WATER RESEARCH COMMISSION

RESEARCH PROJECT - EVALUATION OF FLOOD ESTIMATION TECHNIQUES

PHASE II : AN EVALUATION OF HYDROLOGICAL TECHNIQUES FOR MAKING FLOOD ESTIMATIONS ON SMALL UNGAUGED CATCHMENTS

by

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WATER RESEARCH COMMISSION

AN EVALUATION OF HYDROLOGICAL TECHNIQUES FOR MAKING FLOOD ESTIMATIONS ON SMALL UNGAUGED CATCHMENTS

1 INTRODUCTION

At present hydrologists and engineers in Southern Africa face two major problems in small catchment hydrology:

- availability of small catchment hydrological data
- absence of suitable guidelines on the selection, use and expected accuracy of the different flood estimation techniques.

Hydrological information is needed both for basic design and to assess the hydrological effects of land-use modifications. Although extensive research has been conducted using data from small catchments in Southern Africa, these data are not always readily accessible. In addition to the Department of Water Affairs, 26 organizations currently collect hydrological data on more than 120 catchments.

Selection of a design technique should normally go hand in hand with data availability. Frequently, however, techniques have to be applied with insufficient data. The hydrologist or engineer is usually aware of the data deficiencies but is seldom able to assess the effect on the design solution. Even when there are no constraints on data collection or design, it is sometimes not possible to assess the accuracy associated with hydrological designs. Furthermore, on catchments where designs based on some future land-use modification are needed, gauging of the catchment might provide little information of value at the design stage.

Research by universities and institutes in South Africa and overseas has resulted in numerous methods for simulating the response of a catchment to a storm event. The designer faces the difficult task of selecting an appropriate method with little comparative guidance as to which technique can be expected to produce the most reliable result for the situation at hand. Great reliance is often placed on the selected method and seldom is a sensitivity analysis of the technique conducted.

To help meet the needs of engineers and hydrologists, the Water Research Commission funded a two-phase research project comprising:

- Phase I : Assemble currently available small catchment data into a single national small catchment data bank

- Phase IIA : Based on an evaluation of the available small catchment data, make recommendations on a small catchment monitoring programme

- Phase IIB : Conduct a comparative evaluation of commonly used hydrological techniques for making flood estimations on small ungauged catchments

A third phase, covering the preparation of a small catchment flood estimation design manual, was also envisaged once the first two phases were complete.

Phase I of the project has been completed and is published as Report No 139/1/85 by the Water Research Commission. Phase II of the project is detailed in this report.

For the purposes of this project a small catchment is defined as one which has a hydrological response that is not significantly influenced by the catchment channel storage characteristics (with the upper limit set at 100 km^2).

2 OUTLINE OF THE PROBLEM

As part of Phase I, a questionnaire survey was conducted to help meet the objectives of the project. The purpose of the questionnaire was to:

- identify hydrological data collection activities
- establish hydrological data user requirements
- determine flood estimation technique use

Details of the questionnaire survey results are contained in the Phase I report (Van Schalkwyk et al, 1985). The very large response to the questionnaire survey is indicative of the widespread interest in the project.

The section on the use of flood estimation techniques indicated that a wide variety of techniques are currently being used in South Africa and also highlighted a number of problems. Statistics which are significant to the Phase II investigation are summarised in Table 1, and the highlights are discussed below:

- although the Rational method is still the most commonly used method, use of such methods as the Time-area, USDA Soil Conservation Service (SCS) and Kinematic procedures is significant. In general, all the techniques were found by the respondents to be fairly easy to use but only about 50 percent of the respondents felt that the techniques were sufficiently accurate

- flood estimation techniques are primarily being used to determine peak flows and volume of runoff. Storm hydrograph generation appears to be required less frequently but a significant need was identified.

  It is interesting to note that despite being a peak flow technique, the Rational method is used to generate hydrographs by 12 per cent of the organisations using this technique

- flood estimation techniques are primarily being applied in urban, agricultural, rural and afforested areas which are smaller than 10 square kilometres

- the main problem associated with the use of flood estimation techniques appears to be the availability of adequate data. The survey also identified a lack of familiarity with the technique.

The results of the questionnaire survey substantiated the need for both Phase I and Phase II of the project.

TABLE 1 : SUMMARY OF FLOOD ESTIMATION TECHNIQUE STATISTICS

Question	Rational method (%)	Time-area (%)	SCS (%)	Kine-matic (%)	Other (%)
USE OF TECHNIQUE*	90	34	30	10	26
REASON FOR USE**					
. Easy to use	85	61	56	27	57
. Not familiar with other techniques	18	17	9	9	7
. Technique sufficiently accurate	55	50	38	18	46
WHERE USED**					
. Land-use					
- Urban	80	64	44	36	39
- Agricultural	52	58	75	45	71
- Veld	57	64	66	27	75
- Afforested	28	31	50	9	50
- Mining	15	19	19	9	14
- Other	16	19	12	18	25
. Catchment size					
- 0 to 1 km^2	64	47	66	55	36
- 1 to 10 km^2	85	64	69	64	46
- 10 to 100 km^2	34	55	44	45	75
TYPE OF ANALYSIS**					
. Peak flow	81	72	67	73	68
. Runoff volume	42	59	42	64	57
. Storm hydrograph	12	38	28	55	57
PROBLEMS WITH TECHNIQUE**					
. Insufficient data	35	25	28	18	43
. Lack of computer	4	11	0	0	7
. Not familiar with technique	0	3	6	27	0
. Other	9	11	28	9	25

Based on: * Percentage of respondents using flood estimation techniques
** Percentage of respondents using this technique

3 PROJECT OBJECTIVES

Phase II of this study had two objectives. The first objective was to make recommendations on a small catchment monitoring programme, based on an evaluation of available data. The second objective was to evaluate the ability of commonly used hydrological techniques to make flood estimations on small catchments exhibiting one or more of the following land-uses:

- agriculture
- forestry
- urban development
- natural vegetation conditions
- mining

To fulfill this objective, the following steps were undertaken:

- seven commonly-used flood estimation methods were selected for evaluation
- 26 catchments were identified from Phase I of the study for use in testing the methods
- four measured storm events per catchment were abstracted from the available rainfall records
- catchment parameters required for the different methods were obtained from maps and manuals
- the catchment data, together with both actual and synthetic rainfall distributions, were used in the methods to produce predicted responses.
- the observed catchment values were abstracted from the available runoff records
- the predicted values were compared to the observed values

This report discusses each of these steps in detail and comments are made on the performance of the various hydrological flood estimation methods.

4 FLOOD ESTIMATION TECHNIQUES

4.1 Technique selection

Based on the results of the questionnaire survey conducted during Phase I of the study, the following hydrological flood estimation techniques were identified as being in use in South Africa:

- empirical formulae
- unit hydrograph
- time-area
- kinematic

Investigations indicated that several specific methods within each of the above techniques were being currently used as design tools in South Africa. In order to keep the number of methods to be evaluated within practical limits, it was decided to test one method per technique, and from that method chose a representative model. The selection of a method and model was based on the likelihood of potential users selecting that model ahead of others, based on:

- computer requirements, if any
- data requirements
- complexity
- ease of use
- clarity of output
- present widespread use

4.1.1 Empirical formulae

The Rational method is by far the most widely used of the empirical formulae, with the formula being:

$$Q = CiA$$

where Q = peak flow

C = empirical coefficient

i = average rainfall intensity during time of concentration

A = catchment area

This method, while being the oldest and computationally simplest of the available methods, has spawned numerous variations with different ways of computing the coefficient 'C' and the time of concentration. A variation which is widely available, namely that presented by the National Transport Commission (1983), was adopted for evaluation.

4.1.2 **Unit hydrograph techniques**

Two different formulations of this technique are in widespread use in South Africa, the USDA Soil Conservation Service method (SCS, 1972) and the method described in HRU Report No 1/72 (Midgley and Pitman, 1972), (hereafter referred to as HDYP01). Three versions of the SCS method are in common use, namely the original USDA version (SCS, 1972), the version adapted for South African conditions (Schulze and Arnold, 1979; Schulze, 1984)) and the WASHMO version (Ward et al, 1980; Ward and Stern, 1983). While based on the same principles, these three versions differ in the methods used to calculate initial abstraction, unit hydrograph shape and lag time. It was accordingly decided to evaluate all four models described above.

4.1.3 **Time-area techniques**

The most widely used time-area method is the Illinois Urban Drainage Simulator (ILLUDAS), which has been adapted and tested for South African conditions (Watson, 1981), and made available on micro-computers (Watson, 1983). The commercial micro computer versioon was therefore selected for evaluation.

4.1.4 **Kinematic techniques**

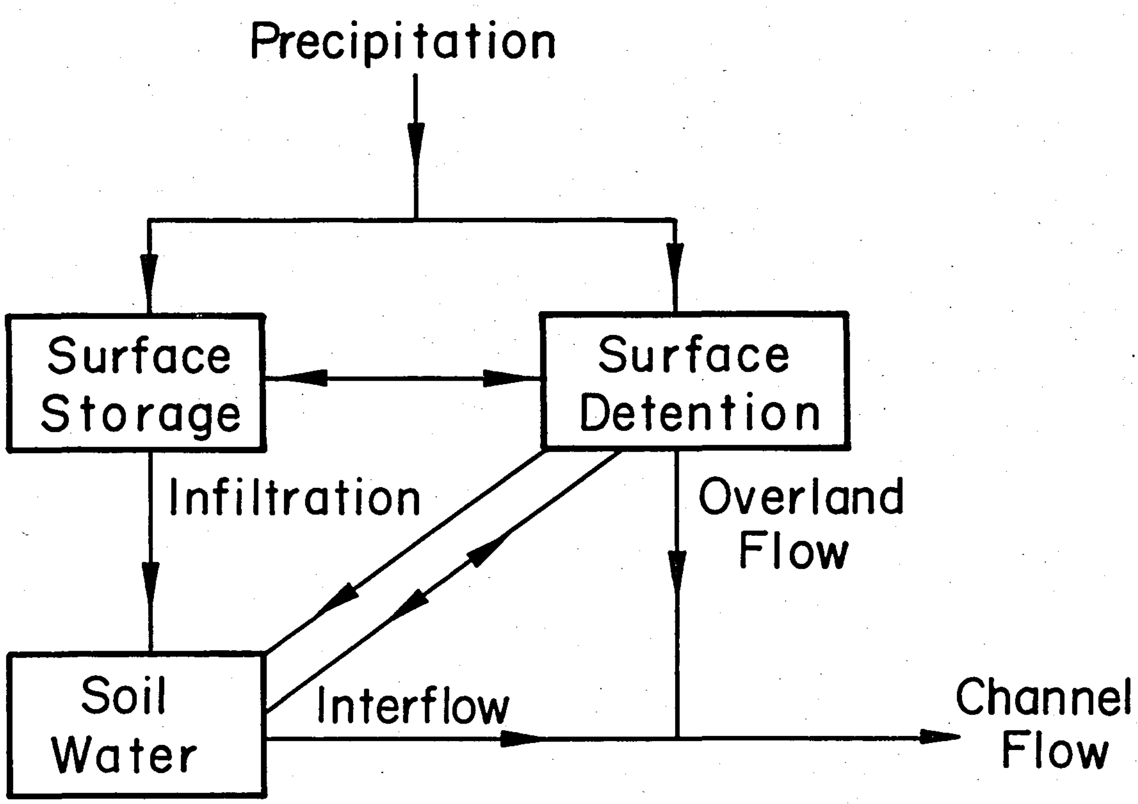
Numerous sophisticated computer models incorporating this technique are available, the best known being the Stormwater Management Model (SWMM) (Huber et al, 1982) and KINE 2 (Constantinides, 1982). These two computer models have not, however, found widespread acceptance in South Africa since they can only be made operational on mainframe computers and, especially for the latter model, require a significant amount of data. A manual technique, based on dimensionless hydrographs developed from kinematic theory, has recently been made available (Constantinides and Stephenson, 1982). However, a recently available computer model developed specifically for South African conditions and operational on micro-computers, namely WITWAT (Green, 1984), has apparently been adopted fairly readily by design organisations (Green, 1984). It was therefore selected for evaluation.

The seven models finally chosen for comparison and evaluation were therefore:

RATIONAL (NTC Model)
SCS-WASHMO
SCS-SA
SCS-USA
HDYP01
ILLUDAS
WITWAT

4.2 **Overview of model components**

The hydrological cycle consists of a complex system of inter-related components. For the purpose of making flood estimations, the cycle is modelled as the fairly simple system illustrated in Fig 1.



