5.11 Comparison with Estimated D_y and Measured D_y for Fairoaks DB

5.2.10 West Ravine Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the West Ravine Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 69% burn of the Kinneloa Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the West Ravine Debris Basin to be used for the future debris prediction. The measured debris yield is 9,331 m^3 between September 17, 1992 and April 1994, while the estimated debris yield by the USCDPM is 11,331 m^3. The difference of the two values is 2,000 m^3. Finally, 8.357 mm/hr and 22.835 mm are selected for the TMRI and TMRA, respectively, for the West Ravine Debris Basin. The summary of the analysis is indicated in Table 5.22.

TABLE 5.22 Summary of Analysis for West Ravine Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
8.357	22.835	9,331	11,331	2,000	21.4

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 5.23 and Fig. 5.12.

TABLE 5.23 Calculation Sheet for West Ravine Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
10/11/1993	0	0	1.016	2.54	8.3566	22.8346	0.69	1		
11/11/1993	0	0	5.08	10.922	8.3566	22.8346	0.69	1		
11/29/1993	0	0	10.414	16.256	8.3566	22.8346	0.69	1		
12/11/1993	0	0	9.906	18.796	8.3566	22.8346	0.69	1		
12/14/1993	0	0	12.192	18.542	8.3566	22.8346	0.69	1		
12/17/1993	0	0	0.762	0.762	8.3566	22.8346	0.69	1		
1/24/1994	0	0	14.224	17.272	8.3566	22.8346	0.69	1		
1/25/1994	0	0	3.048	5.334	8.3566	22.8346	0.69	1		
2/4/1994	0	0	5.08	22.86	8.3566	22.8346	0.69	1		
2/6/1994	0	0	0.762	0.762	8.3566	22.8346	0.69	1		
2/7/1994	0	0	6.096	20.574	8.3566	22.8346	0.69	1		
2/8/1994	0	0	10.16	13.462	8.3566	22.8346	0.69	1		
2/17/1994	0	0	8.128	18.034	8.3566	22.8346	0.69	1		
2/20/1994	2,563	2,563	11.176	32.004	8.3566	22.8346	0.69	1	0	5.34
3/6/1994	0	2,563	2.032	6.604	8.3566	22.8346	0.69	1		
3/7/1994	0	2,563	1.016	2.794	8.3566	22.8346	0.69	1		
3/11/1994	0	2,563	0.254	0.254	8.3566	22.8346	0.69	1		
3/19/1994	0	2,563	7.112	30.988	8.3566	22.8346	0.69	1		
3/24/1994	2,381	4,944	10.16	35.306	8.3566	22.8346	0.69	1	1	5.32
4/9/1994	0	4,944	2.032	2.794	8.3566	22.8346	0.69	1		
4/25/1994	0	4,944	3.302	6.35	8.3566	22.8346	0.69	1		
4/26/1994	3,579	8,523	18.542	22.86	8.3566	22.8346	0.69	1	2	5.29
4/27/1994	2,809	11,331	13.208	23.114	8.3566	22.8346	0.69	1	3	5.26
4/28/1994	0	11,331	0.508	0.762	8.3566	22.8346	0.69	1		
Total	11,331 m^3									

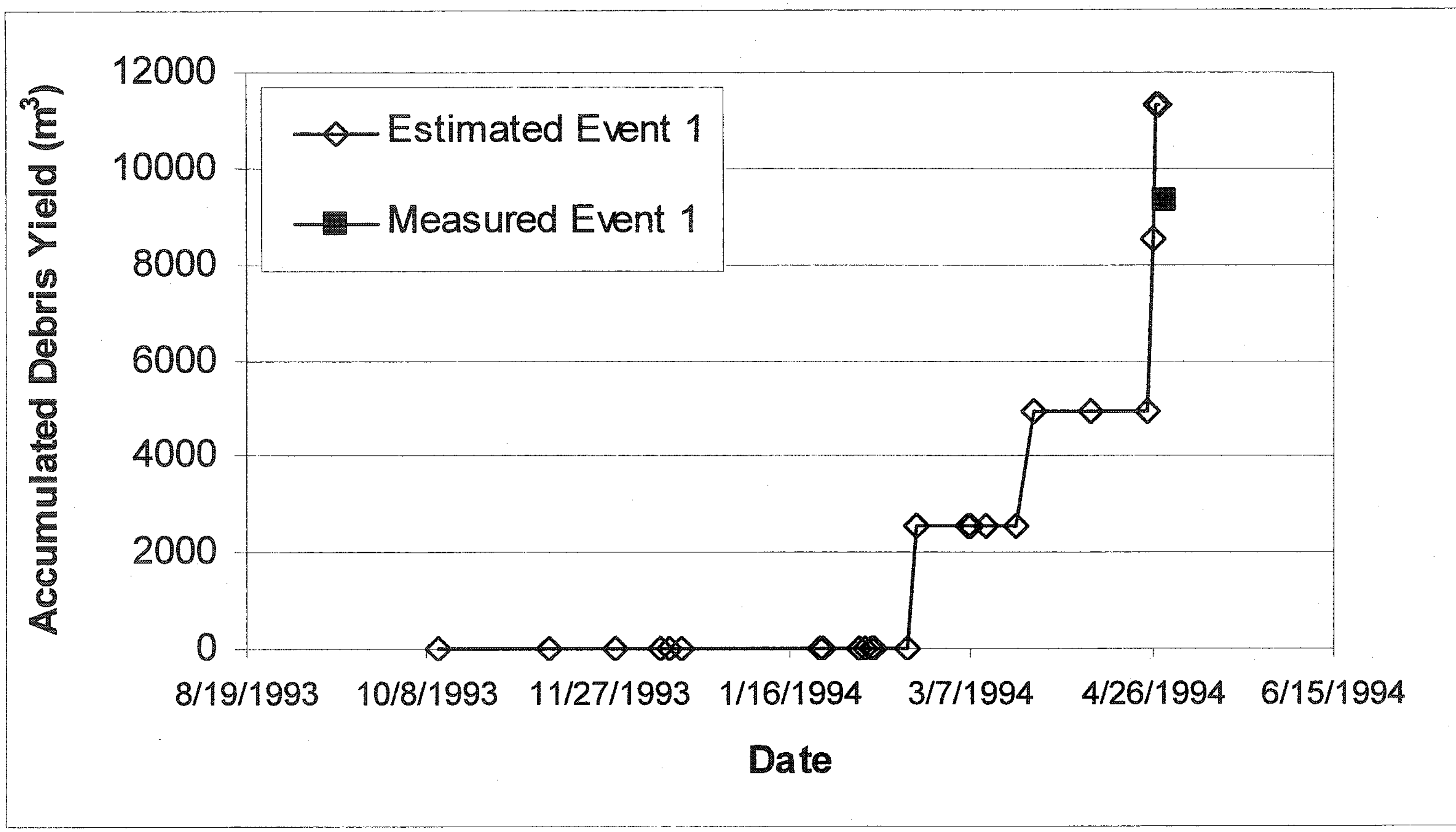

FIG. 5.12 Comparison with Estimated D_y and Measured D_y for West Ravine DB

5.3 Crest Fire

The Crest Fire (Fig. 5.13) of January 26-28, 1984 burned 15 watersheds. The Big Briar and Hay Debris Basins are chosen with 100% of watersheds within the Crest Fire area. Table 5.24 indicates the burn conditions and watershed characteristics of the two watersheds.

TABLE 5.24 Characteristics of Watershed burned by Crest Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Big Briar	5.3	100	509.869	0.972
Hay	52.2	100	352.743	0.991

5.3.1 Precipitation Data

Five precipitation gages are located in the vicinity of the Crest Fire area. Four of them are automatic precipitation gages: Sunset Ridge (Gage No. 683B), Briggs Terrace (Gage No. 373C), Flintridge-Sacred Heart (Gage No. 280C), and Devil's Gate Dam (Gage No. 453D). The La Canada Irrigation Dist. (Gage No. 175B) gage is a standard precipitation gage. Finally, the Briggs Terrace gage is selected for data analysis because it is the only gage with data covering this event.

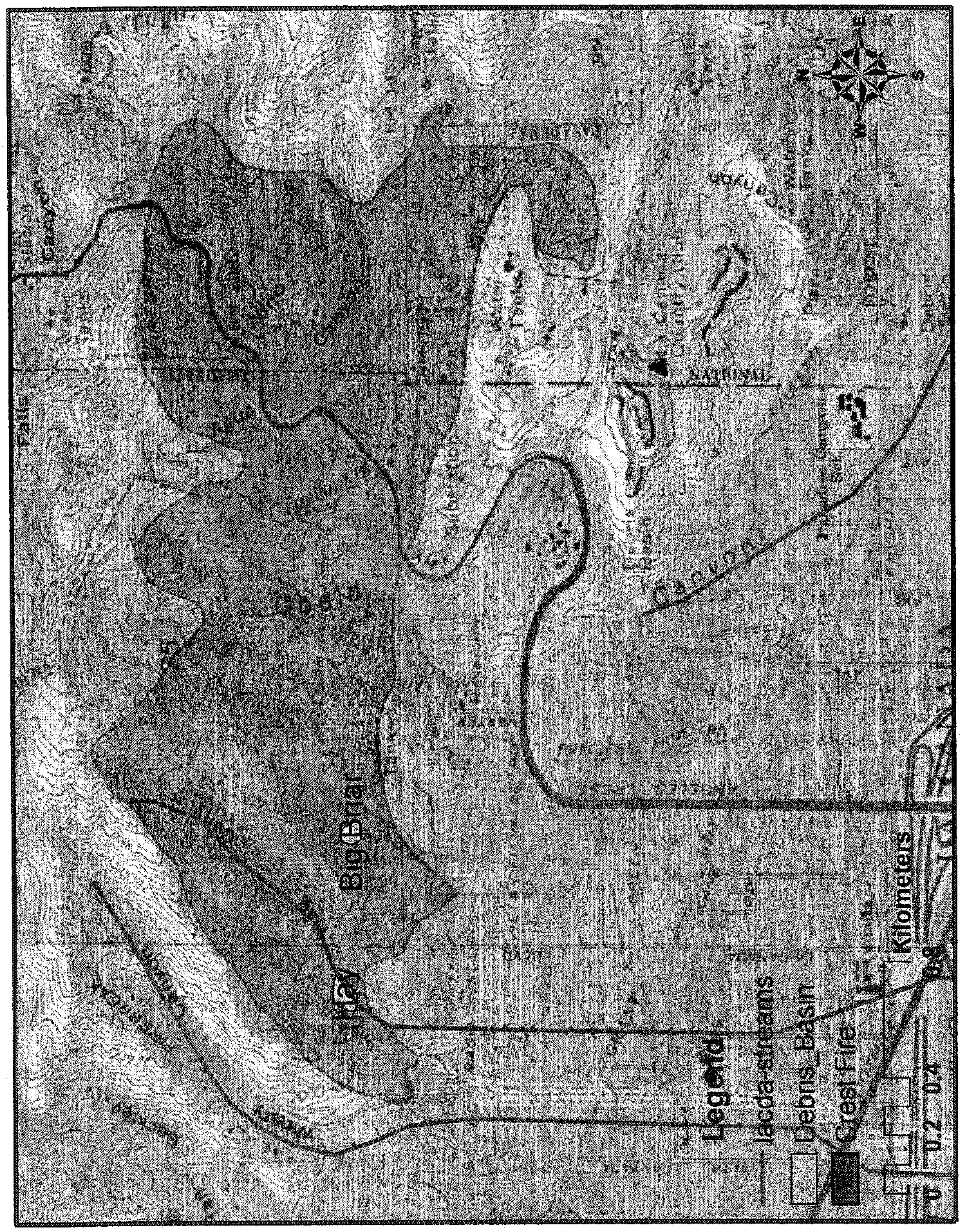

FIG. 5.13 Fire Map of Crest Fire

5.3.2 Big Briar Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Big Briar Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 100% burn of the Crest Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Big Briar Debris Basin to be used for the future debris prediction. The measured debris yield is 552 m^3 between February 7, 1984 and December 18, 1984, while the estimated debris yield by the USCDPM is 524 m^3. The difference of the two values is 28 m^3. Finally, 5.563 mm/hr and 19.025 mm are selected for the TMRI and TMRA, respectively, for the Big Briar Debris Basin. The summary of the analysis is indicated in Table 5.25.

TABLE 5.25 Summary of Analysis for Big Briar Debris Basin

TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
5.563	19.025	552	524	-28	-5.2

The precipitation data are obtained from the Briggs Terrace Raingage Station. The more detailed procedures of calculation are delineated in Table 5.26 and Fig. 5.14.

TABLE 5.26 Calculation Sheet for Big Briar Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
3/14/1984	176	176	7.62	20.32	5.5626	19.0246	1	1	0	6.50
4/6/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
4/19/1984	0	176	2.54	7.62	5.5626	19.0246	1	1		
5/16/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
6/6/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
8/15/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
9/11/1984	0	176	2.54	12.7	5.5626	19.0246	1	1		
9/15/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
9/16/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
10/17/1984	0	176	2.54	2.54	5.5626	19.0246	1	1		
11/8/1984	175	351	7.62	27.94	5.5626	19.0246	1	1	1	6.47
11/12/1984	0	351	2.54	2.54	5.5626	19.0246	1	1		
11/13/1984	0	351	7.62	17.78	5.5626	19.0246	1	1		
11/16/1984	0	351	2.54	2.54	5.5626	19.0246	1	1		
11/21/1984	0	351	7.62	15.24	5.5626	19.0246	1	1		
11/24/1984	0	351	5.08	20.32	5.5626	19.0246	1	1		
11/28/1984	0	351	2.54	2.54	5.5626	19.0246	1	1		
12/3/1984	0	351	2.54	5.08	5.5626	19.0246	1	1		
12/8/1984	0	351	5.08	12.7	5.5626	19.0246	1	1		
12/10/1984	0	351	7.62	12.7	5.5626	19.0246	1	1		
12/15/1984	173	524	7.62	30.48	5.5626	19.0246	1	1	2	6.43
12/18/1984	0	524	5.08	22.86	5.5626	19.0246	1	1		
Total	524 m^3									

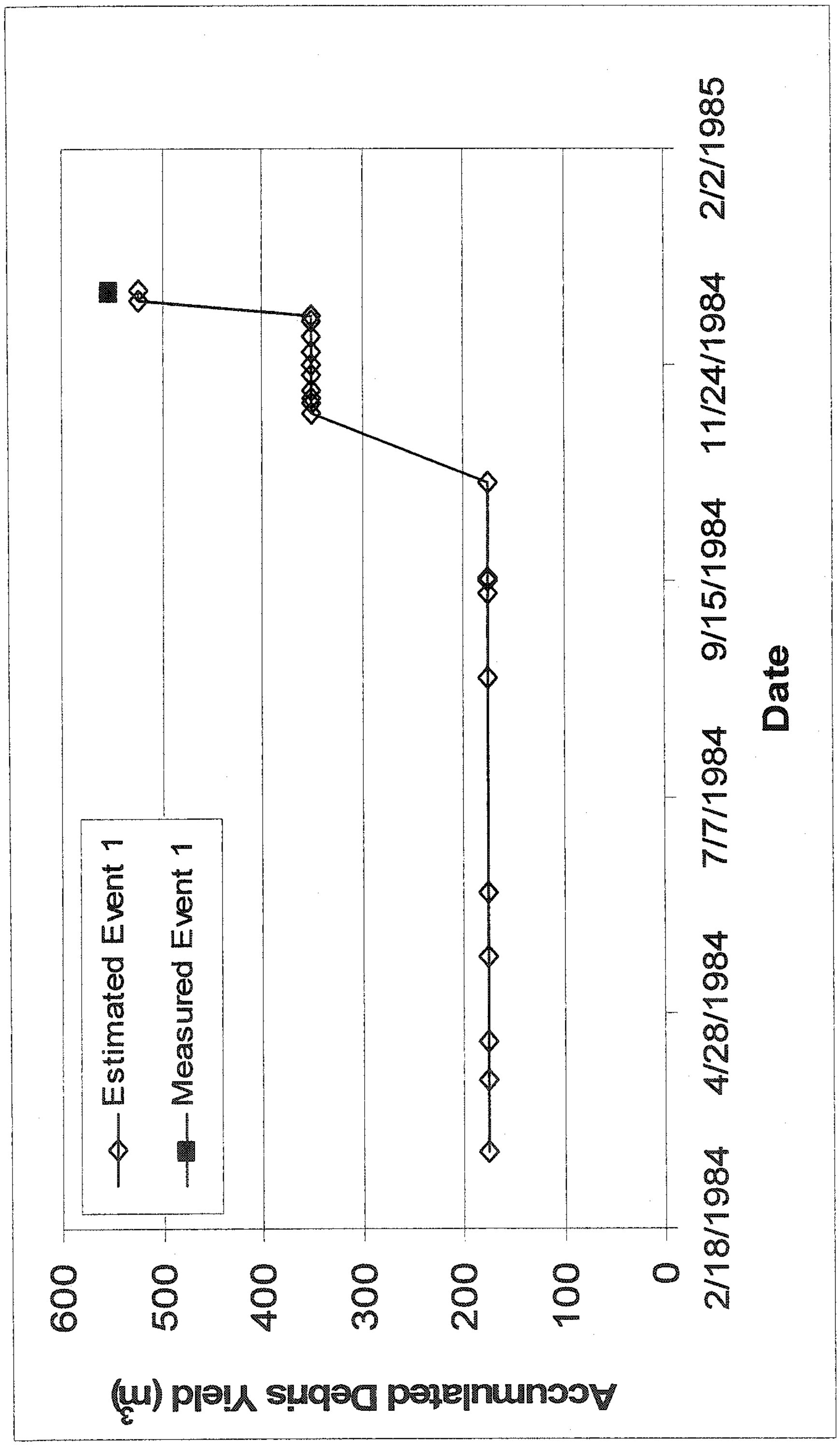

FIG. 5.14 Comparison with Estimated D_y and Measured D_y for Big Briar DB

5.3.3 Hay Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) of the Hay Debris Basin are determined through the trial and error method by minimizing the difference between the measured debris yield caused by the first storm season after 100% burn of the Crest Fire and the estimated debris yield by the USCDPM. The TMRI and TMRA define the hydrologic and geomorphologic characteristics of the Hay Debris Basin to be used for the future debris prediction. For this case, the sequent two debris basin maintenance data are used to analysis the data. For the first case, the measured debris yield is 3,164 m^3 between February 8, 1984 and December 19, 1984, while the estimated debris yield by the USCDPM is 2,769 m^3. The difference of the two values is 395 m^3. For the second case, the measured debris yield is 1,320 m^3 between January 31, 1985 and May 22, 1985, while the estimated debris yield by the USCDPM is 2,742 m^3. The difference of the two values is 1,422 m^3. Although second case is not good result, the difference of the both cases combined is 22.9%. Finally, 7.849 mm/hr and 24.359 mm aree selected for the TMRI and TMRA, respectively, for the Hay Debris Basin. The summary of analysis is indicated in Table 5.27.

TABLE 5.27 Summary of Analysis for Hay Debris Basin

Event	TMRI (mm/hr)	TMRA (mm)	Measured D_y (m^3)	USCDPM (m^3)	Difference (m^3)	Difference (%)
1	7.849	24.359	3,164	2,769	-395	-12.5
2	7.849	24.359	1,320	2,742	1,422	107.8
Total			4,484	5,511	1,027	22.9

The precipitation data are obtained from the Briggs Terrace Raingage Station. The more detailed procedures of calculation are delineated in Tables 5.28 and 5.29, and Fig. 15.

TABLE 5.28 Calculation Sheet for Hay Debris Basin Case I

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
3/14/1984	0	0	7.62	20.32	7.8486	24.3586	1	1		
4/6/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
4/19/1984	0	0	2.54	7.62	7.8486	24.3586	1	1		
5/16/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
6/6/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
8/15/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
9/11/1984	0	0	2.54	12.7	7.8486	24.3586	1	1		
9/15/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
9/16/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
10/17/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
11/8/1984	0	0	7.62	27.94	7.8486	24.3586	1	1		
11/12/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
11/13/1984	0	0	7.62	17.78	7.8486	24.3586	1	1		
11/16/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
11/21/1984	0	0	7.62	15.24	7.8486	24.3586	1	1		
11/24/1984	0	0	5.08	20.32	7.8486	24.3586	1	1		
11/28/1984	0	0	2.54	2.54	7.8486	24.3586	1	1		
12/3/1984	0	0	2.54	5.08	7.8486	24.3586	1	1		
12/8/1984	0	0	5.08	12.7	7.8486	24.3586	1	1		
12/10/1984	0	0	7.62	12.7	7.8486	24.3586	1	1		
12/15/1984	0	0	7.62	30.48	7.8486	24.3586	1	1		
12/18/1984	0	0	5.08	22.86	7.8486	24.3586	1	1		
12/19/1984	2,769	2,769	10.16	43.18	7.8486	24.3586	1	1	0	6.50
Total	2,769 m^3									

TABLE 5.29 Calculation Sheet for Hay Debris Basin Case II

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
2/2/1985	0	0	2.54	5.08	7.8486	24.3586	1	1		
2/9/1985	2,742	2,742	10.16	55.88	7.8486	24.3586	1	1	1	6.47
2/20/1985	0	2,742	2.54	2.54	7.8486	24.3586	1	1		
3/7/1985	0	2,742	2.54	7.62	7.8486	24.3586	1	1		
3/11/1985	0	2,742	5.08	7.62	7.8486	24.3586	1	1		
3/13/1985	0	2,742	2.54	2.54	7.8486	24.3586	1	1		
3/18/1985	0	2,742	7.62	17.78	7.8486	24.3586	1	1		
3/27/1985	0	2,742	5.08	25.4	7.8486	24.3586	1	1		
3/28/1985	0	2,742	2.54	2.54	7.8486	24.3586	1	1		
4/17/1985	0	2,742	2.54	2.54	7.8486	24.3586	1	1		
5/9/1985	0	2,742	2.54	5.08	7.8486	24.3586	1	1		
Total	2,742 m^3									

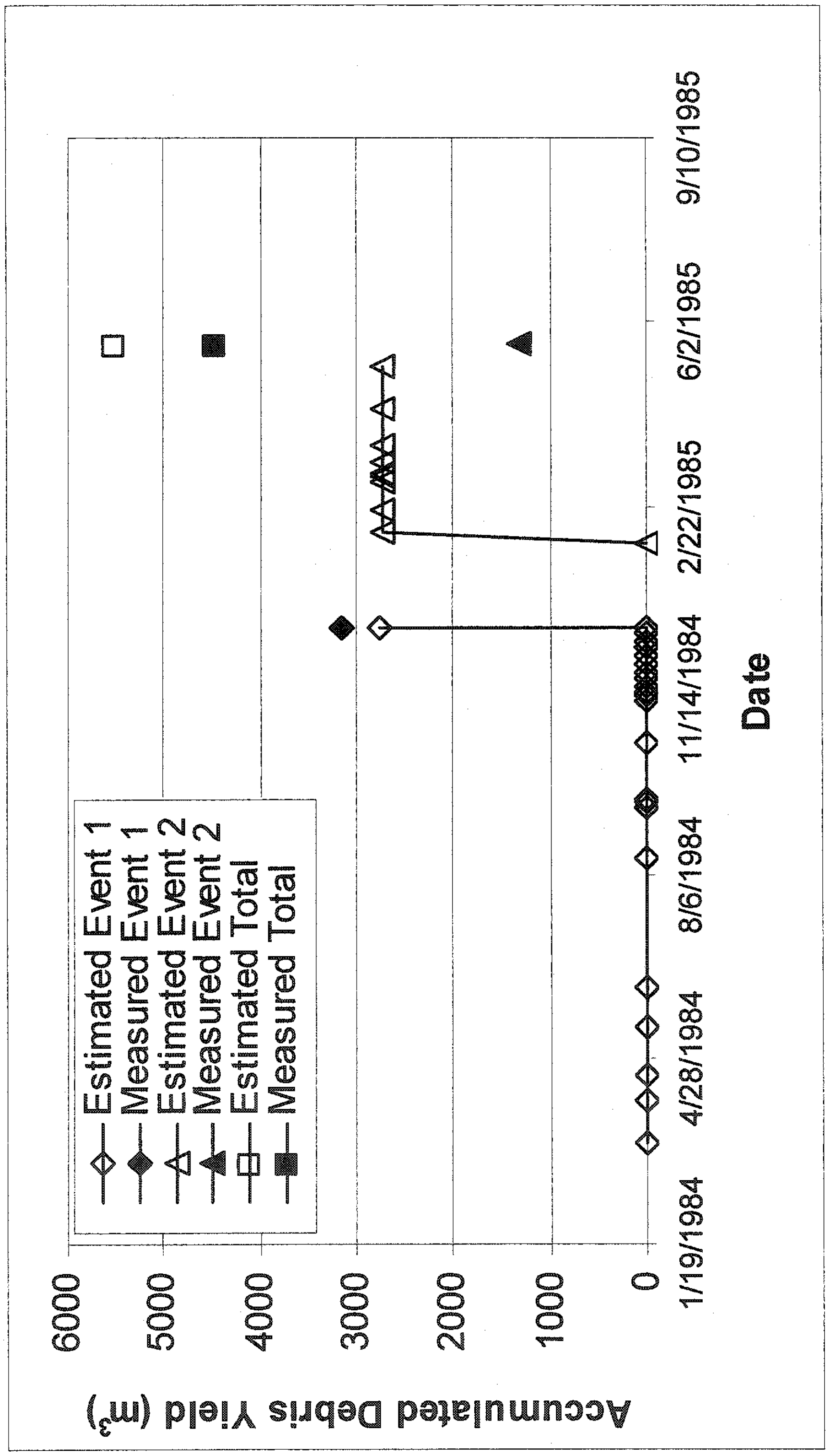

FIG. 5.15 Comparison with Estimated D_y and Measured D_y for Hay DB

5.4 Development of Correlation Graphs

The Threshold Maximum 1-hr Rainfall Intensity (TMRI) is related to the watershed slope because higher slopes can entrain the debris with less intense precipitation. The Threshold Maximum 1-hr Rainfall Intensity (TMRI) and Total Minimum Rainfall Amount (TMRA) are determined by case studies for each debris basin. This is summarized in Table 5.30.

