INSTITUTE OF HYDROLOGY

PREDICTION OF RUNOFF VOLUME FROM FULLY-SEWERED URBAN CATCHMENTS

by

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ABSTRACT

This report describes the development of a mathematical model to predict the volume of runoff from a given rainfall event on a fully-sewered catchment. The model will ultimately be incorporated into a new design method for storm sewer systems. Regression analysis on existing urban catchment data was used in the model development because the translation of rainfall into runoff is a complex physical process. Data from 368 storms on 14 catchments were collated and processed from an archive being established at the Institute. A data set was compiled of rainfall and runoff volumes and pertinent catchment and storm characteristics for each of the 368 events. Analyses performed on the data from individual catchments demonstrated that there was no clear trend from one catchment to another. Analyses performed on the whole data set identified an additive 3-variable form of regression equation, using percentage runoff as dependent variable, as being the most appropriate. This equation will be updated as further data become available.

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INTRODUCTION

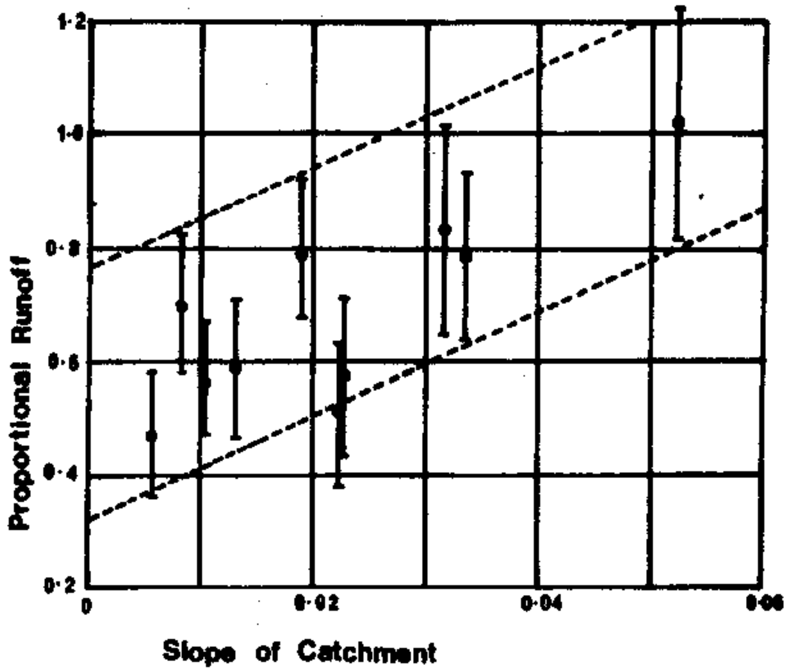
Complementary research programmes at the Hydraulics Research Station and the Institute of Hydrology are concerned with the development of rainfall-runoff simulation models for the improved design of urban storm water systems. The Institute's contribution relates to the above-ground phase of the rainfall-runoff process, the conversion of the rainfall hyetograph into a runoff hydrograph at the inlet to a sewer system (Helliwell *et al.*, 1976).

The hydrological investigation may be subdivided into three parts: (a) the derivation of the volume of runoff (or the losses relating to any given total rainfall volume), (b) the distribution of these losses in time, and (c) the distribution of the runoff volume in time or the attenuation of the effective rainfall profile. Progress in parts (b) and (c) relies on subcatchment experiments in progress at Bracknell, Stevenage, Southampton and Wallingford, using a flow meter developed to measure the discharge through a road gully (Blyth and Kidd, 1977) at the interface between the above and below ground phases of the urban runoff process. However, this report is concerned with part (a) only. And, whilst valuable insights into the volume of runoff may be gained from these experiments, catchment-averaged results may be obtained from existing urban rainfall-runoff data from larger catchments up to 200 ha. Indeed, as indicated in the next section, the random spatial distribution of different surface types and predominance of unquantifiable losses leads to the conclusion that a catchment-averaged approach to the derivation of runoff volume is probably more appropriate than an approach using subcatchment data.

The traditional approach to estimating the volume of runoff stems from the runoff coefficient in the Rational (Lloyd-Davies) Formula. Escritt (1950) has amalgamated the work of a number of researchers who have tabulated runoff coefficients for various types of contributing area and, in some cases, have related overall coefficients to some measure of population density. These coefficients were determined by intuition and empiricism and require subjective judgement to apply in a given situation.

An alternative approach has been to take the runoff coefficient as equal to the proportion of impervious surfaces in the catchment. The Road Research Laboratory (Watkins, 1962) perpetuated this practice, despite the fact that the data they collected suggests lower runoff volumes than the assumption implies. An alternative way of looking at this concept is to assume that there is 100% runoff from impervious surfaces and 0% from pervious surfaces. Both assumptions are doubtful but the errors have a tendency to cancel each other out.

Sarginson (1973) used the summary of the RRL data (Watkins, 1962) to observe the variation of average observed percentage runoff from catchment to catchment. He noted a significant correlation between percentage runoff and average catchment slope, as indicated in Figure 1.



Note: error bars represent one standard deviation of RRL data.

FIGURE 1 Variation of proportional runoff with average catchment slope (after Sarginson)

A number of urban runoff models such as the Chicago Hydrograph Model (Tholin & Keifer, 1960), the University of Cincinnatti Urban Runoff Model (Papadakis & Preul, 1972) and the Storm Water Management Model (Metcalf & Eddy Inc., 1971), attempt to model the volume of runoff deterministically. In general, they assume 100% runoff from impervious surfaces after deducting an allowance for depression storage, and they employ a Horton (1940) type of infiltration model to allow for the losses from the pervious surfaces.

Kaltenbach (1963) related percentage runoff to percentage impervious and maximum five-minute rainfall intensity based on data collected by the Johns Hopkins University in the Eastern United States.

The first part of the work described in this report is concerned with a purely qualitative appraisal of the physical phenomena which control the losses in a sewered catchment. This section concludes with: (i) a list of variables upon which the volume of runoff might be expected to depend, and (ii) a justification for the statistical approach adopted in this work. This is followed in Section II by a description of the data set compiled for the specific purposes of this study and in Section III, the development of a regression model for the prediction of the runoff volume from a given rainfall input. Section IV contains general conclusions drawn from the study.

I: A QUALITATIVE APPRAISAL OF THE LOSSES IN SEWERED CATCHMENTS

The volume of runoff may be defined as being equal to the volume of rainfall minus losses. The losses in urban catchments are caused by the same hydrological processes as in natural catchments, albeit in different proportions. Each of these processes will be discussed so as to identify those catchment and storm variables upon which the total loss might depend. With respect to the volume of runoff, the most significant physical phenomenon in the transition of a catchment from a rural to an urbanised state is the increase in the proportion of impervious surfaces. This increase has the effect of decreasing infiltration, resulting in a reduction of total loss and a corresponding increase in the total volume of runoff. In discussing each of the hydrological loss processes, the catchment area will be divided into pervious and impervious surfaces, although it is realised that there could be subgroups within this division. It is considered that the only significant subgrouping is between roofed and paved areas within the impervious category.

Interception and evaporation

Both interception and evaporation are negligible in fully-sewered urban catchments and therefore unimportant in the determination of runoff volumes. The only effect of evaporation is on the depletion of depression storage between rainfall events and as such, it will affect the immediate antecedent conditions.

Infiltration

The infiltration process in the pervious areas of an urban catchment may be assumed to be identical to that taking place in natural catchments. Assuming a Horton (1940) type of infiltration model (ie. loss rate subtracted from rainfall rate), the infiltration loss from pervious surfaces will be a complex function of the pervious area, the rainfall duration, total depth of rainfall, some measure of rainfall intensity over all or some critical part of the rainfall event, and the Horton coefficients: the initial infiltration capacity (f_o); the equilibrium infiltration capacity (f_c) and the decay constant (k). These in turn are dependent on the soil type and the long-term antecedent wetness of the catchment.

The term 'impervious' as traditionally used is undoubtedly something of a misnomer since it is likely that, of the rain falling on a paved area, some small proportion infiltrates, either through the surface itself or through cracks, joints or faults in the paved surface. The nature and temporal distribution of this infiltration is difficult to determine but may be assumed to be constant. If this assumption is adopted, then the loss due to infiltration over the paved surfaces is a function of the paved area and the storm duration. On the other hand, assuming that the roofed areas are directly connected to the sewer system, any infiltration loss from this source is negligible.

Depression storage

Storage of rainwater on the surface of the catchment, preventing its contribution to runoff, is known as depression storage. In the case of paved surfaces it may be seen as a combination of (i) that layer of water which is being held on the ground by surface tension (initial wetting) and (ii) that water which is being held in surface depressions where the configuration of the ground prevents the water from reaching an inlet. These two components are best combined and depression storage treated as a depth of water spread evenly over the surface. Depression storage is a function only of physical variables, the predominant ones being catchment slope and paved area. Depression storage for pitched roofs may be seen as initial wetting only, and is relatively insignificant. The likely ratio of magnitude of the two components of depression storage would suggest that storage loss for roofed areas is negligible. Depression storage on pervious surfaces will similarly depend on catchment slope and pervious area. However, a complication arises because the depression storage will be depleted by infiltration when the rainfall intensity falls below the infiltration rate. Thus, the loss due to depression storage over pervious surfaces is, to some extent, also a function of those variables affecting the infiltration losses over the pervious areas.

The depression storage on both pervious and impervious surfaces also depends on the immediate antecedent conditions (not to be confused with the longer-term antecedent conditions). If the event is a single cell of a much larger event, then one might expect the depression storage over the paved surfaces, if not the pervious surfaces, to be satisfied. Conversely, an event occurring over a dry catchment might have to satisfy the full depression storage before runoff occurs. In this study the immediate antecedent conditions are treated as a dichotomy, such that depression storage is taken to be either satisfied or unsatisfied corresponding to a wet or dry catchment. This is clearly a simplification, since it is possible to have an event where, immediately prior to the start, the catchment conditions are somewhere between the two extremes. However, the vast majority of events used in this study appeared to fall clearly into one of the two categories outlined above.

Other losses

Perhaps the greatest cause of uncertainty in estimating runoff volumes lies in the interaction of runoff from impervious and pervious surfaces. In most cases, the runoff contribution from pervious areas will travel over the impervious surfaces to reach the sewer system. If this contribution is considered in the same way as rain falling on the impervious surfaces, then it will be subject to the same losses as the latter. In some cases, the above order of occurrence may be partially reversed, as in the case of a footpath separated from road gullies by a grass verge. In this instance, the footpath's contribution is bound to be influenced by the physical characteristics of the grass verge and vice versa. It is impractical to postulate a distributed model for such a complex interaction for use in a design situation.

The other major uncertainty of this type corresponds to the assessment of contributing area. In any given catchment there will almost certainly be a proportion of the pervious surfaces which may not be expected to contribute to the sewer system (in effect, all rainfall will be lost to infiltration). In addition, there will be areas of impervious surface which do not contribute to the sewer system, either because the impervious surfaces were not constructed strictly according to the designer's specifications or due to subsequent effects such as blockage and by-passing of gullies, blockage of downpipes etc. Such losses as these are also not amenable to distributed modelling.

Another cause of rainfall loss is due to a reduced catch by roofs. It is current opinion that a roof will catch a reduced quantity of rainfall due mainly to air turbulence around a building. The reduced catch by a roof will result, to some extent, in an increased catch by other surfaces, although it is unlikely that the magnitude of the increased catch will have as significant an effect on the volume of runoff as the reduced roof catch, because much of it will fall on the walls of buildings and on the back-gardens, from where it will be unlikely to reach the sewer system.

The last loss to be considered does not occur on the ground surface at all but in the sewer system itself where infiltration (in through the pipe joints) or exfiltration (out through the pipe joints) may occur. There is usually a base flow present in almost all storm sewer systems throughout dry periods. This may be due to infiltration, an effective 'negative' loss to the system. Such a baseflow is indicative of some interaction between the system and the surrounding groundwater. To compound the problem, there is no indication as to whether this infiltration is present at a constant rate through all depths of flow or whether it may change into exfiltration at a flow depth greater than the baseflow resulting in an effective loss to the system.

When considered individually, each of the above factors might be regarded as relatively trivial in the context of a design model. Considered together, they represent a major source of error which hinders model calibration on most catchments and justifies the use of simplified concepts.

There are two major conclusions arising out of the above discussion. The first comprises a list of catchment and storm characteristics upon which the losses in fully-sewered urban catchments may be expected to depend. Table 1 is a summary of these characteristics. Some, such as rainfall depth, duration and catchment area, may be reflected directly as catchment or storm variables; others, such as antecedent catchment conditions or soil type, require indexing.

The other major conclusion concerns the complexity of processes in sewered catchments. If a deterministic solution were to be attempted, then all significant aspects of the process should be considered. While some aspects, such as infiltration and depression storage, are amenable to such an approach, others, such as the interaction of surfaces and pipe blockages, are not. It seems that a statistical approach to runoff volume prediction, such as has been used recently for natural catchments (NERC, 1975), is more appropriate.

TABLE 1 Factors affecting rainfall-runoff losses

	IMPERVIOUS AREAS		PERVIOUS AREAS	
Cause of loss	*Catchment characteristics*	*Storm characteristics*	*Catchment characteristics*	*Storm characteristics*
INFILTRATION	impervious area	storm duration	pervious area soil type	storm duration rainfall volume long-term catchment wetness rainfall intensity
DEPRESSION STORAGE	impervious area catchment slope	immediate antecedent wetness	pervious area catchment slope	immediate antecedent wetness infiltration factors
OTHER LOSSES	impervious area roofed area	storm duration rainfall volume		storm duration

II: THE DATA SET

Data from fourteen catchments have been collected and assembled in a suitable form for analysis. Data from seven of the catchments had been used previously by the Transport and Road Research Laboratory in their work on the design of urban sewer systems (Watkins, 1962). Data from the other seven catchments have been collected more recently during university research or under the sponsorship of the Department of the Environment.

Table 2 gives brief details of all fourteen catchments which are fully-sewered and gauged for rainfall and runoff at one or more points. The location of the catchments is shown in Figure 2.

Rainfall-runoff data preparation

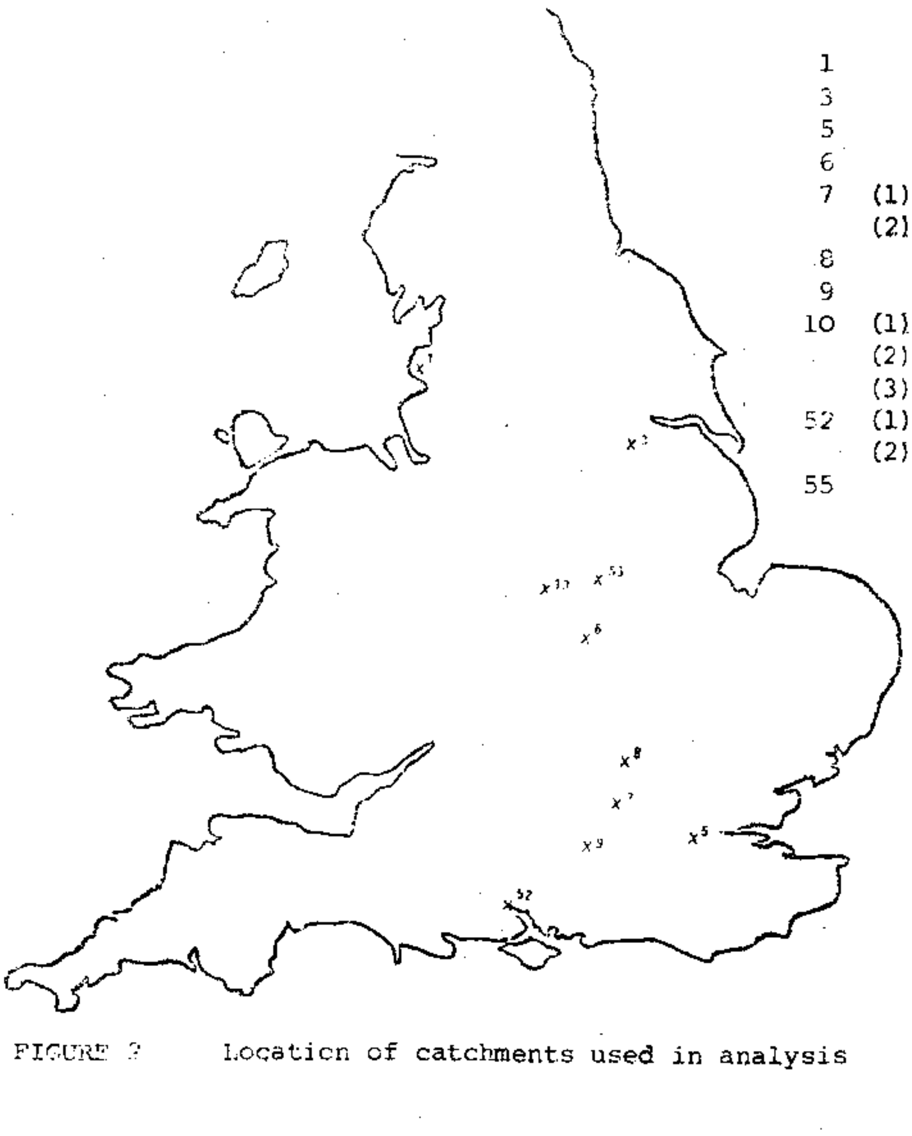
In general, rainfall was measured by one or more autographic raingauges and both rainfall and runoff were recorded on open-scale charts. The objective, in all cases, was to obtain temporal distributions of rainfall and runoff for high intensity storms of up to three hours duration. Data from a certain number of catchments were rejected due to poor quality; only data from catchments with reliable discharge measurements were used.