HYDROLOGICAL CYCLE OF STORM WATER RUNOFF

JOB Nº		FIG Nº
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It was therefore necessary to quantify the following components. for each method:

- precipitation
- surface storage and detention
- infiltration
- overland flow
- interflow
- channel flow

An overview of these components, as related to the models evaluated, is discussed below. The manner in which parameter values were estimated is discussed in Section 4.3.

4.2.1 Precipitation

This component is discussed fully in Section 6.4.

4.2.2 Surface storage and detention

Only ILLUDAS and WITWAT account for these factors explicitly, the others including them with another component of the runoff process. These two models treat these two factors as a single parameter, depression storage, which is given separate values for the two types of catchment surface, pervious and impervious, allowed for by the models.

4.2.3 Infiltration

All the models make provision for estimating infiltration in order to establish rainfall excess, as follows:

- **Rational method**
  Infiltration is not modelled directly. The empirical coefficient 'C' is used to estimate runoff based on land-use, topography and soil type.
- **SCS methods**
  Infiltration is not modelled directly. An empirical curve number is used to determine maximum retention

based on catchment characteristics, and a coefficient of abstraction is used to determine initial losses. The three versions use different values for this co-efficient, with the USA and WASHMO versions using a value of 0,2, and the SA version recommending a value of 0,047 (Schulze and Arnold 1979).

- **HDYP01**

  Infiltration is not modelled directly. Storm loss is estimated from an empirical diagram based on catchment size.

- **ILLUDAS**

  Infiltration is modelled using a modified form of the empirical Horton equation.

- **WITWAT**

  Infiltration is modelled using either a modified form of the empirical Horton equation or a simplified 'initial loss - constant loss' approach. The former approach was used in this study since it is described as an enhancement in the documentation.

While the SCS, ILLUDAS and WITWAT models allow for adjustment of the infiltration estimates based on antecedent moisture conditions, the Rational method and HDYP01 do not. Since these latter two methods are strictly design tools based on statistical analyses of recorded data, antecedent moisture conditions are inherent in these methods.

4.2.4 Overland flow

Overland flow is the movement of rainfall excess over the catchment surface to a defined watercourse. While all the methods assume this process of runoff generation, only WITWAT models the physics of this process, while the remaining methods make an estimate of the runoff response based on an indicator of the time of concentration of the catchment. The procedures used by each of the methods are:

- **Rational method**

  Overland flow is accounted for in two of the variables in the equation, namely 'C' and 'i'. The particular version of this method utilised in this study allows for the steepness of the catchment in computing 'C' for rural areas. The time of concentration of a catchment, calculated from the travel times both for overland flow and along the longest defined watercourse, is used to define the critical storm duration and hence the average rainfall intensity 'i'. The manner in which 'i' is calculated from the time of concentration is discussed in Section 6.4.

- **SCS methods**

  The SCS approach uses synthetic unit hydrograph procedures. The unit hydrograph is developed based on design storm characteristics and catchment characteristics. The three unit hydrograph shapes used by the different versions of the SCS method are:

  - Haan's unit hydrograph with variable shape factor (Haan, 1970)
  - Double triangle (Ward and Stern, 1983)
  - Haan's unit hydrograph with shape factor = 3,75

  The WASHMO version makes use of the first two unit hydrographs, the first for urban catchments and the second for rural. Both the SA and the USA versions make use of the latter unit hydrograph.

The three versions also make use of different lag time formulae for dimensioning the unit hydrographs. The lag time used in the SA version was developed for rural catchments but has been used in the study for all catchments. The formulae used by the WASHMO, SA and USA versions are listed in sequence below:

- $t_L = (0{,}0276L)/(U\sqrt{Y})$ (Ward and Stern, 1983)
- $t_L = (A^{0,35}\ MAP^{\ 1,1})/(41{,}67\ Y^{0,30} I_{30}^{\ 0,87})$ (Schmidt and Schulze, 1984)
- $t_L = L^{0,8}\ (S+25{,}4)^{0,7}/(7069\sqrt{Y})$ (SCS, 1972)

where

t_L = lag time (hrs)

A = area (km^2)

MAP = mean annual precipitation (mm)

Y = average catchment slope (%)

I_{30} = average maximum 30-minutes rain (mm/hr) (calculated from IDF relationships. In the absence of frequency data a 2,3 year R.I. was used in this study (Schulze, 1985)).

L = hydraulic length (m)

U = 100-0,67AG-0,90F-0,80V

AG = % agriculture

F = % forest

V = % veld

S = 25,4(1 000/CN'-10)

CN' = curve number representative of flow resistance

- **HDYP01**

This method uses 10 dimensionless unit hydrographs for 10 zones in South Africa, these unit hydrographs having been derived from observed hydrographs. The time axis of a unit hydrograph is dimensionalised by estimating the catchment lag from the formula:

$t_L = LL_C/\sqrt{S}$ (Midgley and Pitman, 1972)

where

L = length of longest watercourse (km)

L_C = distance from catchment outlet to centroid of catchment, measured along watercourse (km)

S = average slope (m/m)

HDYP01 does not consider overland flow as a component separate from streamflow but considers only the total longest flow path.

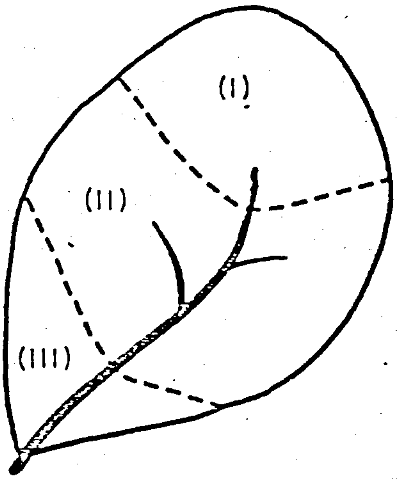
- **ILLUDAS**

This model uses a conceptual model of the runoff process. The model divides the catchment surface into three different types, namely directly connected impervious, indirectly connected impervious and pervious. The indirectly connected impervious portion is assumed to drain instantaneously to the pervious portion, while excess rain on the other two types is translated via time-area diagrams to the point of interest and combined.

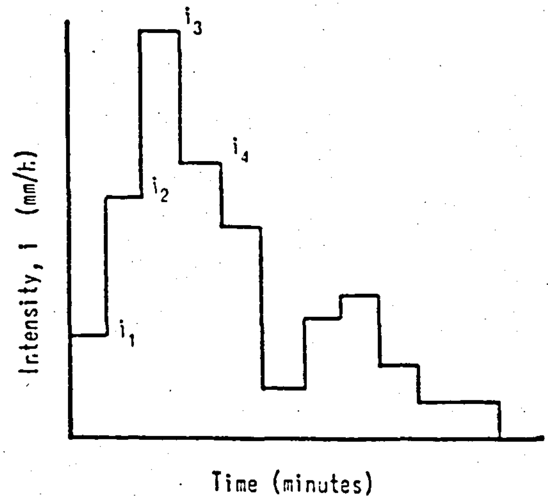
The development of a time-area diagram and the translation process are illustrated in Fig 2 (Watson, 1983). This particular model uses a simplified time-area diagram which has a linear rise to the point where the full area is contributing to runoff, and a horizontal line thereafter. Routing is carried out separately for the paved and grassed portions of the catchment.

- **WITWAT**

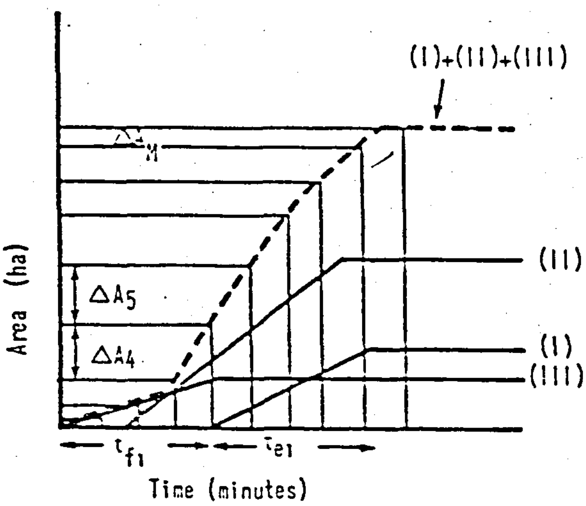
The kinematic technique on which WITWAT is based utilises the continuity equation together with a uniform flow function to predict the hydrological response.



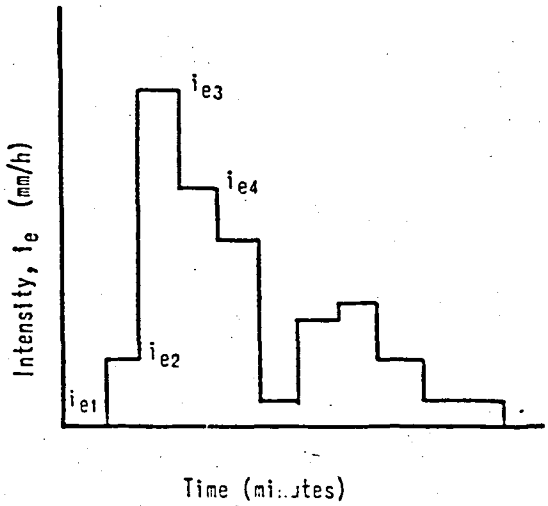
(a) Catchment



(b) Rainfall



(c) Time-area diagram



(d) Excess rainfall

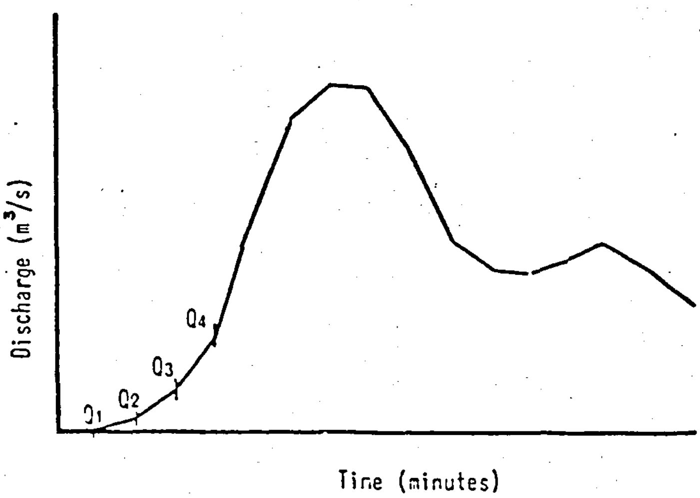
$$Q_1 = \frac{1}{360}\left(i_{e1} \cdot \Delta A_1\right)$$

$$Q_2 = \frac{1}{360}\left(i_{e2} \cdot \Delta A_1 + i_{e1} \cdot \Delta A_2\right)$$

$$Q_3 = \frac{1}{360}\left(i_{e3} \cdot \Delta A_1 + i_{e2} \cdot \Delta A_2 + i_{e1} \cdot \Delta A_3\right)$$

$$Q_n = \frac{1}{360}\left(i_{en} \cdot \Delta A_1 + i_{en-1} \cdot \Delta A_2 + \ldots\ldots\ldots + i_{en-a} \cdot \Delta A_M\right)$$

(e) Computation of hydrograph



CONCEPTS OF TIME AREA ROUTING

(WATSON, 1983)

JOB Nº		FIG Nº
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The continuity equation is a partial differential equation written as:

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = i_e$$

where

q = discharge/unit width

y = flow depth

x = distance from top of catchment

t = time

i_e = rainfall excess rate/unit width

The uniform flow equation can be written in general form as:

$$q = ay^b$$

where

q, y as before

a and b = coefficients dependent on particular equation used

WITWAT uses the Manning uniform flow equation and a numerical technique for solving the continuity equation.

4.2.5 Interflow

Interflow is essentially a subsurface hydrological response to a rainfall event which results in a surface flow at the point of interest. Historically, the subsurface flow response was considered to be very slow, contributing to baseflow several days or weeks after a storm event.

More recently, however, subsurface flow has been found to be an important factor which contributes to the stormflow response (Ward, 1982).

None of the evaluated models account for this factor explicitly. The double triangle unit hydrograph used by the SCS method for rural catchments accounts for subsurface flow implicitly.