Based on the results of these case studies, two graphs are developed to simplify the estimation of the TMRI and TMRA for debris prediction. Fig. 5.16 depicts the relationship between the TMRI (I_c) and Relief Ratio (S). A power regression is used to obtain the equation of data trend, $y = \mathbf{175.05}\boldsymbol{X}^{-0.5491}$, with an R-squared value of 0.9435. Fig. 5.17 depicts the relationship between the TMRI (I_c) and TMRA (P_c). A power regression is also used to obtain the equation of data trend, $y = \mathbf{5.9752}\boldsymbol{X}^{0.6465}$, with an R-squared value of 0.9673. Both equations are obtained with the relatively high R-square values. When using the USCDPM to predict the debris yields, the relief ratio, drainage area, precipitation data, and fire information are needed as well as the TMRI and TMRA values determined from Fig. 5.16 and Fig. 5.17, respectively. By utilizing these two graphs, the USCDPM can be used in the field to predict the accumulated debris yields. It should be noted that when more data become available in the future, these two graphs can be updated, and more accurate results can be expected.

TABLE 5.30 Summary of TMRI and TMRA

Debris Basin	S (m/km)	Area (ha)	TMRI (Ic) (mm/hr)	TMRA (Pc) (mm)
Lannan Basin	405.004	63.9	5.817	17.755
Kinneloa East	444.033	51.8	5.817	18.771
Kinneloa West	475.838	52.2	5.309	17.247
Rubio	280.060	329.0	7.849	22.835
Bailey	337.072	153.8	7.087	21.565
Sunnyside	475.802	5.2	6.325	20.295
Carriage House	433.993	7.7	6.579	20.041
Auburn	521.712	41.3	6.071	18.009
Fairoaks	60.013	54.6	18.263	38.583
West Ravine	286.761	63.9	8.357	22.835
Big Briar	509.869	5.3	5.563	19.025
Hay	352.743	52.2	7.849	24.359

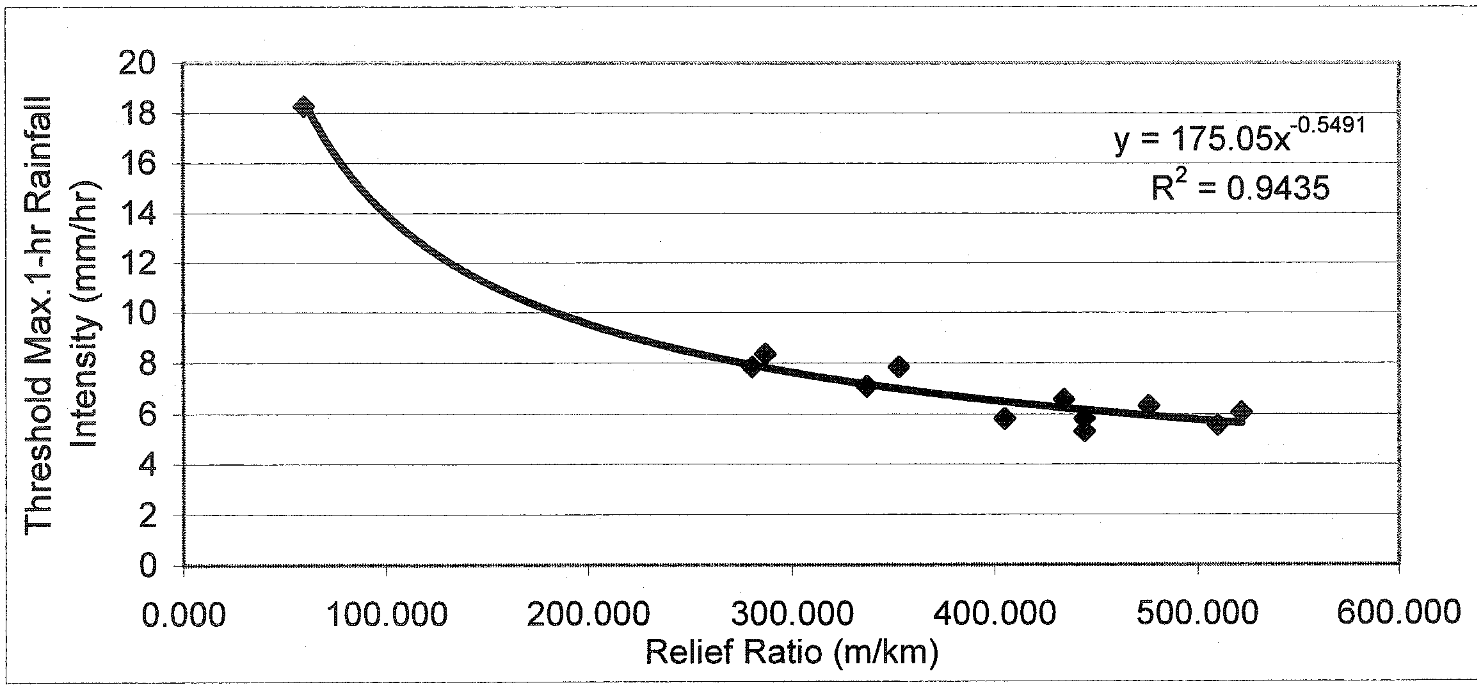

FIG. 5.16 Relationship of Threshold Maximum 1-hr Rainfall Intensity and Relief Ratio

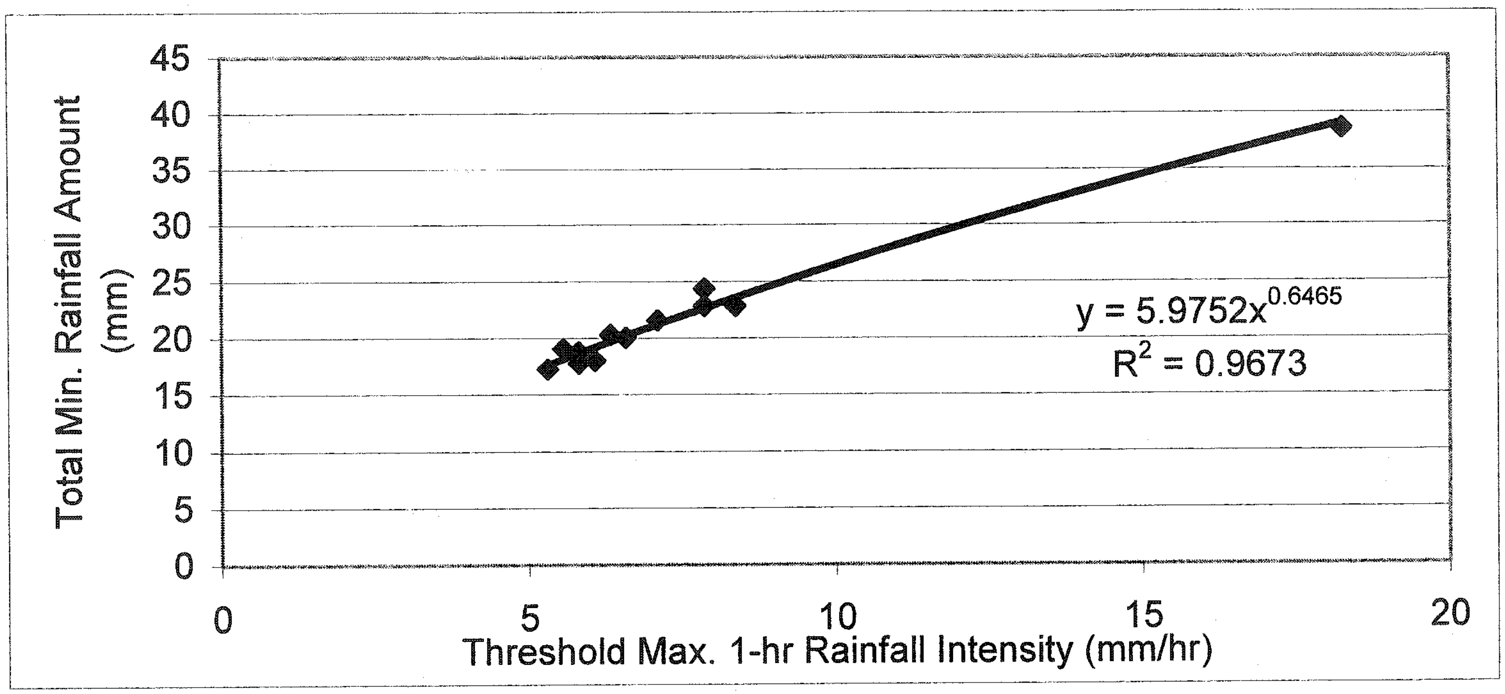

FIG. 5.17 Relationship of Total Minimum Precipitation Amount and Threshold Maximum 1-hr Rainfall Intensity

5.5 Summary of Case Studies for Calibration

The measured yield and estimated yield are compared herein with their differences shown in Table 5.31. From Table 5.31, a range of a difference of 0.6%-31.4% is found when using USCDPM in comparison with the field data. The largest difference (–31.4%) occurs at Fairoaks Debris Basin, in which the relief ratio (**S**) is the smallest among all the watersheds studied. There is not enough data for mild watersheds that have the relief ratio (*S*) in the range of 60-280 m/km because most of the watersheds in San Gabriel Mountains area are of steep slope (large relief ratio). Fig. 5.18 shows the measured debris yield versus the estimated debris yield, and their differences.

TABLE 5.31 Summary of Calibration Results

Debris Basin	S (m/km)	Area (ha)	Fire[1]	% of Burn	TMRI (Ic) (mm/hr)	TMRA (P) (mm)	Measured Dy (m^3)	Estimated Dy (m^3)	Difference (m^3)	Difference (%)
Lannan Case 1	405.004	63.943	1	80	5.817	17.755	13577	13492	-85	-0.6
Lannan Case 2	405.004	63.943	1	80	5.817	17.755	5047	5645	598	11.9
Kinneloa East	444.033	51.802	2	100	5.817	18.771	23627	24651	1024	4.3
Kinneloa West	475.838	52.206	2	100	5.309	17.247	33261	34725	1464	4.4
Rubio	280.060	329.02	2	92	7.849	22.835	17001	21555	4554	26.8
Bailey	337.072	153.79	2	95	7.087	21.565	22948	25873	2925	12.7
Sunnyside	475.802	5.2125	2	100	6.325	20.295	1239	1259	19	1.5
Carriage House	433.993	7.6893	2	90	6.579	20.041	1710	1853	143	8.4
Auburn	521.712	41.279	2	78	6.071	18.009	8364	10084	1721	20.6
Fairoaks	60.013	54.635	2	41	18.263	38.583	1847	1267	-581	-31.4
West Ravine	286.761	63.943	2	69	8.357	22.835	9331	11331	2000	21.4
Big Brial	509.869	5.2611	3	100	5.563	19.025	552	524	-28	-5.2
Hay	352.743	52.206	3	100	7.849	24.359	4484	5511	1027	22.9

Fire[1]- Fire event designation: 1-Santa Anita II Fire, 2-Kinneloa Fire, 3-Crest Fire

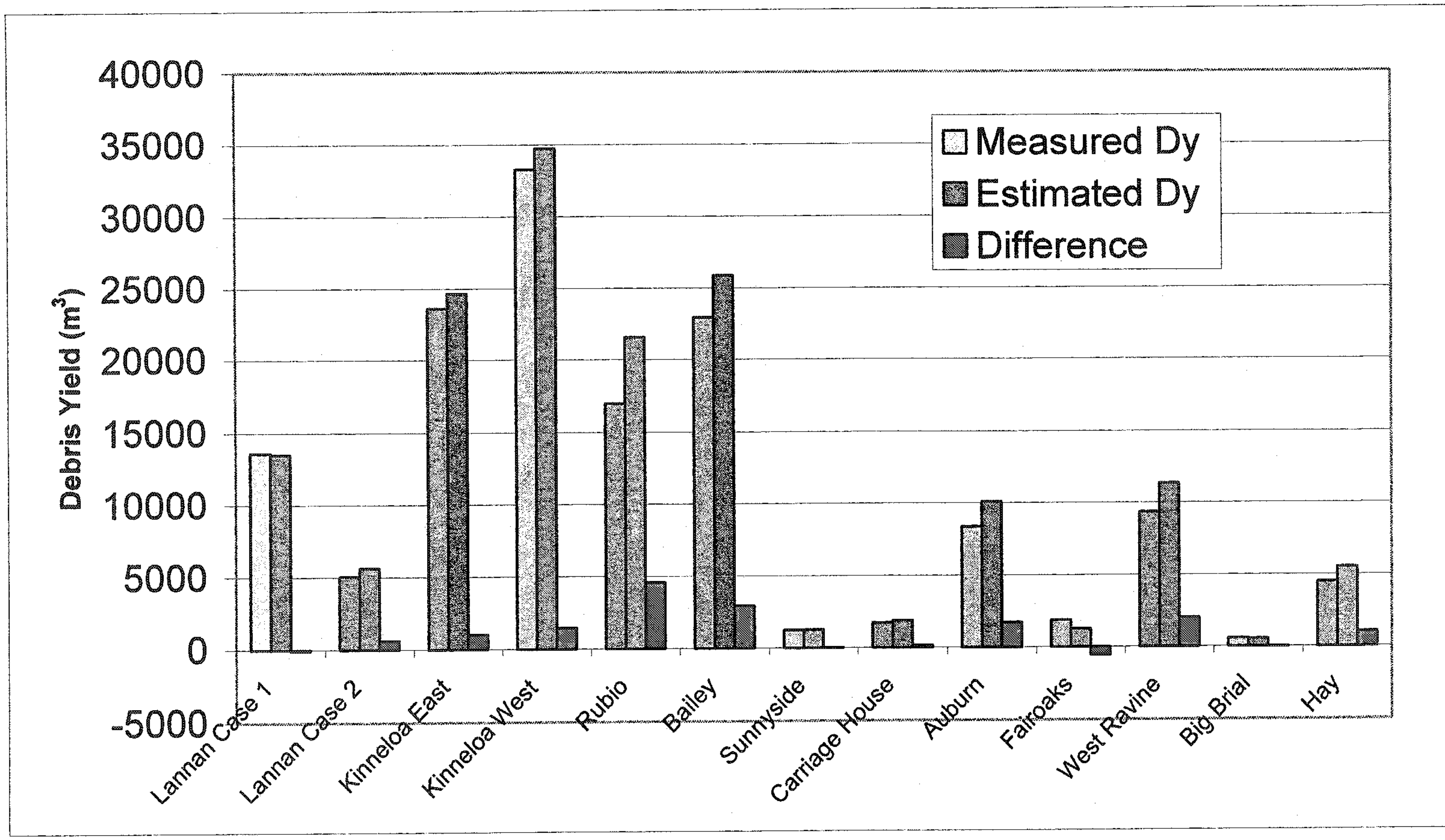

FIG. 5.18 Graphical Comparison of Measured Debris Yield and Estimated Debris Yield

CHAPTER 6

6 Application and Evaluation for Small Watersheds

As shown in the previous two chapters, the USCDPM is developed and further calibrated based on field data obtained between 1938 and 2000 in order to produce a more reliable prediction model for debris yields. After calibration, the USCDPM is used to provide real-time prediction, and the result is then compared with the field data on debris yields from the Mountain Fire. The predicted results will be compared with the USACE Debris Method, LACDPW Debris Method, and prototype data measured at debris basin to verify the applicability of the USCDPM.

6.1 Mountain Fire

The Mountain Fire in the Glendale area (occurred on September 9, 2002) burned over 303 ha (749 acres) of the watershed, including those of the Brand and Childs Debris Basin, as shown on Fig. 6.1 (Storm Report Los Angeles County 2002-2003). Table 6.1 indicates the burn conditions and watershed characteristics of the Brand, Childs, and Auburn Debris Basins.

TABLE 6.1 Characteristics of Watershed burned by Mountain Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Brand	267	90	280	0.992
Childs	81	80	314	0.980
Auburn	41	78	522	0.996

6.1.1 Precipitation Data

Three automatic precipitation gages (Childs Canyon Debris Basin, Downtown Los Angeles Federal Building, and Brand Park (Gage No. 210C)) are located in the vicinity of the Mountain Fire area. The Childs Canyon Debris Basin precipitation gage is chosen for the data analysis because its precipitation data are the most reliable and consistent when compared with the results of other gages.

6.1.2 Additional Example

For comparison purpose, the Auburn Debris Basin is selected as an example because it has one of the steepest watersheds in the San Gabriel Mountains. However there is no fire event post 2000 occurred in the watershed contributory to the Auburn Debris Basin. Therefore, we select an event closest to year 2001 for the Auburn Debris Basin. The Kinneloa fire which occurred on October 27, 1993 is the closest one, as it burned approximately 78% of the watershed of the Auburn Debris basin.

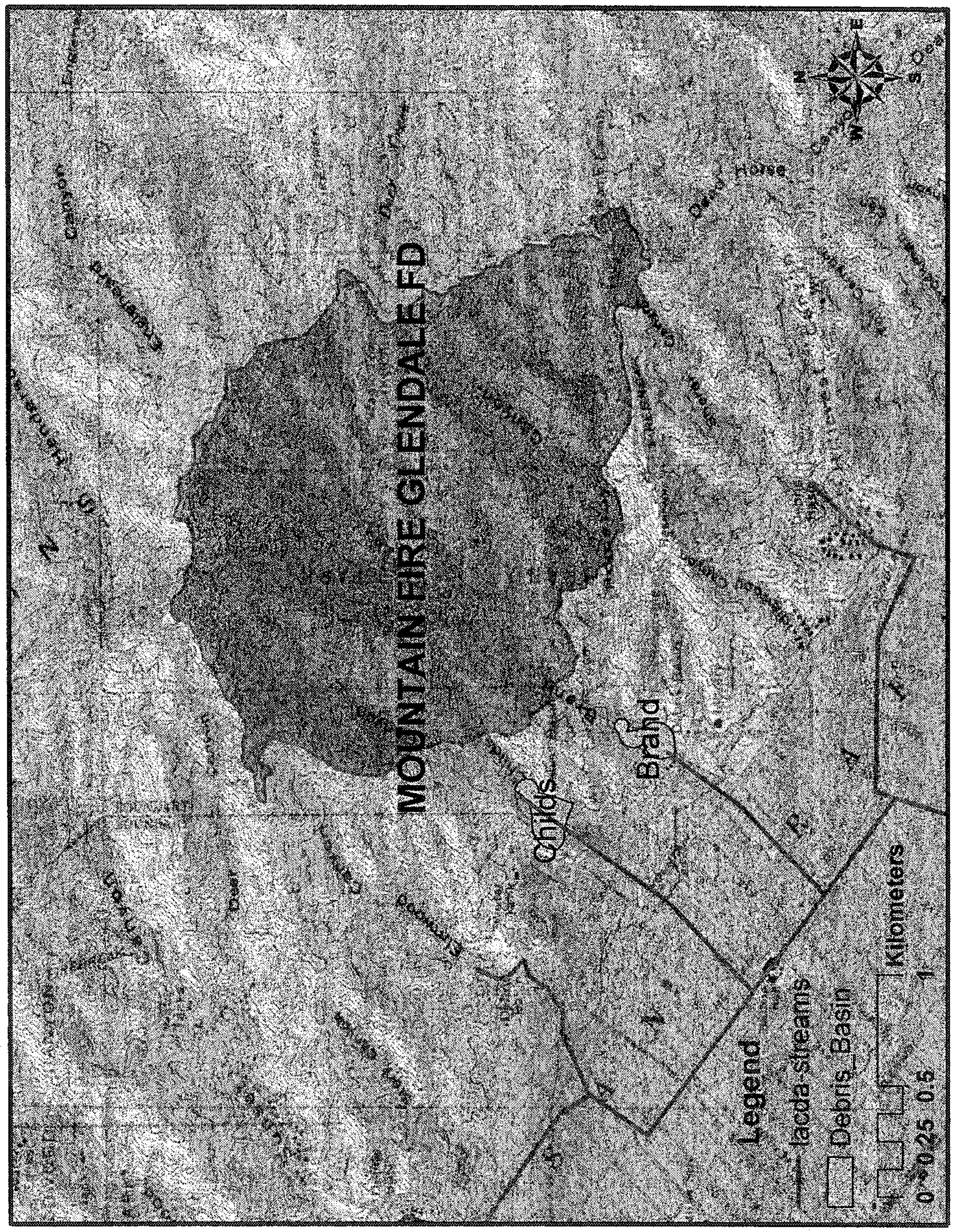

FIG. 6.1 Fire Map of Mountain Fire

6.1.3 Brand Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI=7.953 mm/hr) and the Total Minimum Rainfall Amount (TMRA=22.835 mm) for the Brand Debris basins are determined through the equation $y = \mathbf{175.05}\boldsymbol{X}^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}\boldsymbol{X}^{0.6465}$ of Fig. 5.17, respectively. For the Brand Debris Basin, the measured debris yield is 100,357 m^3 generated with rainfall events between November 8, 2002 and April 2, 2003, while the estimated debris yield by the USCDPM is 90,558 m^3 with precipitation data obtained from the Childs Debris Basin Precipitation Gage. The difference of the two values is 9,799 m^3 (9.8%). The USACE and LACDPW methods are compared with USCDPM in Table 6.2.