For all catchments, raw data were available in the form of rainfall and runoff charts. Individual storm events were extracted for analysis with regard to two main criteria:

(i) Discrete (but not necessarily single-peaked) hydrographs resulting from relatively short and intense rainfall
(ii) Runoff in excess of a specified stage for each flow gauge, ie. 'significant' events.

The chosen events were reduced to a digital record using the Institute's D-MAC digitiser. These records were then transferred to a disc-file record on the Institute's UNIVAC computer as a time series of rainfall (intensity in mm/hour) and runoff (discharge in litres/second) values at one minute intervals throughout each event.

The data for each event were then synchronised (according to chart time) as a rainfall-runoff record and output in both tabular and graphical form. The above data collection exercise was not done solely with the runoff volume studies in mind but with the purpose of creating an archive of urban hydrological data.



1		Blackpool
3		Doncaster
5		Kidbrooke
6		Leicester
7	(1)	Oxhey Housing Estate
	(2)	Oxhey Road
8		WPRL, Stevenage
9		Wildridings, Bracknell
10	(1)	St Marks Road, Derby
	(2)	St Marks Road, Derby
	(3)	St Marks Road, Derby
52	(1)	Lordshill, Southampton
	(2)	Lordshill, Southampton
55		Rise Park, Nottingham

FIGURE 2 Location of catchments used in analysis

TABLE 2 Details of catchments employed in analysis

CATCHMENT NUMBER AND NAME		BRIEF DESCRIPTION OF CATCHMENT	RAINFALL	RUNOFF	SPONSOR	TOTAL AREA (ha)	% IMPERV	PERIOD OF DATA	NO. OF EVENTS
1	BLACKPOOL	medium density residential development-circa 1939	RRL auto-graphic gauge	standing wave flume in combined sewer	RRL	4.02	41.9	1953-1958	46
3	DONCASTER	low density residential development - probably pre-war	RRL auto-graphic gauge	standing wave flume in seaparate sewer	RRL	5.14	30.0	1955-1958	15
5	KIDBROOKE, KENT	small factory area with large concrete yards	RRL auto-graphic gauge Dines auto-graphic gauge	standing wave flume in separaate sewer	RRL	3.42	68.2	1953-1958	70
6	LEICESTER	mixed older-type residential development. High density close to outfall - low density at top of catchment	2 RRL auto-graphic gauges	standing wave flume	RRL	59.50	36.1	1958	39
7(1)	OXHEY HOUSING ESTATE	large residential development	3 RRL auto-graphic gauges	standing wave flume	RRL	247.00	19.8	1953-1959	19
7(2)	OXHEY ROAD	500 m length of road and grass verge in shallow cutting	RRL auto-graphic gauge Dines auto-graphic gauge	V-notch weir	RRL	.73	60.3	1954-1959	6
8	WPRL, STEVENAGE	small factory area similar to Kidbrook	RRL auto-graphic gauge Dines auto-graphic gauge	V-notch weir	RRL	1.39	50.0	1955-1959	26
9	WILDRIDINGS, BRACKNELL	Modern development residential, shops and school	Dines auto-graphic gauge	standing wave flume at outfall	DGWE	17.60	46.2	1974-1975	20
10(1)	ST. MARKS RD 1, DERBY	3 nested catchments mixed-age residential development		stage is measured at 3 points in the system	DGWE	10.40	52.9	1971-1975	15
10(2)	ST. MARKS RD 2, DERBY		Dines auto-graphic gauge		DGWE	8.55	51.0	1971-1975	19
10(3)	ST. MARKS RD 3, DERBY				DGWE	7.23	48.7		39
52(1)	LORDSHILL 1, SOUTHAMPTON	2 small adjacent catchments, modern residential development	Tipping bucket gauge	Arkon air-purge system in prefabricated flumes at outfall	Univ. of S'ton	.8	41.3		29
52(2)	LORDSHILL 2, SOUTHAMPTON					.6	41.7	1974-1975	10
55	RISE PARK NOTTINGHAM	modern residential	Tipping bucket gauge	Dilution gauging	Trent Poly.	62.0	31.1	1974	7

Some of the rainfall-runoff data were poorly synchronised, but this deficiency (although important for modelling the complete process) is irrelevant for modelling volume relationships as long as the causative rainfall can be identified. At the time of digitisation the start and finish points of a rainfall event were chosen to cover adequately the complete storm; later, a reduction of the event was made so that only the period of most intense rain was included. The start of this intense rainfall was arbitrarily defined as the point when the rainfall intensity continuously exceeded 1 mm/hr and the end of the event was defined as the point when the intensity dropped below 1 mm/hr for more than five minutes. The resulting hyetograph was integrated to give a total rainfall volume in mm over the catchment. If there were records from more than one raingauge in or near the catchment, an average rainfall hyetograph was generated using Thiessen polygons.

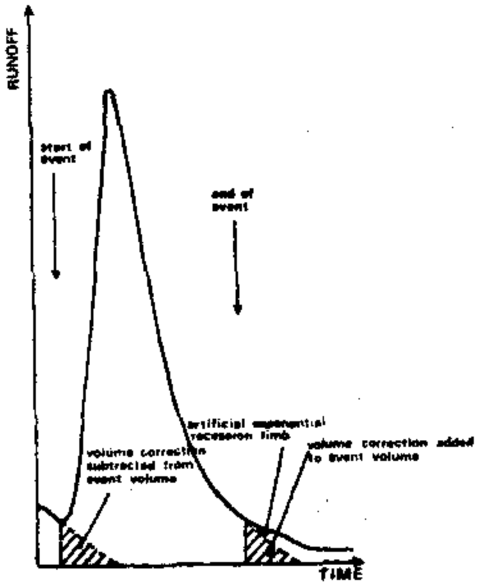


FIGURE 3

Typical corrections made in the derivation of runoff volume

Similarly, the runoff data were reduced to give a single hydrograph for each event. The start of the event was defined as the point where the hydrograph began to rise and the end at a point on the falling limb before it had flattened out (hydrographs from sewered catchments tend to flatten out at a low discharge into long recession limbs not associated with the direct catchment runoff). A typical hydrograph is shown in Figure 3.

A correction was made to account for the volume of direct runoff still in storage at the nominal end of the event, assuming an exponential recession limb from the cutoff point. For a given catchment, the value of the recession constant K (minutes) was obtained from a study of the approximate time of concentration and logarithmic plots of the recession limbs of selected events. For an exponential decay, the volume under a recession associated with a given discharge Q (litres/s) is equal to 60KQ (litres). A similar correction was deducted from the runoff volume where the rising limb of the hydrograph commenced from a non-zero discharge. These volume corrections are illustrated in Figure 3.

The volume of runoff in litres for each event was thus calculated by integration of the hydrograph from start to end, and the above corrections applied. The volume was then converted to an equivalent depth in mm over the paved area so that it was dimensionally comparable with rainfall depth.

Together with the two variables, rainfall volume (PPT) and runoff volume over the paved surface (IMPQ), the basic data set comprises another twelve variables. Of these, six may be defined as catchment characteristics and eight as storm characteristics. The definition of these characteristics together with a number of subsidiary ones (calculated from the basic set), will be treated individually.

Catchment characteristics

The first catchment variable in the data set is the catchment number (CNO), and is used solely for identification.

The second characteristic is the average catchment slope. A number of slope measurements were considered. Finally, the variable SLOPE was defined as the weighted average pipe slope, which was felt to provide a good objective approximation to an average ground slope and was capable of exact replication. Details of lengths and gradients were extracted from a plan of the pipe network and used in the following equation to derive SLOPE:

$$SLOPE = \frac{\sum_{j=1}^{n} S_j L_j}{\sum_{j=1}^{n} L_j} \qquad \ldots (1)$$

where S and L are the slope (%) and length respectively of each individual pipe j in the system, and n is the total number of pipes in the system.

The area characteristics are defined by three variables, TOTA, IMPA, and RATIO. TOTA and IMPA are the total area and impervious area respectively, and RATIO is the ratio of roofed to paved surfaces within the impervious category. A subsidiary variable, defined from the basic set, is the percentage of impervious area, PIMP, obtained from the equation

$$PIMP = \frac{100 \times IMPA}{TOTA} \qquad \ldots (2)$$

The soil type is described using the soil index, SOIL, as employed in the UK Flood Studies Report (NERC, 1975). The soil index is calculated by finding the area of the catchment in each soil type, using the national soil map at a scale of 1 inch to 10 miles (NERC, 1975), which defines five soil classifications from class 1 (very high acceptance, low runoff) to class 5 (very low acceptance, high runoff). A weighted mean of soil fractions was adopted as a soil index with a range of .15 to .50, as given by

$$SOIL = \frac{0.15S_1 + 0.30S_2 + 0.40S_3 + 0.45S_4 + 0.50S_5}{S_1 + S_2 + S_3 + S_4 + S_5} \qquad \ldots (3)$$

where S_n is the catchment area within soil classification n. In practice, each catchment, because of its small relative size, fell wholly within one soil type, and so the calculation was simplified.

Storm characteristics

The first storm variable is the storm number (SNO), and is used for identification only. The next two are the rainfall volume (PPT) and the runoff volume over the paved area (IMPQ), the derivation of which is described above. A subsidiary variable is the runoff volume expressed as a depth over the total catchment area (TOTQ), and is calculated from

$$TOTQ = IMPA \times IMPQ/TOTA \qquad \ldots (4)$$

The immediate antecedent conditions, relating to whether or not the depression storage is satisfied, are indexed by the variable IFWET, which has a value of 1 when the antecedent conditions are dry (depression storage unsatisfied) and of 0 when the reverse is true. It is obtained by a subjective scrutiny of the rainfall charts for the period leading up to the commencement of the event.

The long-term antecedent conditions are indexed by one of three variables. The first is the five-day antecedent precipitation index, API5, and is obtained from the rainfall record prior to a given event. Assuming the daily rainfall to be evenly distributed, the $API5_9$ (the index at 9 a.m. on any given day) was obtained as follows:

$$API5_9 = API5_O \times C + P \times \sqrt{C} \qquad \ldots (5)$$

where $API5_O$ is the value of the index at 9 a.m. on the previous day, P is the rainfall in the preceding 24 hours, and C is the depletion constant taken as 0.5. The value of the API5 at the start of an event was then obtained from the following:

$$API5_T = API5_9 \times C^{\frac{T-9}{24}} + P_{9.T} \times C^{\frac{T-9}{48}} \qquad \ldots (6)$$

where T is the start time of the event. T-9 is the time (in hours) between 9 a.m. on the day of the event and the start of the event. $P_{9.T}$ is the rainfall during T-9 taken to be evenly distributed. If the distribution was known and the rainfall was very unevenly distributed, the adjustment to obtain $API5_T$ was done manually (using a depletion constant of $C^{1/24}$ for every hour).

SMD, the soil moisture deficit, is a further index of antecedent conditions. The SMD value for 9 a.m. on the day of the event was obtained for the nearest SMD station(s) to the catchment. (Data were obtained through the Meteorological Office, Bracknell). If data from more than one station were used, an average was obtained by weighting the individual values on the basis of proximity to the catchment. This value was then reduced by the quantity of rain which fell between 9 a.m. and the start of the event ($P_{9.T}$ above).

CWI, the catchment wetness index, is a subsidiary variable describing antecedent conditions. It was developed in the Flood Studies (NERC, 1975) to provide a compromise between SMD and the rather shorter term index, API5. It is obtained from API5 and SMD using the following equation:

$$CWI = 125 + API5 - SMD \quad \text{(All values in mm)} \qquad \ldots (7)$$

The figure of 125 is introduced with the sole purpose of keeping the CWI positive.

The next variable is the rainfall duration, DUR, defined as the time in minutes between start and end times of intense rainfall as discussed in the section on rainfall-runoff data preparation.

The rainfall intensity is characterised in one of two ways. Kaltenbach (1963) considered that the most significant variable was the average rainfall intensity during the severest 5 minutes of the event. Thus, M5I, the maximum 5-minute rainfall intensity, was extracted from the rainfall record. A subsidiary variable, AVINT, the average rainfall intensity during the event was included as an alternative to the M5I, and is given by:

$$AVINT = 60 \times PPT/DUR \qquad \ldots (8)$$

Dependent variables

Having chosen multiple linear regression analysis to generate a mathematical model, the number of different forms of the model are limited to those in which the parameters occur linearly. Firstly, an additive form ($y = B_o + B_1 x_1 + B_2 x_2 + \ldots$) a multiplicative form ($y = B_o\, x_1^{B_1} . x_2^{B_2} . \ldots$) or some combination of the two (for instance $y = B_o + B_1 x_1 + B_2 x_2 . x_3 + B_3 x_4 + \ldots$) may be adopted and these alternatives will be investigated later. Secondly, a variety of forms of the dependent variable may be adopted depending on the modeller's subjective presuppositions about the mechanics of the system.

For instance, the runoff-volume (in litres) might be the initial choice for the dependent variable. But intuition would suggest that this volume is so strongly (and directly) dependent on the area of the catchment that a better dependent variable could be obtained by dividing the volume by the area - this is because the runoff volume from a given catchment might be expected to be approximately double that from a catchment of half the size, all other things being equal. Thus, a more appropriate dependent variable would be the runoff volume expressed as an equivalent depth over the catchment (as for rainfall volume). This transformation does not mean that catchment area should be excluded from the list of independent variables.

This line of argument can be carried a step further by applying the same reasoning to the rainfall volume as to the catchment area, based on the knowledge that the runoff depth is so strongly dependent on the rainfall depth that benefit could be derived by including the latter in the dependent variable. This is traditionally achieved in one of two ways: (a) by dividing the runoff depth by the rainfall depth to give the proportional runoff (x100 to give the percentage runoff), or (b) by subtracting the runoff depth from the rainfall depth to give the loss.

Finally, the watershed boundaries in an urban catchment may be more closely aligned to the limits of the impervious area alone than to the limits of the whole catchment area. It is possible, therefore, that benefit could be derived from taking the catchment area as equal to the area of impervious surfaces, and deriving the dependent variables accordingly (obtaining a runoff depth by dividing the runoff volume (in litres) by IMPA instead of TOTA).

Based on the above discussion and with no prior evidence to suggest which of the forms of dependent variable might be the most appropriate, regression analyses were performed independently on the four variables as below:

the loss over the total area,
TOTLOSS = PPT - TOTQ ... (9)

the notional loss over the paved area,
IMPLOSS = PPT - IMPQ ... (10)

the percentage runoff over the total area,
TOTPQ = TOTQ/PPT x 100 ... (11)

the notional percentage runoff over the paved area,
IMPPQ = IMPQ/PPT x 100 ... (12)

The variables, TOTLOSS and TOTPQ, are logical and physically understandable. It should be noted that the values of TOTLOSS are always positive whereas values of IMPLOSS range from -17.58 to +11.68. Similarly, TOTPQ has a range from 8.87% to 88.29% whereas IMPPQ sometimes exceeds 100%. Although these anomolies are not desirable from a logical viewpoint, it is felt that the inclusion of all these dependent variables is justified in determining the best form of the equation.