4.2.6 Channel flow

It is always possible to subdivide a catchment, predict the runoff from each sub-catchment and combine the resultant hydrographs by a process of lagging through the watercourse. ILLUDAS and WITWAT specifically recommend that this be done. For the SCS methods, subdivision is normally only deemed desirable, not essential. It is however explicitly provided for in the WASHMO version (Ward and Stern, 1983). Since a distributed parameter approach is generally considered to be more accurate than a lumped approach in a heterogeneous catchment, the lagging procedures suggested by the WASHMO version were utilised for all three SCS methods. Such an approach was considered to be in accordance with a principle underlying the study, namely that all the methods should be tested in the most refined form that a designer is likely to use. The Rational method and HDYP01 account for channel flow as discussed in Section 4.2.4.

Accordingly, catchment discretisation on the basis of land-use, slope, degree of canalisation and soil types was done for the ILLUDAS, WITWAT and SCS methods. The number of sub-catchments depended on the degree of non-homogeneity of the specific catchment and the requirements of each model. No catchment breakdown was performed for the Rational method and HDYP01.

Although both ILLUDAS and WITWAT allow for a complex form of channel routing which considers channel storage, simple time-shift routing was used to conform with the definition of a small catchment adopted for this study.

4.3 Parameter estimation

One of the basic premises behind the study, to conform to the concept of the models being used in 'design' mode, was that no calibration of the methods would be done Accordingly, all parameters were obtained from maps, manuals, hand books and some site visits, with no adjustment being made in the light of the results. In other words, the parameters were estimated using the normal procedures which would be followed by a practising designer. While it is not proposed to deal exhaustively with the manner in which all the parameters were estimated, an outline will be given to indicate the general sources of information.

The required parameters fell into two groups, those obtainable from topographical maps and those from manuals. The first group included parameters such as area, land-uses, vegetation, overland lengths and slopes, and channel lengths and slopes. These were obtained from 1:50 000 topographical maps, maps supplied by the monitoring organizations and the Phase I report (Van Schalkwyk et al, 1985). The estimation of these parameters was done in accordance with the requirements for each method.

The manner in which the second group of parameters was obtained for each component of the hydrological cycle is discussed below, together with the variations from standard usage that were considered necessary.

4.3.1 Precipitation

This component is covered in detail in Section 6.4.

4.3.2 Surface storage and detention

Depression storage values for the different types of catchment surface for both ILLUDAS and WITWAT were obtained from the respective manuals. Difficulty was experienced with values for agricultural and afforested catchments, where no specific values are given. Depression storage values for crop and forest cover were therefore assumed. These values were then used for both models.

4.3.3 Infiltration

For the pervious portions of catchments, soil maps were the primary source of information. Where these were lacking, either discussions with the monitoring organisations or site visits provided the required data. The soil form/ hydrological classification table presented by Schulze and Arnold (1979) and Schulze (1984) was then used to place the soils in their estimated hydrological group; A, A/B, B, B/C, C, C/D or D.

This information was used as follows:

- **Rational method**
  The area covered by the different soil forms were measured and a percentage area calculated for each of four categories: impermeable, semi-permeable, permeable, and very permeable (assumed to correspond to group D, C, B and A soils respectively).

- **SCS methods**
  The soil groupings were combined with land-use and hydrological condition, using the table presented by Schulze and Arnold (1979), to yield curve numbers.

- **HDYP01**
  No soil information was used as all the necessary parameters were map parameters. Storm losses are estimated from an empirical diagram.

Two SWA catchments were included in the selected catchment data set described in Section 5. A variation from standard use was therefore necessary since only South African catchments are included in the report dealing with this method (Midgley and Pitman, 1972). Recourse was therefore made to a diagram presented by Pitman and Stern (1981) showing recorded percentage runoff vs rainfall volume for a number of events for certain large catchments in that country. A best-fit line was drawn on this diagram through catchments in the region of interest, and this line was thereafter used to estimate storm losses for these two catchments.

- **ILLUDAS**

The hydrological soil group was used directly as input to the model. Since this model does not make allowance for the intermediate groupings, any soils falling into the intermediate zones were adjusted, the direction of adjustment being determined by the grouping of the minor soils in the catchment.

For urban portions of catchments, guidelines suggested by Alley and Veenhuis (1983) were followed to separate these areas into effective impervious, non-effective impervious and pervious areas. Although not mentioned in the ILLUDAS documentation, these guidelines provide a realistic basis for determining these parameters.

- **WITWAT**

In the absence of specific guidance in the WITWAT documentation with respect to soil type, initial and final infiltration rates, as well as the rate of decay of infiltration capacity, were determined from the table presented by Constantinides (1982). It is important to note that the values presented by Constantinides are identical to those built into the ILLUDAS model, except that Constantinides interpolated values for the intermediate groupings.

For urban portions of catchments, the guidelines suggested by Alley and Veenhuis (1983) were again followed to separate these areas into effective impervious, non-effective impervious and pervious areas for use in WITWAT. These guidelines are recommended in the WITWAT documentation.

Adjustment for antecedent moisture conditions for each event was performed as follows:

- **Rational method and HDYP01**

  As discussed previously, no adjustment was possible.

- **SCS methods**

  The standard SCS procedure (SCS, 1972) for adjusting curve numbers was followed, this procedure considering three classifications of the five-day antecedent rainfall.

- **ILLUDAS**

  One of the four five-day antecedent rainfall classifications was used as direct input to the model.

- **WITWAT**

  Adjustments to the initial infiltration rates were made according to the table presented by Constantinides (1982). As discussed previously, these adjustments corresponded to those performed internally in ILLUDAS.

4.3.4 Overland flow

Only WITWAT requires non-map parameters for this component. The other models require only map information as follows :

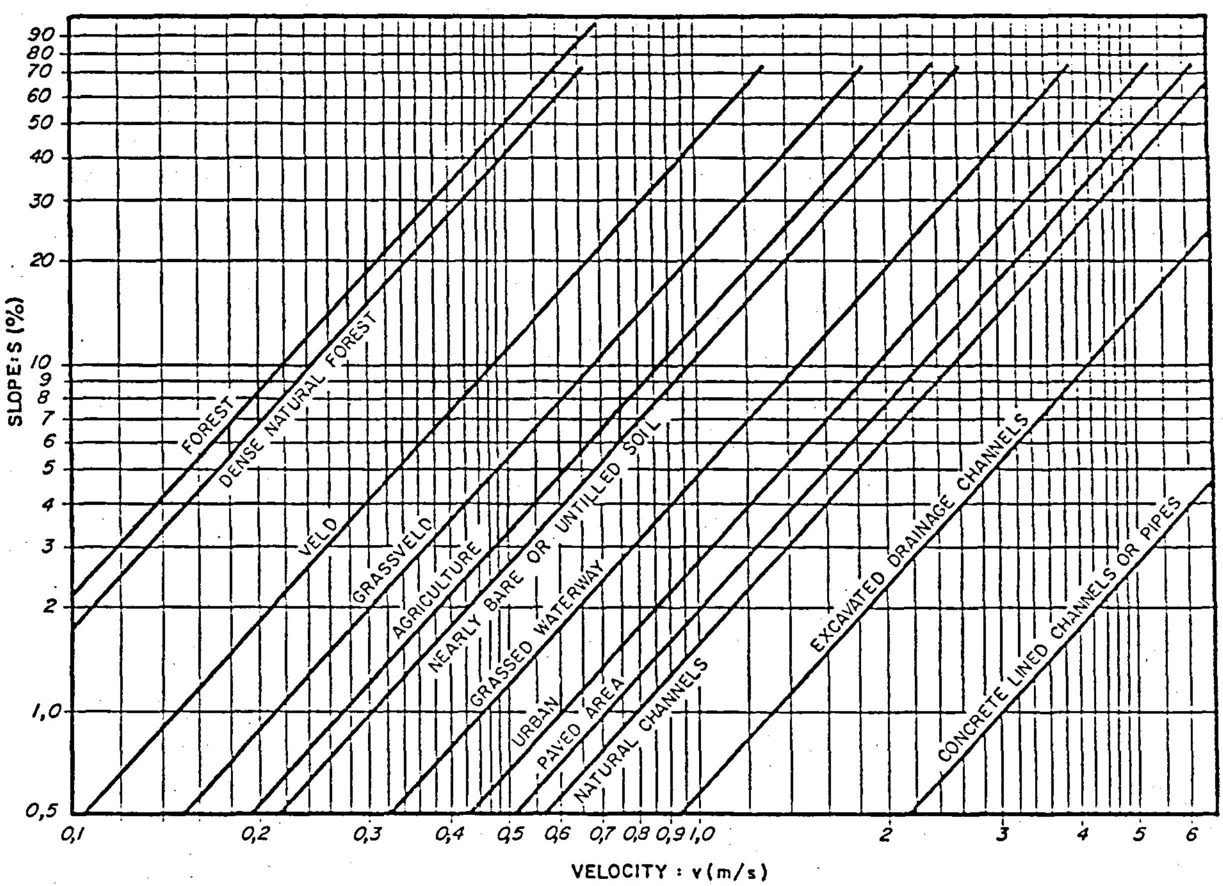
- **HDYP01**
  Although the work by Midgley and Pitman (1972) presents unit hydrographs for HDYP01 only for South Africa, Pitman and Stern (1981) have pointed out that the routing behaviour of certain monitored SWA catchments is fairly similar to that of catchments in the central and northern Transvaal. It was therefore considered reasonable to use the unit hydrograph for this South African region for the two SWA catchments used.
- **ILLUDAS**
  The version used in this study does not have built-in formulae for the calculation of the time of concentration. It was decided not to use the original formulae both because they were extraneous to the technique and because they appeared to be insufficiently flexible for the variety of catchments used. The upland flow method, illustrated in Fig 3, was therefore used.
- **WITWAT**
  WITWAT requires surface roughness information. These were obtained from the WITWAT documentation.

4.3.5 Interflow

None of the methods required parameters for this component.

4.3.6 Channel flow

A standard channel size and roughness, dependent on catchment size and channel type, was adopted for both ILLUDAS and WITWAT, while the channel parameters suggested by the WASHMO version (Ward and Stern, 1983) were used for all three SCS methods. The remaining parameters were map parameters.



OVERLAND FLOW VELOCITY ON SMALL CATCHMENTS
(SCS, 1972)

	JOB Nº		FIG Nº
	CI 3392	WRC – DESIGN TECHNIQUES REPORT	3

Care was taken when assigning values to the different methods for a given catchment so that, as far as possible, all the parameter values chosen for the models were based on the same basic information to ensure that they were all evaluated as objectively as possible.

4.4 Time to estimate parameters

To provide potential users of a model with an estimate of the degree of effort required to use the method, a record was kept of the time taken to obtain each set of parameters in a form suitable for computation. An analysis of this record showed that it took from 30 minutes to 2 hours, with an average of one hour (excluding data collection time, which was highly variable) to obtain the parameter values for a single sub-catchment, regardless of the model. Since the parameter requirements of each model are very similar, this finding was not unexpected.

The total length of time required to obtain a complete parameter set for a catchment was therefore very dependent on the level of catchment discretisation performed. Where discretisation of a catchment was done, it was found that there was an additional time 'overhead' required of about twenty minutes per sub-catchment to define the sub-catchment boundaries.

In consequence the methods for which no catchment breakdown was done, namely the Rational method and HDYP01, required only about one hour to obtain a set of parameters. The time taken for the remaining methods, namely the SCS methods, ILLUDAS and WITWAT, was highly variable, with a range of one hour to four days for a single catchment.

Since the level of discretisation is normally subjectively chosen by a designer, it is not possible to give a clear indication of the degree of effort associated with a particular method.

It is hoped, however, that the times mentioned will be of some use for time budgeting of a design, with the warning that collection of the basic data (maps, etc) generally takes much longer than parameter estimation.

5 TEST CATCHMENTS

5.1 Catchment selection

Phase I of this study identified over 130 monitored small catchments with a wide range of catchment areas, land-uses, topographic and climatic conditions. About 250 small catchments monitored by the Department of Water Affairs were also identified, but were not included in the data base for selection due to the absence of some necessary catchment characteristics and autographic rainfall records.

The objective of the study was to evaluate the chosen methods for a range of catchment land-uses. Catchments, however, occur with widely differing characteristics. It was therefore necessary to group the selected catchments according to these characteristics so that a meaningful analysis could be done. Catchment characteristics recorded in Phase I of this study included geographic location, catchment size, average catchment slope, altitude, mean annual precipitation, shape factor, drainage density, vegetation, land-use and soil type.

Information regarding shape factor and drainage density was sparse, while the details on soil type, catchment slope and altitude were considered to be too vague for meaningful classification. Mean annual precipitation was considered to be a descriptor of climate, with this in turn being to a large extent a function of geographic location. Vegetation was considered to be a sub-set of land-use. The three remaining catchment variables, namely land-use, catchment size and geographic location were therefore used as the basis for catchment selection.