TABLE 6.2 Summary of Analysis for Brand Debris Basin

Method	Estimated D_y (m^3)	Measured D_y (m^3)	Difference (m^3)	Difference (%)
USCDPM	90,558	100,357	-9,799	-10
USACE1	73,877	100,357	-26,479	-26
USACE2	151,417	100,357	51,061	51
LACDPW	107,525	100,357	7,169	7

USACE1-Calculated with antecedent rainfall condition for significant debris yield to occur: Approximately 50.8 mm (2 inches) within an approximately 48-hr period.
USACE2-Calculated with all rainfall events.
LACDPW-Calculated with >0.05 in/hr Maximum 1-hr Rainfall Intensity.
Measured D_y-Measured based on truck counts as no survey of the basin.

The precipitation data are obtained from the Childs Debris Basin Raingage Station. The more detailed procedures of calculation are delineated in Table 6.3 and Fig. 6.2.

TABLE 6.3 Calculation Sheet for Brand Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
11/8/2002	0	0	2.032	11.430	7.953	22.835	0.9	1		
11/9/2002	0	0	2.032	4.826	7.953	22.835	0.9	1		
11/29/2002	0	0	1.016	1.270	7.953	22.835	0.9	1		
12/16/2002	13,110	13,110	8.128	25.400	7.953	22.835	0.9	1	0	6.13
12/20/2002	0	13,110	6.604	23.622	7.953	22.835	0.9	1		
12/28/2002	0	13,110	4.064	6.858	7.953	22.835	0.9	1		
2/11/2003	0	13,110	5.080	28.448	7.953	22.835	0.9	1		
2/12/2003	19,826	32,935	14.986	83.312	7.953	22.835	0.9	1	1	6.10
2/13/2003	14,230	47,166	9.398	95.250	7.953	22.835	0.9	1	2	6.07
2/25/2003	0	47,166	4.318	10.922	7.953	22.835	0.9	1		
2/27/2003	0	47,166	1.016	1.270	7.953	22.835	0.9	1		
3/4/2003	0	47,166	5.080	5.080	7.953	22.835	0.9	1		
3/15/2003	21,689	68,855	17.526	59.944	7.953	22.835	0.9	1	3	6.03
3/16/2003	21,704	90,558	17.780	79.502	7.953	22.835	0.9	1	4	6.00
4/2/2003	0	90,558	1.016	0.040	7.953	22.835	0.9	1		
Total	90,558	m^3								

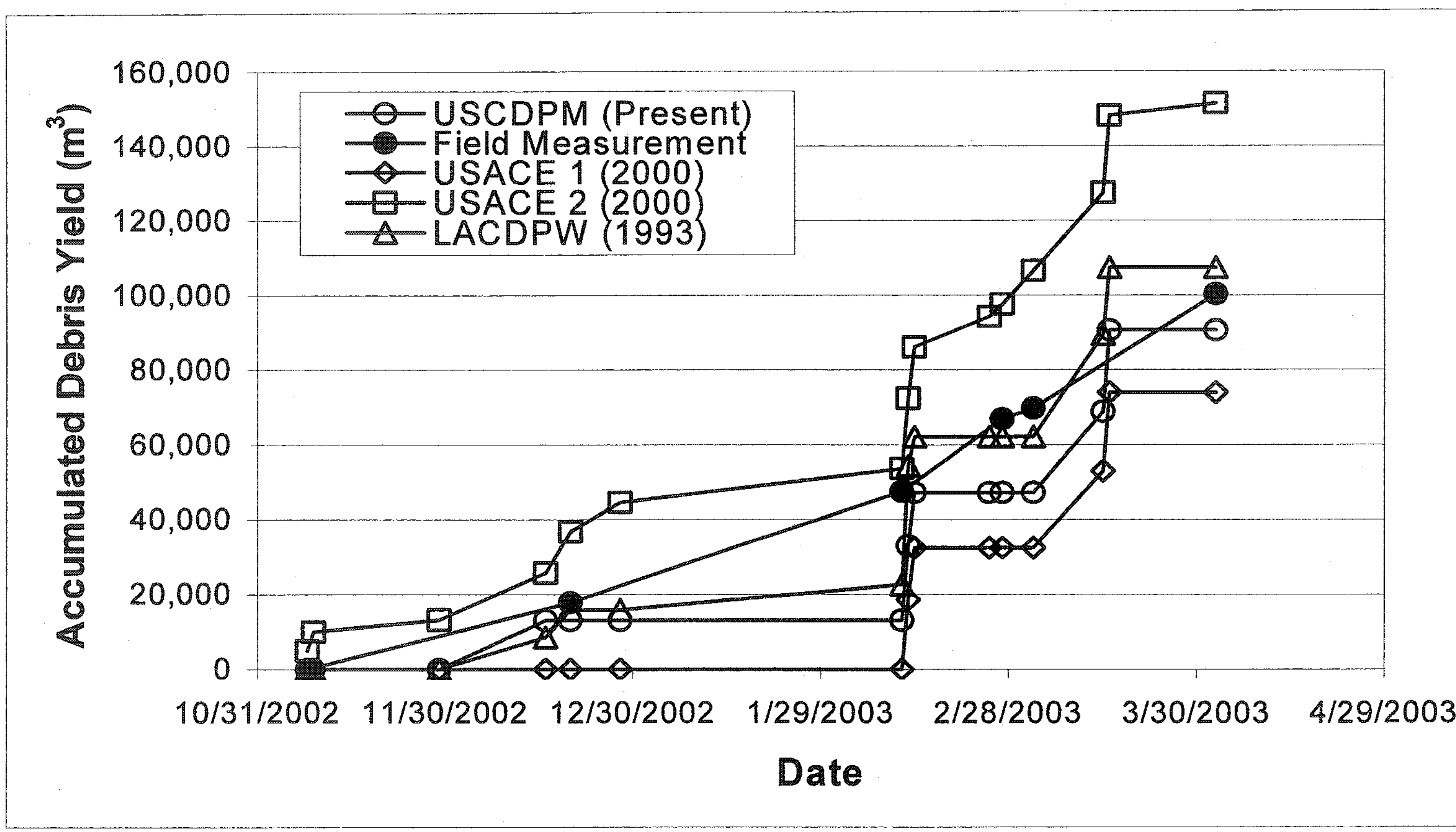

FIG. 6.2 Comparison with Estimated D_y and Measured D_y for Brand DB

6.1.4 Childs Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI=7.466 mm/hr) and the Total Minimum Rainfall Amount (TMRA=21.921 mm) for the Childs Debris basins are determined through the equation $y = \mathbf{175.05}X^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}X^{0.6465}$ of Fig. 5.17, respectively. For the Childs Debris Basin, the measured debris yield is 22,249 m^3 generated with rainfall events between November 8, 2002 and April 2, 2003, while the estimated debris yield by the USCDPM is 20,404 m^3 with precipitation data obtained from the Childs Debris Basin Precipitation Gage. The difference of the two values is 1,845 m^3 (8.3%). The USACE and LACDPW methods are compared with the USCDPM in Table 6.4.

TABLE 6.4 Summary of Analysis for Childs Debris Basin

Method	Estimated D_y (m^3)	Measured D_y (m^3)	Difference (m^3)	Difference (%)
USCDPM	20,404	22,249	-1,846	-8
USACE1	19,263	22,249	-2,987	-13
USACE2	39,493	22,249	17,244	78
LACDPW	42,236	22,249	19,986	90

USACE1-Calculated with antecedent rainfall condition for significant debris yield to occur: Approximately 50.8 mm (2 inches) within an approximately 48-hr period.
USACE2-Calculated with all rainfall events.
LACDPW-Calculated with >0.05 in/hr Maximum 1-hr Rainfall Intensity.
Measured D_y-Measured based on truck counts as no survey of the basin.

The precipitation data are obtained from the Childs Debris Basin Raingage Station. The more detailed procedures of calculation are delineated in Table 6.5 and Fig. 6.3.

TABLE 6.5 Calculation Sheet for Childs Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
11/8/2002	0	0	2.032	11.43	7.466	21.921	0.8	1		
11/9/2002	0	0	2.032	4.826	7.466	21.921	0.8	1		
11/29/2002	0	0	1.016	1.27	7.466	21.921	0.8	1		
12/16/2002	2,950	2950	8.128	25.4	7.466	21.921	0.8	1	0	5.75
12/20/2002	0	2950	6.604	23.622	7.466	21.921	0.8	1		
12/28/2002	0	2950	4.064	6.858	7.466	21.921	0.8	1		
2/11/2003	0	2950	5.08	28.448	7.466	21.921	0.8	1		
2/12/2003	4,464	7414	14.986	83.312	7.466	21.921	0.8	1	1	5.72
2/13/2003	3,206	10620	9.398	95.25	7.466	21.921	0.8	1	2	5.70
2/25/2003	0	10620	4.318	10.922	7.466	21.921	0.8	1		
2/27/2003	0	10620	1.016	1.27	7.466	21.921	0.8	1		
3/4/2003	0	10620	5.08	5.08	7.466	21.921	0.8	1		
3/15/2003	4,889	15509	17.526	59.944	7.466	21.921	0.8	1	3	5.67
3/16/2003	4,895	20404	17.78	79.502	7.466	21.921	0.8	1	4	5.64
4/2/2003	0	20404	1.016	1.016	7.466	21.921	0.8	1		
Total	20,404	m^3								

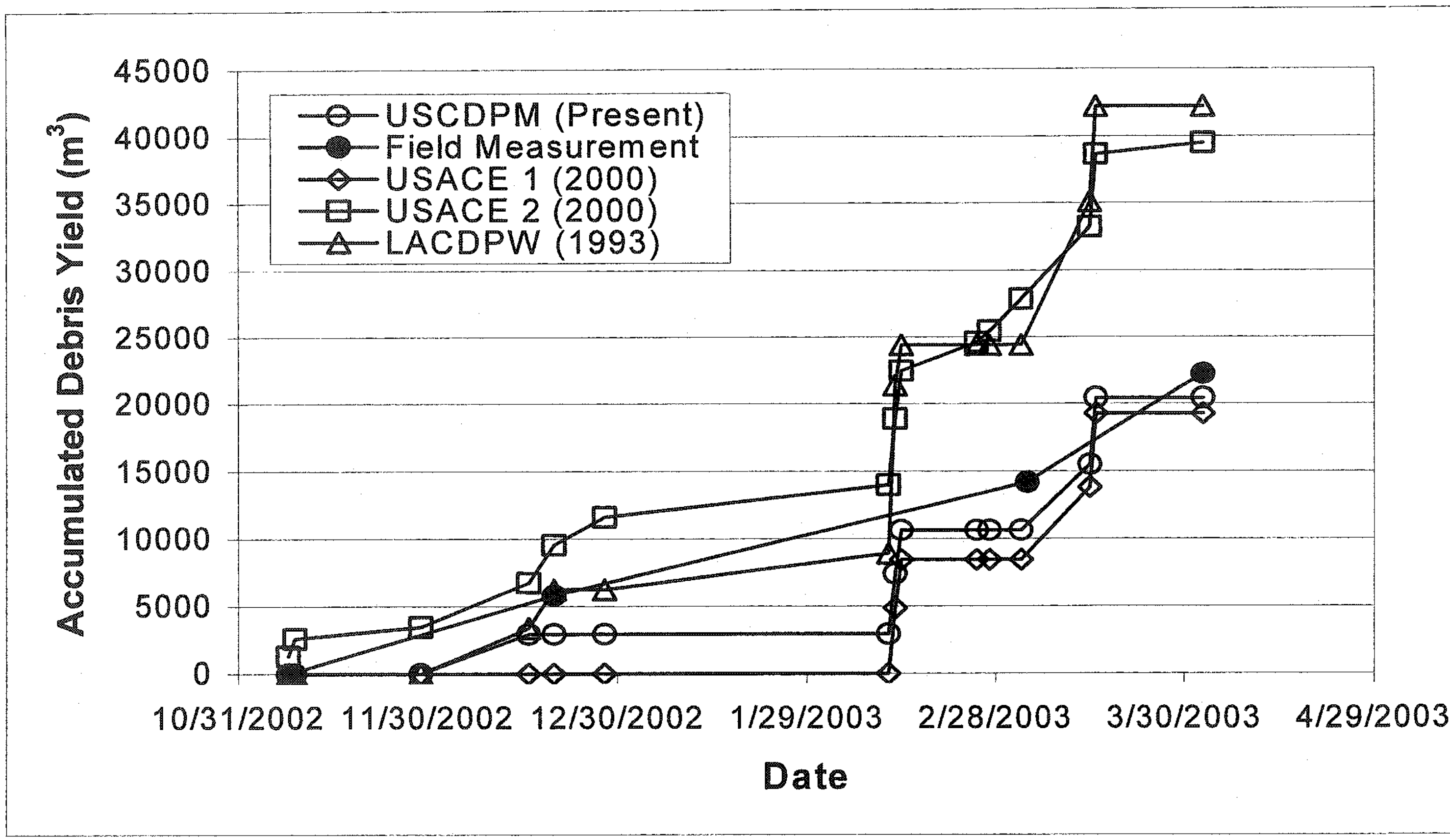

FIG. 6.3 Comparison with Estimated D_y and Measured D_y for Childs DB

6.1.5 Auburn Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity (TMRI=5.655 mm/hr) and the Total Minimum Rainfall Amount (TMRA=18.317 mm) for the Auburn Debris basins are determined through the equation $y = \mathbf{175.05}\boldsymbol{X}^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}\boldsymbol{X}^{0.6465}$ of Fig. 5.17, respectively. For the Auburn Debris Basin, the measured debris yield is 8,364 m^3 generated with rainfall events between October 11, 1993 and March 11, 1994 while the estimated debris yield by the USCDPM is 8,298 m^3 with the precipitation data obtained from the Sierra Madre Station Precipitation Gage. The difference of the two values is 66 m^3, (0.8%). The USACE and LACDPW methods are compared with USCDPM in Table 6.6.

TABLE 6.6 Summary of Analysis for Auburn Debris Basin

Method	Estimated D_y (m^3)	Measured D_y (m^3)	Difference (m^3)	Difference (%)
USCDPM	8,298	8,364	-66	-1
USACE1	0	8,364	-8,364	-100
USACE2	24,044	8,364	15,680	187
LACDPW1	19,913	8,364	11,550	138

USACE1-Calculated with antecedent rainfall condition for significant debris yield to occur: Approximately 50.8 mm (2 inches) within an approximately 48-hr period.
USACE2-Calculated with all rainfall events.
LACDPW-Calculated with >0.05 in/hr Maximum 1-hr Rainfall Intensity.
Measured D_y-Measured based on truck counts as no survey of the basin.

The precipitation data are obtained from the Sierra Madre Raingage Station. The more detailed procedures of calculation are delineated in Table 6.7 and Fig. 6.4.

TABLE 6.7 Calculation Sheet for Auburn Debris Basin

Date	D_y (m^3)	ΣD_y (m^3)	I (mm/hr)	P (mm)	I_c (mm/hr)	P_c (mm)	B_p	B_y	A_p	F
10/11/1993	0	0	1.016	2.540	5.655	18.317	0.78	1		
11/11/1993	0	0	5.080	10.922	5.655	18.317	0.78	1		
11/29/1993	0	0	10.414	16.256	5.655	18.317	0.78	1		
12/11/1993	2,124	2,124	9.906	18.796	5.655	18.317	0.78	1	0	5.68
12/14/1993	2,431	4,555	12.192	18.542	5.655	18.317	0.78	1	1	5.65
12/17/1993	0	4,555	0.762	0.762	5.655	18.317	0.78	1		
1/24/1994	0	4,555	14.224	17.272	5.655	18.317	0.78	1		
1/25/1994	0	4,555	3.048	5.334	5.655	18.317	0.78	1		
2/4/1994	0	4,555	5.080	22.860	5.655	18.317	0.78	1		
2/6/1994	0	4,555	0.762	0.762	5.655	18.317	0.78	1		
2/7/1994	1,493	6,047	6.096	20.574	5.655	18.317	0.78	1	2	5.62
2/8/1994	0	6,047	10.160	13.462	5.655	18.317	0.78	1		
2/17/1994	0	6,047	8.128	18.034	5.655	18.317	0.78	1		
2/20/1994	2,250	8,298	11.176	32.004	5.655	18.317	0.78	1	3	5.59
3/6/1994	0	8,298	2.032	6.604	5.655	18.317	0.78	1		
3/7/1994	0	8,298	1.016	2.794	5.655	18.317	0.78	1		
3/11/1994	0	8,298	0.254	0.254	5.655	18.317	0.78	1		
Total	8,298 m^3									

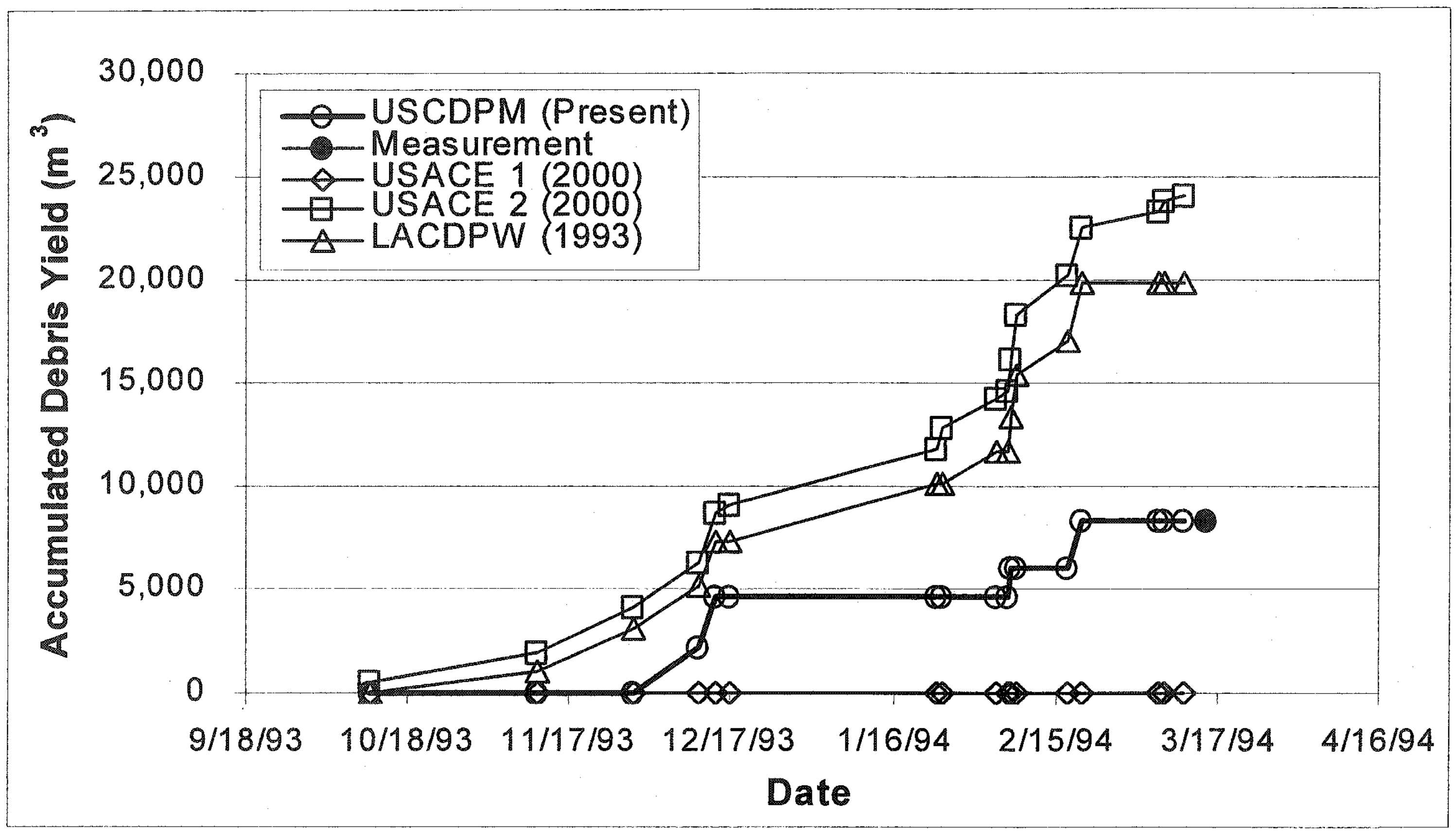

FIG. 6.4 Comparison with Estimated D_y and Measured D_y for Auburn DB

6.2 Evaluation of USCDPM

The Brand Debris Basin and Childs Debris Basin are chosen to cover different size and relief ratio of watersheds from a more recent fire event. The Auburn Debris Basin is added to show the very steep case in this comparison. The differences are related to the measured amounts. A summary of comparison with predicted results is presented in Table 6.8, showing the estimation by the Los Angeles District Debris Methods 1 and 2 of USACE and Debris Method of LACDPW, as well as the prediction by USCDPM for the Brand Debris Basin, Childs Debris Basin, and Auburn Debris Basin.

TABLE 6.8 Comparison of Debris Methods

Debris Basin	Area (ha)	Burn Area (%)	Relief Ratio (m/km)	USCDPM Difference (%)	USACE Method 1 Difference (%)	USACE Method 2 Difference (%)	LACDPW Method Difference (%)
Brand	267	90	280	-9.8	-26	51	7
Childs	81	80	314	-8.3	-13	78	90
Auburn	41	78	522	-0.8	-100	187	138

The Los Angeles District Debris Method of USACE is applied using two different scenarios for estimating the accumulated debris yields generated by subsequent storm events. The Los Angeles District Debris Method 1 of USACE uses the concept that the storm events be screened based on the degree of soil saturation. In areas such as coastal southern California, where some degree of soil saturation is considered necessary to initiate soil movement because of soil binding, precipitation should be used following an antecedent rainfall of approximately 50.8 mm (2-inch) in 48 hours (Amar et al. 1992; Gatwood et al. 2000). From Table 6.8, the results show differences of –26%, -13%, and -100% for the Brand Debris Basin, Childs Debris Basin, and Auburn Debris Basin, respectively.

The Los Angeles District Debris Method 2 of USACE is applied based on the whole storm events for the estimating of debris yields without considering the antecedent rainfall condition. The results have 51%, 78%, and 187% differences for the Brand Debris Basin, Childs Debris Basins, and Auburn Debris Basin, respectively.

The Debris Method of LACDPW has 7%, 90%, and 138% differences for the Brand Debris Basin, Childs Debris Basin, and Auburn Debris Basin, respectively when compared with the field data of collected debris volume. When the USCDPM is applied to predict the debris yields for the Brand Debris Basin, Childs Debris Basin, and Auburn Debris Basin with storm events, the results agree much better (within 9.8% of the measured amounts). The USCDPM apparently gives a closer estimated volume consistently when compared with other methods.

It should be noted that the measured debris yields were computed based on truck counts since the detailed survey of the basins were never available. Based on the results compared among different methods, one could reasonably conclude that the USCDPM can be used to predict the accumulated debris yields with greater consistency and reliability for coastal southern California watersheds having watershed in the range of 25-400 ha.

CHAPTER 7

7 Development of Debris Routing Method for Large Watersheds

Debris routing is a process used to predict the temporal and spatial variations of a debris flow as it moves through the reaches of the watershed. The effects of storage and flow resistance within a sub-watershed channel are reflected by changes in hydrograph shape and timing of the debris flow movement as the debris flow moves from the crest of sub-watershed to a concentration point.