It is difficult to decide at this stage which of the 4 dependent variables is appropriate. A similar exercise for natural catchments (NERC, 1975) concluded that the percentage runoff form of the equation was more appropriate than the loss form. It was decided to perform the analyses using all the dependent variables, and then to compare the four equations obtained.

Table 3 contains a complete list of dependent and independent variables. The complete data set and its associated correlation matrix may be found in the Appendix.

TABLE 3 Definition of variables

	Variable	*Definition*	*Derivation*
BASIC DATA SET	CNO	catchment number	
	SLOPE	catchment slope (weighted average pipe slope) (%)	
	TOTA	total catchment area (ha)	
	IMPA	impervious (paved and roofed) area (ha)	
	RATIO	ratio of roofed area to paved area	
	SOIL	soil type index	
	SNO	storm number	
	PPT	rainfall volume (in mm)	
	IMPQ	runoff volume (in mm over impervious area)	
	IFWET	immediate antecedent wetness dichotomy	
	API5	5-day antecedent precipitation index	
	SMD	soil moisture deficit (in mm)	
	DUR	duration of rainfall event (minutes)	
	M5I	maximum 5-minute rainfall intensity (mm/hr)	
SUBSIDIARY VARIABLES	PIMP	percentage impervious (%)	IMPA/TOTA X 100
	AVINT	average rainfall intensity (mm/hr)	60 PPT/DUR
	TOTQ	runoff volume (in mm over total area)	IMPA X IMPQ/TOTA
	CWI	catchment wetness index	125 +API5 - SMD
DEPENDENT VARIABLES	TOTLOSS	rainfall loss over total area (mm)	PPT-TOTQ
	IMPLOSS	notional rainfall loss over impervious area (mm)	PPT-IMPQ
	TOTPQ	percentage runoff from total area (%)	TOTQ/PPT X 100
	IMPPQ	notional percentage runoff from impervious area (%)	IMPQ/PPT X 100

III: THE ANALYSIS

Multiple linear regressions were fitted using the ASCOP computer package (NCC, 1972) on the Institute's UNIVAC computer, to examine the relationships between variables and thus to derive an equation to predict the volume of runoff that could be expected from a given storm on a given catchment.

The multiple determination coefficient, R^2 (defined as the proportion of explained variance) is a convenient measure of the usefulness of the independent variables for predicting the dependent variable; for this reason R^2 values are quoted throughout.

Individual catchments

In the first stage of analysis, two dependent variables (TOTLOSS and TOTPQ) were chosen and the linear relationship between these and each independent storm variable were examined for each catchment individually. This identified the storm variables which exert the greatest apparent control on the dependent variables.

The most significant variables, overall, for explaining TOTLOSS were PPT and DUR, (PPT being the single most significant for every catchment) followed by M5I, AVINT, SMD, API5, CWI and IFWET in descending order of importance. Details of the appropriate correlations for each catchment can be found in Table 4; R^2 values are given.

Explanation of TOTPQ was not dominated by any one storm variable and it seemed that storm variables were much less useful in the prediction of TOTPQ than they were for predicting TOTLOSS. The three antecedent wetness variables, CWI, SMD and API5 were the most significant followed by M5I, IFWET, PPT, DUR and AVINT. There was very little difference in the ability of any of these variables to predict TOTPQ; they were all relatively poor. Table 4 gives details of these correlations.

The second stage of the analysis on the individual catchment was to do regressions on the 'best' one, two, three and four variables. (The 'best' regression equation being defined as that one having the highest sum of squares due to the regression). It should be noted that the 'best' one variable does not necessarily appear in the 'best' two variable equation and so on (for example see Table 5, showing the TOTPQ analysis for Blackpool). The R^2 results for the Leicester and Nottingham catchments should be noted with caution as the number of variables approaches the number of points, reducing the degrees of freedom to such an extent that it is virtually impossible not to obtain an R^2 value close to 1.0. Table 5 gives details of these regressions.

By obtaining a 'score' for each variable by giving it a weighting according to its frequency of occurrence as the best first, second, third or fourth variable in the regression equations, we find that the

TABLE 4 **Multiple determination coefficients for individual catchment analyses, expressed as percentages**

	BLACKPOOL		DONCASTER		KIDBROOKE		LEICESTER		OXHEY 1		OXHEY 2		STEVENAGE	
	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ
PPT	96.8	0.0	98.3	1.1	95.6	0.6	70.6	64.5	96.5	14.1	70.0	14.9	99.2	1.6
IFWET	15.3	9.6	1.7	0.3	0.2	14.1	0.8	0.2	1.7	1.6	0.4	2.4	0.2	0.0
API5	28.1	3.4	2.3	0.3	1.7	13.2	17.0	0.0	2.2	20.0	0.0	0.8	1.0	2.7
SMD	0.0	17.2	3.9	15.2	0.1	0.7	28.5	85.5	0.7	42.7	0.9	3.6	1.4	2.3
CWI	1.6	18.7	5.3	16.2	0.0	1.7	18.7	90.2	0.4	47.1	0.9	2.6	1.7	1.3
DUR	77.2	0.1	45.4	2.8	61.0	0.5	26.6	93.6	44.7	14.8	24.6	8.5	27.0	0.1
AVINT	1.0	1.2	8.5	9.4	0.1	0.7	1.1	50.9	15.0	0.0	24.6	4.1	2.3	0.2
MSI	17.4	1.0	33.1	21.8	13.0	1.3	15.9	1.8	36.3	0.4	36.0	5.1	29.7	6.9

	BRACKNELL		DERBY 1		DERBY 2		DERBY 3		SOUTHAMPTON 1		SOUTHAMPTON 2		NOTTINGHAM	
	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ	TOTLOSS	TOTPQ
PPT	88.8	0.1	96.4	2.7	98.3	0.5	98.5	0.3	93.3	28.1	99.7	5.0	100.0	78.2
IFWET	4.5	24.9	1.2	9.5	3.3	0.5	0.6	0.3	1.2	34.4	19.2	10.6	1.0	7.5
API5	3.6	55.0	0.3	1.7	4.1	10.3	0.8	0.1	2.3	17.1	1.0	33.6	26.2	16.1
SMD	0.4	32.2	9.4	19.3	0.0	23.1	0.0	6.6	1.7	0.9	2.0	0.0	44.7	19.5
CWI	0.8	41.2	9.0	18.2	0.1	24.2	0.0	6.2	2.2	2.3	1.7	0.6	28.9	11.5
DUR	54.0	0.1	87.3	2.7	72.6	0.8	71.2	1.1	84.6	17.2	54.3	2.3	25.1	47.4
AVINT	5.9	2.2	2.9	1.3	0.8	0.1	0.9	9.3	14.4	11.3	0.7	0.2	70.0	39.9
MSI	16.1	0.1	0.3	5.0	23.6	0.0	24.0	12.1	3.7	0.1	7.7	2.7	72.8	31.6

TABLE 5 **Best n-variable regressions for individual catchment analyses**

REGRESSION OF TOTPQ ON BEST 1-4 STORM VARIABLES FOR INDIVIDUAL CATCHMENTS

CATCHMENT	BEST N VARIABLES n=1	n=2	n=3	n=4	3 VARIABLE REGRESSION EQUATION SHOWING R^2 VALUE	
BLACKPOOL	CWI	IFWET, SMD	IFWET, SMD, MSI	PPT, DUR, MSI, CWI	50.3-3.82 IFWET-.183 SMD -.177 MSI	R^2=.29
DONCASTER	MSI	MSI, CWI	DUR, MSI, AVINT	DUR, MSI, CWI, AVINT	30.1+.092 DUR -.506 MSI+.628 AVINT	R^2=.36
KIDBROOKE	IFWET	IFWET, API5	PPT, IFWET, API5	PPT, IFWET, DUR, MSI	43.7+.329 PPT-5.61 IFWET+.536 API5	R^2=.17
LEICESTER	DUR	API5, DUR	IFWET, API5, DUR	IFWET, API5, SMD, DUR	440.-45.0 IFWET-7.14 API5-2.42 DUR	R^2=1.00
OXHEY H.E	CWI	PPT, CWI	IFWET, DUR, CWI	IFWET, DUR, MSI, CWI	4.55+3.04 IFWET+.073 DUR+.148 CWI	R^2=.61
OXHEY ROAD	PPT	PPT, SMD	SMD, DUR, AVINT	PPT, IFWET, API5, SMD	44.5+.065 SMD+.306 DUR+.570 AVINT	R^2=.20
STEVENAGE	MSI	MSI, AVINT	DUR, MSI, AVINT	IFWET, API5, MSI, AVINT	20.6+.034 DUR-.109 MSI+.286 AVINT	R^2=.28
BRACKNELL	API5	SMD, CWI	SMD, DUR, CWI	IFWET, SMD, DUR, CWI	-108.+1.05 SMD-.077 DUR+1.19 CWI	R^2=.69
DERBY 1	SMD	IFWET, CWI	IFWET, MSI, CWI	IFWET, SMD, MSI, CWI	23.2+8.60 IFWET+.406 MSI+.136 CWI	R^2=.31
DERBY 2	CWI	CWI, AVINT	IFWET, API5, SMD	IFWET, API5, SMD, AVINT	36.3+4.80 IFWET+.841 API5-.096 SMD	R^2=.27
DERBY 3	MSI	SMD, MSI	SMD, MSI, AVINT	IFWET, SMD, MSI, AVINT	47.5-.052 SMD-.127 MSI-.384 AVINT	R^2=.18
SOUTHAMPTON 1	IFWET	PPT, IFWET	PPT, IFWET, API5	PPT, IFWET, SMD, CWI	20.5+1.61 PPT-7.66 IFWET+.748 API5	R^2=.60
SOUTHAMPTON 2	API5	API5, MSI	IFWET, API5, AVINT	IFWET, API5, DUR, AVINT	23.5-2.31 IFWET+.530 API5+.087 AVINT	R^2=.42
NOTTINGHAM	PPT	PPT, MSI	PPT, MSI, AVINT	PPT, IFWET, API5, MSI	653.-31.1 PPT+11.2 MSI-28.8 AVINT	R^2=.95

REGRESSION OF TOTLOSS ON BEST 1-4 STORM VARIABLES FOR INDIVIDUAL CATCHMENTS

CATCHMENT	BEST N VARIABLES n=1	n=2	n=3	n=4	3 VARIABLE REGRESSION EQUATION SHOWING R^2 VALUE	
BLACKPOOL	PPT	PPT, CWI	PPT, IFWET, CWI	PPT, DUR, MSI, CWI	.599+.573 PPT+.175 IFWET-.005 CWI	R^2=.97
DONCASTER	PPT	PPT, MSI	PPT, MSI, AVINT	PPT, DUR, MSI, AVINT	-.335+.690 PPT+.038 MSI-.036 AVINT	R^2=.99
KIDBROOKE	PPT	PPT, IFWET	PPT, IFWET, DUR	PPT, IFWET, DUR, MSI	-.203+.546 PPT+.228 IFWET+.003 DUR	R^2=.96
LEICESTER	PPT	PPT, SMD	PPT, SMD, MSI	PPT, IFWET, SMD, AVINT	-.829+.593 PPT+.025 SMD+.010 MSI	R^2=.97
OXHEY H.E.	PPT	PPT, CWI	PPT, DUR, CWI	PPT, IFWET, DUR, CWI	1.92+.784 PPT-.015 DUR-.017 CWI	R^2=.99
OXHEY ROAD	PPT	PPT, MSI	PPT, SMD, MSI	PPT, API5, MSI, CWI	.549+.214 PPT-.003 SMD+.010 MSI	R^2=.73
STEVENAGE	PPT	PPT, MSI	PPT, MSI, AVINT	PPT, DUR, MSI, AVINT	-.058+.749 PPT+.015 MSI-.020 AVINT	R^2=1.00
BRACKNELL	PPT	PPT, API5	PPT, API5, SMD	PPT, API5, DUR, AVINT	.051+.629 PPT-.069 API5+.008 SMD	R^2=.96
DERBY 1	PPT	PPT, DUR	PPT, DUR, MSI	PPT, DUR, MSI, AVINT	.799+.728 PPT-.012 DUR-.056 MSI	R^2=.97
DERBY 2	PPT	PPT, CWI	PPT, CWI, AVINT	PPT, DUR, MSI, CWI	.432+.584 PPT-.005 CWI+.021 AVINT	R^2=.99
DERBY 3	PPT	PPT, DUR	PPT, SMD, DUR	PPT, IFWET, DUR, MSI	-.013+.679 PPT+.002 SMD-.006 DUR	R^2=.98
SOUTHAMPTON 1	PPT	PPT, IFWET	PPT, IFWET, API5	PPT, IFWET, API5, DUR	.320+.618 PPT+.408 IFWET-.036 API5	R^2=.96
SOUTHAMPTON 2	PPT	PPT, API5	PPT, IFWET, API5	PPT, IFWET, API5, AVINT	.108+.721 PPT+.032 IFWET-.020 API5	R^2=1.00
NOTTINGHAM	PPT	PPT, API5	PPT, API5, AVINT	PPT, IFWET, API5, AVINT	.291+.706 PPT-.016 API5+.009 AVINT	R^2=1.00

only result which confirms those made earlier in this section is that PPT is overwhelmingly the most significant variable in explaining the variation in TOTLOSS. The other variables used in explaining TOTLOSS are, in order of frequency of occurrence, M5I, DUR, API5, IFWET, CWI, AVINT and SMD.

The reason for DUR becoming less important than was suggested earlier is that it is strongly correlated with PPT, so that once PPT has been included, there is little benefit to be derived from the inclusion of DUR. This is true also of the three antecedent wetness variables and gives a biassed view of their importance. If API5, SMD and CWI are considered together for the purposes of the above 'scoring' then this combined catchment wetness variable becomes more significant than all the other variables except PPT.

The frequency of occurrence of each storm variable in the 'best' regression equations to predict TOTPQ is as follows: IFWET, M5I, CWI, API5 and SMD, PPT, DUR and AVINT. If the three wetness variables are again considered together, this combined description then becomes the most important variable.

In conclusion to this part of the analysis it is emphasised that, for the explanation of TOTLOSS, the most appropriate variables seem to be PPT, a catchment wetness indicator and M5I, and for the explanation of TOTPQ, a catchment wetness indicator followed by M5I and IFWET seem most appropriate.

A further conclusion that can be made at this stage is the inconsistency of coefficients between catchments. It had been hoped that some pattern of regression coefficients from one catchment to another might have emerged, but no such pattern was observed.

The complete data set

In the second stage of analysis all catchments were considered together, allowing the introduction of catchment characteristics. These regressions were carried out with both loss (TOTLOSS and IMPLOSS) and both percentage runoff (TOTPQ and IMPPQ) descriptions as dependent variables. The only constraint on the selection of the best prediction equations, using from one to five variables, was the exclusion of the variables CNO, SNO, IMPQ, API5, SMD, RATIO and the other dependent variables. API5 and SMD were excluded to save time and cost because only one antecedent wetness variable was considered necessary in the final equation - CWI is a combination of the other two and also appeared most significant in the examination of individual catchments. RATIO was excluded because it was not considered a useful variable on its own. Tables 6 to 9 show how the regressions altered for the successive introduction of significant variables for the four dependent variables.