5.1.1 Land-use

While it was initially assumed that catchments with five different land-uses would be available for use in Phase II of the study, Phase I failed to identify any with mining as the predominant land-use. Accordingly, the land-use variable was assigned four values, namely predominantly urban, agricultural, afforested or undeveloped (veld).

5.1.2 Catchment size

As discussed earlier in this report, a small catchment was defined for practical purposes as one with a catchment area less than 100 km^2. However, the methods selected for evaluation were not all applicable over this range. In order to ensure that the division of catchment size coincided with the range of applicability of the methods, the catchment size variable was assigned three values, namely 0-1 km^2, 1-10 km^2 and 10-100 km^2.

5.1.3 Geographic location

In order to determine which regions of the country to select, the following criteria were used:

- economic activity, since this would relate directly to the number and importance of flood estimation studies undertaken in the region
- sufficient monitored catchments with reliable and easily available flood event records for evaluation purposes
- sufficient catchments with different land-uses and sizes.

Based on the above, three regions were demarcated, namely the Highveld, the Natal coastal region and the Western Cape.

Two catchments from South West Africa were included to give a preliminary indication of the performance of methods in a semi-arid region.

Combining the three parameters led to a 36-element matrix. While ideally each element should have contained one catchment for analysis purposes, it was found that there was an excess of catchments for certain elements and none for others. Therefore, two catchments (K4M03 and Q9M21) which lay outside the demarcated regions were used and one catchment (Q9M21) was categorised as being in the 10-100 km^2 range, although it was just smaller than this range. Sixteen elements could not be filled. For the two land-uses (urban and agriculture) which had a paucity of catchments, some elements were allocated more than one catchment.

In all, 26 catchments were selected. Table 2 shows the selection matrix. The relevant details of the selected catchments are given in Table 3, and the location of the catchments is shown in Fig 4.

It is important to note that the three catchment variables were not used as a rigid classification system, but were used to ensure a sufficiently diverse range of catchments.

TABLE 2 : CATEGORISATION OF SELECTED CATCHMENTS

		REGION			
Land-use	Size (km^2)	Highveld	Natal Coastal	Western Cape	South West Africa
Urban	0-1	HBS01	PINE1	-	-
	1-10	-	-	-	-
	10-100	MPS01	-	CCCR03 CCCR05	-
Agriculture	0-1	-	101, 102 103, 104	-	-
	1-10	C8M24	-	-	-
	10-100	C8M25	-	-	-
Afforested	0-1	-	V1M21*	G2M03	-
	1-10	X2M39	W1M14	G2M02	-
	10-100	-	-	K4M03*	-
Undeveloped	0-1	-	W1M17	G2M06	-
	1-10	X2M42	W1M16	G2M07	-
	10-100	-	W1M15	Q9M21*	2991M08 2991M10

* Catchments not fitting exactly into category

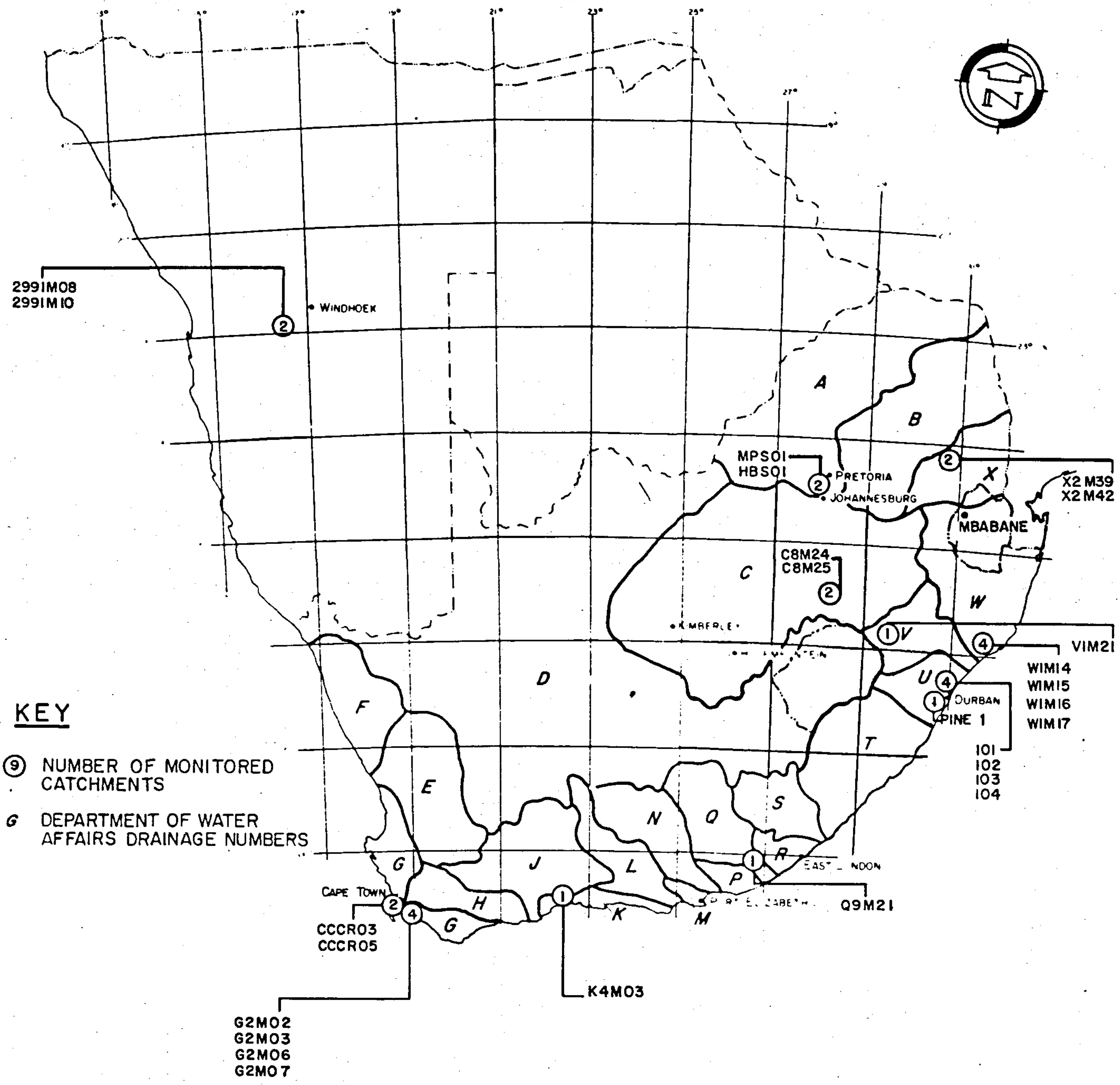
Q9M21 Eastern Province

K4M03 Eastern Province

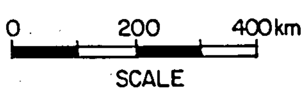
V1M21 Afforestation percentage variable

TABLE 3 : DESCRIPTION OF SELECTED CATCHMENTS

Catch-ment	Location	Monitoring Organisation	Catch-ment Area (km^2)	Land-Use (%)			
				Urban	Agri-culture	Forest	Undeve-loped
HBS01	Johannesburg	University the Wit-watersrand	0,67	95	0	0	5
MPS01			10,36	69	0	0	31
PINE1	Pinetown	CSIR	0,12	100	0	0	0
CCCR03	Cape Town	Cape Town City Council	20,00	80	8	5	7
CCCR05	Cape Town		85,00	65	30	0	5
101	Tongaat	S A Sugar Association	0,04	0	100	0	0
102	Tongaat		0,04	0	100	0	0
103	Tongaat		0,04	0	100	0	0
104	Tongaat		0,05	0	100	0	0
C8M24	Bethlehem	Hydrological Res Institute	9,00	0	50	0	50
C8M25	Bethlehem		83,00	0	50	0	50
G2M02	Stellenbosch	Department of Environment Affairs: Forestry Branch	2,01	0	0	83	17
G2M03	Stellenbosch		0,27	0	0	100	0
G2M06	Stellenbosch		0,12	0	0	0	100
G2M07	Stellenbosch		2,46	0	0	0	100
X2M39	Nelspruit		1,65	0	0	90	10
X2M42	Nelspruit		1,59	0	0	34	66
V1M21	Winterton		0,45	0	0	90	10
K4M03	George	Rhodes University	71,00	0	0	58	42
Q9M21	Grahamstown		9,10	0	0	0	100
W1M14	Empangeni	University of Zululand	1,20	0	0	93	7
W1M15	Empangeni		13,65	0	4	4	92
W1M16	Empangeni		3,22	0	7	8	85
W1M17	Empangeni		0,67	0	7	2	91
2991M08	Windhoek	Dept of Water Affairs SWA	38,40	0	0	0	100
2991M10	Windhoek		81,60	0	0	0	100



LOCATION OF SELECTED SMALL CATCHMENTS



	JOB Nº		FIG Nº
	CI 3392	WRC – DESIGN TECHNIQUES REPORT	4

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5.2 Catchment and method combinations

Each method or model has limitations, either stated explicitly by the developers or proponents of the method, or deduced from the available literature.

Geographic location was not considered to be a limiting factor for any of the methods evaluated. Limitations imposed by the other catchment variables, viz land-use and catchment size, which were accepted for use in this study are:

- **Rational method**
  - no limit on land-use
  - although it has been suggested that it should be used for catchments less than 15 km^2 (Midgley and Pitman, 1972), it has been widely used for catchments in excess of 100 km^2 (Alexander, 1982). It was therefore applied to all catchment sizes.
- **SCS methods**
  - no limit on land-use
  - a catchment size of 8 km^2 is normally taken as the upper limit of the SCS approach. However, since catchment discretisation was being done in this study, it was decided not to place a limit on overall catchment size provided that in general no sub-catchment was larger than 8 km^2
- **HDYP01**
  - although developed from rural catchment data, two urban catchments (CCCR03 and CCCR05) contained significant rural and low-density residential areas. Therefore this method was evaluated on these two urban catchments
  - developed for catchments in the range 10-5 000 km^2. It was therefore only used for catchments in the 10-100 km^2 range.

- **ILLUDAS**
  - although specifically developed for urban areas, it has been tested on rural catchments by original developers as described by Watson (1981), and it was therefore applied to all land-uses
  - while no size limitation has been explicitly stated, it was decided for this study that for larger catchments the number of sub- catchments required to keep to the philosophy of the method would be excessive. The upper limit was taken to be the largest catchment evaluated in the manual on the model, namely 10 km^2.
- **WITWAT**
  - although specifically developed for urban areas, it has been tested on rural catchments (Green, 1984), and it was therefore applied to all land-uses
  - while no size limitation has been explicitly stated, it was decided for this study that for larger catchments the number of sub-catchments required to keep to the philosophy of the method would be excessive. The upper limit was taken to be the largest catchment evaluated in the manual on the model, namely 1 km^2.

In summary,

- geographic region was not taken as a limiting factor for any of the models
- land-use considerations were varied only once, where HDYP01 was used for urban catchments CCCR03 and CCCR05

- the catchment size range used for each model was:
  - RATIONAL : 0-100 km^2
  - SCS : 0-100 km^2
  - HDYP01 : 10-100 km^2
  - ILLUDAS : 0-10 km^2
  - WITWAT : 0-1 km^2

Discretisation was done for SCS, ILLUDAS and WITWAT. The number of sub-catchments ranged between 1 and 24 per catchment. Details of the catchment breakdown are shown in Table 4.

The catchment MPS01, although 10 km^2, was taken as an exception to the above rule. It was decided that, since it was predominantly urban, it would be used to evaluate both ILLUDAS and WITWAT. Catchments CCCR03 and CCCR05, while still predominantly urban, were considered to be too large for ILLUDAS and WITWAT.