7.1 Development of the Simplified Muskingum Routing Equation for USCDPM

The Muskingum routing equation can be shown as followed:

$$\boldsymbol{O_2 = C_1 I_2 + C_2 I_1 + C_3 O_1} \tag{7.1.1}$$

where: $C_1 = \dfrac{\Delta t - 2KX}{2K(1-X) + \Delta t}$

$C_2 = \dfrac{\Delta t + 2KX}{2K(1-X) + \Delta t}$

$C_3 = \dfrac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t}$

where: K = Travel Time of the floodwave through the reach

X = Dimensionless Weighting Factor, ranging from 0.0 to 0.5

Δt = Time Interval

The subscripts 1 and 2 in Eq. (7.1.1) indicated the beginning and end respectively, of a time interval Δt. The routing coefficients C_1, C_2, and C_3 are defined in terms of Δt, K, and X.

The debris routing equation is obtained by simplifying the Muskingum routing Eq. (7.1.1) because the time interval (Δt=1day) is much bigger than the travel time (K). The debris routing equation is simply depicted as:

$$Q_t = RI_t = \left(\frac{\Delta t - 2KX}{2K(1-X)+\Delta t} \right) I_t \tag{7.1.2}$$

where: Q_t = Rate of Outflow from the Routing Reach (m^3/day)

I_t = Rate of Inflow to the Routing Reach (m^3/day)

R = Dimensionless Debris Routing Factor

K = Travel Time of the debris flow through the reach (day)

X = Dimensionless Weighting Factor, ranging from 0.0 to 0.5

Δt = Time Internal (1day)

7.2 Determination of the Muskingum K and X

In an ungaged situation, a value for K can be estimated as travel time of the debris through routing reach. The debris velocity (V_d) is less than the average velocity at a given cross section for a given discharge. The average velocity Eq. (7.2.3) of the natural mountain channel is developed based on data provided by LACDPW. The effective slope Eq. (7.2.4) is developed based on the slope correction curve of mountain channels (LACDPW Hydrology/Sedimentation Appendix, 1993).

The debris velocity Eq. (7.2.1) can be determined by multiplying a debris velocity coefficient (C_{dv}) with the average velocity. The debris velocity coefficient (C_{dv}) is determined to be 0.12. This is determined by minimizing the residuals between the measured and estimated debris yields. Therefore the travel time K can be calculated with Eq. (7.2.2).

$$V_d = C_{dv} V \tag{7.2.1}$$

$$K = \frac{L}{V_d} \tag{7.2.2}$$

where: V_d = Debris Velocity (m/sec)

C_{dv} = Debris Velocity Coefficient

V = Average Velocity of Natural Mountain Channel (ft/sec)

$$= 5.4801 \times S_{eff}^{0.492} \times Q_p^{0.33} \tag{7.2.3}$$

where: S_{eff} = Effective Slope (m/m)

$$= 1.4223 S_{map}^3 - 2.1484 S_{map}^2 + 1.1642 S_{map} + 0.0007 \tag{7.2.4}$$

where: S_{map} = Map Slope (m/m)

$$Q_p = 0.2778 C_d i A$$

where: Q_p = Peak Water Discharge (m^3/sec)

C_d = Runoff Coefficient

I = Rainfall Intensity (mm/hr)

A = Sub-watershed Area (km^2)

L = Length of the Routing Reach (m)

After K has been estimated, a value for X can be determined through trial and error. Assume a value for X, and then calculate debris yield with parameter at the concentration point. Compare the total routed debris yields from sub-watersheds with measured debris yield at debris basin. Make adjustments to X to obtain the desired fit. Determination of the Muskingum X value in ungaged areas can be very difficult. X ranges between 0.0 and 0.5, with 0.0 providing the maximum attenuation and 0.5 no attenuation. Calibration has shown that for a steep channel in the mountain watershed, an X value of 0.35 is reasonable. Adjustments to the original estimate of K may also be necessary to obtain the best overall fit between estimated and measured debris yields.

7.3 Procedure for Application of USCDPM to Large Watersheds

1. Divide the watershed based on slopes, tributaries, and sub-watershed acreages (Approximately 30-250 ha).
2. Calculate debris yield generated by each storm event from each sub-watershed using USCDPM.
3. Calculate total debris yield through all sub-watersheds using the debris routing method at the concentration point for each storm event.
4. Add all debris yields generated by all storm events which have occurred during the storm season.

CHAPTER 8

8 Calibration of Debris Routing Method for Large Watersheds

The William Fire (September 22, 2002) in the Azusa to Claremont area is used to calibrate the routing method of USCDPM for large watersheds. The William Fire burned over 15,054 ha including the watershed of Little Dalton Wash. Due to high temperatures, Santa Ana winds, steep topography, and intense fire, control of the fire's perimeter was severely hampered. The fire burned at high to moderate intensity and destroyed over 60 residences (Storm Report Los Angeles County 2002-2003). Three factors (Muskingum parameter (X), Debris Velocity Coefficient (C_{dv}), and Runoff Coefficient (C_d)) are determined as 0.35, 0.12, and 0.45, respectively, via the model calibration that minimized the residuals between the measured and estimated debris yields.

The Big Dalton Dam precipitation gage (223C) is chosen for the data analysis because its precipitation data are closest in proximity to the Little Dalton Watershed and are consistent with measured debris yield data through the data screening. The watershed of Little Dalton Debris Basin was burned 89% by the William Fire as shown on Fig. 8.1. Table 8.1 indicates the burn conditions and watershed characteristics of the Little Dalton watershed.

TABLE 8.1 Characteristics of Watershed burned by William Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Little Dalton	853	89	93	1.04

The Threshold Maximum 1-hr Rainfall Intensity and the Total Minimum Rainfall Amount for all sub-watersheds of the Little Dalton debris basin are shown on Table 8.2 and are determined through the equation $y = \mathbf{175.05}X^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}X^{0.6465}$ of Fig. 5.17, respectively.

TABLE 8.2 Sub-Watershed Characteristics of Little Dalton Debris Basin

Sub-Watershed	I_c (mm/hr)	P_c (mm)	S (m/km)	A (ha)
WS1	11.216	28.515	149.015	229.712
WS2	7.722	22.400	294.112	56.295
WS3	8.244	23.369	261.053	82.773
WS4	8.251	23.382	260.624	82.216
WS5	6.876	20.782	363.290	24.967
WS6	6.039	19.110	460.101	16.221
WS7	6.863	20.756	364.562	14.074
WS8	8.135	23.168	267.459	62.418
WS9	11.802	29.469	135.817	284.497

8.1 Procedure Used for Applying USCDPM to Little Dalton Debris Basin

1. The watershed of Little Dalton Debris Basin is divided based on slopes, tributaries, and sub-watershed acreages (14-284 ha) as shown on Fig. 8.2.
2. USCDPM is applied to calculate the debris yields generated by each effective storm event from all sub-watersheds (Fig. 8.3) based on watershed characteristics of each sub-watershed indicated in Table 8.2.

3. The debris routing method is used to calculate the total debris yield through all sub-watersheds at the concentration point for each effective storm event as depicted in Fig. 8.3.

4. All debris yields generated by all storm events which occurred during the storm season are added and summarized in Table 8.3.

The detailed calculations are depicted in Fig. 8.3 and Table 8.3 for the Little Dalton Debris Basin. The measured debris yield generated with rainfall events between September 28, 2002 and December 29, 2002 is 64,000 m^3 while the estimated debris yield calculated by the USCDPM with precipitation data obtained from the Big Dalton Dam precipitation gage is 59,930 m^3. The difference of the two values is -4,070 m^3, (-6.4%).

TABLE 8.3 Summary of Calculation for Little Dalton Debris Basin

Date	Routed Dy (m3)	Accu. Routed Dy (m3)	I (mm/hr)	P (mm)	Ic (mm/hr)	Pc (mm)	Burn% (BP)/100	#of Yr after Burn(By)
9/28/2002	0	0	1.9812	2.9718	11.802	29.469	0.89	1
9/29/2002	0	0	0.9906	0.9906	11.802	29.469	0.89	1
11/8/2002	10,300	10,300	8.9408	83.2612	11.802	29.469	0.89	1
11/9/2002	1,369	11,669	6.9596	65.5066	11.802	29.469	0.89	1
11/29/2002	0	11,669	4.953	4.953	11.802	29.469	0.89	1
11/30/2002	17,809	29,478	18.923	24.892	11.802	29.469	0.89	1
12/16/2002	30,452	59,930	11.9634	45.212	11.802	29.469	0.89	1
12/17/2002	0	59,930	0.9906	0.9906	11.802	29.469	0.89	1
12/20/2002	0	59,930	5.969	26.797	11.802	29.469	0.89	1
12/29/2002	0	59,930	1.9812	4.953	11.802	29.469	0.89	1
Total	59,930 m3							

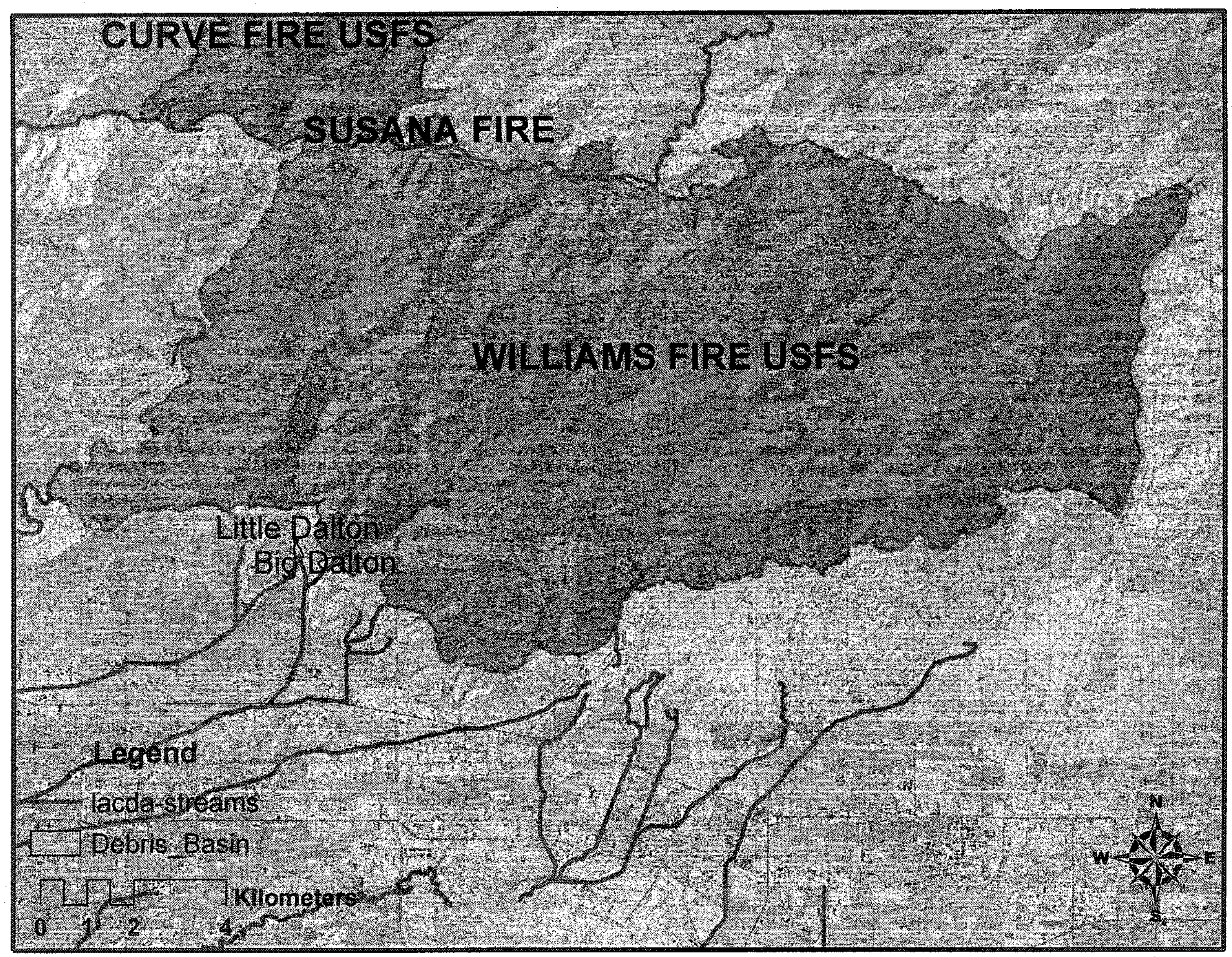

FIG. 8.1 Fire Map of William Fire

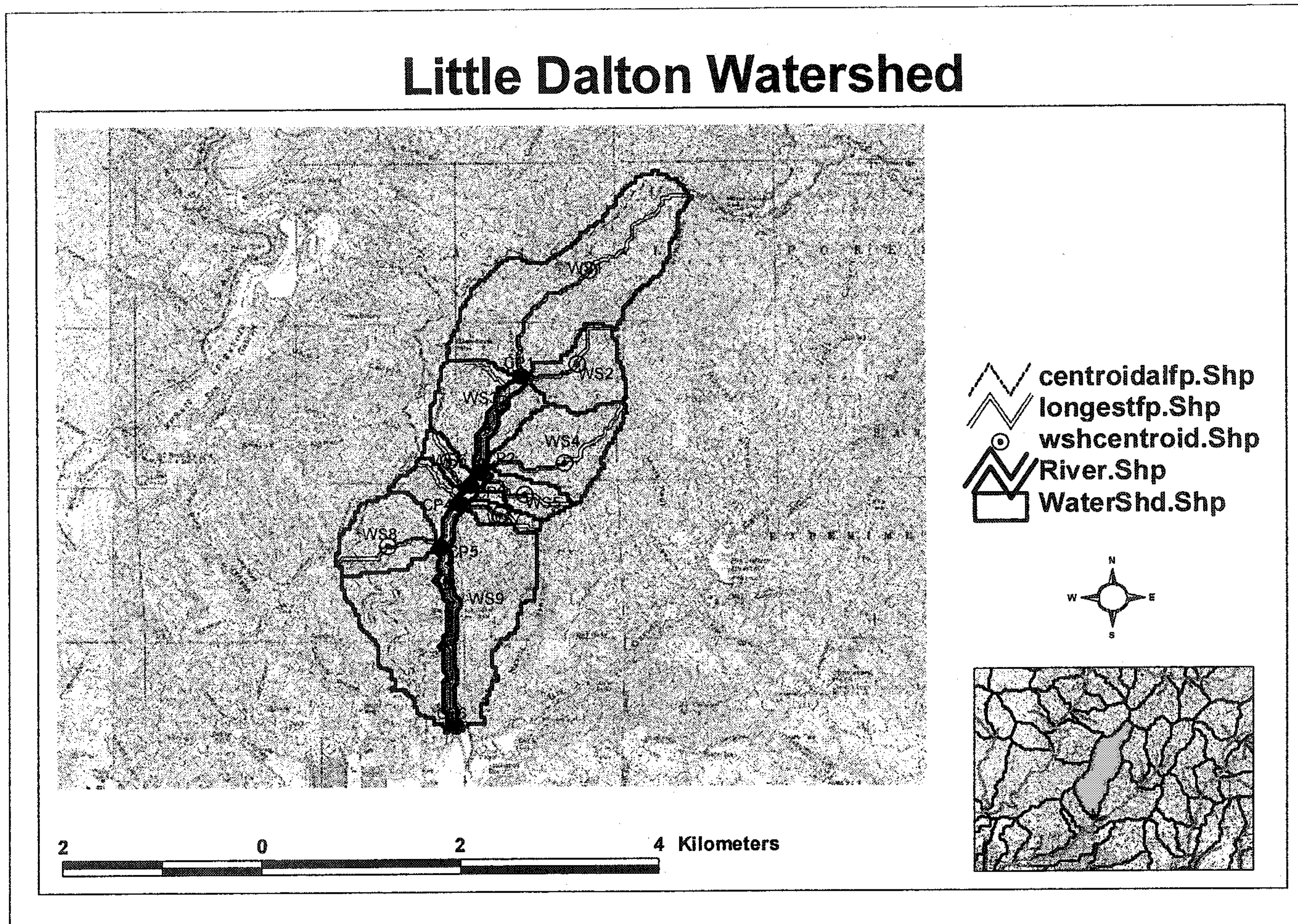

FIG. 8.2 Little Dalton Watershed

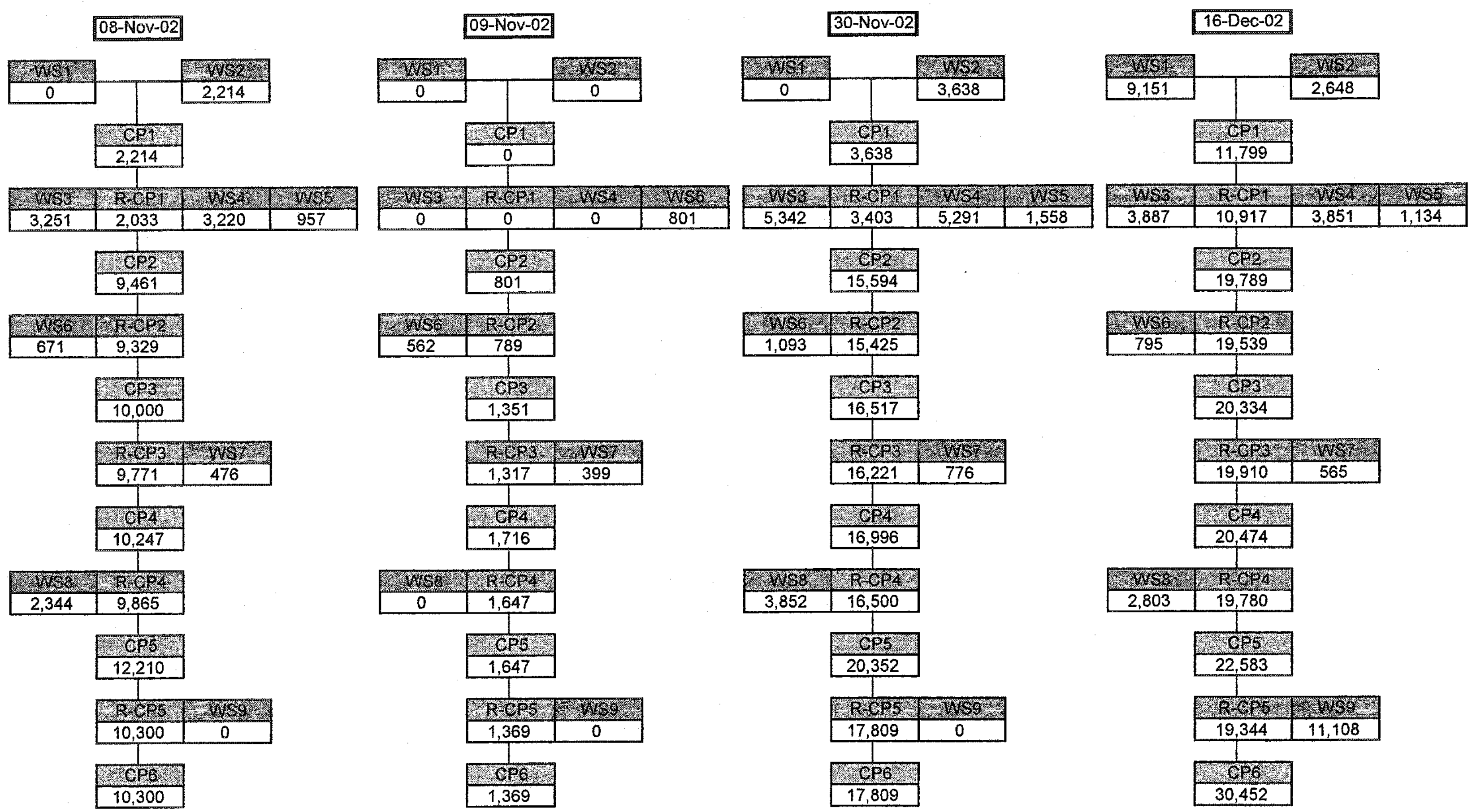

FIG. 8.3 Debris Yields Routing Diagrams for Little Dalton Debris Basin

CHAPTER 9

9 Application and Evaluation for Large Watersheds

After calibration, the USCDPM is directly applied to predict the debris yields from the large watersheds caused by subsequent storm events after the Padua Fire, Grand Prix Fire, and Old Fire (October and November, 2003) in the San Gabriel Mountains and San Bernardino Mountains and the results are then compared with the field data. The Padua, Grand Prix, and Old Fire burned nearly 36,826 ha including the watersheds of Cucamonga Creek Debris Basin, Deer Creek Debris Basin, and Day Creek Debris Basin. Precipitation data are collected from three precipitation gages (Demens Creek Debris Basin (DCDB), Mt. Baldy (MTBY), and San Antonia Dam (SNTO)), located in vicinity of the Grand Prix Fire area. The Mt. Baldy (MTBY) precipitation gage is chosen for the data analysis because its precipitation data are reliable and its elevation is closer to the average elevation of watersheds. The watersheds of above three debris basin burned 100% by the Grand Prix Fire as shown on Fig. 9.1.

TABLE 9.1 Characteristics of Watershed burned by Old Fire

Watershed Name	Drainage Area (ha)	Burn (%)	Relief Ratio (m/km)	Watershed Correlation Factor
Cucamonga Creek	2,915	100	157	1
Deer Creek	966	100	244	1
Day Creek	1,262	100	211	1

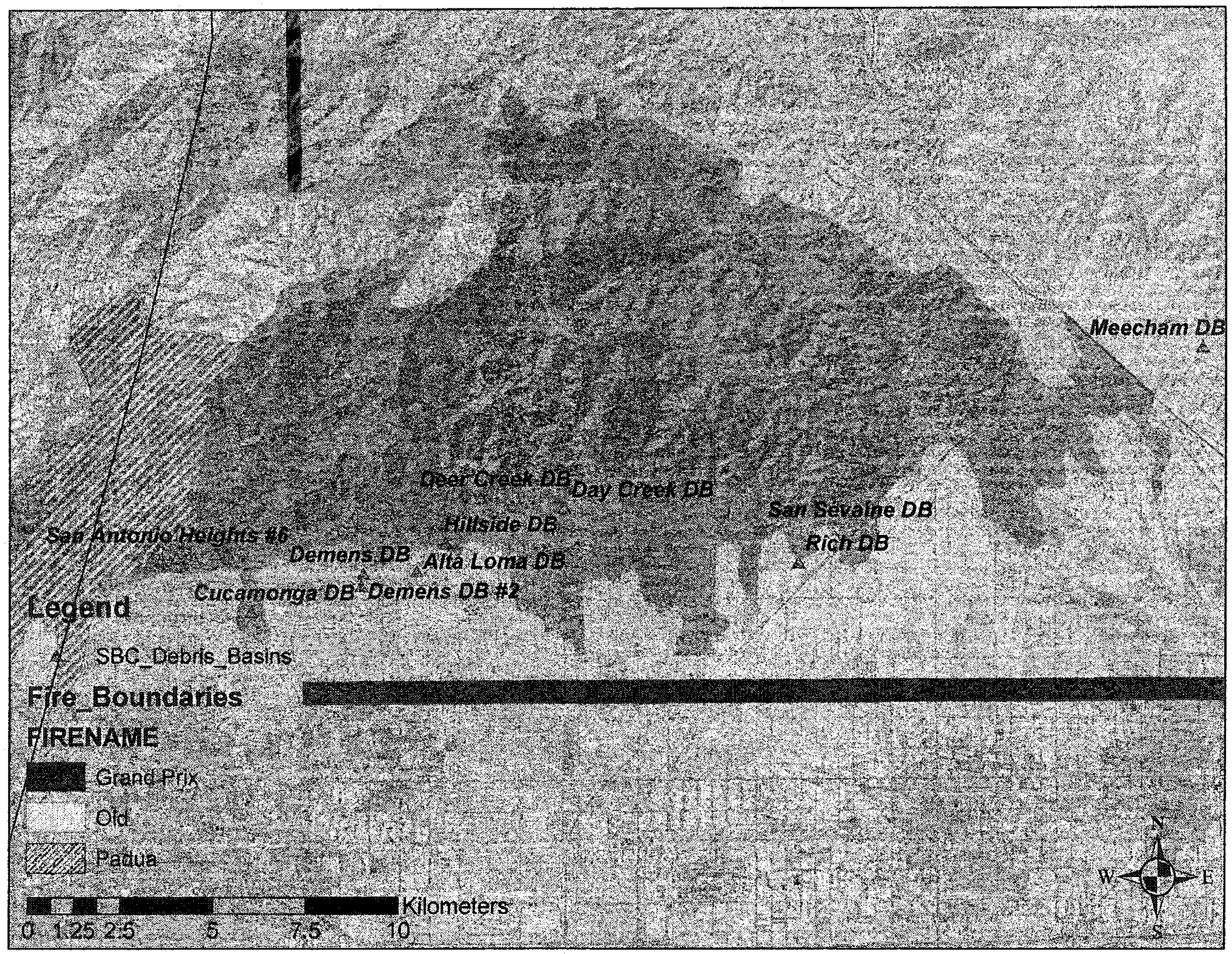

FIG. 9.1 Fire Map of Grand Prix Fire

9.1 Cucamonga Creek Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity and the Total Minimum Rainfall Amount for the Cucamonga Creek Debris Basin are determined through the equation $y = \mathbf{175.05}X^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}X^{0.6465}$ of Fig. 5.17, respectively. The watershed of Cucamonga Creek Debris Basin is divided based on slopes, tributaries, and sub-watershed acreages (44-245 ha) as shown on Fig. 9.2. USCDPM is applied to calculate the debris yields (Fig. 9.3) generated by each effective storm event from all sub-watersheds based on watershed characteristics of each sub-watershed indicated in Table 9.2.