An assessment of the magnitude of the residual mean square, as the number of variables increases, indicates the best cut-off point for the number of variables to be included in the prediction equation. A plot

TABLE 6 Regression of TOTLOSS on best variables

VARIABLE	COEFFICIENT	ST. ERROR	T-VALUE	R	R^2
CONSTANT	- .00408	.08528	- .0478		
PPT	.61395	.01066	57.5675	.9490	.9005
CONSTANT	2.1312	.20514	10.3889		
PPT	.59403	.00939	63.2358		
PIMP	- .04094	.00367	-11.1545	.9622	.9258
CONSTANT	4.6950	.32943	14.2519		
SOIL	-4.1885	.44607	- 9.3897		
PPT	.59986	.00846	70.8819		
PIMP	- .06169	.00397	-15.5408	.9697	.9403
CONSTANT	4.2762	.33101	12.9186		
SOIL	-3.9827	.43485	- 9.1588		
PPT	.65132	.01339	48.6481		
DUR	- .00408	.00084	- 4.8665		
PIMP	- .05671	.00399	-14.2306	.9716	.9439
CONSTANT	4.441	.32989	13.4623		
SOIL	-3.5834	.44448	- 8.0620		
PPT	.64953	.01321	49.1743		
DUR	- .00393	.00083	- 4.7450		
CWI	- .00383	.00113	- 3.3982		
PIMP	- 0.5738	.00393	-14.5887	.9725	.9457

TABLE 7 Regression of IMPLOSS on best variables

VARIABLE	COEFFICIENT	ST. ERROR	T-VALUE	R	R^2
CONSTANT	1.1396	.12263	9.2936		
TOTA	- .01060	.00183	-5.7779	.2891	.0836
CONSTANT	2.1551	.23329	9.2380		
TOTA	- .01024	.00178	-5.7644		
CWI	- .01405	.00278	-5.0565	.3789	.1436
CONSTANT	1.6367	.24833	6.5911		
TOTA	- .01204	.00176	-6.8531		
PPT	.10390	.02067	5.0271		
CWI	- .01486	.00270	-5.5128	.4463	.1992
CONSTANT	1.1582	.27522	4.2083		
TOTA	- .01228	.00174	-7.0699		
DUR	.00580	.00126	4.5942		
M5I	.03463	.00693	4.9966		
CWI	- .01506	.00264	-5.6991	.4834	.2337
CONSTANT	1.8926	.37686	5.0219		
TOTA	- .01162	.00174	-6.6977		
SOIL	-2.6455	.93734	-2.8223		
DUR	.00610	.00125	4.8601		
M5I	.03614	.00689	5.2472		
CWI	- .01239	.00278	-4.4499	.5002	.2502

TABLE 8 Regression of TOTPQ on best variables

VARIABLE	COEFFICIENT	ST. ERROR	T-VALUE	R	R^2
CONSTANT	9.8353	2.4960	3.9404		
PIMP	.59820	.04884	12.2472	.5392	.2907
CONSTANT	-30.115	4.2433	- 7.0969		
SOIL	63.867	5.8312	10.9527		
PIMP	.92127	.05168	17.8274	.6828	.4661
CONSTANT	-33.353	4.1202	- 8.0951		
SOIL	55.081	5.8229	9.4594		
CWI	.08262	.01483	5.5696		
PIMP	.93192	.04971	18.7466	.7128	.5081
CONSTANT	-46.628	5.2768	- 8.8363		
IMPA	.23850	.06096	3.9126		
SOIL	62.569	6.0238	10.3869		
CWI	.08579	.01457	5.8869		
PIMP	1.1090	.06652	16.6709	.7266	.5280
CONSTANT	-44.820	5.3268	- 8.4142		
IMPA	.23720	.06069	3.9084		
SOIL	62.016	6.0033	10.3303		
IFWET	- 2.3856	1.1613	- 2.0543		
CWI	.08290	.01458	5.6865		
PIMP	1.1129	.06625	16.7974	.7304	.5334

TABLE 9 Regression of IMPPQ on best variables

VARIABLE	COEFFICIENT	ST. ERROR	T-VALUE	R	R^2
CONSTANT	43.864	4.1138	10.6626		
SOIL	100.65	10.409	9.6694	.4511	.2035
CONSTANT	37.449	3.9913	9.3827		
SOIL	75.901	10.463	7.2545		
CWI	.21584	.03161	6.8277	.5419	.2937
CONSTANT	37.083	3.8897	9.5336		
IMPA	.42840	.09465	4.5260		
SOIL	69.288	10.298	6.7282		
CWI	.21789	.03080	7.0734	.5756	.3313
CONSTANT	- 8.6932	10.896	- .7979		
IMPA	.81206	.12587	6.4518		
SOIL	102.20	12.438	8.2167		
CWI	.22679	.03009	7.5364		
PIMP	.61553	.13735	4.4814	.6053	.3664
CONSTANT	- 6.0369	11.030	- .5473		
IMPA	.81015	.12568	6.4463		
SOIL	101.39	12.431	8.1558		
IFWET	- 3.5057	2.4047	- 1.4579		
CWI	.22253	.03019	7.3716		
PIMP	.62135	.13720	4.5289	.6083	.3701

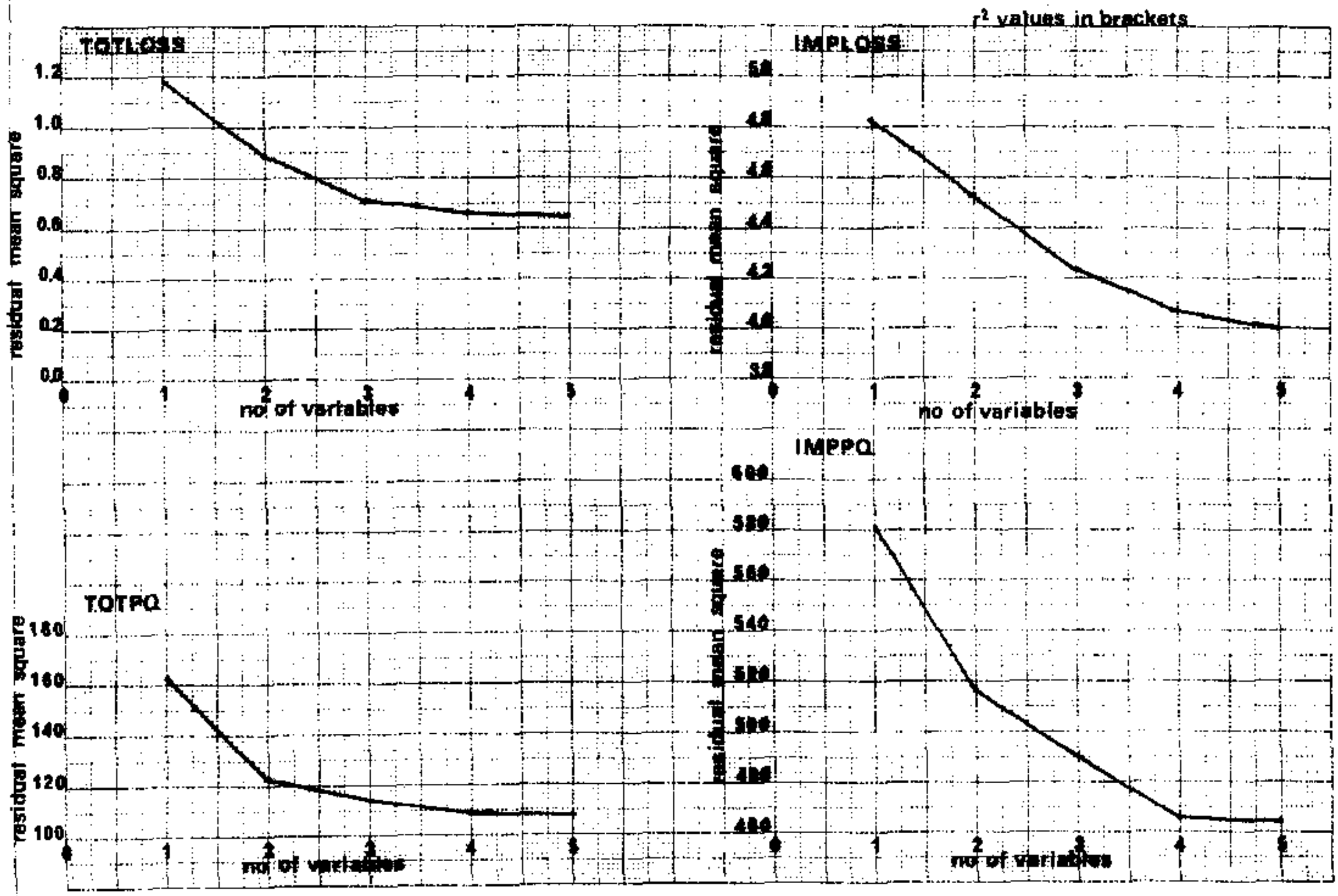


FIGURE 4 Appropriate cut-off points for the loss and percentage runoff regressions

of the residual mean square against the number of variables is shown in Figure 4 for the loss and for the percentage runoff dependent variables. From this it appears that three variables are most appropriate in the prediction of TOTLOSS and four variables in the prediction of IMPLOSS, TOTPQ and IMPPQ.

This gives the following 'best' equations:

TOTLOSS	=	4.70-4.19 SOIL + .600 PPT - .0617 PIMP	... (13)
IMPLOSS	=	1.16 - .0123 TOTA + .00580 DUR + .0346 M5I - .0151 CWI	... (14)
TOTPQ	=	-46.6 + -.239 IMPA + 62.6 SOIL + .0858 CWI + 1.11 PIMP	... (15)
IMPPQ	=	-8.69 + .812 IMPA + 102 SOIL + .227 CWI + .616 PIMP	... (16)

Looking at the R^2 value (from Tables 6 to 9) for these four equations, we find that 94.0% of the variation in TOTLOSS is explained, 23.4% for IMPLOSS, 52.8% for TOTPQ and 36.6% for IMPPQ. This suggests that the variables calculated using runoff over the total area (rather than the depth of runoff over the paved area) are easier to predict. It is also evident that a far larger percentage of the variance in TOTLOSS is explained compared to the variance explained for TOTPQ.

Comparison of equations

It was felt that the selection of the best equation for predicting the runoff from urban catchments should not be made solely with regard to the R^2 values. A comparison of the four different equations (13 to 16 shown above) was made by using each equation to predict each of the other dependent variables in turn. At first sight, the manipulation of regression equations might seem theoretically unattractive. However, if the four equations are considered as mathematical models (the fact that they are derived through regression analysis is irrelevant), then their performance may be tested against a number of objective functions. The objective functions are, in this case, the proportion of explained variance of each of the dependent variables. In addition, a further objective function was used to test the four models deriving from a measurement and prediction of the absolute volume of runoff in litres. Table 10 shows the results of this comparison, a maximisation of the first four and a minimisation of the last objective functions being desirable. At first sight, the negative R^2 values seem erroneous; the explanation is that the model is inferior to an estimate equal to the average value of the dependent variable. The circled values of the objective functions in the leading diagonal are the multiple determination coefficients derived from the regression analyses shown in Tables 6 to 9.

The chief conclusion to be drawn from Table 10 is that the percentage runoff equations are more appropriate than the loss equations. The fact that they do better after manipulation at explaining the variance of the loss dependent variables means that the percentage runoff form of the regression provides a more realistic model of the actual processes. Conversely, the loss equations provide a poor prediction of the percentage runoff variables. In terms of the objective functions, there is little to choose between the two percentage runoff equations. The higher value of the multiple determination coefficient would seem to favour the TOTPQ equation.

TABLE 10 Comparison of regression equations

		OBJECTIVE FUNCTION				
		R^2 TOTLOSS	R^2 IMPLOSS	R^2 TOTPQ	R^2 IMPPQ	$\sum\left[\frac{(Q_{PRED}-Q_{OBS})}{Q_{OBS}}\right]^2$
DEPENDENT VARIABLE	TOTLOSS	(.94)	.04	-.19	-1.96	179
	IMPLOSS	.94	(.23)	.01	-.26	67
	TOTPQ	.96	.42	(.53)	.32	42
	IMPPQ	.96	.40	.52	(.37)	38

Examination of the residuals

As a final aid in the examination of the most appropriate equation the residuals for all equations were studied. For the TOTPQ equation, plots of (a) residuals against observed rainfall volume (PPT), (b) residuals against observed TOTPQ, and (c) residuals against predicted TOTPQ, are shown in Figures 5 to 7. For further examination, each catchment is plotted using a different symbol. The two major points arising out of these plots are (i) the tendency of the model to overestimate low percentage runoffs and to underestimate high percentage runoffs (see Figure 6), which is to be expected, and (ii) the fact that the larger residuals tend to occur for 'smaller' rainfall events (see Figure 5).

Refinement of the final equation

The analyses described above concluded that the most appropriate model was the TOTPQ regression given in equation 15. Beyond this, a number of adjustments and refinements were made to this equation before a final form was adopted.

Firstly, the form of the four-variable equation leaves something to be desired in that the combination of IMPA and PIMP is intuitively very unsatisfactory (there is an inverse correlation of .63 between them). Table 8 shows that dropping IMPA from the final equation makes very little difference to the performance of the model (as indexed by the multiple determination coefficient). Thus the three-variable form was adopted, given by:

$$TOTPQ = -33.4 + .932PIMP + 55.1SOIL + .0826CWI \qquad \ldots (17)$$

It was further observed that the statistical population from which the values of SMD and API5 were derived has a marked tendency to embrace summer storm events (whereas the natural catchment data set from which the CWI was derived - NERC, 1975 - comprises mainly winter season events). During the summer season, SMD values are generally high and API5 values low (in the data set used here, average values of API5 and SMD are 5.67 mm and 57.8 mm respectively). It was thus felt that CWI was too heavily weighted in favour of SMD and that some modified index might be more appropriate. A modified definition of the catchment wetness index (and renamed the urban catchment wetness index, UCWI) was used given by:

$$UCWI = 125 + (n * API5) - SMD \qquad \ldots (18)$$

where n is some weighting factor.

Regressions were done for integer values of n between 1 and 12. It was found that the R^2 value was highest for a value of n equal to 8. ASCOP outputs for the original definition (n=1) and for the n=8 case are shown in Figures 8 and 9 respectively. Using this modified definition, the following equation was adopted as being more suitable than that given in equation 17:

FIGURES 5, 6 and 7 <u>Plots of residuals against precipitation, observed TOTPQ and predicted TOTPQ</u>

Key

Blackpool

Doncaster

Kidbrooke

Leicester

Oxhey Housing Estate

Oxhey Road

W.P.R.L., Stevenage

Wildridings, Bracknell

Derby 1

Derby 2

Derby 3

Southampton 1

Southampton 2

Nottingham

FIGURE 5

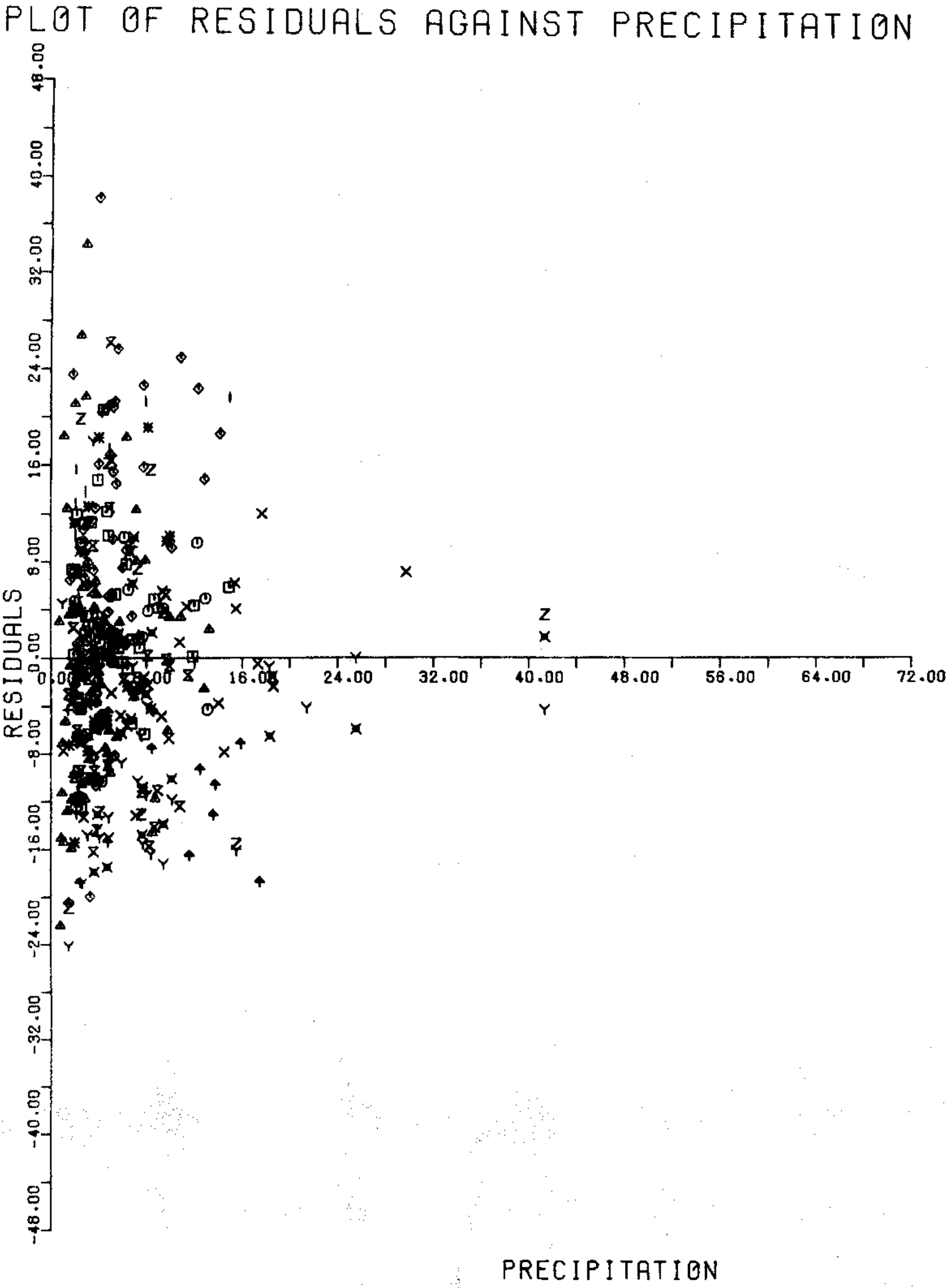

PLOT OF RESIDUALS AGAINST PRECIPITATION
RESIDUALS
PRECIPITATION
48.00
40.00
32.00
24.00
16.00
8.00
0.00
-8.00
-16.00
-24.00
-32.00
-40.00
-48.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00