TABLE 4 : NUMBER OF SUB-CATCHMENTS PER CATCHMENT

Catchment Name	Size (km^2)	SCS Methods	ILLUDAS	WITWAT
HBS01	0,67	2	18	18
MPS01	10,36	11	22	22
PINE1	0,12	1	13	13
CCCR03	20,00	12	-	-
CCCR05	85,00	24	-	-
101	0,04	1	1	1
102	0,04	1	1	1
103	0,04	1	1	1
104	0,05	1	1	1
C8M24	9,00	7	22	-
C8M25	83,00	8	-	-
G2M02	2,01	1	13	-
G2M03	0,27	1	2	2
G2M06	0,12	1	4	4
G2M07	2,46	2	9	-
X2M39	1,65	3	10	-
X2M42	1,59	2	10	-
V1M21	0,45	1	8	5
K4M03	71,00	2	-	-
Q9M21	9,10	5	-	-
W1M14	1,20	1	5	-
W1M15	13,65	10	-	-
W1M16	3,22	5	10	-
W1M17	0,67	1	9	9
2991M08	38,40	6	-	-
2991M10	81,60	12	-	-

6 EVENT SELECTION

In the selection of rainfall runoff events, it was vital that the method of selection of storms and runoff hydrographs did not favour one model over the others and thereby influence the evaluation. A set of selective criteria relevant to all models were therefore chosen to minimise bias and the selection method performed to reduce subjectivity in the approach.

6.1 Selection criteria

While a large number of storm events per catchment was desirable for evaluation of the models, this would impact markedly on the study programme. It was therefore decided to select four rainfall-runoff events per catchment to keep the study within practical time limits. The event selection process was based on the following criteria:

- events should be amongst the largest on record, since the methods are generally used for extreme event prediction

- hydrographs should be single-peaked and relatively smooth, both to conform to the appearance of a standard design event and to facilitate the analysis of the results

- events should be isolated to enable the separation of baseflow from quickflow

- the amount of rainfall during the preceding five days should be available for the determination of antecedent moisture conditions

- storm duration should not exceed 20 hours to facilitate the input of the hyetograph to the models at a reasonable time step (see section 6.4).

6.2 Selection methodology

The event selection process was hampered by the variety of formats in which the data were made available, as shown in Table 5.

TABLE 5 : EVENT DATA FORMATS

Format	Rainfall Data Medium	Runoff Data Medium	No of Catchments
A	Paper charts	Paper charts	11
B	Computer tape	Computer tape	9
C	Paper charts	Computer tape	4
D	Computer printout	Computer printout	4

Events in a form suitable for immediate use were available for only four of the catchments (all of format D). The remaining events had to be selected from partial or complete rainfall and runoff records. The methods by which this was accomplished are described below:

- **Format A**
  - (i) scan through runoff stage charts and select a number of potential events
  - (ii) find corresponding rainfall charts for each gauge within or near catchment and note rainfall in preceding five days
  - (iii) using event selection criteria, determine the four most suitable events
  - (iv) manually digitise the rainfall and runoff charts
  - (v) transform runoff stage values to flow values using the rating table
  - (vi) capture data on computer for further processing.

- **Format B**
  - (i) Obtain computer tape readable on the SRK computer system

(ii) develop software for determining all peak flows/stages above a certain level on record where record length precluded a manual search
(iii) identify a number of the largest peaks on record
(iv) develop software to plot hydrograph over a specified time period on a graphics computer terminal, converting stage to flow values where necessary
(v) develop software to plot correspondingly hyetographs overlaying the hydrograph
(vi) using event selection criteria, determine the four most suitable events
(vii) store the selected events on computer for further processing.

Steps (ii), (iv) and (v) were required for the data acquired from each monitoring organisation since each had the data stored in a different computer format.

- **Format C**

(i) Obtain computer tape readable on the SRK computer system
(ii) develop software for determining all peak flows/stages above a certain level on record where record length precluded a manual search
(iii) identify a number of the largest peaks on record
(iv) develop software to plot hydrograph over a specified time period on a graphics computer terminal, converting stage to flow values where necessary
(v) select a number of potential events
(vi) find corresponding rainfall charts for each gauge within or near catchment and note rainfall in preceding five days
(vii) using event selection criteria, determine the four most suitable events
(viii) manually digitise the rainfall charts
(ix) capture rainfall data and store runoff data on computer for further processing.

- **Format D**
  - (i) capture data on computer
  - (ii) plot data on graphics terminal for checking purposes

All the selected event data were stored in a standard computer format to facilitate their further processing.

The two SWA catchments, 2991M08 and 2991M10 each contained a dam commanding a significant proportion of the catchment areas. Fortunately, information about the state of the dam was provided with the event data (in format D) so only those events for which the dams either did not spill or were full at the start of rainfall were selected, and the contributing area adjusted accordingly.

6.3 Data transformation

6.3.1 Runoff transformation

The selected recorded hydrographs were separated into quickflow and baseflow components by producing a line with a slope of 1,13 mm/day/day from the beginning of the stream rise until it intersected the recession limb of the hydrograph, as suggested by Hewlett and Hibbert (1967). The quickflow component was thereafter taken as the runoff resulting from the storm event.

6.3.2 Rainfall transformation

By plotting the cumulative rainfall distribution together with the quickflow hydrograph on a graphics computer terminal, any obvious clock errors were corrected and periods of rainfall after the termination of runoff were removed.

For events with more than one rainfall record, a combined hyetograph was produced by multiplying the ordinates of each cumulative rainfall distribution by their relative weight determined by the Thiessen polygon method, and adding the distributions. This approach obviated the need for areal reduction factors (ARF), commonly used in design to allow for spatial non-uniformity of rainfall, as the majority of larger catchments for which the ARF was significant contained more than one raingauge.

Finally, the cumulative rainfall distributions were replotted and insignificant periods of rainfall removed, to facilitate their transformation into synthetic distributions.

A summary of the events selected for each catchment is shown in Appendix A. The catchments are grouped according to the organization responsible for monitoring the catchment. Information shown in each table is:

- catchment
- event
- year and month in which the event took place
- rainfall information including day, starting time in minutes after 0h00, antecedent rain, depth and duration of rainfall and number of rain gauges used
- runoff information including day and starting time in minutes after 0h00, peak flow, time to peak and volume of runoff

6.4 Synthetic rainfall distributions

A design storm event is normally obtained by taking a specified frequency of occurrence, together with a storm duration estimated from the critical response time of the catchment, and using these to obtain a precipitation depth from historical depth-duration frequency relationships such as those presented in HRU Report No 2/78 (Midgley and Pitman, 1978). This precipitation depth is then distributed in time according to any one of various synthetic distributions. However, the real-event modelling approach considered most appropriate for this study precluded the use of this procedure, and actual causative storms were used as input to the methods.

While it was initially assumed that precipitation depth and storm duration, used in conjunction with a synthetic time distribution of rainfall, would suffice as input to the methods, it soon became apparent in the event selection process that the hydrograph shapes were closely related to the actual time distribution of the rainfall. It was decided that, since it would have proved difficult to distinguish between the effect of a simplified rainfall input and the effect of inadequacies in a model, it would be necessary to utilise the actual rainfall distributions as well as synthetic distributions.

While numerous synthetic rainfall distributions have been developed and used, often in circumstances far different from those for which they were originally derived, only those distributions which were both recommended by the developers of the models and based on South African data were included in this study. The following suitable distributions were identified :

- **SCS methods**
  SA type I, II, III, IV (Schulze, 1984). These distributions are considered by Schulze to be of a preliminary nature.

- **HDYP01**
  Hydrological Research Unit distribution (Van Wyk and Midgley 1966, Midgley and Pitman 1972).

- **ILLUDAS, WITWAT**
  Chicago distribution, using local IDF parameters (Green, 1984; Watson, 1983).

The range of catchment sizes for which a particular distribution was applicable was determined by using the same size ranges as were assumed for the models. The following catchment size ranges were therefore used:

- Actual : 0-100 km^2
- SCS : 0-100 km^2
- HRU : 10-100 km^2
- Chicago : 0-10 km^2

While a particular distribution is recommended only for a certain method, it was decided to use all the applicable distributions with all the applicable models on a catchment in a given size range, both because rainfall distributions are external to the principles of a method and to facilitate comparison of the effects of different distributions on the predictions.

A particular problem arose with the rainfall input to the Rational method, since it requires a statistical measure of rainfall based on intensity-duration-frequency diagrams. However, one of the assumptions of this method is that the peak runoff from a catchment is caused by the most intense period of a storm, with the length of this period being equal to the estimated time of concentration of the catchment. This problem was therefore bypassed in this study by extracting the most intense periods of rainfall from the actual and synthetic distributions and using the average intensity over the period as input to the Rational method.

A computer program was used to generate the synthetic rainfall distributions for direct incorporation in the data files stored for each catchment, with input being precipitation depth, storm duration and the necessary parameters for each synthetic distribution. The actual rainfall distribution had already been stored on computer file during event selection.

A problem arose with the number of rainfall ordinates that some of the methods would accept. Since the study was being done with real storm events, rainfall duration was not limited to a few hours, as would commonly be the case for design storms, but varied up to an imposed limit of 20 hours. The number of rainfall ordinates was not a problem for either the Rational method, which required only a single value, or HDYP01, which required hourly rainfall, but was a problem for the SCS methods, ILLUDAS and WITWAT, the original versions of which allowed only about 100 rainfall ordinates. A coarse hyetograph description could have been acceptable except for the fact that all three programs required the hyetograph time-step to be the same as the calculation time-step. It was felt that using calculation time-steps of up to 12 minutes would be too inaccurate for the models, so the programs themselves were amended. This was easily accomplished for the SCS methods and WITWAT, but proved time-consuming for ILLUDAS because access to the secured program code was difficult. The SCS methods were adjusted to allow 400 ordinates, while WITWAT and ILLUDAS were adjusted to allow up to 200. All rainfall distributions for the SCS methods were therefore generated with a three minute time-step, with the same time-step for ILLUDAS and WITWAT for storms up to 10 hours long and a six-minute time-step for longer storms.

7 MANUAL CALCULATIONS AND COMPUTER RUNS

When it is considered that the study was aimed at evaluating 7 different methods on 26 catchments, utilising 4 storm events per catchment with rainfall distributed in 4 different ways, it is readily apparent that a significant number of manual and computer runs were required. Not all combinations of these factors were in fact tested which reduced the number of runs required, but more than 1 650 were still necessary.

7.1 Combination of methods, catchments and storm patterns

Based on the assumptions of suitability of method and synthetic rainfall distribution to catchment size (discussed in Sections 5.2 and 6.4), the catchments were classified as code 1, 2 or 3, depending on their size range, with MPS01 being an exception to this rule. For each code, the following methods and rainfall distributions were applicable:

- Code 1 (0 - 1 sq km)
  - Rational method, SCS methods, ILLUDAS and WITWAT
  - Actual, SCS and Chicago distributions

- Code 2 (1 - 10 sq km)
  - Rational method, SCS methods and ILLUDAS
  - Actual, SCS and Chicago distributions

- Code 3 (10 - 100 sq km)
  - Rational method, SCS methods and HDYP01
  - Actual, SCS and HRU distributions

Table 6 shows a breakdown of the number of runs required per method and per catchment. Two of the catchments have only three selected storm events, these being the only suitable events that could be extracted from the record.

TABLE 6 : NUMBER OF COMPUTER RUNS REQUIRED

Catch-ment	Code	No of Events	Rational	SCS WASHMO	SCS SA	SCS USA	ILLUDAS	WITWAT	HDYPO1	Total
HBS01	1	4	12	12	12	12	12	12	0	72
MPS01	1	3	9	9	9	9	9	9	0	54
PINE1	1	4	12	12	12	12	12	12	0	72
CCCR03	3	4	12	12	12	12	0	0	12	60
CCCR05	3	4	12	12	12	12	0	0	12	60
101	1	4	12	12	12	12	12	12	0	72
102	1	4	12	12	12	12	12	12	0	72
103	1	4	12	12	12	12	12	12	0	72
104	1	4	12	12	12	12	12	12	0	72
C8M24	2	4	12	12	12	12	12	0	0	60
C8M25	3	4	12	12	12	12	0	0	12	60
G2M02	2	4	12	12	12	12	12	0	0	60
G2M03	1	4	12	12	12	12	12	12	0	72
G2M06	1	4	12	12	12	12	12	12	0	72
G2M07	2	4	12	12	12	12	12	0	0	60
X2M39	2	4	12	12	12	12	12	0	0	60
X2M42	2	3	9	9	9	9	9	0	0	45
V1M21	1	4	12	12	12	12	12	12	0	72
K4M03	3	4	12	12	12	12	0	0	12	60
Q9M21	3	4	12	12	12	12	0	0	12	60
W1M14	2	4	12	12	12	12	12	0	0	60
W1M15	3	4	12	12	12	12	0	0	12	60
W1M16	2	4	12	12	12	12	12	0	0	60
W1M17	1	4	12	12	12	12	12	12	0	72
2991M08	3	4	12	12	12	12	0	0	12	60
2991M10	3	4	12	12	12	12	0	0	12	60
TOTAL			306	306	306	306	210	129	96	1659

7.2 Methodology of computation

The significant number of runs necessitated the adoption of computer-based data handling, with as little manual intervention as possible. Computer programs were used to run six of the methods, with only the Rational method being done manually. Four of the models, the SCS methods and HDYP01, were made operational on a minicomputer, while ILLUDAS and WITWAT were obtained as packages for a microcomputer. A data and calculation sheet sufficed for the Rational method.