The debris routing method is used to calculate the total debris yield through all sub-watersheds at the concentration point for each effective storm event as depicted in Fig. 9.3. All debris yields generated by all storm events which occurred during the storm season are added and summarized in Table 9.3. The measured debris yield generated by rainfall events between November 1, 2003 and January 2, 2004 is 348,010 m^3 while the estimated debris yield by the USCDPM is 306,981 m^3 with the precipitation data obtained from the Big Dalton Dam precipitation gage. The difference of the two values is –41,029 m^3, (-12%) as indicated in Fig. 9.4.

TABLE 9.2 Sub-Watershed Characteristics of Cucamonga Creek Debris basin

Sub-Watershed	I_c (mm/hr)	P_c (mm)	S (m/km)	A (ha)
WS1	5.331	17.630	577.378	76.005
WS2	6.125	19.285	448.427	93.897
WS3	6.120	19.275	449.078	121.988
WS4	5.872	18.765	484.301	88.754
WS5	5.850	18.721	487.531	72.392
WS6	6.079	19.191	454.679	74.223
WS7	7.108	21.233	341.972	53.528
WS8	5.795	18.608	495.966	148.847
WS9	5.015	16.946	645.445	43.972
WS10	6.310	19.659	424.792	98.991
WS11	6.085	19.203	453.840	88.934
WS12	7.529	22.037	307.976	82.549
WS13	6.649	20.337	386.132	122.538
WS14	5.687	18.382	513.332	92.246
WS15	6.091	19.216	453.003	84.561
WS16	7.676	22.315	297.292	131.535
WS17	8.914	24.580	226.405	119.756
WS18	9.502	25.616	201.547	191.888
WS19	9.502	25.616	398.664	230.426
WS20	8.032	22.978	273.746	117.605
WS21	5.835	18.689	489.912	122.068
WS22	9.625	25.830	196.880	244.536
WS23	9.954	26.397	185.213	185.613
WS24	9.077	24.870	219.059	98.221
WS25	17.444	37.939	66.667	130.023

TABLE 9.3 Summary of Calculation for Cucamonga Creek Debris Basin

Date	Dy (m^3)	Accu. Dy (m^3)	I (mm/hr)	P (mm)	Ic (mm/hr)	Pc (mm)	Burn %(BP)/100	#of Yr after Burn(By)
11/1/2003	0	0	4.826	26.162	0.297	2.726	1	1
11/12/2003	69,394	69,394	7.874	22.352	0.297	2.726	1	1
12/25/2003	237,587	306,981	24.13	151.13	0.297	2.726	1	1
1/2/2004	0	306,981	1.778	11.43	0.297	2.726	1	1
Total	306,981 m^3							

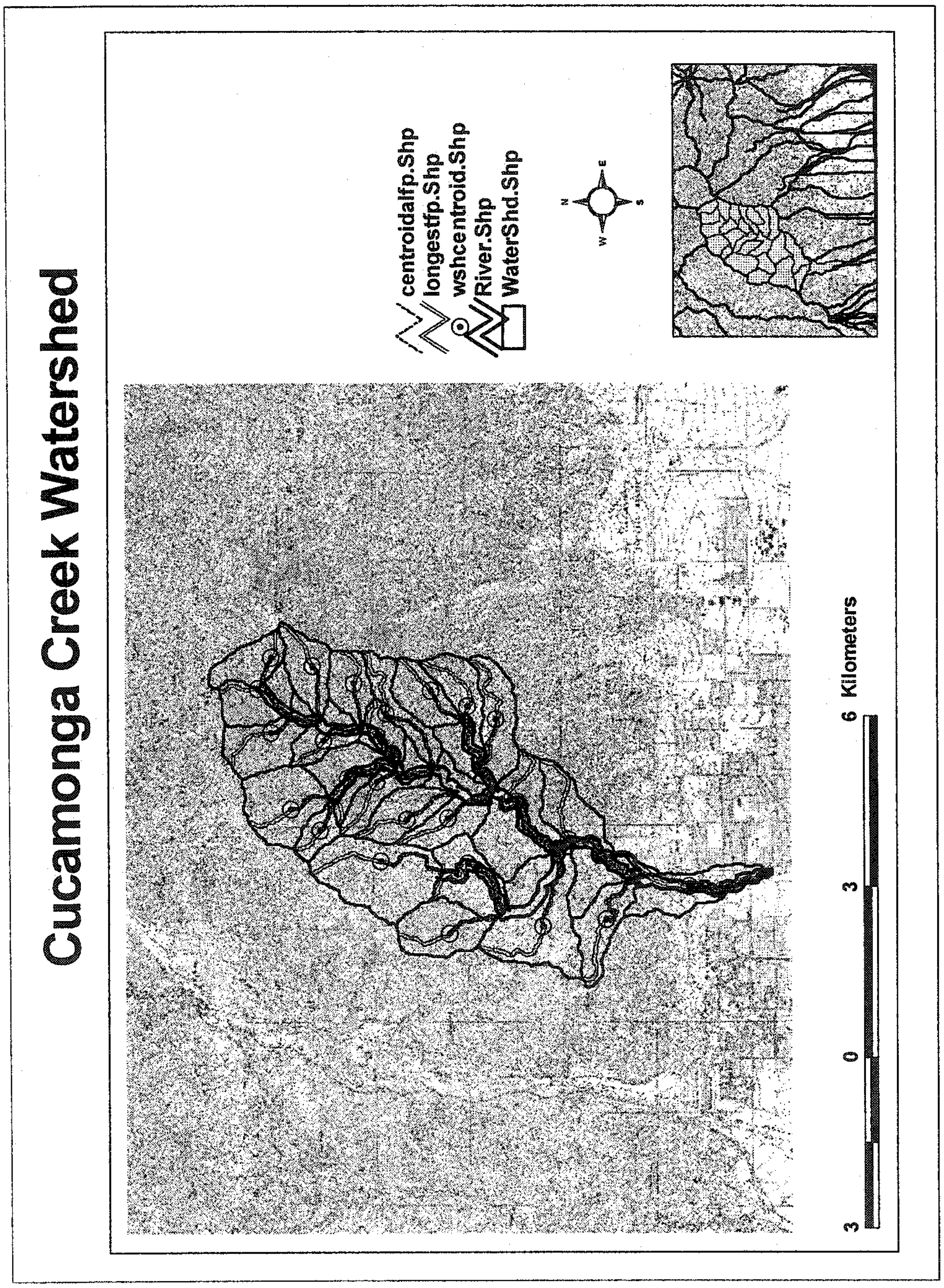

FIG. 9.2 Cucamonga Creek Watershed

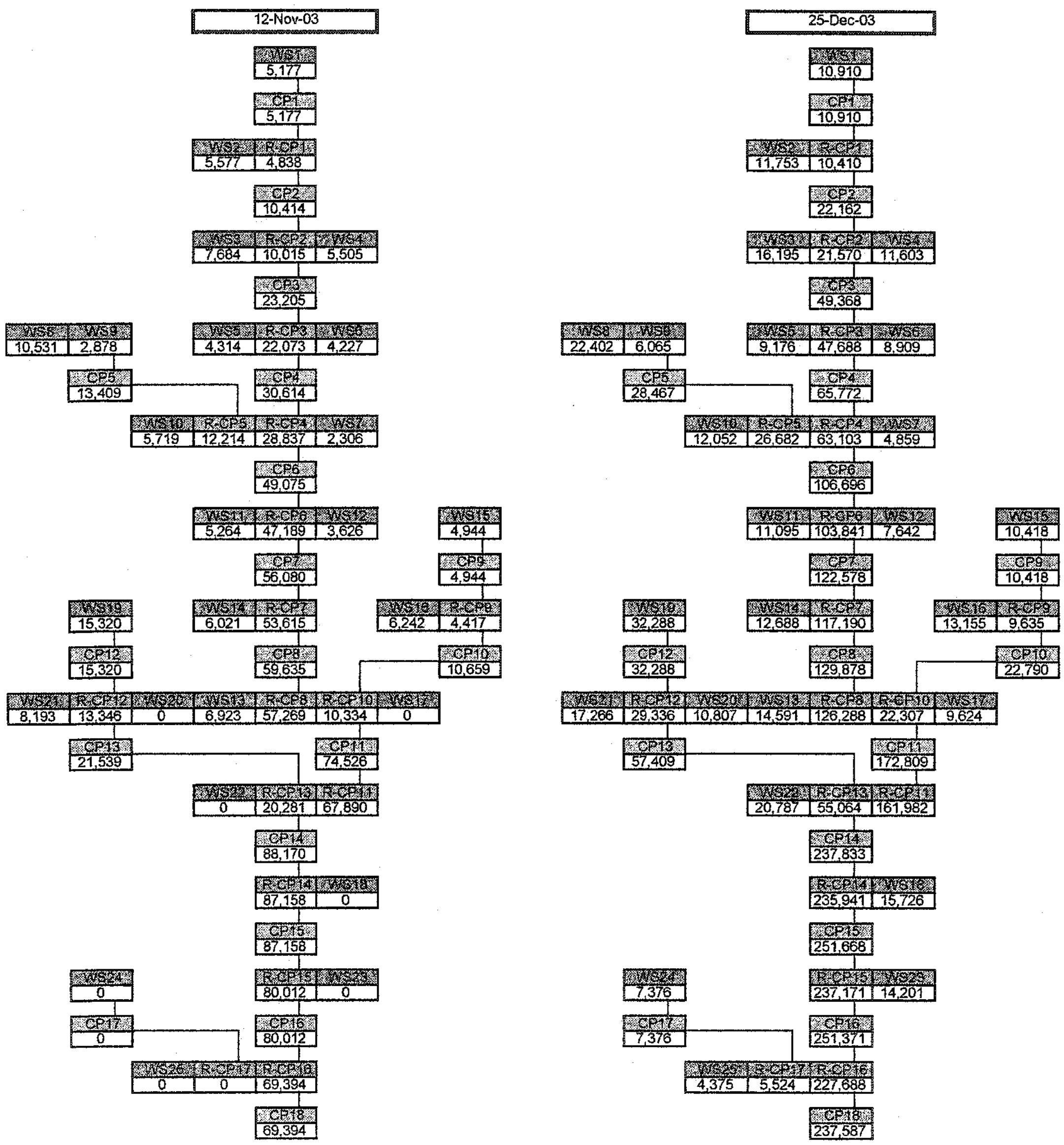

FIG. 9.3 Debris Yields Routing Diagrams for Cucamonga Creek Debris Basin

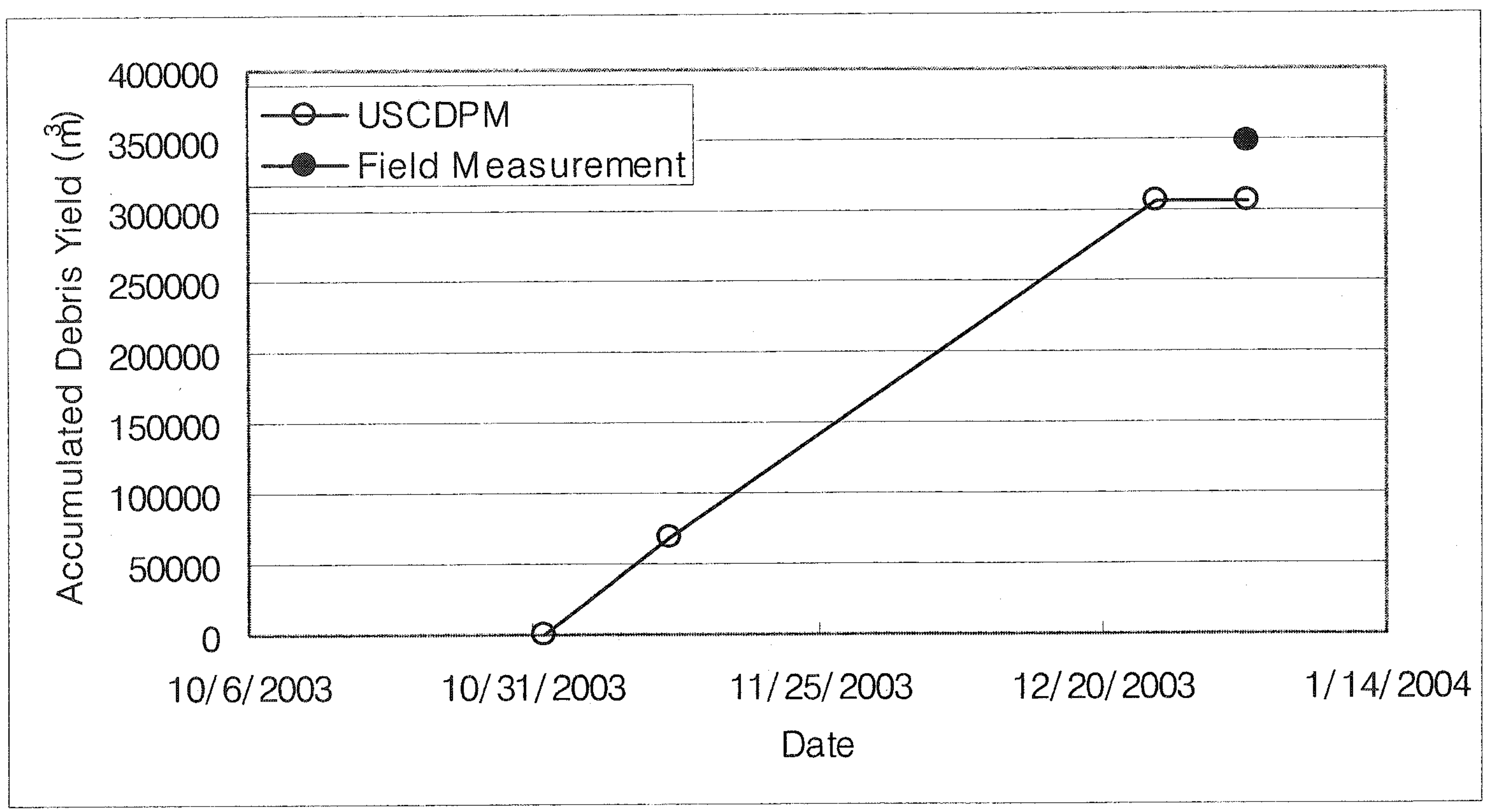

FIG. 9.4 Comparison with Estimated D_y and Measured D_y for Cucamonga Creek Debris Basin

9.2 Deer Creek Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity and the Total Minimum Rainfall Amount for the Deer Creek debris basin are determined through the equation $y = \mathbf{175.05}X^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}X^{0.6465}$ of Fig. 5.17, respectively. The watershed of Deer Creek Debris Basin is divided based on slopes, tributaries, and sub-watershed acreages (30-180 ha) as shown on Fig. 9.5. USCDPM is applied to calculate the debris yields (Fig. 9.6) generated by each effective storm event from all sub-watersheds based on watershed characteristics of each sub-watershed indicated in Table 9.4.

TABLE 9.4 Sub-Watershed Characteristics of Deer Creek Debris Basin

Sub-Watershed	I_c (mm/hr)	P_c (mm)	S (m/km)	A (ha)
WS1	5.541	18.076	538.149	115.223
WS2	6.859	20.748	364.962	179.919
WS3	6.480	20.000	404.705	95.939
WS4	7.358	21.713	321.075	82.159
WS5	8.021	22.959	417.036	89.504
WS6	6.374	19.789	399.527	72.992
WS7	6.526	20.092	293.935	60.473
WS8	7.724	22.405	372.971	72.312
WS9	6.777	20.589	359.145	90.205
WS10	6.919	20.867	298.766	29.721
WS11	7.655	22.276	298.766	77.836

The debris routing method is used to calculate the total debris yield through all sub-watersheds at the concentration point for each effective storm event as depicted in Fig. 9.6. All debris yields generated by all storm events which occurred during the storm season are added and summarized in Table 9.5. The measured debris yield generated by rainfall events between November 1, 2003 and January 2, 2004 is 160,768 m^3 while the estimated debris yield by the USCDPM is 132,317 m^3 with the precipitation data obtained from the Big Dalton Dam precipitation gage. The difference of the two values is –28,451 m^3, (-17.7%) as indicated in Fig. 9.7.

TABLE 9.5 Summary of Calculation for Deer Creek Debris Basin

Date	Dy (m^3)	Accu. Dy (m^3)	I (mm/hr)	P (mm)	Ic (mm/hr)	Pc (mm)	Burn %(BP)/100	#of Yr after Burn(By)
11/1/2003	0	0	4.826	26.162	7.655	22.276	1	1
11/12/2003	36,600	36,600	7.874	22.352	7.655	22.276	1	1
12/25/2003	95,717	132,317	24.13	151.13	7.655	22.276	1	1
1/2/2004	0	132,317	1.778	11.43	7.655	22.276	1	1
Total	132,317 m^3							