FIGURE 6

PLOT OF RESIDUALS AGAINST OBSERVED TOTPQ

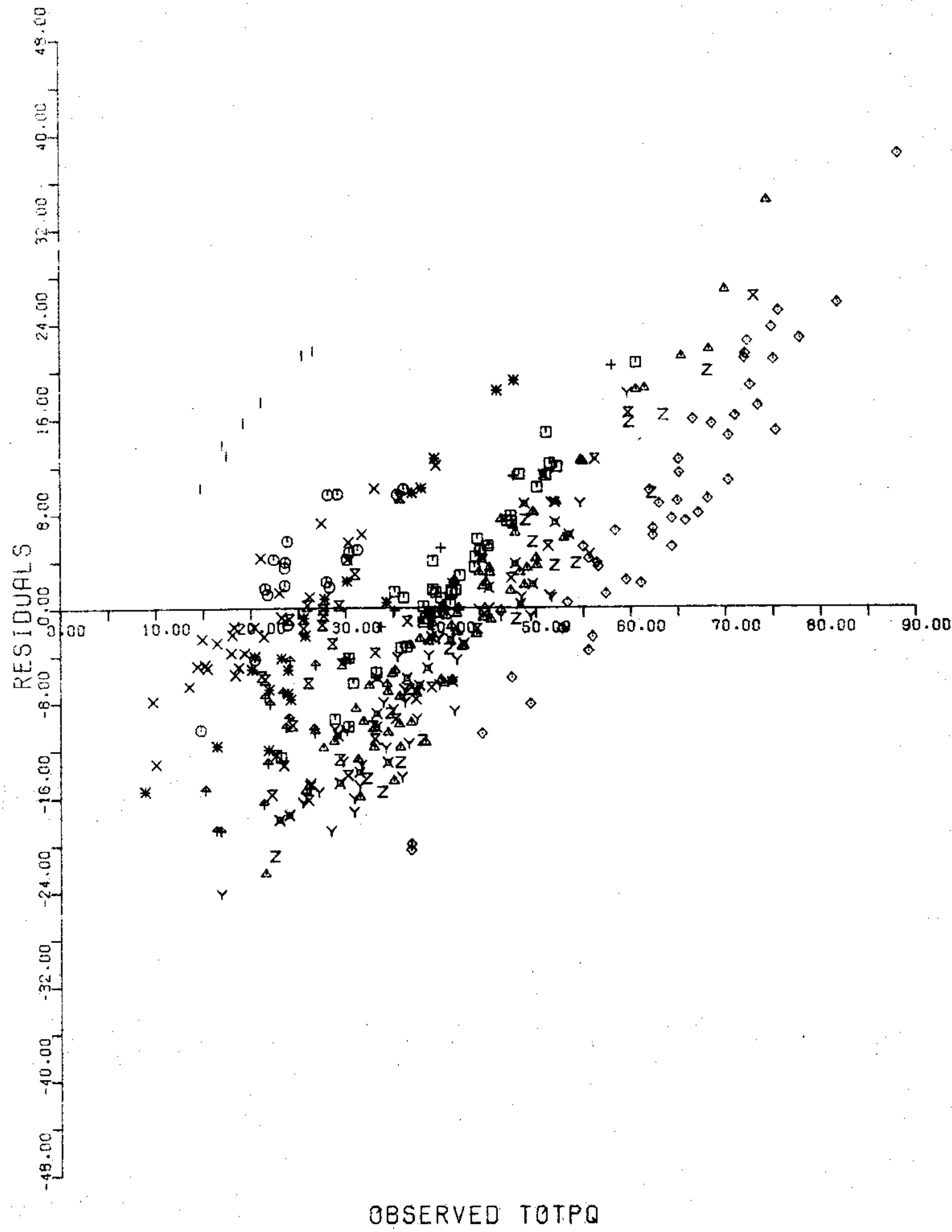
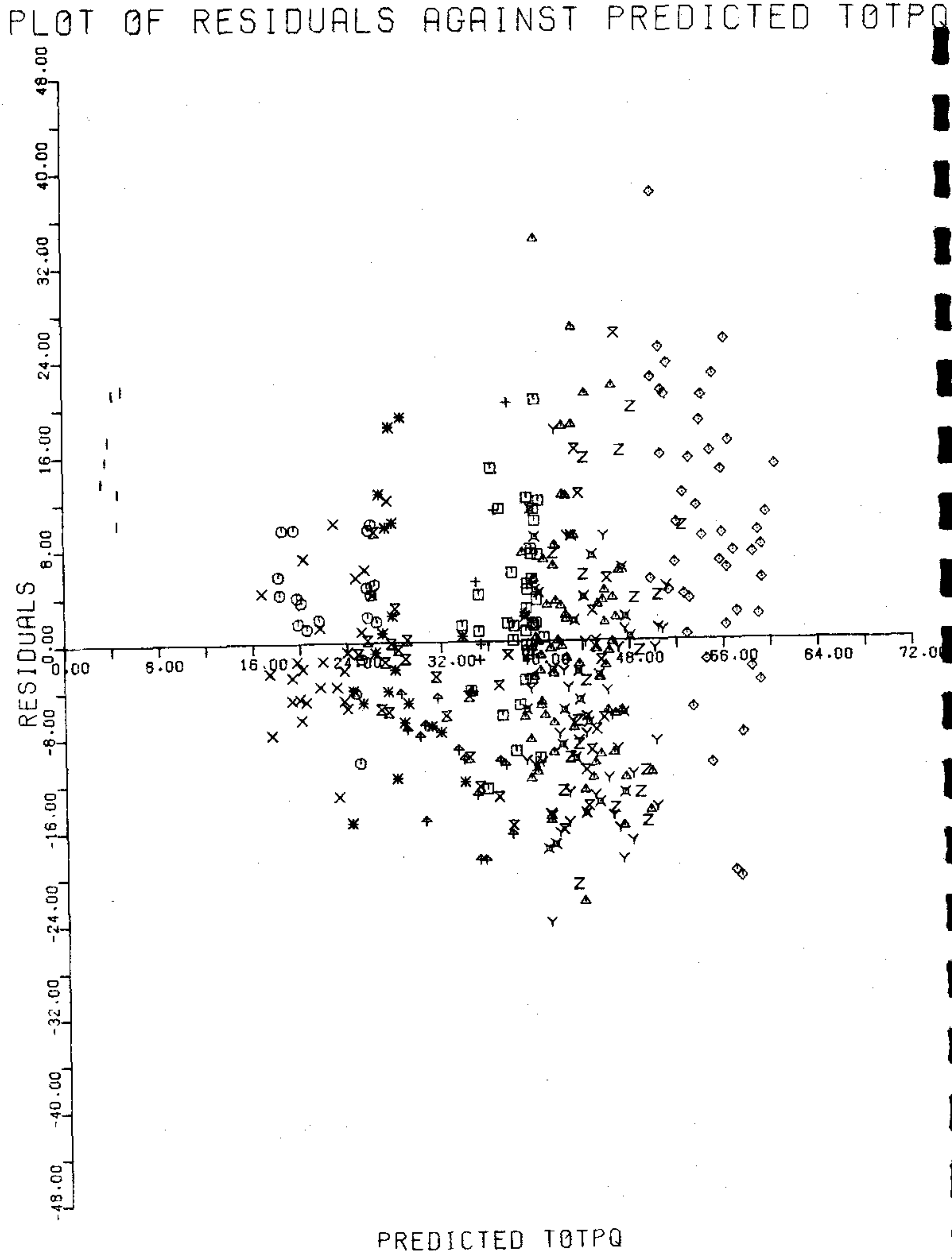


FIGURE 7


PLOT OF RESIDUALS AGAINST PREDICTED TOTPQ
RESIDUALS
48.00
40.00
32.00
24.00
16.00
8.00
0.00
-8.00
-16.00
-24.00
-32.00
-40.00
-48.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
PREDICTED TOTPQ

$$TOTPQ = -33.6 + .924PIMP + 53.4SOIL + .0649UCWI \qquad \ldots (19)$$

The plot of the residuals against predicted TOTPQ for equation 15 shown in Figure 7 do not display any trend, indicating that no better fit was likely to be achieved by transforming the variables. However, a multiplicative form of the model was tested by performing a regression analysis on the logarithmic transforms of the variables. The variables came into the analysis in the same order as that shown in Table 8. This resulted in a three-variable equation given by:

$$TOTPQ = .640\ PIMP^{.953}SOIL^{.243}\ UCWI^{.139} \qquad \ldots (20)$$

This equation explained 51% of the variance in log (TOTPQ) and, undertaking the same kind of comparison test demonstrated in Table 10, explains 47% of the variance in TOTPQ. As such, the multiplicative form of the equation is considered slightly inferior to the additive version.

A partial multiplicative form of the model was then considered. A complete analysis of all possible combinations is clearly impracticable but two possibilities appeared to show some promise. Firstly, a multiplicative combination of the soil index with the percentage of pervious area resulted in the following equation:

$$TOTPQ = -55.6 + 1.32PIMP + 1.13SOIL\ (100-PIMP) + .0655UCWI \qquad \ldots (21)$$

This equation explains only 51% of the variance in TOTPQ. Secondly, a multiplicative combination of SOIL and UCWI resulted in:

$$TOTPQ = -10.3 + .790PIMP + .237SOIL.UCWI \qquad \ldots (22)$$

This equation explains 49% of the variance of TOTPQ. This result is not altogether surprising bearing in mind the fact that it has one less degree of freedom than equation 19.

Finally, it was considered prudent to investigate whether the percentage runoff was dependent on the return period of the rainfall event (intuition suggests that the percentage runoff might increase for rarer events). A return period was generated (NERC, 1975) for each event based on the total rainfall volume and the storm duration (a more rigorous approach would be to use the maximum rainfall volume during some critical duration for each catchment - but the approach used was much simpler and was considered to provide a satisfactory approximation). The return period and the percentage runoff have a correlation coefficient of -.13. A regression of the residuals of equation 19 on the return period yielded a correlation coefficient of .01. Based on the above analyses of this data set, it was concluded that the percentage runoff was independent of the return period.

FIGURE 8 ASCOP output for TOTPQ regression (UCWI weighting factor n = 1)

TITLE VOLUME OF RUNOFF ANALYSIS

MULTIPLE REGRESSION ANALYSIS USING 3 VARIABLES EACH WITH 368 POINTS DATA MATRIX ONE

REGRESSION EQUATION DESCRIBING VARIABLE TOTPQ

VARIABLE	COEFFICIENT	STANDARD ERROR	T-VALUE	PROB	MUL COR COF
CONSTANT	-.333530+002***	.412116+001	-8.0951	.0000	
SOIL	.550814+002***	.582294+001	9.4594	.0000	.9704418
CWI	.826215-001***	.148345-001	5.5696	.0000	.8927395
PIMP	.931919+000***	.497115-001	18.7460	.0000	.9758073

MATRIX CONTAINING VARIANCES AND COVARIANCES OF REGRESSION COEFFICIENTS

	SOIL	CWI	PIMP
SOIL	.339067+002	-.234007-001	.155912+000
CWI	-.234007-001	.220062-003	.283708-004
PIMP	.155912+000	.283708-004	.247123-002

ANALYSIS OF VARIANCE OF FIT

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	ROOT MEAN SQUARE	VAR-RATIO	PROB
DUE TO REGRESSION	.426780+005	3	.142260+005	.119273+003	125.3147	.0000
ABOUT REGRESSION	.413220+005	364	.113522+003	.106547+002		
TOTAL	.840000+005	367	.228883+003	.151289+002		

UNREPLICATED DEPENDENT VARIABLE - NO GOODNESS OF FIT TEST IS POSSIBLE

MULTIPLE DETERMINATION COEFFICIENT = .508071
MULTIPLE CORRELATION COEFFICIENT = .712791

DETERMINANT = .592432+000

FIGURE 9 ASCOP output for TOTPQ regression (UCWI weighting factor n = 8)

TITLE VOLUME OF RUNOFF ANALYSIS

MULTIPLE REGRESSION ANALYSIS USING 3 VARIABLES EACH WITH 368 POINTS DATA MATRIX ONE

REGRESSION EQUATION DESCRIBING VARIABLE TOTPQ

VARIABLE	COEFFICIENT	STANDARD ERROR	T-VALUE	PROB	MUL COR COF
CONSTANT	-.335922+002***	.401631+001	-4.3639	.0000	
SOIL	.533706+002***	.567621+001	9.4025	.0000	.9702944
UCWI	.648544-001***	.920176-002	7.0480	.0000	.9885908
PIMP	.923916+000***	.485431-001	19.0329	.0000	.9757728

MATRIX CONTAINING VARIANCES AND COVARIANCES OF REGRESSION COEFFICIENTS

	SOIL	UCWI	PIMP
SOIL	.322193+002	-.137037-001	.151202+000
UCWI	-.137037-001	.846724-004	.345541-005
PIMP	.151202+000	.345541-005	.235644-002

ANALYSIS OF VARIANCE OF FIT

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	ROOT MEAN SQUARE	VAR-RATIO	PROB
DUE TO REGRESSION	.445414+005	3	.148471+005	.121849+003	136.9628	.0000
ABOUT REGRESSION	.394586+005	364	.108403+003	.104117+002		
TOTAL	.840000+005	367	.228883+003	.151289+002		

UNREPLICATED DEPENDENT VARIABLE - NO GOODNESS OF FIT TEST IS POSSIBLE

MULTIPLE DETERMINATION COEFFICIENT = .530255
MULTIPLE CORRELATION COEFFICIENT = .728196

DETERMINANT = .605584+000

IV: CONCLUSIONS

General conclusions

Some specific conclusions were discussed in the previous section. This section draws more general conclusions related to the whole analysis exercise.

By way of summary, the final equation adopted as most suitable for prediction of the volume of runoff is given by:

$$TOTPQ = -33.6 + .924PIMP + 53.4SOIL + .0649UCWI \quad \ldots (23)$$

where TOTPQ is the percentage runoff (runoff expressed as mm over the total catchment area),
PIMP is the percentage impervious,
SOIL is the soil index,
and UCWI is the urban catchment wetness index, given by (125 + 8API5 - SMD).

This equation is that deemed most appropriate from the analyses discussed in Section III. It explains 53% of the variance of TOTPQ (correlation coefficient .73). The values of Student's t quoted in Figure 9 demonstrate that the regression coefficients of the dependent variables are highly significant (much greater than at the .01% level).

The unexplained variance is 47%. Of this, it is likely that approximately half can be ascribed to error in the data. The remainder is due to the inability of the regression model to simulate the very complex processes highlighted in Section I.

It is important that equation 23 is not used outside the limits of the data set. The limits of the data are as follows:

PIMP:	20-70%	
SOIL:	.15-.45	
UCWI	0-330	(API5 0-32 mm SMD 0-125 mm)

Soil index values cover almost the whole range as defined by equation 3 in Section II, and there are therefore no limitations in this respect. Values of the catchment wetness indices cover a range which one might expect to encompass most situations, although some caution might be necessary under very wet conditions. PIMP has the strongest influence of the three dependent variables, and it is essential that the equation is not used outside the 20-70% limitations.