The selected events were stored on the minicomputer, and a computer program was used to generate the applicable rainfall distributions in the format required by each of the computer-based models. Including the rainfall data with the captured parameters was a relatively simple operation for the methods operational on the same minicomputer, but the manual transferral of these data to the microcomputer proved to be timeconsuming. Accordingly, a link between the two computers was installed to speed up this process.

A brief description of the methodology used to run each method for a single catchment follows:

- **Rational method**
  - time of concentration was calculated manually
  - a computer program was used, with time of concentration as its single parameter, to calculate the average intensity of the most intense period of rainfall for each distribution
  - coefficient "C" was calculated manually
  - peak flow was calculated from the formula

- **SCS methods**
  - the parameters common to all three versions, plus the unique parameters for each version, were captured as a skeleton data file
  - the applicable rainfall data files were merged with the skeleton file using utility software
  - the combined files were then run sequentially through three computer programs, each being a slightly different version of a basic program to allow for the differences between the three versions being evaluated

- **HDYP01**
  - a skeleton data file was captured
  - the applicable rainfall data files were merged and these files used as input to the program

- **ILLUDAS**
  - a skeleton data file was captured
  - the applicable rainfall files were transferred to the micro-computer and the combined files used as input to the program.

- **WITWAT**
  - same methodology as for ILLUDAS

(Both the ILLUDAS and WITWAT programs required modification to read the rainfall data off disc instead of from the keyboard. A three line coding adjustment sufficed for WITWAT, but since the program code for ILLUDAS was secured, it was necessary to write a separate rainfall module for this program).

7.3 Checking of data and results

In handling the significant volume of data required by the study, the possibility existed that inadvertent errors could influence the final results.

The following steps were therefore undertaken to minimise the occurrence of errors in the input data and in the computer-based models:

- the selected storm events as finally stored on the minicomputer were checked against the original data sources for major discrepancies

- verification runs using sample data sets were done for all the computer-based models. This was especially necessary since some program modifications had been made

- the catchment data sheets for the different models were compared for each catchment prior to the data being captured on computer. This helped identify discrepancies in both measured and judgemental parameters

- in order to identify catchment data capturing errors, the results from the first run of a method on a catchment were checked against the observed values for reasonableness. If the difference was large, the captured data was checked against the original data sheets. It should be noted that no adjustment was made unless the large discrepancy was caused by a data capturing error. The results from the remaining runs on a catchment were not checked since only the rainfall and antecedent moisture parameters varied. Since the rainfall data files were created and transferred within a thoroughly checked computer-based system, no checks were considered necessary

- the personnel running a particular model remained unchanged as their experience enabled them to identify incorrect data before commencing a run.

As the runs were completed, the relevant results were captured on the minicomputer, creating one results file per catchment. Since more than 5 000 values were captured, the results were recaptured once all the runs were complete, and the two independently created sets of data were compared via a computer program to check for errors.

The results of the simulations for each catchment for each model and each rainfall distribution are given in Appendix B. The table for each catchment shows:

- model
- rainfall distribution
- the observed peak flow and runoff volume
- the predicted peak flow and runoff volume

8 ANALYSIS OF RESULTS

8.1 Comparison measures

The objective of the study was to compare observed catchment responses with the responses predicted by the different design methods. It was initially intended to do this comparison based on the following measures:

- time to peak
- volume of runoff
- peak runoff rate

It was noted during the event selection process when rainfall and runoff events were abstracted from computer tapes and paper charts, that gross differences existed between clock times at the rainfall and the runoff gauges for the majority of catchments. Clock times for runoff events were accepted and time to peak is shown in the selected event summaries in Appendix A. Abstraction of time to peak values from some of the simulation results proved to be difficult due to differences in format, reporting of results and terminology. It was considered that reporting of these values may be misleading. It was also considered that a comparison based on time to peak would not be as meaningful as the other comparisons. Accordingly, the remaining two measures, volume of runoff and peak runoff rate were used for evaluating the methods.

8.2 Statistical methods used in the analysis

The statistical technique used to analyse the results had to fulfill two requirements:

- it should be readily comprehensible to the average end-user of the research

- it should be unbiased, ie the absolute magnitudes of the results should not influence the outcome. This requirement was of major importance since it was intended to group results from very diverse catchments.

Reference was made to previous studies (Mostaghimi and Mitchell, 1982; and others) and to an extensive literature survey conducted by Green (1985) to identify potentially suitable techniques. The conclusion reached was that the majority of similar studies were conducted on a small number of catchments with a relatively large number of selected events, with the analysis being performed on a per catchment basis. Consequently these approaches were not considered applicable to the case at hand since they did not meet the second requirement.

The statistical approach finally selected used the ratio of the predicted value to the observed value in standard statistical procedures. The ratio was defined as:

$$Z_i = P_i/O_i$$

where P_i = predicted value for event i

O_i = observed value for event i

Z_i therefore can have a lower bound of zero, no upper bound and has a target value of 1,0.

Three statistical parameters were calculated:

Mean $(\bar{Z}) = \Sigma Z_i/N$

Std deviation $= (\Sigma(Z_i - \bar{Z})^2/N)^{0,5}$

Std error $= (\Sigma(Z_i - Z_t)^2/N)^{0,5}$

where

N = number of events

Z_t = 'target'value (1,0)

These three parameters enabled the following interpretations to be made:

- Mean : the average over- or under-prediction
- Standard deviation : the degree of scatter, or consistency of prediction, about the mean
- Standard error : the degree of scatter, or consistency of prediction, about the 'target' value.

Since the latter two parameters provide similar information, attention in the interpretation of the analysis was focused on the means and standard errors.

In addition, it was considered vital that the statistical ratio analysis be backed up by a visual representation of the results to aid the interpretation. Scatter diagrams of predicted versus observed values were therefore produced. Linear regression analysis of these values, which included the best fit line and correlation coefficients, was then done. The standard error of the values was also calculated. The terminology and definitions used for the regression statistics were:

A = intercept of best-fit line on Y axis
B = slope of best-fit line
R^2 = coefficient of determination
Std error = $(\varepsilon\,(P_i - O_i)^2/N)^{0,5}$

The statistical approach, therefore, consisted of the ratio analysis using standard statistical parameters together with scatter diagrams with regression statistics.

The statistical analysis was performed for each model for both volume and peak flow prediction, with the analysis being done in two stages. In the first stage, the results obtained from the runs utilising the actual rainfall distribution were analysed in detail, with the catchments grouped for each catchment variable in turn (land-use, catchment size geographic region). In the second stage, the results from the runs with synthetic rainfall

were analysed, but only for all the catchments combined.
The reasoning behind this two-stage approach was:

- The results using actual rainfall represented the 'best attempt' by the models, with errors being due only to the catchment parameters chosen and the limitations of the models themselves. A detailed analysis of model performance for this case would therefore be the most relevant.

- The results using synthetic rainfall distributions could be compared to results using actual rainfall and their effect on model prediction could be interpreted. While detailed analyses of these results could have been done, this was deemed unnecessary both because the number of analyses would have been indigestible and because it was considered that the effects could be more clearly discerned if looked at on a global basis.

8.3 Analyses using actual rainfall distribution

The results of the statistical ratio analysis are presented in two tables in Appendix C. Table C.1 shows the results for volume and Table C.2 for peak flow prediction.

Scatter diagrams of predicted versus observed values for volume and peak flow were then undertaken. A decision had to be taken on which of the three catchment variables (land use, size or location) to use in the plots. The objective of the study was firstly to look at the ability of the techniques to make flood estimations on small catchments with differing land use, and so scatter diagrams were constructed per land use. A log-log scale was used purely for clarity, since clustering tended to obscure the diagrams when plotted to a normal scale. The resulting eight diagrams (volume and peak flow for four land-uses) are presented in figures C1 - C8.

Standard regression analysis was then performed on the results on the land-use scatter diagrams. Regression coefficients, correlation coeffients and standard error for both volume and peak flow for each land-use category are presented in Table C.3 in Appendix C.

It was considered by researchers when reviewing the selected events that some of the events, although the largest on record, were still small when compared to events which might be used for design purposes. It was considered that removing the smaller events could influence the interpretation significantly. Two approaches were used :

. in the first approach, all events with rainfall less than 20 mm were excised and the remaining results were then processed. The scatter diagrams are presented as Figures D1 to D8. The regression analysis was performed and the results presented in Table D.1 of Appendix D.

. in the second approach, the approximate recurrence interval of each event was calculated using estimates of catchment time of concentration. The small recurrence interval events were then excised and the remaining values again subjected to plotting on scatter diagrams and regression analysis. The results are presented in Figures D9 - D16 and Table D.2 in Appendix D.

It was also considered important to review the ability of each of the models to make flood estimations on all catchments, and so a set of scatter diagrams for volume and peak flow were constructed per model. These scatter diagrams are presented as Figures E1 to E13 and the results of the regression analysis are presented in Table E.1 in Appendix E.

8.4 Analyses using synthetic rainfall distributions

The ratio statistical approach was used for volume and peak flow analyses on all the results of the simulations using synthetic rainfall distributions. For this analysis all the catchments were lumped per model and were not analysed by catchment characteristic. It was evident that the effects of synthetic distribution could be more easily discerned on a global basis. The results of this analysis are presented in Table F.1 in Appendix F.

8.5 Interpretation of results of analysis

Interpretations of the results from the first stage of analysis, ie actual rainfall distributions, are discussed in Sections 8.6 and 8.7, while interpretations of the second stage (synthetic rainfall distributions) are made in Section 8.8.

A word of caution is necessary. There are two other potential causes of error in prediction besides the model limitations:

- Errors in measured storm and runoff data: Even with the best gauges, sampling errors are always present. Compounding these inherent errors in the data is the possibility of undetected gauge malfunctions. To minimise this possibility every attempt was made to obtain reliable data from well-monitored catchments. In addition, hyetographs were utilised from as many rain gauges as possible and the hyetograph behaviour was compared to the hydrograph behaviour to check for anomalies.

- Catchment parameters: While these parameters were determined as carefully as possible, on a few occasions information was lacking. This was particularly true for storm events which had occurred some years ago, where the precise land-use within a catchment could not be accurately determined. For some catchments soil information was skimpy and for certain methods (eg ILLUDAS and WITWAT) certain parameters had to be subjectively estimated where the manuals did not provide guidance for a particular land-use.

Since all the methods were given the same basic catchment data (eg area, lengths, slopes, land-uses, soil types), any major errors of the above two types could theoretically be detected by looking at the complete result summaries in Appendix B, as all the methods would have predicted values far removed from the observed values. This information is, however, predominantly lost in the statistical analysis. Care should therefore be exercised in drawing generalisations from the results.

8.6 Volume prediction using actual rainfall distribution

An interpretation of the volume prediction by each of the models for each of the three catchment variables is given below.

8.6.1 Land-use

The interpretation was undertaken as follows:

- the ratio analysis was interpreted. A good model would have a mean = 1 and a low standard error
- the scatter diagrams and regression statistics for all events were then reviewed to check the ratio analysis
- the scatter diagrams and regression statistics for the larger events (design storms) were then reviewed to assess any changes

Considering each of the four land-uses in turn:

- **Urban** : the two models specifically tailored for urban catchments, ILLUDAS and WITWAT, performed most consistently (mean equal to one and smallest standard error). All three SCS methods underpredicted on average, with SCS-SA very low, and were less consistent. HDYP01 did not perform well, but its average over-prediction is contrary to what could be expected. The scatter diagrams of all events and of design storms confirmed the above findings except that SCS-SA improved.

- **Agricultural :** all the models, excepting HDYP01, performed badly on the agricultural catchments. The probable cause of this lies in the four agricultural plot catchments (101, 102, 103 and 104). These very small catchments lie side by side, with almost identical soil types and map parameters, with all being in a bare fallow (ploughed and disced) condition at the time of the selected events. Yet, despite being similar from a modeller's viewpoint, an examination of the records showed that they behave in an anomalous fashion (see, for example, events C and D). Consideration was given to removing the anomalous events from the analysis, but it was felt that this could be a case of adjusting reality to suit the models. The only model not run on these plots was HDYP01, which performed reasonably well on a single catchment. The scatter diagrams confirmed the findings except for SCS-SA where agreement on the larger catchments was reasonable.