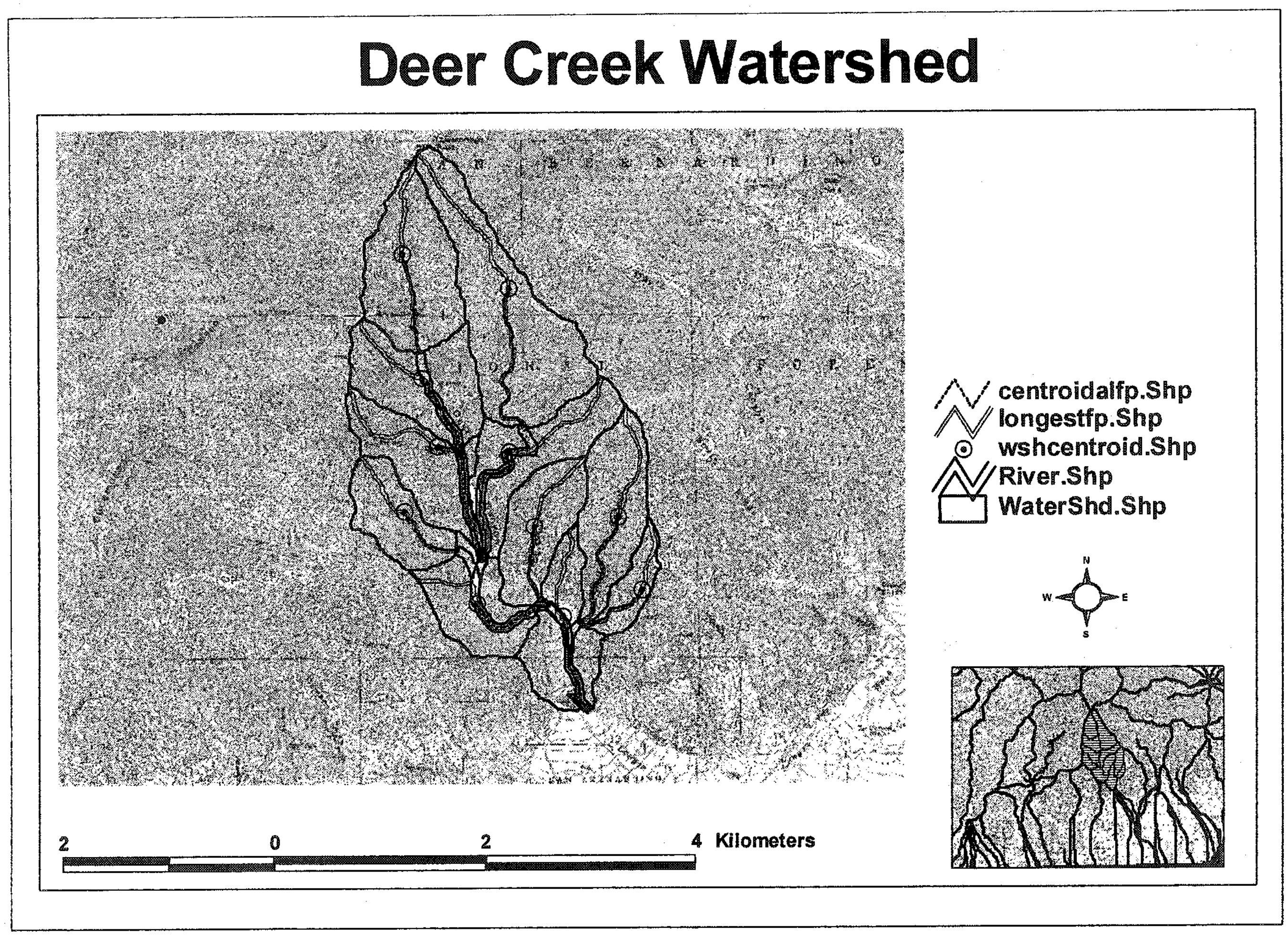

FIG. 9.5 Deer Creek Watershed

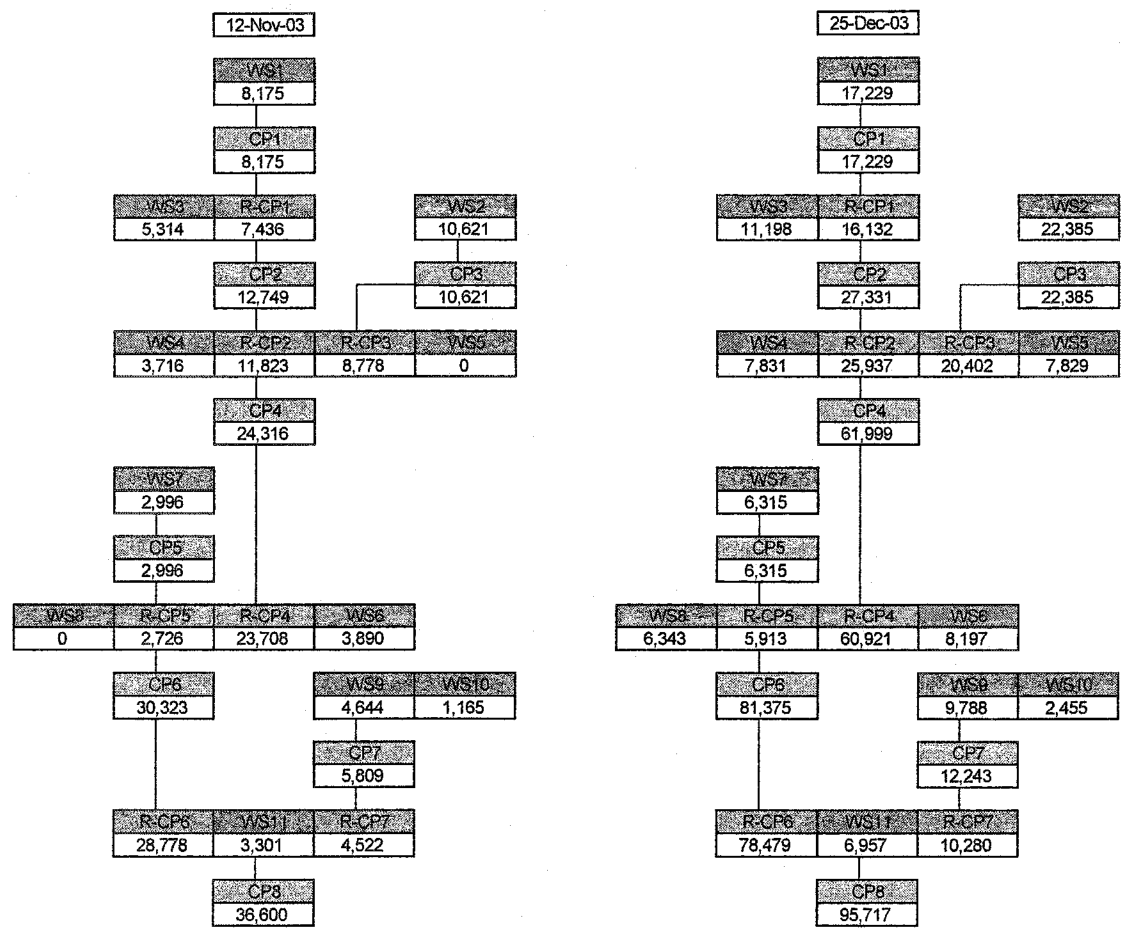

FIG. 9.6 Debris Yields Routing Diagrams for Deer Creek Debris Basin

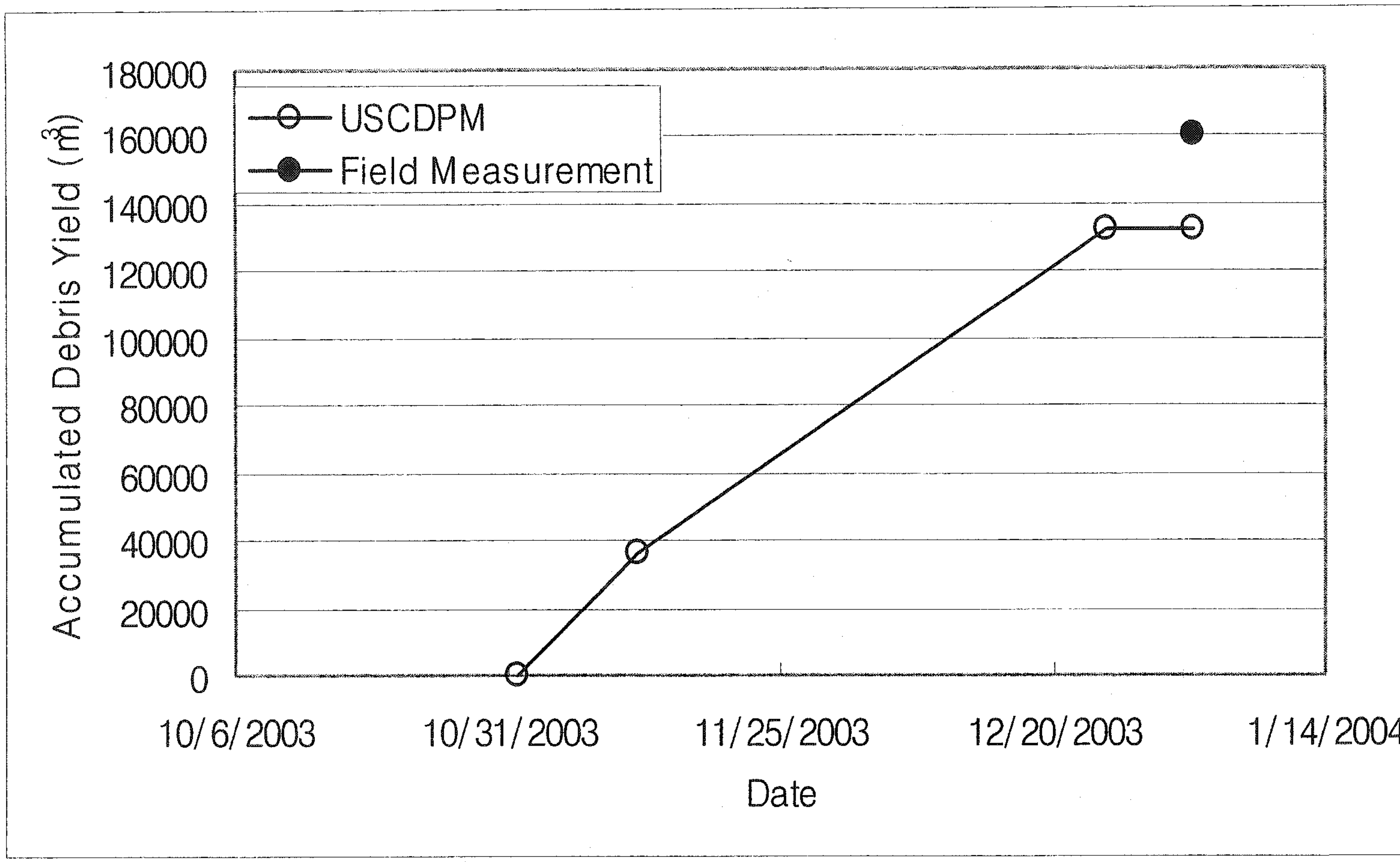

FIG. 9.7 Comparison with Estimated D_y and Measured D_y for Deer Creek Debris Basin

9.3 Day Creek Debris Basin

The Threshold Maximum 1-hr Rainfall Intensity and the Total Minimum Rainfall Amount for the Day Creek debris basin are determined through the equation $y = \mathbf{175.05}X^{-0.5491}$ of Fig. 5.16 and the equation $y = \mathbf{5.9752}X^{0.6465}$ of Fig. 5.17 respectively. The watershed of Deer Creek Debris Basin is divided based on slopes, tributaries, and sub-watershed acreages (34-172 ha) as shown on Fig. 9.8. USCDPM is applied to calculate the debris yields (Fig. 9.9) generated by each effective storm event from all sub-watersheds based on watershed characteristics of each sub-watershed indicated in Table 9.6.

TABLE 9.6 Sub-Watershed Characteristics of Day Creek Debris Basin

Sub-Watershed	I_c (mm/hr)	P_c (mm)	S (m/km)	A (ha)
WS1	5.513	18.017	543.164	58.742
WS2	4.877	16.642	679.207	40.629
WS3	6.221	19.480	435.934	128.452
WS4	5.553	18.101	536.042	37.387
WS5	5.909	18.842	478.750	73.203
WS6	7.136	21.286	339.551	68.059
WS7	6.112	19.258	450.183	77.496
WS8	7.515	22.012	308.975	98.661
WS9	6.131	19.298	447.611	33.614
WS10	6.338	19.717	421.339	171.813
WS11	6.738	20.512	376.903	113.732
WS12	7.582	22.139	304.009	165.919
WS13	6.661	20.359	384.954	56.591
WS14	9.902	26.308	186.984	137.479

The debris routing method is used to calculate the total debris yield through all sub-watersheds at the concentration point for each effective storm event as depicted in Fig. 9.9. All debris yields generated by all storm events which occurred during the storm season are added and summarized in Table 9.7. The measured debris yield generated by rainfall events between November 1, 2003 and January 2, 2004 is 148,046 m^3 while the estimated debris yield by the USCDPM is 169,511 m^3 with the precipitation data obtained from the Big Dalton Dam precipitation gage. The difference of the two values is 21,465 m^3, (14.5%) as indicated in Fig. 9.10.

TABLE 9.7 Summary of Calculation for Day Creek Debris Basin

Date	Dy (m^3)	Accu. Dy (m^3)	I (mm/hr)	P (mm)	Ic (mm/hr)	Pc (mm)	Burn %(BP)/100	#of Yr after Burn(By)
11/1/2003	0	0	4.826	26.162	9.902	26.308	1	1
11/12/2003	48,689	48,689	7.874	22.352	9.902	26.308	1	1
12/25/2003	120,822	120,822	24.13	151.13	9.902	26.308	1	1
1/2/2004	0	0	1.778	11.43	9.902	26.308	1	1
Total	169,511 m^3							

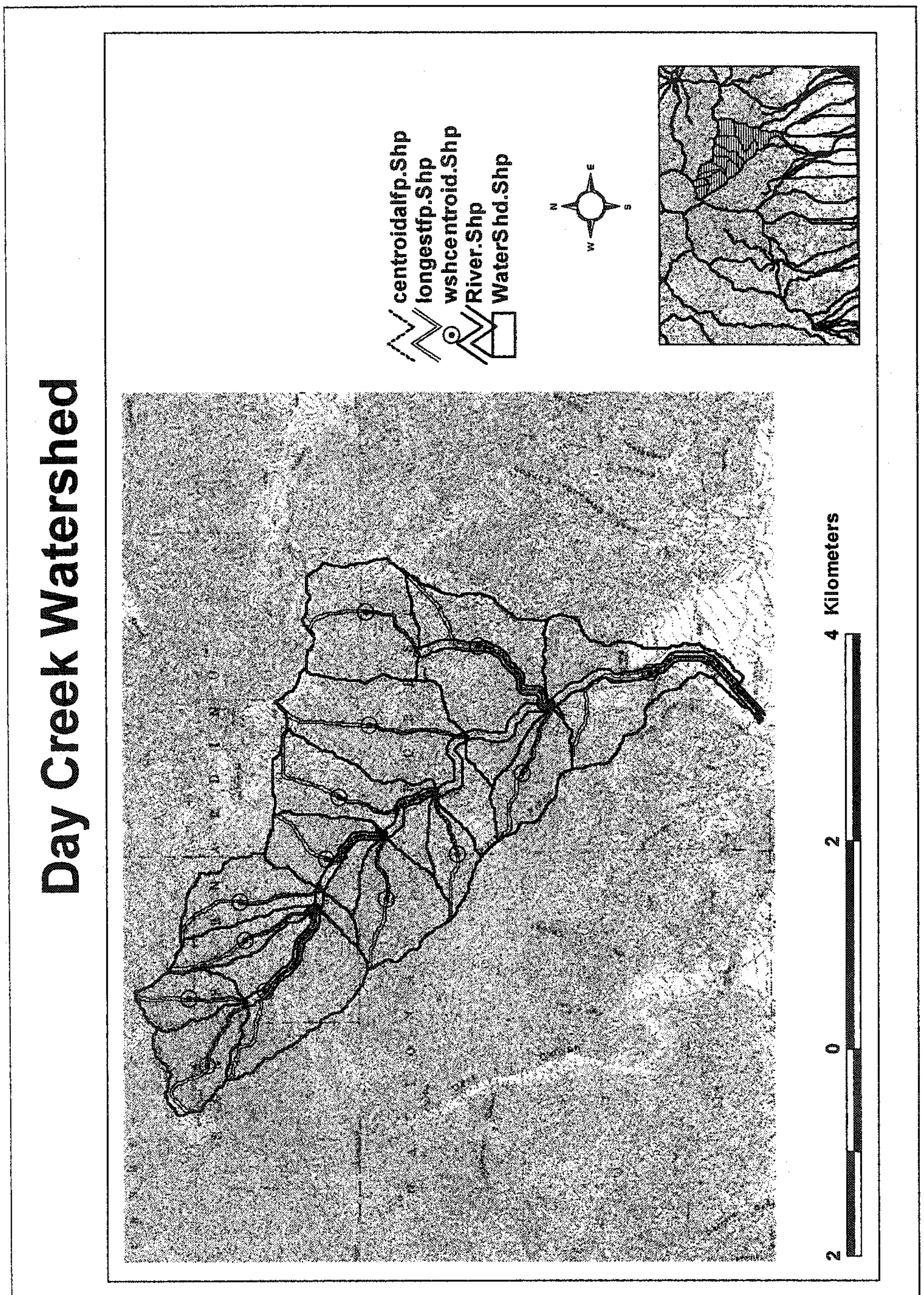

FIG. 9.8 Day Creek Watershed

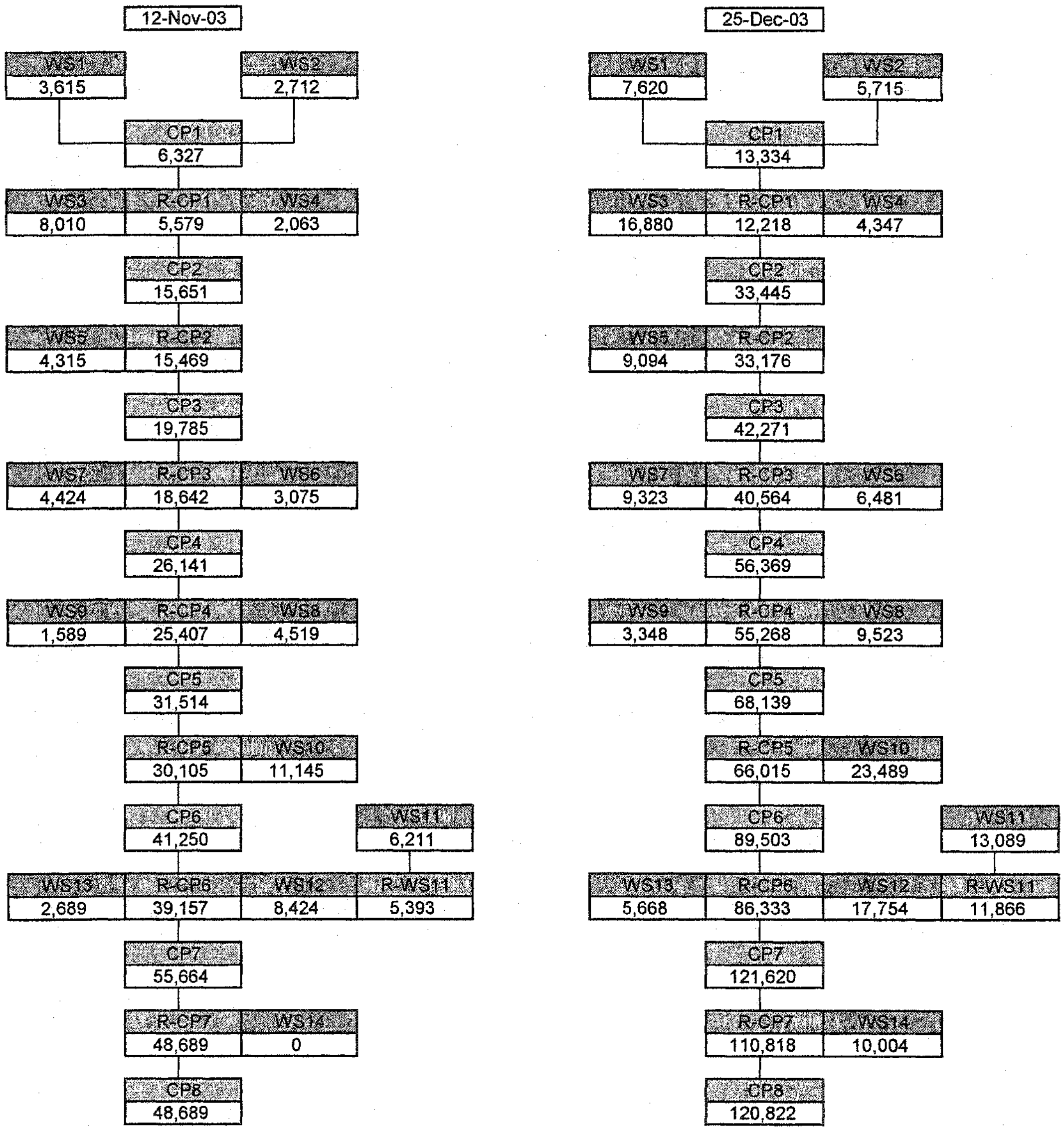

FIG. 9.9 Debris Yields Routing Diagrams for Day Creek Debris Basin

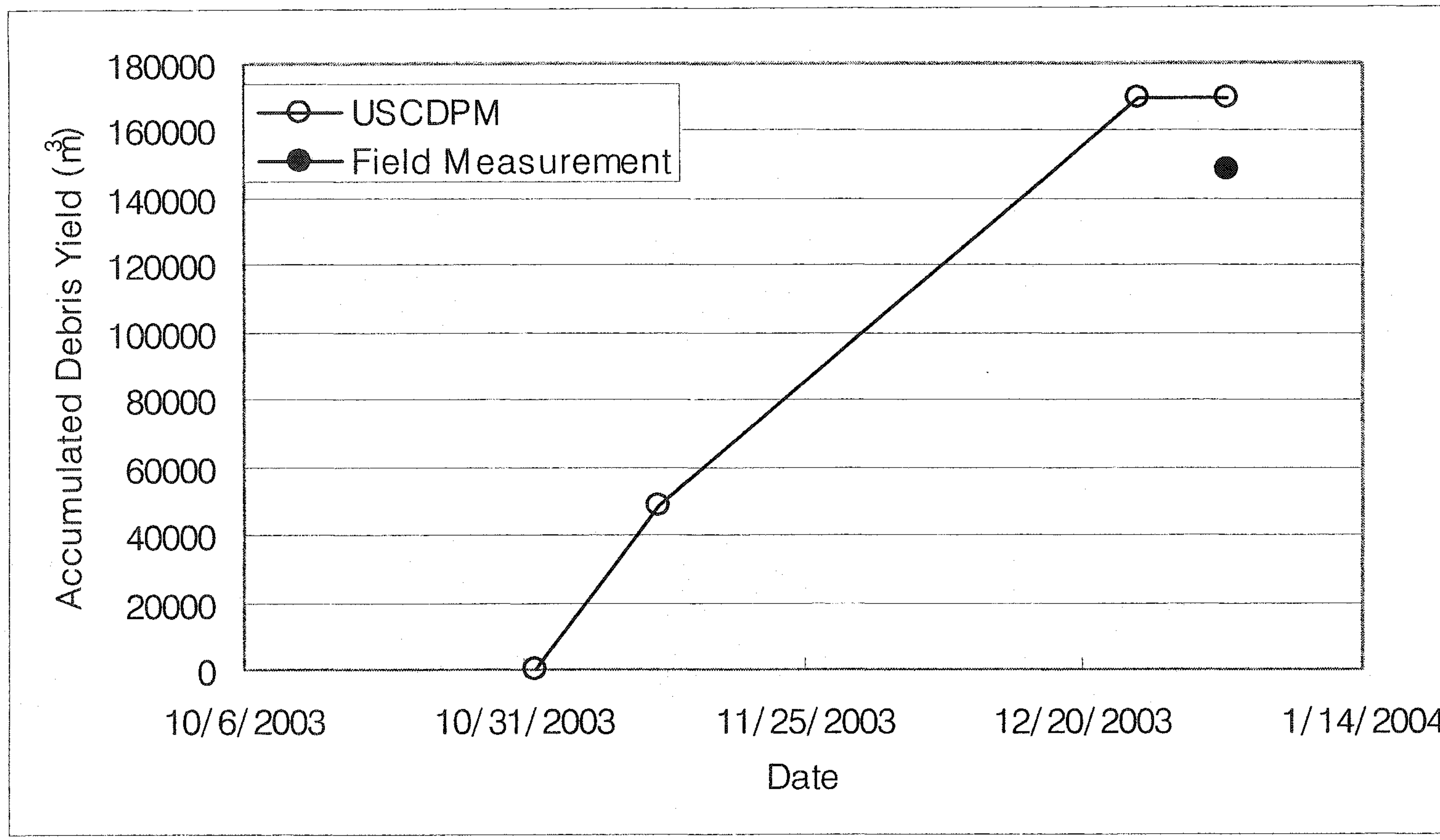

FIG. 9.10 Comparison with Estimated D_y and Measured D_y for Day Creek Debris Basin

The Cucamonga Creek Debris Basin, Deer Creek Debris Basin, and Day Creek Debris Basin are chosen to cover the large watershed from the Grand Prix fire (2003) event. The predicted debris yields and the measured values have been compared and summarized in Table 9.8.

TABLE 9.8 Summary of Predicted and Measured Results

Watershed	Estimated Debris Yield (m^3)	Measured Debris Yield (m^3)	Difference (m^3)	Difference (%)
Cucamonga Creek	306,981	348,010	-41,029	-12
Deer Creek	132,317	160,768	-28,451	-18
Day Creek	169,511	148,046	21,465	14

When the USCDPM is applied to predict the debris yields for the Cucamonga Creek Debris Basin, Deer Creek Debris Basin, and Day Creek Debris Basin with storm events, the results are in good agreement within 18% of the measured amounts. USCDPM apparently gives closer estimated volume consistently when compared with field data.

It should be noted that the measured amounts are the average values of survey data from USACE and SBCDPW. Based on the predicted results compared with field data, one could reasonably conclude that the USCDPM can be used to predict the accumulated debris yields using the debris routing method with consistency and reliability for Coastal Southern California watersheds in the range of 400-3,000 ha.

9.4 Development of Debris Rating Curve

It is useful to relate the debris discharge to the water discharge in the application of USCDPM to large watersheds. The debris discharge rates are plotted against the corresponding peak water discharge on logarithmic scale based on results of large watershed studies. This is shown on Fig. 9.11. The average specific weight of debris is calculated based on the sediment data of the reservoir, where the sediment is composed of 20% sand, 40% silt, and 40% clay, and the sediments are all submerged. The specific weights are 1,490 kg/m^3 (93.0 pcf), 1,224 kg/m^3 (76.4 pcf), and 993 kg/m^3 (62.0 pcf) for sand, silt, and clay, respectively. The average specific weight of the entire deposit is then $1490 \times 0.20 + 1224 \times 0.4 + 993 \times 0.40 = 1185$ kg/m^3 (74.0 pcf) (Vanoni, V.A., 1975). The debris yields for each individual watershed can be obtained directly from the debris rating curve shown in Fig. 9.11 with the peak discharge rates from the streamflow record. This rating curve eliminates the need for computing the debris yield for individual watersheds.

The effect of wildfire on debris yield is determined by changing the fire factor of USCDPM in terms of the percentage of burn. Therefore, additional graphs are developed to estimate the debris yields with different burn percentages. This is shown in Fig. 9.12. Using these rating curves, we can obtain the potential debris yield for the burned watersheds.