The discussion in Section I indicated a number of variables upon which the volume of runoff might depend. In the regression analysis which followed, a number of these proved to be insignificant. It would have been more satisfactory if storm variables had exerted a stronger control on the final equation adopted - in fact the inferior equation 14, using IMPLOSS as the dependent variable, contains more of the variables upon which one might intuitively have hoped that the volume of runoff might depend. The exclusion of these variables does not mean that they do not in some degree control the runoff volume process, but that their influence becomes insignificant in the context of the model adopted.

The inclusion of a catchment wetness index in the final equation has significant implication. Except where calibration of the model has been allowed, even the more sophisticated urban simulation models do not make allowance for the variation of antecedent catchment wetness conditions. These analyses suggest that the antecedent wetness exerts quite a strong control on the runoff volume.

Two of the variables excluded merit special attention, the first of which is the depression storage dichotomy, IFWET. The implication of its exclusion is that the volume of depression storage is small compared to the rainfall volume, which is especially true for large storm events. This is not to say that a depression storage submodel is not an important component of a complete above-ground model, because the fact that it needs to be satisfied at the beginning of an event has a profound effect on the timing of the response hydrograph.

The second excluded variable which deserves some mention is the catchment slope. Bearing in mind the findings of Sarginson (1973), its exclusion is at first sight somewhat surprising. But the correlation matrix in the Appendix shows that there is a strong inverse correlation between slope (SLOPE) and percentage impervious (PIMP) (the implication being that society has a tendency to build in flat valleys rather than on the sides of hills!). It is likely then that the effect identified by Sarginson is included implicitly by the inclusion of the percentage of impervious area.

Future work

The number of catchments (14) contributing to the data set is smaller than is desirable for a statistical analysis of this type. For this reason, it is intended to extend the data set to include data from a number of other catchments. In mind at the moment are data from catchments at Stevenage, Crawley, Nottingham and Hendon. It is intended to incorporate further catchments without degrading the quality of the data. Further data can be obtained by extending the existing archive to include further rainfall events on some of the catchments used in this study. It is further hoped that some catchments having data of dubious quality at present might be incorporated when theoretical discharge calibrations have been checked by dilution gauging. When these data become available, the final equation will simply be amended without the extensive analyses described here.

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T H E
A P P E N D I X

A complete listing
of the 368 data points
used in the analysis
and
a correlation matrix
for the complete data set.

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	API5	SMD	DUR	M5I
1	3.97	4.82	2.02	.59	.45	1	3.94	4.81	0	9.29	42.31	21	18.10
1	3.97	4.82	2.02	.59	.45	2	3.40	3.92	0	12.36	38.00	26	10.35
1	3.97	4.82	2.02	.59	.45	3	5.69	4.90	1	3.80	50.29	34	17.46
1	3.97	4.82	2.02	.59	.45	4	2.31	1.59	1	10.99	22.86	18	14.25
1	3.97	4.82	2.02	.59	.45	5	11.86	10.82	1	.17	12.87	129	11.28
1	3.97	4.82	2.02	.59	.45	6	1.93	1.89	0	18.02	.00	7	21.42
1	3.97	4.82	2.02	.59	.45	7	3.50	3.25	1	1.56	.76	21	28.04
1	3.97	4.82	2.02	.59	.45	8	2.18	2.04	1	1.10	47.25	12	18.74
1	3.97	4.82	2.02	.59	.45	9	7.35	6.80	1	7.76	25.73	57	20.27
1	3.97	4.82	2.02	.59	.45	10	14.92	15.63	1	.15	13.46	110	26.35
1	3.97	4.82	2.02	.59	.45	11	6.42	5.89	1	1.42	.00	24	30.35
1	3.97	4.82	2.02	.59	.45	121	12.99	12.50	1	1.71	.00	50	60.67
1	3.97	4.82	2.02	.59	.45	122	4.80	5.75	0	9.45	.00	35	23.87
1	3.97	4.82	2.02	.59	.45	131	2.95	2.90	1	6.00	.00	24	20.71
1	3.97	4.82	2.02	.59	.45	132	2.82	3.44	1	8.41	.00	12	24.99
1	3.97	4.82	2.02	.59	.45	133	4.38	6.34	0	10.38	.00	25	20.45
1	3.97	4.82	2.02	.59	.45	141	5.20	4.36	1	1.69	64.95	39	18.04
1	3.97	4.82	2.02	.59	.45	142	2.53	1.83	0	5.39	59.82	30	15.24
1	3.97	4.82	2.02	.59	.45	15	7.42	7.09	1	2.59	2.54	38	39.76
1	3.97	4.82	2.02	.59	.45	17	2.96	3.08	0	11.03	.00	18	15.78
1	3.97	4.82	2.02	.59	.45	181	5.41	5.81	1	6.54	.00	30	23.44
1	3.97	4.82	2.02	.59	.45	182	6.80	6.75	0	10.26	.00	54	33.74
1	3.97	4.82	2.02	.59	.45	191	6.78	5.37	1	1.25	7.80	38	24.54
1	3.97	4.82	2.02	.59	.45	192	4.10	4.03	0	7.99	.00	20	31.76
1	3.97	4.82	2.02	.59	.45	20	4.70	5.78	1	1.72	.00	26	24.25
1	3.97	4.82	2.02	.59	.45	21	2.02	2.09	0	11.74	.00	10	18.68
1	3.97	4.82	2.02	.59	.45	22	2.37	2.16	1	2.28	.00	18	17.17
1	3.97	4.82	2.02	.59	.45	23	1.80	2.02	1	5.48	.00	12	15.14
1	3.97	4.82	2.02	.59	.45	24	3.37	2.88	0	18.12	18.82	15	33.10
1	3.97	4.82	2.02	.59	.45	25	3.64	2.63	1	13.28	.00	17	37.01
1	3.97	4.82	2.02	.59	.45	45	5.95	5.61	1	1.15	12.88	22	28.13
1	3.97	4.82	2.02	.59	.45	46	3.15	3.16	1	9.72	8.56	31	13.66
1	3.97	4.82	2.02	.59	.45	47	8.65	9.12	1	9.85	8.35	45	32.97
1	3.97	4.82	2.02	.59	.45	48	2.24	1.95	0	6.12	.00	10	24.29
1	3.97	4.82	2.02	.59	.45	49	2.55	1.41	1	7.50	47.29	8	28.32
1	3.97	4.82	2.02	.59	.45	50	7.85	5.77	1	.85	24.62	59	24.59
1	3.97	4.82	2.02	.59	.45	51	2.18	2.72	0	13.99	.46	15	15.30

THE APPENDIX

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	P[illegible]T	IMPQ	IFWET	APIS	SMD	DUR	M5I
1	3.97	4.82	2.02	.59	.45	52	6.30	7.13	1	5.77	.37	45	27.49
1	3.97	4.82	2.02	.59	.45	53	6.01	5.64	0	5.54	.0[illegible]	32	31.53
3	1.56	5.14	1.54	1.09	.45	1	2.71	2.16	1	.48	7.37	1[illegible]	[illegible]
3	1.56	5.14	1.54	1.09	.45	2	2.0	2.03	1	3.0[illegible]	4.[illegible]5	18	14.87
3	1.56	5.14	1.54	1.09	.45	3	9.36	9.41	0	4.81	2.[illegible]9	63	31.54
3	1.56	5.14	1.54	1.09	.45	4	2.51	2.97	1	7.1[illegible]	6.00	15	24.[illegible]3
3	1.56	5.14	1.54	1.09	.45	5	2.91	2.72	1	5.46	6.0[illegible]	13	29.81
3	1.56	5.14	1.54	1.09	.45	6	12.94	13.51	1	6.16	.0[illegible]	1[illegible]	25.36
3	1.56	5.14	1.54	1.09	.45	8	6.12	7.38	1	2.89	.03	37	13.[illegible]5
3	1.56	5.14	1.54	1.09	.45	9	3.24	3.06	0	7.92	.05	25	19.48
3	1.56	5.14	1.54	1.09	.45	101	2.65	2.58	0	1[illegible].84	85.12	16	20.17
3	1.56	5.14	1.54	1.09	.45	102	7.64	5.49	0	13.50	83.[illegible]9	30	39.91
3	1.56	5.14	1.54	1.09	.45	11	5.41	3.93	0	14.81	76.0[illegible]	34	30.93
3	1.56	5.14	1.54	1.09	.45	12	5.36	4.2[illegible]	0	19.46	68.28	27	2[illegible].42
3	1.56	5.14	1.54	1.09	.45	13	6.49	5.17	1	1.75	90.63	28	29.25
3	1.56	5.14	1.54	1.09	.45	14	8.93	6.69	1	1.86	89.43	54	35.40
3	1.56	5.14	1.54	1.09	.45	15	12.25	1[illegible].5[illegible]	1	2.39	87.12	27	49.27
3	1.56	5.14	1.54	1.09	.45	16	8.12	6.41	1	14.38	85.06	14	64.69
3	1.56	5.14	1.54	1.09	.45	17	3.89	3.06	1	7.82	73.92	10	38.09
3	1.56	5.14	1.54	1.09	.45	18	13.08	8.92	1	.45	13.[illegible]8	49	42.12
3	1.56	5.14	1.54	1.09	.45	19	4.29	2.1[illegible]	1	1.0[illegible]	10.4[illegible]	19	3[illegible].25
5	1.39	3.42	2.37	1.14	.15	1	.79	.25	1	.87	6[illegible].29	13	5.90
5	1.39	3.42	2.37	1.14	.15	12	1.35	.62	1	1.57	65.48	31	6.13
5	1.39	3.42	2.37	1.14	.15	2	4.56	2.39	1	.19	74.48	96	5.58
5	1.39	3.42	2.37	1.14	.15	3	.95	.48	1	.07	94.13	83	2.02
5	1.39	3.42	2.37	1.14	.15	4	1.03	.39	1	.14	97.76	69	3.19
5	1.39	3.42	2.37	1.14	.15	5	.86	.3[illegible]	1	1.03	98.78	15	5.21
5	1.39	3.42	2.37	1.14	.15	6	2.20	1.19	1	1.97	1[illegible]4.[illegible]7	14	20.20
5	1.39	3.42	2.37	1.14	.15	7	1.62	.93	1	2.64	1[illegible]7.60	3[illegible]	4.85
5	1.39	3.42	2.37	1.14	.15	8	1.18	.61	1	4.75	110.74	6	12.61
5	1.39	3.42	2.37	1.14	.15	9	2.1[illegible]	1.26	1	1.23	97.28	1[illegible]	16.00
5	1.39	3.42	2.37	1.14	.15	10	2.91	3.18	1	1.07	1[illegible]0.82	16	16.18
5	1.39	3.42	2.37	1.14	.15	1[illegible]	2.06	1.46	0	4.23	107.18	18	12.83
5	1.39	3.42	2.37	1.14	.15	12	3.77	2.65	1	7.33	10[illegible].81	54	10.70
5	1.39	3.42	2.37	1.14	.15	13	1.70	.69	1	4.31	12[illegible].92	5	20.[illegible]7
5	1.39	3.42	2.37	1.14	.15	14	13.2[illegible]	8.05	1	2.03	123.57	158	2[illegible].66
5	1.39	3.42	2.37	1.14	.15	515	3.79	2.[illegible]4	1	7.7[illegible]	1[illegible]9.[illegible]8	34	27.12

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPO	IFWET	API5	SMD	DUR	M5I
5	1.39	3.42	2.33	1.14	.15	15	3.63	2.67	0	15.76	58.37	27	20.63
5	1.39	3.42	2.33	1.14	.15	161	2.59	1.31	1	5.60	58.93	27	20.17
5	1.39	3.42	2.33	1.14	.15	162	.69	.49	1	7.58	56.49	9	6.95
5	1.39	3.42	2.33	1.14	.15	18	2.04	1.96	1	3.69	64.26	19	16.1[illegible]
5	1.39	3.42	2.33	1.14	.15	19	10.85	7.82	1	1.2[illegible]	45.72	73	30.98
5	1.39	3.42	2.33	1.14	.15	20	3.35	2.28	1	6.50	41.91	17	22.03
5	1.39	3.42	2.33	1.14	.15	211	3.80	2.48	1	.21	50.80	34	14.02
5	1.39	3.42	2.33	1.14	.15	212	4.20	2.70	0	4.25	46.18	19	36.25
5	1.39	3.42	2.33	1.14	.15	22	2.92	2.93	0	8.03	41.76	22	20.69
5	1.39	3.42	2.33	1.14	.15	23	3.69	1.93	1	2.17	49.78	18	29.17
5	1.39	3.42	2.33	1.14	.15	24	1.92	1.04	1	.0[illegible]	34.54	21	10.[illegible]8
5	1.39	3.42	2.33	1.14	.15	25	5.15	3.69	1	1.37	32.74	88	16.63
5	1.39	3.42	2.33	1.14	.15	26	2.43	1.44	1	4.04	37.03	34	9.77
5	1.39	3.42	2.33	1.14	.15	27	2.66	2.07	1	3.96	32.26	24	12.80
5	1.39	3.42	2.33	1.14	.15	28	4.8[illegible]	2.87	1	.01	40.13	62	11.83
5	1.39	3.42	2.33	1.14	.15	29	4.47	2.89	1	2.10	101.76	37	14.18
5	1.39	3.42	2.33	1.14	.15	30	7.89	5.76	0	5.64	97.16	128	12.44
5	1.39	3.42	2.33	1.14	.15	31	2.82	1.92	1	.03	124.46	10	28.96
5	1.39	3.42	2.33	1.14	.15	32	5.54	2.64	1	.41	123.44	31	34.52
5	1.39	3.42	2.33	1.14	.15	33	3.82	2.53	0	5.17	1[illegible]8.21	25	29.5[illegible]
5	1.39	3.42	2.33	1.14	.15	34	2.78	1.60	0	8.33	114.58	19	25.5[illegible]
5	1.39	3.42	2.33	1.14	.15	35	9.90	6.56	0	8.17	98.86	28	46.96
5	1.39	3.42	2.33	1.14	.15	361	2.79	2.14	1	.77	73.23	24	16.49
5	1.39	3.42	2.33	1.14	.15	362	2.04	1.25	1	2.65	70.59	39	6.84
5	1.39	3.42	2.33	1.14	.15	37	6.30	5.61	0	7.15	91.06	23	42.40
5	1.39	3.42	2.33	1.14	.15	38	2.49	2.56	0	14.1[illegible]	87.58	16	19.67
5	1.39	3.42	2.33	1.14	.15	41	5.24	3.09	1	.25	108.71	40	16.09
5	1.39	3.42	2.33	1.14	.15	42	1.3[illegible]	1.07	1	3.25	87.30	10	9.49
5	1.39	3.42	2.33	1.14	.15	43	7.1[illegible]	5.74	1	4.67	85.22	48	24.75
5	1.39	3.42	2.33	1.14	.15	441	5.73	3.80	1	3.70	89.41	79	12.91
5	1.39	3.42	2.33	1.14	.15	442	1.04	.94	0	9.18	83.69	11	1[illegible].43
5	1.39	3.42	2.33	1.14	.15	45	7.14	5.21	1	2.66	94.57	80	12.2[illegible]
5	1.39	3.42	2.33	1.14	.15	46	3.36	1.91	1	4.21	97.79	22	20.06
5	1.39	3.42	2.33	1.14	.15	47	5.35	3.28	1	5.08	90.53	30	24.92
5	1.39	3.42	2.33	1.14	.15	48	7.34	4.79	1	3.48	84.61	64	15.81
5	1.39	3.42	2.33	1.14	.15	49	2.27	1.28	1	2.42	.00	12	23.01
5	1.39	3.42	2.33	1.14	.15	50	1.71	.79	1	1.14	26.67	24	13.54