- **Afforested :** SCS-WASHMO and -USA gave good predictions while SCS-SA over predicted. ILLUDAS and WITWAT performed poorly. HDYP01 performed acceptably considering that it was used on only one catchment. The scatter diagrams confirmed the interpretation except for WASHMO and USA where the significant number of zero runoff predictions shown in the scatter diagrams indicate that the statistical measures for these models are misleading.

- **Veld :** SCS- WASHMO and -USA appear to have performed adequately, while SCS-SA over predicted. The performance of ILLUDAS and WITWAT was acceptable. HDYP01 performed reasonably on the larger catchments. The scatter diagrams showed that WASHMO and USA versions gave a significant number of zero runoff predictions, SCS-SA improved, ILLUDAS was poor and the other interpretations were confirmed.

8.6.2 Catchment size

The only observation which can be made is that the performance of all the methods appears to improve with increasing catchment size, which runs counter to logic. This apparent anomaly can possibly be explained by examining the land-uses contained within each size category. The 0-1 size range contains the agricultural plots discussed previously. The 1-10 size range contains an even number of afforested and veld catchments, thus explaining the relatively good performances of the SCS methods. The 10-100 size range contains mostly urban and veld catchments, with the performance of the models on these land-uses being echoed here. Meaningful conclusions about the effect of catchment size would require a larger and more even distribution of land-uses within each size range, and therefore no conclusions can be drawn here.

8.6.3 Geographic region

Comments similar to those made for catchment size apply here, and it would be fallacious to conclude from this set of statistics that a technique worked better in some parts of the country than in others.

The only observations which will therefore be made concern the SWA catchments. These two catchments were included in order to obtain a preliminary estimate of model performance in a semi-arid region. The results indicate that the models tested performed reasonably, although all of the SCS methods and HDYP01 over-predicted.

8.6.4 Summary by model

Meaningful conclusions could only be drawn about land-use, with the ratio statistics for catchment size and region yielding no inferrable patterns. Scatter diagrams per model were therefore constructed and are presented in Appendix E. A summary for each method for the range of land-uses is given below.

- **SCS methods** : all the models under-predicted on average on the urban catchments. From the statistics it appears as if they all performed reasonably well on the rural catchments, with the SA version giving higher predictions than the other two versions. However, the significant number of zero runoff predictions shown on the scatter diagrams for both the WASHMO and USA versions indicate that the statistics have painted a better picture of these two methods than may in fact be the case. The curve number technique was originally developed for substantial precipitation events of a more or less continuous nature lasting up to 24 hours. In this study short duration storms, often with relatively small amounts of precipitation, have been used. The curve number technique allows no runoff until initial abstractions are satisfied by rainfall. Even after initial abstractions are filled, the runoff volume as a percentage of precipitation volume increases rather slowly for low precipitation amounts and curve numbers. The result is a low prediction of runoff. This is verified somewhat by the fact that the SA version predicted runoff better than the USA version or WASHMO. The SA version uses a much lower coefficient of initial abstraction so is not as sensitive to rainfall prior to the analysed portion of the rainfall event

- **ILLUDAS** : on urban catchments this model performed well, as could be anticipated. Its performance on agriculture was reasonable, but the other land-uses was poor.

- **WITWAT** : This model performed well on the urban catchments, and reasonably on the agriculture and veld catchments, indicating that the recommended parameters for the Horton infiltration equation are adequate for situations where vegetation does not play a major role. Its performance on the other land-uses was poor.

- **HDYP01** : this method gave overestimates on all land-uses. Considering that the method is not strictly applicable for real-event modelling, the predictions appear to be reasonable. However, the small sample sizes mean that the results should be viewed with caution.

8.7 Peak flow prediction using actual rainfall distribution

An interpretation of the peak flow prediction for each of the three catchment variables by each of the models is given below:

8.7.1 Land-use

Considering each of the four land-uses, namely urban, agricultural, afforested and veld, in turn, and using the same method of interpretation:

- **Urban** : The Rational method over-predicted on average which is in line with other studies on this technique. All three SCS methods underpredicted. ILLUDAS performed well. WITWAT underpredicted on average. HDYP01 over-predicted. The scatter diagram for all events and design storms confirmed these findings with SCS-SA improving.

- **Agricultural :** The peak flow predictions for agricultural catchments are excessive for all the models, with the error being much larger than that for volume prediction. The scatter diagrams confirmed these findings with SCS-SA and HDYP01 showing some improvement.

- **Afforested:** The Rational method performed particularly poorly with extreme overprediction. WASHMO and USA appear to have performed adequately on average on the afforested catchments, while SA over predicted. ILLUDAS and WITWAT had excessive over predictions and HDYP01 performed adequately on a single catchment. The scatter diagrams confirmed their results except for WASHMO and USA which predicted zero runoff for a significant number of events.

- **Veld:** The Rational method again performed badly. WASHMO and USA appear to have performed on average adequately on the veld catchments with SA over predicting. WITWAT performed well, especially for the events of larger absolute magnitude. Conversely, ILLUDAS did not perform well. HDYP01 appears to have performed adequately. From the scatter diagrams results were confirmed but, again, the WASHMO and USA versions gave a significant number of zero runoff predictions.

8.7.2 Catchment size and region

As for volume prediction, no significant trends could be detected for these two catchment variables.

8.7.3 Summary by model

In general, the methods performed better for volume prediction than for peak flow prediction. This indicates both that the loss prediction capability of the methods is better than their ability to route the resulting excess flows, and that the estimations of the loss parameters were reasonable.

A summary for each method by land-use (except agriculture) is given below. For the agricultural land uses, and assuming that the four small plots discussed previously have the over-riding influence on the statistics, it can be concluded that the models are less capable of routing the excess flows correctly than of determining storm losses on these catchments. In discussions with the organization monitoring these catchments, it became apparent that interflow was the predominant runoff mechanism. The inability of the models to allow for this mechanism is therefore the probable major reason for their poor performance.

- **Rational method** : this method only performed reasonably on the urban catchments. On rural catchments the predictions were very high. The reason for the poor predictions on rural catchments appears to lie in the inability of the coefficient 'C', if the recommended partial coefficients for slope, permeability and vegetation are used, to take on the very low values required. The fact that each of these variables has only a partial effect on the combined 'C' means that an over-riding hydrological variable, such as very permeable soils or dense vegetation, has a diminished influence on the estimated runoff. Thought should possibly be given to weighting the partial coefficients to allow for over-riding influences.

- **SCS methods** : The models again underpredicted on the urban catchments. From the statistics they all appear to perform reasonably on the rural catchments but there were again a significant number of zero runoff predictions for both WASHMO and USA

- **ILLUDAS** : The peak flow predictions on urban catchments were excellent. Its performance on other land-uses was poor, indicating that the routing algorithms or parameters are the major inadequacies. A comparison of predicted and observed hydrographs showed that this model did not retard flow sufficiently, producing very spiky hydrographs. The poor performance highlights the need for testing and consequent parameter guidance, not presently available, on these land-uses.

- **WITWAT** : The model surprisingly under predicted on urban catchments but performed well on veld catchments which indicates that parameter guidance is reasonable, possibly as a result of recent research on this technique on this type of catchment. Its performance on other land-uses was poor for similar reasons as ILLUDAS.

- **HDYP01** : This model gave consistent over-predictions on all land-uses, especially urban catchments.

8.8 Effect of synthetic rainfall distributions

The statistical ratio analysis was performed on the results of all the simulations for all the catchments for both volume and peak flow. The results of the analysis are presented in Table F.1 in Appendix F.

In looking at the effect of the synthetic distributions, the shapes of the hyetographs must be borne in mind. Both the Chicago and SCS distributions give low-intensity rainfall at the beginning and end of the storm, with intensities rising sharply towards the middle of the storm. The peak intensity of the Chicago hyetograph was taken to occur at 0,4 of the storm duration, while the SCS hyetograph, being symmetrical, peaks at the middle of the storm. The HRU hyetograph, in contrast, resembles an exponential curve with high-intensity rainfall occurring at the beginning of the storm and decreasing with time.

The effect of this peakiness of the synthetic hyetographs becomes more marked as the time interval used to discretise the hyetographs is decreased. Since a 3 minute time interval was used for all the SCS methods and the majority of ILLUDAS and WITWAT runs (6 minutes being used in some cases), very high intensities were observed in the rainfall data files. The rainfall files for HDYP01, which was used with a one-hour time-step, did not display the same effect.

8.8.1 **Volume prediction**

The total runoff volume predicted by the SCS methods should not vary with different rainfall patterns, since this is a function of the total rainfall volume, initial abstraction and curve number only. This expectation was fulfilled for the Chicago and SCS distributions, but a difference was observed for the HRU distribution. A possible reason for this discrepancy lies in the numerical techniques used in the computer program itself. This program utilised linear integration of the hydrograph to obtain the runoff volume and, since the HRU distribution gave rise to very spiky hydrographs, it is therefore likely that numerical inaccuracies gave rise to the discrepancy.

ILLUDAS and WITWAT displayed some sensitivity to the rainfall distribution, as could be expected due to the form of the infiltration algorithm used, but the trends were not consistent. HDYP01 was insensitive to rainfall pattern, as storm losses were computed independently.

8.8.2 Peak flow prediction

The methodology used to define average rainfall intensity for the Rational method, which was similar to the manner in which IDF relationships are normally derived, provides an interesting insight into the comparison of the synthetic distributions with the actual rainfall for the events selected. Provided that one can assume the critical catchment response times predicted by the different hydrological methods to be of the same order of magnitude, a comparison can be made between the intensities given by the synthetic distributions for the critical storm durations and the actual average intensities by comparing the peak flow predictions for the Rational method. This comparison shows that, for the rainfall events used, the Chicago and SCS distributions over-predicted the average intensities by a factor of 2 and 3 respectively, while the HRU distribution under-predicted by a factor of 1/3.

These relationships hold approximately for the SCS methods, while ILLUDAS and WITWAT, whose routing procedures are sensitive to high-intensity rainfall, showed even higher factors for the Chicago and SCS distributions. HDYP01 was expectedly the least sensitive to the SCS and HRU distributions.

8.8.3 Summary

Volumes were predictably unaffected by the synthetic distributions for the SCS methods and HDYP01, while ILLUDAS and WITWAT displayed some sensitivity.

All the models, excepting HDYP01, were markedly affected by the synthetic rainfall patterns in predicting peak flows. Using both the Chicago and SCS distributions, the predictions erred on the side of caution, but using the HRU distribution, the predictions were low from a design viewpoint.

9 SUMMARY AND CONCLUSIONS

The study was aimed at fulfilling two objectives:

- to evaluate the ability of commonly-used hydrological techniques to make flood estimations on small catchments

- to make recommendations on the monitoring of small catchments

To fulfil the first objective, seven hydrological models, selected from the empirical formula, unit hydrograph, time-area and kinematic techniques, were evaluated. A total of 102 observed events on 26 diverse catchments were abstracted from the records and used in the evaluation. Catchment parameters for each of the methods were obtained from maps and the relevant manuals. The bulk of the calculations were performed by computer with both the measured rainfall time distribution and synthetic distributions being used as input to the models. This was done to separate the effects of model limitations and parameter inaccuracies from the effects of simplified rainfall.

The analysis of the results was based on two measures of models performance, namely, volume and peak flow. The statistical approach used the ratio of predicted to observed values and standard statistical procedures were used to condense the results. Three catchment characteristics, viz land use, size of catchment and geographic region, were used to disaggregate the results of the analysis.

Scatter diagrams showing plots of predicted versus observed values were produced to provide a visual aid for interpretation of the ratio statistics. These diagrams were produced per land-use category as no interpretation could be drawn from the other two catchment characteristics.

The analysis of the results for different land-uses indicated that urban catchments could be adequately modelled by some of the models, but flood prediction on rural catchments was far less reliable. In general, the ability of the methods to predict volume of runoff was found to be better than their ability to determine peak flow rates.

Synthetic rainfall distributions were shown to have a minor effect on volume prediction, but a major effect on peak flow prediction. The commonly used Chicago and SCS distributions appear to be very conservative idealisations of actual rainfall from a design viewpoint, while the less-used HRU distribution appears to cause under-prediction. If the cost implications of over-design and the hazards of under-design are considered, these findings are clearly of importance.