To compare the debris flow generated primarily by overland flows with the channel erosion generated by streamflow, the Santa Anita Canyon rating curve (Chow, V.T., 1964) is compared with the results from the large watershed study of

USCDPM in Fig. 9.13. It is interesting to note the difference in slopes of the two curves. The slope (0.8783) of USCDPM debris rating curve is much milder than the slope (1.3628) of Santa Anita Canyon rating curve. This is due to the fact that the debris flow from the mountain watershed is much denser than that in the streamflow. Therefore, the debris flow is much heavier than water flow, and has a more perspective of the threat involved. Figs. 9.11 and 9.12 show debris rating curves for debris flow in the Southern California area.

The present model, USCDPM, provides two major benefits for management of debris flows:

1. It can more efficiently manage the existing debris basins by optimum scheduling of debris removal immediately following a major event. This will allow restoring the storage capacity before the occurrence of subsequent storms.
2. It can effectively respond to emergency situations to protect human lives and to lessen the risks of economic damage by predicting more accurately the post-fire subsequent debris yields based on real-time precipitation data from gages linked with National Weather Service weather forecasts.

The present model is developed for prediction of debris yields for sub-basins in the San Gabriel Mountains within Los Angeles County and San Bernardino County. The use of the model in other areas should be tested in other regions with different hydrologic characteristics.

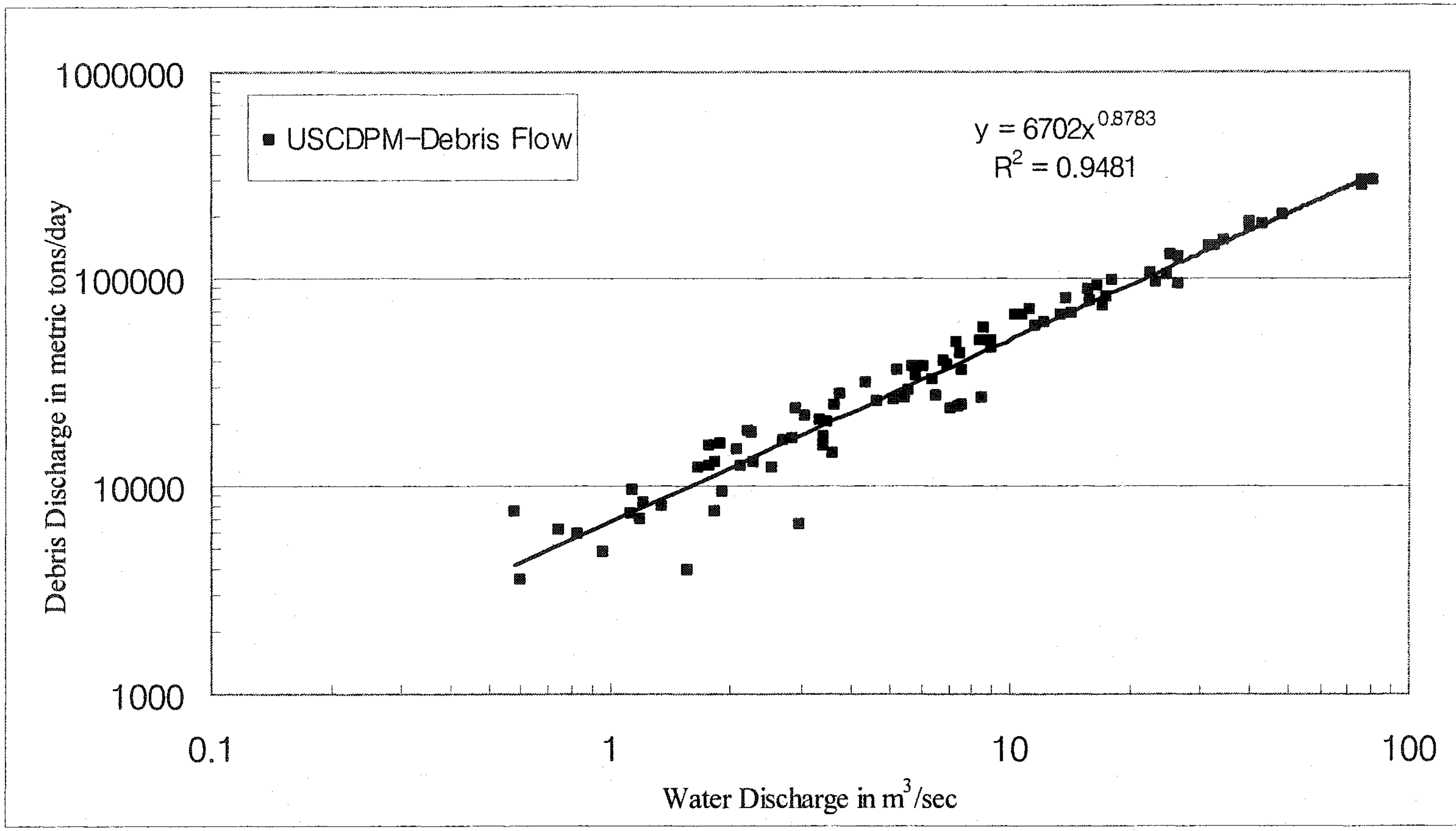

FIG. 9.11 Water Discharge versus Debris Discharge Curve for San Gabriel Mountains, CA

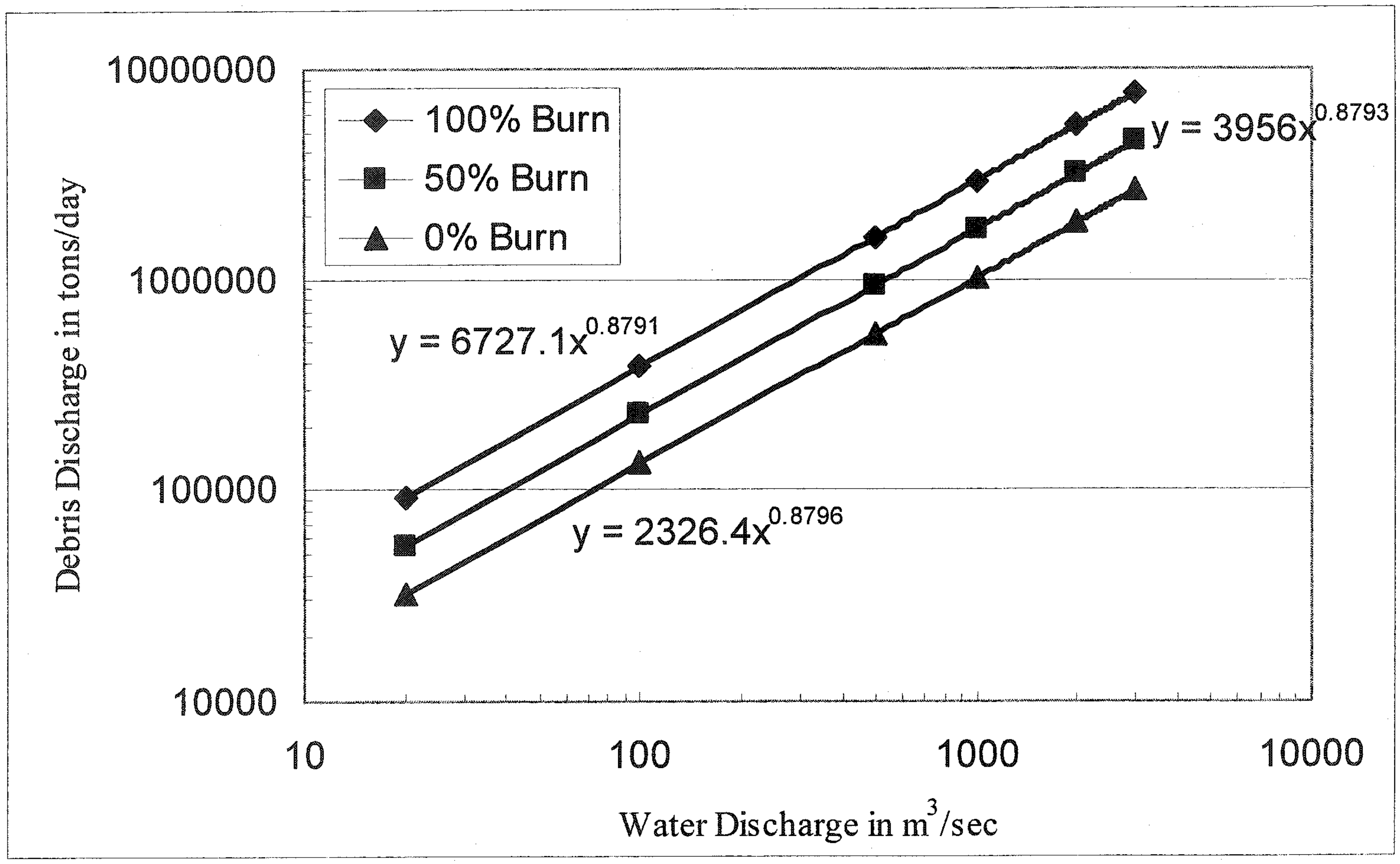

FIG. 9.12 Water Discharge versus Debris Discharge Curve with Different Burn Percentage

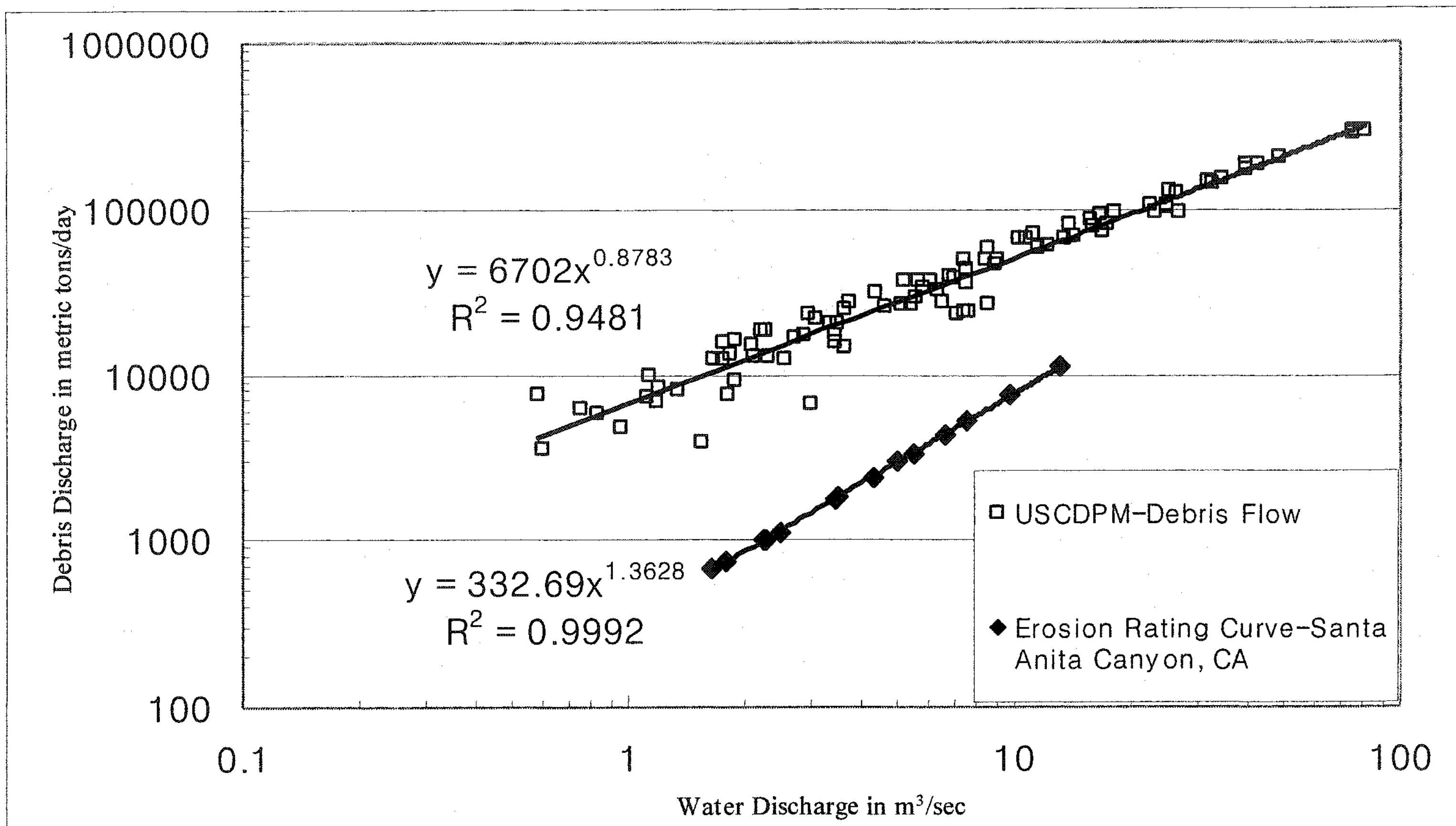

FIG. 9.13 Comparison of Debris Rating Curve of Mountain Watersheds (USCDPM) with Erosion Rating Curve of Stream (Chow, V.T, 1964)

CHAPTER 10

10 Limitations, Conclusions, and Recommendation

The limitations of the present USCDPM and the conclusions drawn from this study are presented in this chapter. Based on the results of this study, some recommendations are also made for the future research.

10.1 Limitations of USCDPM

The USCDPM has been shown to produce good results when compared with field data. However, it is worthwhile to discuss limitations of the present USCDPM.

10.1.1 Geographic Location Constraints

At the current stage of the study, USCDPM appears to be applicable to sub-basins in the San Gabriel Mountains within Los Angeles County and San Bernardino County. Expanded use of the model to other areas needs to be verified with additional local field measurements to show applicability of the model.

10.1.2 Topographic Constraints

The model was applied to the San Gabriel Mountain watersheds characterized on steep mountain areas. For watersheds with mild characteristics where agricultural, residential, commercial, and industrial areas, the model has to be tested in areas characterized as mild.

10.2 Conclusions Drawn from the Present Study

Major conclusions from the present study can be summarized as:

1. Most of the existing debris basins in Southern California were designed based on a single design storm event. Thus removal of debris following any significant event is required to maintain the functionality of the debris basins. Small and steep watersheds must be more concerned with maintaining the storage capacity of the debris basin in anticipation of the subsequent storm events, since small and steep watersheds generally generate significant debris even for minor rainfall events.
2. The results have shown that two prior debris yield computation methods based on USACE LA Debris Method (2000) and LACDPW Method (1993) are not adequate for estimating real-time debris yields. On the other hand, the present USCDPM appears to provide fairly reliable results in the prediction of debris yields generated by several subsequent rainfall events after a wildfire for all watersheds in the range of 25-3,000 ha (62-7,413 acres).
3. USCDPM can provide a reasonable and reliable estimation of debris yields. This will enable the operators of debris basins to have more control for scheduling cleanout of the debris basins. This will also allow the operators to develop rapid response strategies in emergency situation.

10.3 Recommendation for Future Research

Following this study, several future research directions are possible based on the results of this thesis. Some of these for the model extension can be listed as follow:

1. More research effort is required to expand the use of the model to other areas. Adequate field data on debris production are essential for model calibration in order that this model may be applied with confidence for a wider range of conditions in engineering applications.
2. More research effort is required to develop a user-friendly software interface (application software) for USCDPM to yield more efficient solution process for general engineering application.
3. More research effort on debris production due to landslides after wildfire and subsequent storm events is needed.

REFERENCE LIST

1. *2002-2003 Storm Report Los Angeles County* (2003). County of Los Angeles Department of Public Works, Alhambra, California.

2. Amar A.C., and Gatwood E.J. (1992). "Los Angeles District Method for Prediction of Debris Yield from Coastal Southern California Watersheds." U.S. Army Corps of Engineers, Los Angeles District.

3. Burton J.A. (2002). "Analysis Production Methods for Selected Southern California Burned Watersheds," M.S. thesis, Department of Civil Engineering, California State University at Long Beach.

4. Cannon, S.H., Garter, J.E., Rupert, M.G., and Michael J.A. (2003). Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Grand Prix and Old Fires of 2003, Southern California." *USGS Open File Report 03-475.*

5. Cannon, S.H., Garter, J.E., Rupert, M.G., and Michael J.A. (2004). "Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Padua Fire of 2003, Southern California." USGS *Open File Report 2004-1072.*

6. Chleborad, A.F. (2003). "Preliminary Evaluation of a Precipitation Threshold for Anticipating the Occurrence of Landslides in the Seattle, Washington." *USGS Open-File Report 03-463.*

7. Chow, V.T. (1964). *Handbook of Applied Hydrology*, McGraw-Hill, New York.

8. Ferrell, W.R. (1959). "Report on debris reduction studies for mountain watersheds." Los Angeles County Flood Control District, Dam and Conservation Branch.

9. Gatwood, E., Pedersen, J., and Casey, K. (2000). "Los Angeles District Method for prediction of debris yield." U.S. Army Corps Engineers, Los Angeles District.

10. Genevois, R., Berti, M., Ghirotti, M., Simoni, A., and Tecca, P.R. (1999). "Debris Flow Management and Risk Assessment in the Alpine Region" Commission of the European Communities.

11. George, D., and Mallery, P. (1999). *SPSS for Windows*, Allyn & Bacon.

12. Gindi, I., Schleikorn M., Ward, W., Kwan, B., Soriano, L., Howe, H., Derakhshani, M., Khachikian, H., Moreno, M., and Ma, A. (1993). "Sedimentation Manual" Los Angeles County Department of Public Works, Alhambra, Ca.

13. Jin, M. and Fread, D.L. (1997). "One-Dimensional Routing of Mud/Debris Flow Using NWS FLDWAV Model." *First International Conference on Debris-Flow Hazards Mitigation*: Mechanics, Prediction, and Assessment, San Francisco, California, August 7-9, 1997.

14. Johnson D.M. (1989). *Probability and Statistics.* South-Western Publishing, Cincinnati, Ohio.

15. Laigle, D. and Coussot, P. (1997). "Numerical Modeling of Mudflows." *Journal of Hydraulic Engineering*, 123 (7), 617-623.

16. Linsley, R.K., Franzini, J.B., Freyberg, D.L., and Tchobanoglous, G. (1992). *Water-Resources Engineering*. Forth Edition, McGraw-Hill, New York.

17. Mainali A.P. and Rajaratnam N. (1991). *Hydraulics of Debris Flows A Review*, Water Resources Engineering Report (WRE 91-2) Depart. of Civil Eng. University of Alberta, Canada.

18. McCuen, R.H., and Hromadka, T.V. II (1996). *Estimating debris volumes for flood control*, Lighthouse Publications.

19. Middleton J., Syhaphom, S., Grim, J., and Collins, W. (2004). "EWP-Greenwood Ave, San Bernardino County, CA." *Natural Resources Conservation Service, File Code 390-14.*

20. National Academy of Sciences (1996). *Alluvial Fan Flooding*, National Academy Press Washington, D.C..

21. O'Brien, J.S., Julien, P.Y., and Fullerton, W.T. (1993). "Two Dimensional Water Flood and Mudflow Simulation." *Journal of Hydraulic Engineering*, 119 (2), 244-261.

22. Ponce, V.M. (1989). *Engineering hydrology principle and practices*, Prentice Hall.

23. Rowe, P.B., Countryman, C.M., and Storey, H.C. (1949). "Probable Peak Discharges and Erosion Rates from Southern California Watersheds As Influenced by Fire." USDA, Forest Service, California, Forest and Range Experimental Station.

24. Rowe, P.B., Countryman, C.M., and Storey, H.C. (1954). "Hydrologic Analysis Used to Determine Effects of the Fire on Peak Discharge and Erosion Rates in Southern California Watersheds." USDA, Forest Service and Range Experimental Station.

25. Sherman D.J., Barron, K.M., and Ellis, J.T. (2002). "Retention of Beach Sands by Dams and Debris Basin in Southern California." *Journal of Coastal Research*, Special Issue 36, 2002.

26. Swan, R.C. (2000). "Debris Management Planning for the 21st Century." *Natural Hazards Review,* ASCE, 1(4), 222-225.

27. Tatum F.E. (1963). "A New Method of Estimating Debris-Storage Requirements for Debris Basin," *Second National Conference on Sedimentation of the Subcommittee on Sedimentation*, ICWR, Jackson, Mississippi, 28 January– 1 February 1963.

28. Troxell H.C. and Peterson J.Q. (1937). "Flood in La Canada Valley, California, January 1, 1934." *USGS Water Supply Paper 796-c*, Washington, D.C.

29. USACE (1973). *Corps of Engineers Methods for Predicting Sediment Yields, Appendix*. EM 1110-2-4000, 15 Dec 1989.

30. VanDine D.F. (1996). *Debris Flow Control Structures for Forest Engineering*. Res. Br., B.C. Min. For., Victoria, B.C., Work. Pap. 08/1996.

31. Vanoni, V.A. (1975). *Sedimentation engineering, ASCE manuals and reports on engineering practice No. 54.* Published by the American Society of Civil Engineers, New York, NY.