CNU	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	P/T	IMPQ	IFWET	API5	SMD	DUR	MSI
5	1.39	3.42	2.33	1.14	.15	51	4.49	2.30	1	.13	106.53	17	3[illegible].19
5	1.39	3.42	2.33	1.14	.15	521	3.16	1.40	1	.2	1[illegible]7.09	32	18.2[illegible]
5	1.39	3.42	2.33	1.14	.15	52[illegible]	.90	.38	1	2.81	[illegible]3.94	7	10.05
5	1.39	3.42	2.33	1.14	.15	53	2.4[illegible]	1.23	1	7.48	1[illegible]0.[illegible]9	18	15.8[illegible]
5	1.39	3.42	2.33	1.14	.15	54	2.4[illegible]	1.49	1	3.95	93.07	23	17.34
5	1.39	3.42	2.33	1.14	.15	5[illegible]	2.20	1.3[illegible]	0	7.85	8[illegible].34	14	21.3[illegible]
5	1.39	3.42	2.33	1.14	.15	56	4.98	2.33	1	4.1[illegible]	98.30	26	37.6[illegible]
5	1.39	3.42	2.33	1.14	.15	57	12.81	7.12	1	.32	106.91	21	[illegible].03
5	1.39	3.42	2.33	1.14	.15	58	4.85	3.19	1	4.12	85.17	33	30.15
5	1.39	3.42	2.33	1.14	.15	591	2.21	1.47	0	16.82	55.43	14	16.10
5	1.39	3.42	2.33	1.14	.15	592	1.52	1.12	0	18.57	53.04	16	8.30
5	1.39	3.42	2.33	1.14	.15	60	6.96	4.32	1	2.56	49.84	58	43.40
5	1.39	3.42	2.33	1.14	.15	61	9.76	5.91	1	5.26	31.72	98	15.72
5	1.39	3.42	2.33	1.14	.15	62	2.40	1.67	1	2.05	4[illegible].71	13	24.24
5	1.39	3.42	2.33	1.14	.15	63	2.83	1.37	1	2.09	58.17	8	32.09
5	1.39	3.42	2.33	1.14	.15	64	8.71	4.57	1	.18	23.8[illegible]	94	14.09
5	1.39	3.42	2.33	1.14	.15	65	8.47	4.36	0	1[illegible].76	10.49	87	2[illegible].6[illegible]
6	1.89	59.50	21.50	.86	.45	2	1.39	1.17	1	4.72	36.58	14	7.32
6	1.89	59.50	21.50	.86	.45	3	2.31	2.56	1	5.9[illegible]	34.80	40	5.83
6	1.89	59.50	21.50	.86	.45	4	2.5[illegible]	2.48	0	8.03	32.16	40	6.93
6	1.89	59.50	21.50	.86	.45	5	2.24	2.09	1	7.48	32.6[illegible]	19	16.16
6	1.89	59.50	21.50	.86	.45	6	2.0[illegible]	2.64	0	13.97	24.41	54	4.94
6	1.89	59.50	21.50	.86	.45	7	4.26	6.85	1	3.5[illegible]	.0[illegible]	82	10.[illegible]8
71	3.13	247.00	49.00	1.12	.45	1	1.7[illegible]	1.5[illegible]	0	8.3[illegible]	57.58	1[illegible]	14.33
71	3.13	247.00	49.0	1.12	.45	2	5.08	4.2[illegible]	1	4.32	81.03	34	28.24
71	3.13	247.00	49.0	1.12	.45	31	2.20	1.50	[illegible]	5.31	73.35	5[illegible]	5.9[illegible]
71	3.13	247.00	49.0[illegible]	1.12	.45	32	6.73	5.23	0	7.36	70.96	40	19.40
71	3.13	247.00	49.0[illegible]	1.12	.45	4	9.26	6.72	1	6.10	83.64	39	28.51
71	3.13	247.00	49.0[illegible]	1.12	.45	5	18.64	20.12	[illegible]	6.73	31.8[illegible]	38	84.06
71	3.13	247.00	49.0[illegible]	1.12	.45	6	7.12	3.60	1	2.05	34.06	34	23.69
71	3.13	247.00	49.0[illegible]	1.12	.45	7	15.49	23.61	1	2.89	.00	67	43.36
71	3.13	247.00	49.0[illegible]	1.12	.45	8	6.96	5.23	0	6.51	105.46	45	26.78
71	3.13	247.00	49.0[illegible]	1.12	.45	9	29.73	41.2[illegible]	0	13.26	78.25	179	43.86
71	3.13	247.00	49.0[illegible]	1.12	.45	10	1[illegible].60	[illegible]	4.91	39.47	13	62.3[illegible]
71	3.13	247.00	49.0[illegible]	1.12	.45	11	4.35	4.1[illegible]	0	8.6[illegible]	34.52	17	28.72
71	3.13	247.00	49.0[illegible]	1.12	.45	12	14.0[illegible]	13.68	0	13.50	46.02	79	42.69
71	3.13	247.00	49.0[illegible]	1.12	.45	13	18.56	17.10	[illegible]	3.45	74.91	41	57.92

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPO	IFWET	API5	SMD	DUR	M5I
71	3.13	247.00	49.00	1.12	.45	14	7.80	8.02	0	17.85	64.32	78	13.17
71	3.13	247.00	49.00	1.12	.45	15	5.85	4.48	1	5.08	74.93	30	32.98
71	3.13	247.00	49.00	1.12	.45	16	15.41	24.67	1	7.92	12.40	55	[illegible]
71	3.13	247.00	49.00	1.12	.45	17	17.67	35.25	1	20.43	1.93	[illegible]	31.56
71	3.13	247.00	49.00	1.12	.45	18	[illegible]	12.08	1	.55	106.96	38	65.33
71	3.13	247.00	49.00	1.12	.45	19	8.11	7.39	0	4.15	70.28	44	27.16
71	3.13	247.00	49.00	1.12	.45	20	9.32	14.25	0	6.02	19.10	51	33.26
71	3.13	247.00	49.00	1.12	.45	21	6.38	5.91	0	4.23	26.77	26	35.87
71	3.13	247.00	49.00	1.12	.45	22	3.61	4.77	0	9.97	17.93	18	20.93
71	3.13	247.00	49.00	1.12	.45	23	3.97	4.61	1	3.32	25.27	18	21.55
71	3.13	247.00	49.00	1.12	.45	24	14.48	7.08	1	.24	97.79	22	105.96
71	3.13	247.00	49.00	1.12	.45	25	10.76	12.50	1	4.03	53.09	36	69.97
72	.93	.78	.47	.00	.45	11	3.28	2.01	0	5.36	32.54	25	14.89
72	.93	.78	.47	.00	.45	12	1.47	.90	0	7.79	29.52	18	9.29
72	.93	.78	.47	.00	.45	13	5.37	4.41	0	9.18	27.66	40	19.60
72	.93	.78	.47	.00	.45	2	5.08	5.43	1	3.77	2.42	38	23.95
72	.93	.78	.47	.00	.45	3	3.12	3.23	1	1.10	34.22	18	25.37
72	.93	.78	.47	.00	.45	4	3.84	3.54	0	11.23	[illegible]	18	25.96
72	.93	.78	.47	.00	.45	5	3.12	3.48	1	[illegible]	[illegible]	[illegible]	26.24
72	.93	.78	.47	.00	.45	8	4.81	4.39	1	1.35	110.08	24	19.57
72	.93	.78	.47	.00	.45	10	5.36	6.42	0	7.56	104.27	28	23.43
72	.93	.78	.47	.00	.45	[illegible]	5.27	6.57	0	17.20	74.16	16	39.08
72	.93	.78	.47	.00	.45	112	4.01	4.73	0	[illegible]	[illegible]	[illegible]	41.76
72	.93	.78	.47	.00	.45	113	5.48	6.40	0	26.35	64.46	21	45.37
72	.93	.78	.47	.00	.45	114	6.02	6.43	0	31.80	58.72	28	28.17
72	.93	.78	.47	.00	.45	12	2.84	2.94	0	8.23	48.48	25	12.68
72	.93	.78	.47	.00	.45	13	6.31	6.01	1	4.98	39.35	16	46.66
72	.93	.78	.47	.00	.45	15	3.74	[illegible]	1	[illegible]	78.86	44	12.59
72	.93	.78	.47	.00	.45	16	14.16	17.08	1	1.88	61.49	66	34.19
72	.93	.78	.47	.00	.45	17	5.60	7.61	0	12.65	46.94	29	27.21
72	.93	.78	.47	.00	.45	19	7.76	[illegible]	1	14.18	60.05	69	14.49
72	.93	.78	.47	.00	.45	20	4.92	[illegible]	[illegible]	20.29	50.83	40	13.72
72	.93	.78	.47	.00	.45	21	6.76	6.35	1	4.61	74.80	25	38.63
72	.93	.78	.47	.00	.45	22	2.83	2.96	0	10.62	67.69	20	18.99
72	.93	.78	.47	.00	.45	23	3.96	3.47	1	6.77	60.65	24	20.49
72	.93	.78	.47	.00	.45	24	12.88	[illegible]	1	17.15	1.70	51	35.91
72	.93	.78	.47	.00	.45	25	3.78	2.78	1	2.56	51.76	19	21.80

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	API5	SMD	DUR	MSI
72	.93	.78	.47	.00	.45	26	12.32	14.81	1	.40	107.44	32	56.73
72	.93	.78	.47	.00	.45	27	4.85	5.80	1	4.47	98.30	38	17.06
72	.93	.78	.47	.00	.45	281	1.85	2.30	1	3.93	95.12	13	12.10
72	.93	.78	.47	.00	.45	282	1.93	1.78	1	4.29	94.69	19	9.56
72	.93	.78	.47	.00	.45	283	1.62	1.57	1	7.03	91.79	14	[illegible]
72	.93	.78	.47	.00	.45	291	5.25	5.98	1	2.32	72.13	26	22.67
72	.93	.78	.47	.00	.45	292	3.44	3.72	0	5.82	68.50	16	24.10
72	.93	.78	.47	.00	.45	30	10.12	11.45	0	10.69	12.70	51	43.64
72	.93	.78	.47	.00	.45	32	6.29	6.78	1	1.39	38.66	50	18.14
72	.93	.78	.47	.00	.45	34	3.59	3.92	0	10.97	18.82	17	32.21
72	.93	.78	.47	.00	.45	35	4.29	4.35	0	12.72	14.17	[illegible]	28.67
72	.93	.78	.47	.00	.45	36	5.04	4.98	1	2.90	25.80	19	40.24
72	.93	.78	.47	.00	.45	37	2.74	3.20	1	7.15	1.45	17	20.88
72	.93	.78	.47	.00	.45	381	5.20	5.35	1	5.80	88.35	25	20.52
72	.93	.78	.47	.00	.45	382	2.70	2.39	0	10.14	83.27	12	26.72
72	.93	.78	.47	.00	.45	383	3.96	3.12	0	12.50	80.47	29	24.33
72	.93	.78	.47	.00	.45	41	4.81	4.51	0	15.37	90.98	21	40.60
72	.93	.78	.47	.00	.45	42	7.77	8.59	1	.12	97.91	34	42.79
72	.93	.78	.47	.00	.45	43	7.48	6.95	0	[illegible]	[illegible]	18	[illegible]
72	.93	.78	.47	.00	.45	461	4.02	5.89	1	1.43	107.45	20	[illegible]
72	.93	.78	.47	.00	.45	462	10.89	13.67	0	4.72	103.89	27	46.97
81	2.13	1.39	.69	.64	.30	1	8.52	4.14	1	2.34	[illegible]	[illegible]	15.47
81	2.13	1.39	.69	.64	.30	2	2.45	.83	0	21.73	50.83	16	17.13
81	2.13	1.39	.69	.64	.30	31	12.45	6.03	1	8.66	63.53	21	72.5[illegible]
81	2.13	1.39	.69	.64	.30	32	4.83	2.92	0	14.43	56.60	9	42.57
81	2.13	1.39	.69	.64	.30	33	17.41	5.73	0	17.54	52.84	23	151.25
81	2.13	1.39	.69	.64	.30	4	3.18	1.52	1	5.52	54.71	5	37.9[illegible]
81	2.13	1.39	.69	.64	.30	6	8.45	3.66	1	.36	105.6[illegible]	52	24.93
81	2.13	1.39	.69	.64	.30	7	4.78	2.12	1	.70	93.39	25	30.53
81	2.13	1.39	.69	.64	.30	8	15.85	7.47	0	11.26	99.16	70	35.71
81	2.13	1.39	.69	.64	.30	9	4.77	1.46	1	.85	80.85	24	34.06
81	2.13	1.39	.69	.64	.30	10	13.55	5.95	1	.06	36.58	108	28.85
81	2.13	1.39	.69	.64	.30	11	11.57	4.98	1	4.47	6.63	77	28.64
81	2.13	1.39	.69	.64	.30	12	3.63	1.95	0	8.40	21.81	1	34.80
81	2.13	1.39	.69	.64	.30	13	13.72	7.39	1	4.78	13.47	82	31.30
81	2.13	1.39	.69	.64	.30	14	4.1[illegible]	2.2[illegible]	1	.33	75.69	20	41.07
91	4.96	11.60	5.36	.52	.45	1	3.68	2.81	1	6.34	6.80	42	21.0[illegible]

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	API5	SMD	DUR	M5I
91	4.96	11.60	5.36	.52	.45	2	6.16	5.85	0	9.91	.00	36	18.99
91	4.96	11.60	5.36	.52	.45	31	4.91	5.98	1	2.17	14.00	38	20.95
91	4.96	11.60	5.36	.52	.45	32	8.65	5.68	0	5.68	9.95	90	12.40
91	4.96	11.60	5.36	.52	.45	41	2.77	2.19	1	1.63	84.50	24	14.86
91	4.96	11.60	5.36	.52	.45	42	8.24	3.96	1	3.28	82.57	70	17.85
91	4.96	11.60	5.36	.52	.45	5	[illegible]	2.15	1	2.63	94.40	24	16.45
91	4.96	11.60	5.36	.52	.45	6	5.09	6.59	0	19.09	34.00	48	14.73
91	4.96	11.60	5.36	.52	.45	7	3.58	2.02	1	1.66	30.75	46	[illegible]
91	4.96	11.60	5.36	.52	.45	8	8.93	6.39	1	1.83	8.80	98	14.38
91	4.96	11.60	5.36	.52	.45	9	9.62	10.69	0	16.01	.00	71	19.41
91	4.96	11.60	5.36	.52	.45	10	4.95	7.83	0	24.92	.00	26	[illegible]
91	4.96	11.60	5.36	.52	.45	121	1.89	1.94	1	1.84	.00	14	14.53
91	4.96	11.60	5.36	.52	.45	122	1.05	.85	0	4.05	.00	9	9.18
91	4.96	11.60	5.36	.52	.45	13	9.89	8.36	1	[illegible]	.00	154	20.74
91	4.96	11.60	5.36	.52	.45	14	17.35	16.76	1	3.91	.00	146	26.04
91	4.96	11.60	5.36	.52	.45	15	2.74	1.39	1	4.63	98.10	13	[illegible]
91	4.96	11.60	5.36	.52	.45	16	10.79	5.30	1	.13	[illegible]	25	59.47
101	1.12	10.40	5.50	.44	.45	2	3.80	2.94	1	3.10	94.75	32	17.29
101	1.12	10.40	5.50	.44	.45	9	7.64	5.50	0	6.06	39.97	30	37.46
101	1.12	10.40	5.50	.44	.45	13	41.32	[illegible]	1	[illegible]	46.82	841	15.68
101	1.12	10.40	5.50	.44	.45	14	7.59	5.13	0	7.41	47.11	95	18.06
101	1.12	10.40	5.50	.44	.45	19	6.86	8.07	1	4.17	.00	167	12.36
101	1.12	10.40	5.50	.44	.45	20	9.43	9.67	1	2.53	[illegible]	99	16.94
101	1.12	10.40	5.50	.44	.45	21	15.48	9.91	1	.00	32.84	232	13.68
101	1.12	10.40	5.50	.44	.45	22	4.83	5.80	1	.00	56.70	114	20.88
101	1.12	10.40	5.50	.44	.45	23	4.07	3.69	1	1.15	[illegible]	66	9.69
101	1.12	10.40	5.50	.44	.45	24	3.50	3.29	1	.47	94.72	29	15.55
101	1.12	10.40	5.50	.44	.45	27	3.84	2.34	1	2.81	67.97	43	20.52
101	1.12	10.40	5.50	.44	.45	28	2.46	3.17	1	[illegible]	50.63	12	17.33
101	1.12	10.40	5.50	.44	.45	29	4.86	3.19	1	2.16	102.25	[illegible]	26.34
101	1.12	10.40	5.50	.44	.45	30	8.39	9.50	0	5.53	97.95	42	30.93
101	1.12	10.40	5.50	.44	.45	31	3.06	2.12	1	.78	101.75	34	11.96
101	1.12	10.40	5.50	.44	.45	321	4.09	2.27	1	1.25	[illegible]	31	16.89
101	1.12	10.40	5.50	.44	.45	322	2.88	1.79	0	4.85	[illegible]	89	7.29
101	1.12	10.40	5.50	.44	.45	323	1.48	.63	0	7.52	[illegible]	41	3.02
101	1.12	10.40	5.50	.44	.45	33	7.28	6.74	1	.54	125.00	53	24.05
102	1.22	8.55	4.36	.49	.45	1	[illegible]	[illegible]	1	.27	54.94	147	77.33