APPENDIX A: DEBRIS BASIN DATA USED IN DEVELOPMENT OF REGRESSION EQUATION

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Aliso	Dec-70	2.96	1.15	2	2.86	6.5
Aliso	Mar-78	3.46	1.18	2	2.86	3.69
Aliso	Feb-83	3.47	1.4	2	2.86	3
Auburn	Jan-56	3.24	1.3	2.72	1.62	3.37
Auburn	Feb-62	4.38	1.3	2.72	1.62	5.43
Auburn	Dec-65	3.7	1.19	2.72	1.62	3.92
Auburn	Jan-69	4.02	1.6	2.72	1.62	3.49
Auburn	Feb-78	3.18	1.44	2.72	1.62	3
Auburn	Jan-79	3.57	0.88	2.72	1.62	6.5
Auburn	Jan-79	3.78	1	2.72	1.62	6.5
Auburn	Feb-79	3.9	1.1	2.72	1.62	6.5
Auburn	Mar-79	3.64	1	2.72	1.62	6.5
Auburn	Feb-80	4.38	1.63	2.72	1.62	5.98
Auburn	Mar-83	3.62	1.48	2.72	1.62	4.23
Bailey	Jan-54	4.04	0.87	2.53	2.19	5.01
Bailey	Feb-56	3.16	0.66	2.53	2.19	4.12
Bailey	Mar-42	3.7	1.3	2.53	2.19	4.31
Bailey	Jan-69	4.13	1.6	2.53	2.19	3
Bailey	Mar-78	3.5	1.44	2.53	2.19	3
Bailey	Jan-79	3.05	0.88	2.53	2.19	6.5
Bailey	Jan-79	3.38	1	2.53	2.19	6.5
Bailey	Feb-79	3.84	1.1	2.53	2.19	6.5
Bailey	Mar-79	3.13	0.88	2.53	2.19	6.5
Bailey	Mar-79	3.18	1	2.53	2.19	6.5

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Bailey	Feb-98	4.58	1.63	2.53	2.19	5.98
Bailey	Sep-83	3.51	1.48	2.53	2.19	4.08
Beatty	Feb-80	3.92	0.7	2.34	1.85	3
Big Briar	Feb-80	3.33	1.51	2.71	0.72	3
Big Briar	Feb-83	3.57	1.58	2.71	0.72	3
Big Dalton	Nov-65	3.43	1.29	2.08	2.83	4
Big Dalton	Jan-69	4.41	1.39	2.08	2.83	3.49
Big Dalton	Feb-83	2.84	1.3	2.08	2.83	3
Blanchard	Jan-69	3.76	1.33	2.38	2.12	3
Blanchard	Mar-76	3.28	0.74	2.38	2.12	6.2
Blanchard	Feb-78	4.02	1.65	2.38	2.12	4.95
Bluegum	Jan-69	3.22	1.33	2.37	1.69	3
Bluegum	Feb-69	3.55	1.3	2.37	1.69	3
Bluegum	Feb-76	3.88	1.74	2.37	1.69	6.5
Bluegum	Feb-78	4.23	1.65	2.37	1.69	5.14
Bluegum	Mar-78	4.1	1.4	2.37	1.69	5.09
Brace	Mar-83	3.55	1.44	2.44	1.88	5.09
Bradbury	Jan-56	3.45	1.35	2.39	2.25	3.71
Bradbury	Dec-65	3.48	1.25	2.39	2.25	3.83
Bradbury	Jan-69	4.23	1.56	2.39	2.25	3
Bradbury	Feb-69	4.13	1.38	2.39	2.25	3
Bradbury	Mar-78	3.55	1.44	2.39	2.25	3
Bradbury	Feb-80	3.87	1.58	2.39	2.25	3
Bradbury	Feb-83	3.64	1.4	2.39	2.25	5.14

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Brand	Dec-65	3.71	1.12	2.45	2.43	5.53
Brand	Jan-66	2.81	1.29	2.45	2.43	5.46
Brand	Jan-69	3.89	1.31	2.45	2.43	4.12
Brand	Feb-69	3.56	1.01	2.45	2.43	4.09
Brand	Mar-78	4.18	1.25	2.45	2.43	3
Brand	Feb-80	3.81	1.44	2.45	2.43	3
Brand	Mar-83	3.5	1.4	2.45	2.43	3
Carriage House	Feb-79	3.9	1.18	2.64	0.89	6.5
Carriage House	Feb-80	4.42	1.63	2.64	0.89	5.98
Carter	Jan-56	3.53	1.3	2.69	1.5	3
Carter	Dec-61	3.95	1.06	2.69	1.5	6.13
Carter	Feb-62	4.27	1.3	2.69	1.5	6.13
Carter	Jan-69	3.71	1.6	2.69	1.5	3.6
Carter	Feb-69	3.13	1.24	2.69	1.5	3.59
Carter	Mar-78	3.01	1.44	2.69	1.5	3
Carter	Feb-79	3.73	1.1	2.69	1.5	6.5
Carter	Mar-79	2.81	0.88	2.69	1.5	6.5
Carter	Mar-79	3.2	1	2.69	1.5	6.5
Carter	Feb-80	4.33	1.63	2.69	1.5	5.98
Carter	Mar-83	3.22	1.48	2.69	1.5	4.22
Cassara	Feb-78	4.16	1.48	2.21	1.74	4
Cassara	Feb-83	3.61	1.4	2.21	1.74	3.39
Chamberlain	Mar-75	3.36	1.19	2.32	1.02	3
Childs	Sep-65	3.89	1.3	2.5	1.91	5.78

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Childs	Jan-69	3.55	1.31	2.5	1.91	4.12
Childs	Feb-69	3.23	1.01	2.5	1.91	4.09
Childs	Mar-78	3.61	1.25	2.5	1.91	3
Childs	Feb-80	3.36	1.44	2.5	1.91	3
Childs	Feb-81	3.98	1.18	2.5	1.91	5.75
Childs	Feb-83	3.33	1.48	2.5	1.91	4.67
Cloud Creek	Mar-76	3.99	1.74	2.72	0.72	6.5
Cloud Creek	May-77	2.63	1.1	2.72	0.72	5.78
Cloud Creek	Feb-78	4.14	1.66	2.72	0.72	5.14
Cloud Creek	Mar-78	4.12	1.4	2.72	0.72	5.09
Cloud Creek	Feb-80	3.5	1.51	2.72	0.72	4.25
Cloud Creek	Feb-83	3.82	1.58	2.72	0.72	3.58
Cloudcraft	Dec-73	3.41	1.21	2.49	1.74	6.5
Cloudcraft	Mar-78	2.96	1.3	2.49	1.74	4.22
Cloudcraft	Feb-80	3.51	1.48	2.49	1.74	3.81
Cooks	Jan-54	3.06	1.18	2.38	2.18	3
Cooks	Nov-65	3.51	1.47	2.38	2.18	3.34
Cooks	Jan-69	3.64	1.41	2.38	2.18	3
Cooks	Feb-78	4.11	1.66	2.38	2.18	5.14
Cooks	Feb-80	3.91	1.51	2.38	2.18	4.27
Cooks	Feb-83	3.9	1.58	2.38	2.18	3.66
Deer	Dec-65	3.82	1.12	2.39	2.19	5.25
Deer	Jan-69	4.18	1.31	2.39	2.19	4
Deer	Feb-69	3.84	1.01	2.39	2.19	3.98

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Deer	Mar-78	4.05	1.25	2.39	2.19	3
Deer	Feb-80	3.52	2.44	2.39	2.19	3
Dunsmuir	Mar-38	4.44	1.51	2.45	2.34	4.17
Dunsmuir	Feb-78	4.19	1.66	2.45	2.34	5.14
Dunsmuir	Mar-78	4.14	1.4	2.45	2.34	5.09
Elmwood	Jun-65	4.06	1.3	2.55	1.91	6.08
Elmwood	Jan-69	3.39	1.31	2.55	1.91	4.12
Elmwood	Mar-78	3.54	1.25	2.55	1.91	3
Elmwood	Feb-80	3.7	1.44	2.55	1.91	3
Elmwood	Jan-81	4.05	1.18	2.55	1.91	6.5
Emerald East	Jan-69	3.17	1.13	1.77	1.62	3.33
Emerald East	Feb-69	3.18	1.02	1.77	1.62	3.33
Emerald East	Mar-78	3.35	1.66	1.77	1.62	3
Emerald East	Feb-80	3.12	1.35	1.77	1.62	3
Englewild	Jan-69	4.52	1.51	2.42	2.02	6.5
Englewild	Feb-69	4.05	1.33	2.42	2.02	6.5
Englewild	Mar-78	2.92	1.18	2.42	2.02	3.38
Englewild	Feb-80	3.96	1.58	2.42	2.02	3
Fairoaks	Nov-65	3.67	1.32	1.78	1.74	3
Fairoaks	Jan-69	4.1	1.44	1.78	1.74	3
Fairoaks	Feb-80	2.66	0.88	1.78	1.74	3
Fairoaks	Feb-83	2.98	1.4	1.78	1.74	3
Fern	Jan-54	2.66	1.08	2.41	1.91	3
Fern	Jan-56	2.59	1.25	2.41	1.91	3

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Fern	Jul-63	3.82	1.35	2.41	1.91	4.26
Fern	Nov-65	4.02	1.32	2.41	1.91	3.61
Fern	Feb-69	4.16	0.4	2.41	1.91	3.35
Fern	Mar-78	3.63	1.48	2.41	1.91	3
Fern	Feb-80	3.32	0.88	2.41	1.91	3
Fern	Feb-83	3.4	1.4	2.41	1.91	3
Fieldbrook	Mar-04	2.62	1.18	2.31	1.96	3.62
Fieldbrook	Sep-83	2.58	1.2	2.31	1.96	3
Golf Course	Dec-74	2.91	1.19	2.06	1.92	3
Golf Course	May-77	2.88	1	2.06	1.92	3
Gordon	Feb-80	3.02	1.58	2.34	1.67	3
Gordon	Feb-83	1.66	1.3	2.34	1.67	3
Gould	Nov-65	3.92	1.23	2.16	2.09	3.28
Gould	Feb-69	3.84	1.24	2.16	2.09	3
Gould	Feb-80	3.73	1.51	2.16	2.09	3
Gould	Feb-83	3.49	1.58	2.16	2.09	3
Haines	Feb-69	3.78	1.33	2.32	2.6	3
Halls	Mar-38	4.59	1.45	2.35	2.31	3.93
Halls	Jan-54	3.06	1.18	2.35	2.31	3
Halls	Jan-56	3.14	1.25	2.35	2.31	3
Halls	Nov-65	3.28	1.23	2.35	2.31	3
Halls	Feb-69	4.28	1.24	2.35	2.31	3
Halls	May-77	3.58	1.1	2.35	2.31	3
Halls	Feb-78	4.04	1.63	2.35	2.31	3

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Halls	Feb-80	3.89	1.51	2.35	2.31	3
Halls	Feb-83	3.91	1.58	2.35	2.31	3
Harrow	Jan-69	4.56	1.56	2.52	2.05	6.5
Harrow	Feb-69	3.87	1.16	2.52	2.05	6.5
Harrow	Mar-78	3.18	1.18	2.52	2.05	3.37
Harrow	Mar-83	3.35	1.58	2.52	2.05	3
Hay	Mar-38	4.43	1.45	2.55	1.72	4.18
Hay	Jun-63	3.35	1.29	2.55	1.72	4.64
Hay	Nov-65	3.51	1.23	2.55	1.72	3.92
Hay	Jan-69	3.85	1.37	2.55	1.72	3.44
Hay	Feb-69	3.11	1.16	2.55	1.72	3.43
Hay	Mar-78	3.81	1.63	2.55	1.72	3
Hay	Feb-80	3.36	1.51	2.55	1.72	3
Hay	Feb-83	3.3	1.58	2.55	1.72	3
Hillcrest	Nov-65	3.27	1.12	2.52	1.96	5.53
Hillcrest	Jan-69	3.83	1.31	2.52	1.96	4.09
Hillcrest	Feb-80	3.05	1.44	2.52	1.96	3
Hillcrest	Feb-83	2.25	1.4	2.52	1.96	3
Hook East	Jan-69	4.62	1.56	2.6	1.67	6.5
Hook East	Feb-69	4.39	1.16	2.6	1.67	6.5
Hook East	Mar-78	3.55	1.18	2.6	1.67	3.37
Hook East	Feb-80	3.59	1.58	2.6	1.67	3
Hook West	Feb-80	3.8	1.58	2.51	1.67	3
Jasmine	Mar-90	3.49	0.88	2.1	1.42	3.33

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Jasmine	Mar-83	3.5	1.1	2.1	1.42	3
Kinneloa East	Dec-65	3.52	1.44	2.65	1.72	3
Kinneloa West	Jan-69	4.3	1.49	2.65	1.72	6.5
Kinneloa West	Feb-78	3.29	1.18	2.65	1.72	3.38
Kinneloa West	Jan-69	4.41	1.49	2.68	1.72	6.5
Kinneloa West	Feb-69	3.95	1.3	2.68	1.72	6.5
Kinneloa West	Feb-76	3.99	1.14	2.68	1.72	3.61
Kinneloa West	Feb-78	3.32	1.18	2.68	1.72	3.38
Kinneloa West	Mar-78	3.54	1.4	2.68	1.72	3.37
Kinneloa West	Feb-80	3.7	1.63	2.68	1.72	3
Kinneloa West	Feb-83	3.83	1.48	2.68	1.72	3
Lannan	Jan-56	3.23	1.3	2.61	1.81	4.73
Lannan	Jan-69	3.6	1.44	2.61	1.81	3
Lannan	Feb-80	4.03	1.63	2.61	1.81	3.24
Lannan	Feb-83	3.08	1.48	2.61	1.81	3
Las Flores	Feb-62	4.21	1.3	2.52	2.07	5.59
Las Flores	Dec-65	3.86	1.32	2.52	2.07	4.22
Las Flores	Jan-69	4.02	1.44	2.52	2.07	3.63
Las Flores	Feb-80	3.95	0.88	2.52	2.07	3
Las Flores	Feb-83	3.7	1.4	2.52	2.07	3
La Tuna	Jan-56	2.97	1.1	1.94	3.14	3
La Tuna	Nov-65	3.17	1.1	1.94	3.14	3
La Tuna	Jan-69	3.33	1.1	1.94	3.14	3
La Tuna	Feb-83	3.55	1.44	1.94	3.14	4.11

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Laurel Ridge	Dec-78	3.76	1.4	2.3	0.89	3.52
Limekiln	Nov-65	3.53	1.64	1.94	2.98	3.48
Limekiln	Jan-69	3.08	1.12	1.94	2.98	3.24
Limekiln	Feb-69	3.23	1.11	1.94	2.98	3.24
Limekiln	Dec-70	2.99	1.15	1.94	2.98	5.94
Limekiln	Mar-83	3.28	1.4	1.94	2.98	3.56
Lincoln	Nov-65	3.56	1.32	2.16	2.04	3
Lincoln	Jan-69	4.03	1.44	2.16	2.04	3.33
Lincoln	Feb-78	2.95	1.18	2.16	2.04	3
Lincoln	Mar-78	3.37	1.72	2.16	2.04	3
Lincoln	Feb-80	3.22	0.88	2.16	2.04	3
Lincoln	Feb-83	2.84	1.4	2.16	2.04	3
Linda Vista	Jun-77	1.97	1	2.21	1.98	3
Linda Vista	Feb-78	3.12	1.25	2.21	1.98	3
Little Dalton	Mar-62	4.22	1.21	2.04	2.94	5.23
Little Dalton	Nov-65	3.63	1.29	2.04	2.94	3.87
Little Dalton	Jan-69	4.35	1.37	2.04	2.94	3.61
Little Dalton	Feb-78	3.05	1.25	2.04	2.94	3
Little Dalton	Feb-83	2.83	1.3	2.04	2.94	3
Maddock	Feb-69	3.97	1.56	2.56	1.85	3
Maddock	Feb-69	3.57	1.38	2.56	1.85	3
Maddock	Mar-78	2.7	1.44	2.56	1.85	3
Maddock	Feb-80	3.81	1.58	2.56	1.85	3
Maddock	Feb-83	2.5	1.4	2.56	1.85	5.09

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
May #1	Nov-65	3.5	1.43	2.48	2.27	3
May #1	Nov-66	3.35	1.59	2.48	2.27	3
May #1	Dec-66	4.35	1.18	2.48	2.27	6.5
May #1	Feb-69	3.35	1.06	2.48	2.27	5.09
May #1	Feb-76	3.93	1	2.48	2.27	3.4
May #1	Feb-78	3.29	0.93	2.48	2.27	3
May #1	Mar-78	3.05	1.1	2.48	2.27	3
May #1	Feb-80	2.98	1.4	2.48	2.27	3
May #1	Mar-83	3.66	1.51	2.48	2.27	3
May #2	Nov-65	3.44	1.43	2.32	1.37	3
May #2	Jan-69	3.97	1.19	2.32	1.37	5.14
May #2	Feb-76	4.05	1	2.32	1.37	3.4
May #2	Feb-80	3.26	1.4	2.32	1.37	3
May #2	Feb-83	3.79	1.51	2.32	1.37	3
Morgan	Jan-69	3.68	1.37	2.44	2.19	3.48
Morgan	Feb-69	3.2	1.39	2.44	2.19	3.47
Morgan	Mar-78	3.32	1.4	2.44	2.19	3
Morgan	Feb-83	2.87	1.3	2.44	2.19	5.6
Mull	Feb-80	3.32	1.58	2.38	1.59	3
Mullally	May-77	2.83	1.1	2.45	1.95	3.96
Mullally	Feb-78	3.93	1.63	2.45	1.95	3.73
Mullally	Feb-80	3.44	1.51	2.45	1.95	3.46
Mullally	Feb-83	3.84	1.58	2.45	1.95	3.33
Pickens	Mar-38	4.38	1.45	2.29	2.6	4.11

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Pickens	Jan-54	2.93	1.13	2.29	2.6	3
Pickens	Jan-56	2.95	1.23	2.29	2.6	3
Pickens	Nov-65	3.94	1.23	2.29	2.6	3.7
Pickens	Jan-69	3.84	1.41	2.29	2.6	3.29
Pinelawn	Dec-74	3.36	1.18	2.65	0.72	3
Pinelawn	Feb-76	4.2	1.74	2.65	0.72	6.5
Pinelawn	May-77	4.25	1.1	2.65	0.72	5.69
Pinelawn	Feb-78	4.03	1.63	2.65	0.72	5.09
Pinelawn	Feb-80	4.14	1.51	2.65	0.72	4.25
Pinelawn	Mar-83	3.85	1.58	2.65	0.72	3.63
Rowley Upper	Feb-78	4.24	1.66	2.27	1.91	4.48
Rubio	Nov-65	3.42	1.32	2.45	2.52	3.04
Rubio	Jan-69	4.05	1.44	2.45	2.52	3
Rubio	Feb-69	3.24	0.86	2.45	2.52	3
Rubio	Mar-78	3.2	1.48	2.45	2.52	3
Rubio	Feb-80	4.19	0.88	2.45	2.52	6.5
Rubio	Feb-83	3.56	1.4	2.45	2.52	4.49
Ruby	Nov-65	3.45	1.21	2.22	1.86	3
Ruby	Jan-69	3.8	0.81	2.22	1.86	3
Ruby	Feb-80	3.54	1.58	2.22	1.86	3
Santa Anita	Jan-65	3.7	0.94	2.28	2.65	3
Santa Anita	Jan-69	4.33	1.44	2.28	2.65	3
Santa Anita	Feb-80	3.56	1.63	2.28	2.65	3
Santa Anita	Feb-83	3.76	2.48	2.28	2.65	3
Sawpit	Jan-56	3.01	1.35	2.36	2.86	4.24

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Sawpit	Nov-65	3.58	1.21	2.36	2.86	3.33
Sawpit	Jan-69	4.32	1.56	2.36	2.86	3
Sawpit	Feb-83	3.55	1.4	2.36	2.86	3.59
Schoolhouse	Jun-63	4.36	1.12	2.36	1.86	6.5
Schoolhouse	Nov-65	3.59	1.51	2.36	1.86	4.59
Schoolhouse	Jan-69	3.23	1.14	2.36	1.86	3.78
Schoolhouse	Mar-78	3.22	1.08	2.36	1.86	3
Ascwartz	Feb-78	3.83	1.48	2.15	1.84	5.09
Ascwartz	Feb-83	3.93	1.4	2.15	1.84	3.65
Shields	Mar-38	4.56	1.51	2.7	0.89	4.22
Shields	Jan-56	2.77	1.28	2.7	0.89	3
Shields	Nov-65	3.5	1.47	2.7	0.89	3.89
Shields	Jan-66	3.85	1.42	2.7	0.89	3.89
Shields	Jan-69	3.29	1.33	2.7	0.89	3.37
Shields	Feb-69	3.23	1.3	2.7	0.89	3.37
Shields	Feb-76	3.83	1.74	2.7	0.89	6.5
Shields	Feb-78	4.29	1.66	2.7	0.89	5.09
Sierra Madre Dam	Jan-54	3.85	1.28	2.35	2.79	6.5
Sierra Madre Dam	Jan-56	2.61	1.3	2.35	2.79	5.14
Sierra Madre Dam	Jan-65	2.33	0.86	2.35	2.79	3.74
Sierra Madre Dam	Jan-69	4.04	1.21	2.35	2.79	3.38
Sierra Madre Dam	Feb-78	3.4	1.44	2.35	2.79	3
Sierra Madre Villa	Mar-62	4.38	1.03	2.43	2.58	4.63
Sierra Madre Villa	Feb-69	4.31	1.24	2.43	2.58	3.35

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Snover	Mar-38	4.43	1.45	2.4	1.74	4.53
Snover	Jan-69	4.04	1.43	2.4	1.74	3
Snover	Feb-69	3.52	1.31	2.4	1.74	3
Snover	Mar-78	4.33	1.63	2.4	1.74	3
Snover	Feb-80	3.72	1.51	2.4	1.74	3
Snowdrop	Feb-80	3.34	0.88	1.99	1.56	3
Snowdrop	Mar-83	3.09	1.1	1.99	1.56	3
Starfall	Dec-74	3.6	1.18	2.61	1.53	3
Starfall	Feb-76	3.77	1.74	2.61	1.53	6.5
Starfall	May-77	2.63	1.1	2.61	1.53	5.78
Starfall	Feb-78	4.3	1.66	2.61	1.53	5.14
Starfall	Feb-80	4.09	1.51	2.61	1.53	4.27
Starfall	Feb-83	3.35	1.58	2.61	1.53	3.66
Stetson	Feb-78	3.19	1.08	2.35	1.88	3
Sturtevant	Jan-69	3.11	1.44	2.56	0.89	3
Sturtevant	Feb-78	3.41	1.4	2.56	0.89	4.11
Sturtevant	Feb-80	3.14	1.63	2.56	0.89	3.68
Sturtevant	Feb-83	2.32	1.48	2.56	0.89	3.42
Sullivan	Feb-83	3.32	1.53	1.8	2.79	3.71
Sunnyside	Feb-83	2.69	1.48	2.68	0.72	4.25
Sunset	Nov-65	3.47	1.12	2.49	2.06	5.6
Sunset	Jan-69	3.38	1.31	2.49	2.06	3.9
Sunset	Dec-74	2.37	1.35	2.49	2.06	3
Sunset	Feb-80	3.95	1.44	2.49	2.06	3

Debris Basin	Flood Date	Log D_y	Log I_m	Log S	Log A	F
Sunset	Feb-83	3.58	2.4	2.49	2.06	3
Turnbull	Oct-68	3.46	1.12	2.03	2.41	6.5
Turnbull	Jan-69	3.45	1.05	2.03	2.41	5.98
Turnbull	Feb-69	3.28	1.06	2.03	2.41	5.87
Turnbull	Mar-78	2.92	2.4	2.03	2.41	3
Turnbull	Feb-83	2.98	1.3	2.03	2.41	3
Turnbull	Aug-83	2.42	0.88	2.03	2.41	3
Ward	Nov-65	3.22	1.47	2.51	1.5	3.43
Ward	Jan-69	3.49	1.33	2.51	1.5	3
Ward	Feb-69	3.75	1.3	2.51	1.5	3
Ward	Feb-76	3.19	1.74	2.51	1.5	6.5
Ward	Feb-78	4.29	1.66	2.51	1.5	5.14
Ward	Mar-78	4.38	1.4	2.51	1.5	5.09
Ward	Feb-80	4.06	1.51	2.51	1.5	4.27
Ward	Mar-83	4.16	1.58	2.51	1.5	3.65
West Ravine	Mar-38	4.64	1.83	2.46	1.81	5.03
West Ravine	Jan-56	3.2	1.25	2.46	1.81	3
West Ravine	Jan-66	4.05	1.35	2.46	1.81	3
West Ravine	Jan-69	4.3	1.37	2.46	1.81	3
West Ravine	Mar-83	3.23	1.25	2.46	1.81	3
Wildwood	Jan-69	3.56	1.21	1.95	2.23	3.33
Wildwood	Feb-78	3.83	1.3	1.95	2.23	3.37
Wildwood	Feb-80	3.54	1.4	1.95	2.23	3.34
Wildwood	Feb-83	3.37	1.4	1.95	2.23	3

Debris Basin	Flood Date	Log Dy	Log Im	Log S	Log A	F
Wilson	Nov-65	3.24	1.43	2.26	2.83	4.01
Wilson	Dec-74	3.72	0.91	2.26	2.83	3.3
Wilson	Feb-80	2.78	1.4	2.26	2.83	3
Wilson	Feb-83	3.25	1.51	2.26	2.83	3
Winery	Jan-69	4.13	1.37	2.44	1.67	3.35
Winery	Feb-69	3.44	1.16	2.44	1.67	3.35
Winery	Mar-78	3.91	1.63	2.44	1.67	3
Winery	Feb-80	3.52	1.51	2.44	1.67	3
Winery	Mar-83	3.35	1.58	2.44	1.67	3
Zachau	Feb-69	3.99	1.33	2.45	1.96	3
Zachau	Feb-76	4.19	1.74	2.45	1.96	6.5
Zachau	Feb-78	4.38	1.66	2.45	1.96	5.14
Zachau	Mar-78	4.33	1.4	2.45	1.96	5.09

Original Data Source: USACE Los Angeles District