CNG	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	API5	SMD	DUR	M5I
102	1.22	8.55	4.36	.49	.45	2	3.80	2.53	1	3.10	94.75	32	17.29
102	1.22	8.55	4.36	.49	.45	51	2.1	1.23	1	2.03	84.66	32	7.82
102	1.22	8.55	4.36	.49	.45	52	2.17	1.54	1	3.92	82.28	30	8.35
102	1.22	8.55	4.36	.49	.45	6	8.10	6.10	1	4.36	86.36	183	17.09
102	1.22	8.55	4.36	.49	.45	71	3.64	2.50	1	5.87	78.36	24	14.50
102	1.22	8.55	4.36	.49	.45	72	4.74	4.10	0	9.23	74.36	44	30.34
102	1.22	8.55	4.36	.49	.45	8	18.31	16.65	1	8.42	40.64	321	18.09
102	1.22	8.55	4.36	.49	.45	10	10.12	6.79	1	1.29	40.77	34	32.54
102	1.22	8.55	4.36	.49	.45	11	7.98	5.74	0	14.85	34.14	96	37.48
102	1.22	8.55	4.36	.49	.45	12	2.50	1.84	1	4.87	38.78	32	8.65
102	1.22	8.55	4.36	.49	.45	13	41.32	31.81	1	3.33	46.82	841	15.68
102	1.22	8.55	4.36	.49	.45	14	7.59	5.94	0	7.41	47.11	95	18.06
102	1.22	8.55	4.36	.49	.45	15	5.66	5.72	0	7.52	.00	84	7.45
102	1.22	8.55	4.36	.49	.45	161	3.58	3.63	0	11.84	.00	56	9.92
102	1.22	8.55	4.36	.49	.45	163	.97	1.06	0	15.96	.00	16	3.96
102	1.22	8.55	4.36	.49	.45	17	3.89	2.74	1	4.65	.00	72	5.62
102	1.22	8.55	4.36	.49	.45	18	5.95	4.84	1	4.71	.00	120	26.01
102	1.22	8.55	4.36	.49	.45	19	6.86	6.66	1	4.17	.00	167	12.36
102	1.22	8.55	4.36	.49	.45	20	9.43	5.71	1	2.53	20.84	99	16.94
102	1.22	8.55	4.36	.49	.45	21	15.48	9.38	1	.00	32.84	230	13.68
102	1.22	8.55	4.36	.49	.45	22	4.83	3.00	1	.00	56.70	114	20.86
102	1.22	8.55	4.36	.49	.45	23	4.07	2.51	1	1.15	40.20	66	9.69
102	1.22	8.55	4.36	.49	.45	2121	2.60	1.45	1	2.45	32.62	83	3.74
102	1.22	8.55	4.36	.49	.45	2122	2.29	2.18	1	4.22	30.02	17	11.25
102	1.22	8.55	4.36	.49	.45	24	3.50	4.10	1	.47	94.72	29	15.5[illegible]
102	1.22	8.55	4.36	.49	.45	251	2.01	1.57	1	1.80	80.42	43	7.35
102	1.22	8.55	4.36	.49	.45	252	6.60	6.69	1	3.71	85.82	86	18.06
102	1.22	8.55	4.36	.49	.45	26	7.71	4.11	1	6.75	89.51	79	33.14
102	1.22	8.55	4.36	.49	.45	27	3.84	2.73	1	2.81	67.97	43	20.50
102	1.22	8.55	4.36	.49	.45	28	2.46	2.64	1	5.03	50.63	12	17.33
102	1.22	8.55	4.36	.49	.45	29	4.86	2.50	1	2.16	102.25	21	26.34
102	1.22	8.55	4.36	.49	.45	30	8.39	4.19	0	5.53	97.95	42	30.93
102	1.22	8.55	4.36	.49	.45	31	3.06	1.58	1	.78	101.75	34	11.96
102	1.22	8.55	4.36	.49	.45	321	4.09	2.34	1	1.25	117.94	31	16.88
102	1.22	8.55	4.36	.49	.45	322	2.80	1.70	0	4.85	113.54	89	7.29
102	1.22	8.55	4.36	.49	.45	323	1.48	.49	0	7.52	110.04	41	3.02
102	1.22	8.55	4.36	.49	.45	33	7.28	4.12	1	.54	125.0	53	24.05

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	API5	SMD	DUR	M5I
102	1.22	8.55	4.36	.49	.45	34	21.42	14.90	1	.90	109.95	169	36.89
103	1.08	7.23	3.52	.56	.45	1	25.04	19.12	1	.27	54.94	147	77.33
103	1.08	7.23	3.52	.56	.45	2	3.80	2.60	1	3.10	94.75	32	17.29
103	1.08	7.23	3.52	.56	.45	3	8.45	7.16	1	2.58	94.95	107	41.45
103	1.08	7.23	3.52	.56	.45	51	2.11	1.92	1	2.03	84.68	32	7.82
103	1.08	7.23	3.52	.56	.45	52	2.17	1.98	1	3.92	82.28	30	8.35
103	1.08	7.23	3.52	.56	.45	71	3.64	1.72	1	5.87	78.36	24	14.50
103	1.08	7.23	3.52	.56	.45	72	4.74	2.34	0	9.23	74.36	44	30.34
103	1.08	7.23	3.52	.56	.45	8	18.31	14.21	1	8.42	40.64	321	18.09
103	1.08	7.23	3.52	.56	.45	9	7.64	4.61	0	6.06	39.97	30	37.46
103	1.08	7.23	3.52	.56	.45	10	10.12	6.91	1	1.19	44.77	34	32.54
103	1.08	7.23	3.52	.56	.45	11	7.98	6.96	0	14.85	34.14	96	37.48
103	1.08	7.23	3.52	.56	.45	12	2.50	2.46	1	4.87	38.78	32	8.65
103	1.08	7.23	3.52	.56	.45	13	41.32	38.25	1	3.33	46.82	841	15.68
103	1.08	7.23	3.52	.56	.45	14	7.59	6.40	0	7.41	47.11	95	18.06
103	1.08	7.23	3.52	.56	.45	15	5.66	5.78	0	7.52	.00	84	7.45
103	1.08	7.23	3.52	.56	.45	161	3.58	3.56	0	11.84	.00	50	9.92
103	1.08	7.23	3.52	.56	.45	17	3.89	2.75	1	4.65	.00	72	5.62
103	1.08	7.23	3.52	.56	.45	18	5.95	5.04	1	4.71	.00	122	26.01
103	1.08	7.23	3.52	.56	.45	19	6.86	7.55	1	4.17	.00	167	12.36
103	1.08	7.23	3.52	.56	.45	20	9.43	6.09	1	2.53	22.84	99	16.94
103	1.08	7.23	3.52	.56	.45	22	4.83	3.30	1	.00	56.70	114	20.88
103	1.08	7.23	3.52	.56	.45	23	4.07	3.23	1	1.15	40.20	66	9.69
103	1.08	7.23	3.52	.56	.45	2121	2.60	2.00	1	2.45	32.62	83	3.74
103	1.08	7.23	3.52	.56	.45	2122	2.29	2.45	1	4.22	30.02	17	11.25
103	1.08	7.23	3.52	.56	.45	251	2.01	2.10	1	1.80	88.42	43	7.33
103	1.08	7.23	3.52	.56	.45	252	6.60	6.62	1	3.71	85.82	86	18.06
103	1.08	7.23	3.52	.56	.45	26	7.71	4.62	1	6.75	89.51	79	33.14
103	1.08	7.23	3.52	.56	.45	27	3.84	3.08	1	2.81	67.97	43	20.50
103	1.08	7.23	3.52	.56	.45	28	2.46	2.63	1	5.00	50.63	12	17.33
521	2.93	.80	.33	.48	.40	2	4.19	3.06	1	6.74	89.37	31	10.81
521	2.93	.80	.33	.48	.40	3	8.40	4.73	1	.00	87.31	78	7.98
521	2.93	.80	.33	.48	.40	4	3.69	2.14	1	13.07	80.60	24	16.04
521	2.93	.80	.33	.48	.40	5	6.47	4.04	1	2.36	82.48	61	10.79
521	2.93	.80	.33	.48	.40	61	2.36	.94	1	8.39	88.30	18	9.67
521	2.93	.80	.33	.48	.40	62	2.37	1.26	0	12.56	83.94	11	16.32
521	2.93	.80	.33	.48	.40	7	2.21	1.49	1	6.36	98.48	14	13.28

CNO	SLOPE	TOTA	IMPA	RATIO	SOIL	SNO	PPT	IMPQ	IFWET	APIS	SMD	DUR	M5I
521	2.93	.80	.33	.48	.40	8	3.18	3.04	0	3.56	98.44	26	12.73
521	2.93	.80	.33	.48	.40	9	9.68	8.69	0	5.69	94.58	95	10.75
521	2.93	.80	.33	.48	.40	10	3.71	2.30	0	1.37	100.77	17	20.98
521	2.93	.80	.33	.48	.40	11	9.97	9.19	0	6.56	80.59	74	14.41
521	2.93	.80	.33	.48	.40	12	8.13	9.42	0	7.58	80.73	50	21.45
521	2.93	.80	.33	.48	.40	13	4.02	4.48	0	13.54	98.13	16	27.85
521	2.93	.80	.33	.48	.40	14	3.12	1.83	0	.95	36.03	16	22.49
521	2.93	.80	.33	.48	.40	15	4.52	3.76	0	10.[illegible]	22.80	8	40.67
521	2.93	.80	.33	.48	.40	16	2.0[illegible]	1.06	1	.73	13.18	5	20.[illegible]
521	2.93	.80	.33	.48	.40	18	4.73	2.31	1	.21	112.48	8	43.0[illegible]
521	2.93	.80	.33	.48	.40	19	2.34	1.16	0	1.90	123.44	8	17.49
521	2.93	.80	.33	.48	.40	521	2.0[illegible]	.43	1	.97	125.00	4	24.00
521	2.93	.80	.33	.48	.40	722	1.50	.87	1	5.84	50.24	3	18.00
522	4.94	.60	.25	1.00	.40	7	2.21	1.14	1	6.36	98.48	14	13.28
522	4.94	.60	.25	1.00	.40	8	3.18	1.95	0	3.56	98.44	26	12.73
522	4.94	.60	.25	1.00	.40	9	9.68	6.42	0	5.69	94.58	95	10.75
522	4.94	.60	.25	1.00	.40	10	3.71	1.80	0	1.37	100.77	17	20.98
522	4.94	.60	.25	1.00	.40	11	9.97	6.63	0	6.56	80.59	74	14.41
522	4.94	.60	.25	1.00	.40	12	8.13	5.72	0	7.58	80.73	50	21.45
522	4.94	.60	.25	1.00	.40	13	4.02	2.99	0	13.54	98.13	16	27.83
522	4.94	.60	.25	1.00	.40	14	3.12	1.95	0	.95	36.03	16	22.49
522	4.94	.60	.25	1.00	.40	15	4.52	3.21	0	10.[illegible]	22.80	8	40.67
522	4.94	.60	.25	1.00	.40	16	2.0[illegible]	1.17	1	.73	13.18	5	20.[illegible]
522	4.94	.60	.25	1.00	.40	17	11.52	7.62	0	2.87	77.48	22	50.28
522	4.94	.60	.25	1.00	.40	18	4.73	2.95	1	.21	112.48	8	43.00
522	4.94	.60	.25	1.00	.40	19	2.34	1.35	0	1.90	123.44	8	17.49
522	4.94	.60	.25	1.00	.40	20	3.57	3.06	0	6.57	11[illegible].56	20	18.68
522	4.94	.60	.25	1.00	.40	722	1.50	1.03	1	5.84	50.24	3	18.00
55	4.24	62.00	19.22	.98	.15	1	2.06	.98	1	.98	93.1[illegible]	28	18.03
55	4.24	62.00	19.22	.98	.15	2	15.00	12.88	1	.27	87.00	52	61.74
55	4.24	62.00	19.22	.98	.15	3	4.88	3.37	1	1.71	102.52	31	19.87
55	4.24	62.00	19.22	.98	.15	4	2.09	1.18	0	6.12	97.59	26	12.83
55	4.24	62.00	19.22	.98	.15	5	2.95	1.62	1	1.02	108.68	34	12.95
55	4.24	62.00	19.22	.98	.15	6	2.11	1.31	1	2.35	105.47	21	12.66
55	4.24	62.00	19.22	.98	.15	7	7.98	6.56	1	.64	96.51	116	9.79

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	TOTPQ	IMPPQ	TOTLOSS	IMPLOSS	SLOPE	TOTA	IMPA	PIMP	RATIO	SOIL	PPT	IFWET	API5	SMD	DUR	M5I	CWI	AVINT
TOTPQ	1.00	.63	-.30	-.39	-.37	-.36	-.36	.54	-.49	.04	-.05	-.06	.23	-.16	.03	-.10	.18	-.16
IMPPQ	.63	1.00	-.00	-.73	.05	.26	.25	-.26	-.29	.45	.14	-.15	.32	-.41	.04	.08	.44	-.01
TOTLOSS	-.30	-.00	1.00	.27	.10	.33	.32	-.34	.12	.15	.95	.07	-.07	-.03	.67	.47	.02	.16
IMPLOSS	-.39	-.73	.27	1.00	-.06	-.29	-.28	.18	.09	-.22	.16	.10	-.26	.23	.18	.13	-.26	.06
SLOPE	-.37	.05	.10	-.06	1.00	.22	.22	-.54	.19	.16	-.00	-.13	.04	-.20	-.12	.07	.19	.21
TOTA	-.36	.26	.33	-.29	.22	1.00	.99	-.64	.34	.16	.21	-.08	.05	-.03	-.01	.24	.04	.14
IMPA	-.36	.25	.32	-.28	.22	.99	1.00	-.63	.35	.15	.20	-.06	.03	-.03	.01	.21	.04	.09
PIMP	.54	-.26	-.34	.18	-.54	-.64	-.63	1.00	-.15	-.57	-.19	.11	-.07	.23	.00	-.22	-.23	-.23
RATIO	-.49	-.29	.12	.09	.19	.34	.35	-.15	1.00	-.61	-.02	.07	-.16	.13	-.06	.00	-.15	.02
SOIL	.04	.45	.15	-.22	.16	.16	.15	-.57	-.61	1.00	.17	-.12	.17	-.34	.09	.11	.35	.08
PPT	-.05	.14	.95	.16	-.00	.21	.20	-.19	-.02	.17	1.00	.07	-.03	-.07	.78	.42	.07	.09
IFWET	-.06	-.15	.07	.10	-.13	-.08	-.06	.11	.07	-.12	.07	1.00	-.61	.06	.12	-.07	-.13	-.09
API5	.23	.32	-.07	-.26	.04	.05	.03	-.07	-.16	.17	-.03	-.61	1.00	-.22	-.09	.13	.34	.12
SMD	-.16	-.41	-.03	.23	-.20	-.03	-.03	.23	.13	-.34	-.07	.06	-.22	1.00	-.08	-.01	-.99	.06
DUR	.03	.04	.67	.18	-.12	-.01	.01	.00	-.06	.09	.78	.12	-.09	-.08	1.00	-.08	.06	-.29
M5I	-.10	.08	.47	.13	.07	.24	.21	-.22	.00	.11	.42	-.07	.13	-.01	-.08	1.00	.03	.73
CWI	.18	.44	.02	-.26	.19	.04	.04	-.23	-.15	.35	.07	-.13	.34	-.99	.06	.03	1.00	-.04
AVINT	-.16	-.01	.16	.06	.21	.14	.09	-.23	.02	.08	.09	-.09	.12	.06	-.29	.73	-.04	1.00