The conclusions drawn regarding the performance of the models are considered valid for their use in real-event modelling. However, a word of caution must be given regarding the validity of the conclusions for the models as design tools. Design flood prediction is normally concerned with extreme events. While every attempt was made to obtain the largest suitable events from the available records, no guarantee can be given that the selected events were large from a design perspective. The significant number of zero runoff predictions made by two of the methods, the WASHMO and USA versions of the SCS method, may indicate that many of the selected events have a short return period. An attempt was made to address this aspect. Two further analyses were done, the first where all events with rainfall less than 20 mm were excised and the second, where events considered small from approximate recurrence interval calculation were removed prior to re-analysis. It is considered that these are not really satisfactory approaches for determining the relative magnitude of an event. The conclusions drawn from these two further analyses, however, did not change the overall outcome of the conclusions.

The second objective of the study was met during the catchment selection process. In attempting to complete the selection matrix (refer to Table 2) it became apparent that many of the catchments indentified in Phase I of this study displayed similar characteristics, while there was a paucity of monitored catchments displaying other characteristics. There is therefore a definite need for monitoring many more urban and agricultural catchments, as well as a need for monitoring afforested and veld catchments with sizes greater than ten square kilometers.

Finally, mention must be made of the quality of the documentation available for each model. In general, the documentation was found to be satisfactory, with the exception of the WASHMO version of the SCS method. No comprehensive manual on this approach was available although a description, users guides and listing of the WASH program are given in Ward, Haan and Tapp, 1979. For the remaining models, minor inadequacies of the documentation which were discovered were communicated to the relevant authors were possible.

10 RECOMMENDATIONS

Arising from the study, two categories of recommendations are considered appropriate, those dealing with the use of the models, and those covering further research.

10.1 Use of the methods

Making categorical recommendations on the use of the models is difficult due to the uncertainties inherent in the study. These uncertainties include:

- limited sample size
- possibility of undetected errors in observed data
- possibility of many of the storm events being small from a design perspective
- the methods were evaluated using a real-event modelling approach. In consequence, measured rainfall prior to each event was used to determine the antecedent moisture conditions. However, a designer would normally have to subjectively select a value for this parameter when necessary. This selected value may have a marked effect on the predictions when the methods are used as design tools
- flood prediction is influenced by the subjective decisions made by a designer in determining parameter values, the authors being no exception

Despite these uncertainties, which are common to most research of this nature, tentative recommendations will nonetheless be made. It should be noted that these recommendations are based on the performance of the methods with measured rainfall as input, ie their 'best chance' performance. The designer should bear in mind the influence of the synthetic rainfall patterns, which he is obliged to use, when judging the reliability of his predictions.

The recommendations are limited to the use of the methods for different land-uses only, since no clear trends for different catchment sizes and geographic regions could be discerned in this study.

The **tentative** recommendations are:

- **Urban catchments:**
  The sample size was small and recommendations should be viewed with caution.

  - **ILLUDAS** : Strongly recommended, with both volume and peak flow estimates likely to be reliable and consistent
  - **WITWAT** : Recommended for volume predictions, but under-prediction of peak flow is possible.

- **Agricultural catchments** :
  The sample size and bias due to catchment distribution make recommendations difficult.

  - **SCS methods** : Although these models gave on average over-predictions of volume and peak flow, they, and in particular SCS-SA, may be used for agricultural catchments in the absence of more reliable catchment data.
  - **WITWAT** : This model gave on average reasonable predictions of volume but high peak flow predictions. WITWAT, however, lacks sufficient parameter guidelines for these catchments.
  - **HDYP01** : Recommended for larger catchments, with estimates being likely to cause slight over-design.

- **Afforested catchments** :
  - **SCS - WASHMO and USA** : Although these methods gave reasonable average estimations in the study, with WASHMO being more reliable for peak flow estimates, this was due to a balancing of zero runoff predictions and over-predictions. Since

zero runoff is unlikely to be encountered in design, no clear recommendations on their use as design methods can be made, except that variations in prediction are possible

- **SCS - SA :** May be used, but volume estimations are variable and peak flow estimations are likely to be high.
- **HDYP01 :** Recommended for larger catchments, estimates likely to cause slight over-design.

- **Veld Catchments :**
  - **SCS-WASHMO and USA :** Similar behaviour to that on agricultural catchments was observed in this study, with a reasonable average being caused by a balancing of predictions. No clear recommendations can therefore be made, except that variations in prediction are possible.
  - **SCS-SA :** May be used for volume and peak flow estimation, with slight over-prediction being likely.
  - **WITWAT :** Recommended, as this study indicated reasonable predictions for both volume and peak flow.
  - **HDYP01 :** Recommended for larger catchments, the study having indicated slightly high predictions.

10.2 Further Research

While this study has been able to draw conclusions and make tentative recommendations on the use of the methods evaluated, further research would be desirable both to enhance this study and to provide designers with improved guidance on parameter estimation.

The following avenues of research are therefore recommended:

- confidence in this study would be improved by testing the methods with more storm events per selected catchment. This would also reduce the effects of any errors in observed data which may be present

- since many of the catchments presently monitored have similar characteristics, the setting up of more monitoring programmes on catchments with different characteristics is considered warranted. Monitoring of more urban and agricultural catchments would be a first priority

- although this study has indicated that, in general, the models do not perform adequately with uncalibrated parameters, the method developers have shown that they do work adequately with calibrated parameters. A logical follow-on to this study would therefore be to provide improved parameter estimation guidelines by calibrating the catchment parameters for each method. Since most of the required data is at hand, this research could be undertaken cost-effectively

- further research into realistic synthetic rainfall distributions is clearly warranted because designers will use synthetic rainfall distributions for design flow estimation. The study shows that extreme over predictions are possible with some of these distributions.

At the beginning of this project a third phase, covering the preparation of a design manual, was envisaged. This phase evidently cannot be undertaken yet. However, if the third recommendation above is implemented, preferably in conjunction with the recommendations to improve the data base, a manual could thereafter be prepared in collaboration with the model developers. Such a manual would clearly be of benefit. Until such time as a manual is prepared, however, it is hoped that this report will be of use in giving guidance to designers and in indicating to model developers the areas requiring improvement.

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CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
HBS01	A	1983	12	16	691	40	16.8	63	1	16	691	4.619	179	8506
	B	1983	12	30	752	10	5.1	37	1	30	752	1.024	244	1008
	C	1983	12	30	1156	15	5.6	31	1	30	1156	2.502	9	1913
	D	1984	1	1	296	31	21.6	105	1	1	296	4.424	14	6661
MPS01	A	1985	1	21	763	65	8.3	33	3	21	763	4.347	100	53329
	B	1983	3	7	990	0	4.3	21	5	7	975	1.293	25	3925
	C	1983	1	19	1040	32	6.0	51	5	19	1105	1.156	10	6897

TABLE A.1 : SELECTED EVENT SUMMARY

MONITORING ORGANIZATION : UNIVERSITY OF THE WITWATERSRAND

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
PINE1	A	1981	4	25	1210	2	13.1	43	1	25	1210	1.665	36	1166
	B	1979	2	13	1106	5	16.5	125	1	13	1106	1.192	20	1258
	C	1981	4	29	1202	23	9.4	43	1	29	1202	1.105	24	725
	D	1979	11	4	1101	0	5.4	23	1	4	1101	.931	11	411

TABLE A.2 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : COUNCIL FOR SCIENTIFIC AND IND. RESEARCH

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
CCCR03	A	1983	9	3	180	32	40.5	378	1	3	360	5.556	240	100698
	B	1981	7	19	555	35	45.0	303	1	19	720	7.292	240	116815
	C	1981	7	10	900	23	28.5	683	1	10	1080	6.023	180	95197
	D	1979	5	29	870	82	59.6	573	3	29	1020	8.802	150	175470
CCCR05	A	1981	12	20	105	0	14.0	153	1	20	120	9.804	90	80604
	B	1981	1	25	840	20	40.5	498	1	25	1020	10.056	120	181554
	C	1980	2	10	405	3	22.9	498	2	10	540	4.588	420	57348
	D	1979	10	19	1365	11	10.5	258	1	19	1380	9.780	120	83088

TABLE A.3 : SELECTED EVENT SUMMARY

MONITORING ORGANIZATION : CAPE TOWN CITY COUNCIL

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
101	A	1981	1	31	1375	7	102.0	218	1	31	1380	.611	60	3779
	B	1981	2	18	1310	25	53.0	108	1	18	1320	.048	27	162
	C	1983	1	14	1350	48	34.5	266	1	14	1350	.006	180	70
	D	1984	1	7	1260	0	34.5	51	1	7	1260	.006	37	59
102	A	1981	1	31	1375	7	102.0	218	1	31	1380	.611	71	2963
	B	1981	2	18	1310	25	53.0	108	1	18	1320	.069	35	194
	C	1983	1	14	1350	48	34.5	266	1	14	1350	.005	183	30
	D	1984	1	7	1260	0	34.5	51	1	7	1260	.016	20	199
103	A	1981	1	31	1375	7	102.0	218	1	31	1380	.835	58	2384
	B	1981	2	18	1310	25	53.0	108	1	18	1320	.981	24	1610
	C	1983	1	14	1350	48	34.5	266	1	14	1350	.009	195	38
	D	1984	1	7	1260	0	34.5	51	1	7	1260	.104	10	234
104	A	1981	1	31	1375	7	102.0	218	1	31	1380	1.177	63	4284
	B	1981	2	18	1310	25	53.0	108	1	18	1320	.994	30	2587
	C	1983	1	14	1350	48	34.5	266	1	14	1350	.069	190	535
	D	1984	1	7	1260	0	34.5	51	1	7	1260	.148	30	739

TABLE A.4 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : SOUTH AFRICAN SUGAR ASSOCIATION

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
C8M24	A	1981	12	22	895	14	25.5	38	1	22	895	4.398	60	23170
	B	1981	2	11	20	46	27.4	348	1	11	84	2.257	126	32847
	C	1981	12	30	970	0	27.1	273	1	30	996	2.024	90	15398
	D	1981	2	9	1335	38	17.4	88	1	9	1356	1.700	84	15298
C8M25	A	1981	2	5	1085	0	17.9	148	4	5	1085	11.854	150	114573
	B	1981	2	10	1420	19	32.3	403	3	11	66	21.228	288	475896
	C	1981	2	14	990	43	11.5	103	3	14	990	23.685	295	316673
	D	1981	12	30	945	0	30.8	283	6	30	948	5.243	300	112297

TABLE A.5 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : HYDROLOGICAL RESEARCH INSTITUTE

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL DAY	RAINFALL START TIME min.	RAINFALL ANTECEDENT RAIN mm.	RAINFALL DEPTH OF RAIN mm.	RAINFALL DURATION min.	RAINFALL NO. OF GAUGES	RUNOFF DAY	RUNOFF START TIME min.	RUNOFF PEAK FLOW cu.m/sec	RUNOFF TIME TO PEAK min.	RUNOFF VOLUME cu.m.
G2M02	A	1967	6	9	840	123	88.0	1200	1	9	869	.432	1002	15764
	B	1974	8	21	60	83	81.0	1200	1	21	53	.356	912	16917
	C	1977	4	19	600	13	86.0	483	1	19	678	.321	255	4642
	D	1978	4	7	600	29	36.7	303	2	7	610	.264	210	2001
G2M03	A	1977	7	11	660	41	79.9	1083	3	11	704	.091	562	3696
	B	1977	4	19	440	16	39.0	598	3	19	592	.091	252	1252
	C	1976	9	25	1020	2	97.9	1083	3	25	1012	.048	801	2036
	D	1964	6	5	1260	34	15.9	483	2	5	1301	.051	110	275
G2M06	A	1963	7	21	900	15	103.6	903	1	21	878	.028	873	607
	B	1977	7	11	720	27	95.0	963	1	11	731	.022	570	762
	C	1962	8	26	240	36	46.3	963	1	26	246	.023	297	427
	D	1962	6	24	1140	91	62.7	783	1	24	1104	.011	757	274
G2M07	A	1963	7	24	1080	107	38.6	903	1	24	1111	2.357	336	49048
	B	1967	10	6	1020	34	36.6	423	1	6	1091	2.266	330	38820
	C	1977	7	8	780	82	29.5	603	1	8	792	1.617	303	30950
	D	1977	5	15	480	126	8.5	423	1	15	608	1.310	254	17292
V1M21	A	1969	2	21	1050	7	49.1	543	2	21	1050	.026	450	501
	B	1969	3	27	840	35	25.8	523	2	27	840	.068	210	1674
	C	1969	12	19	1140	18	22.3	33	2	19	1140	.039	90	286
	D	1971	1	7	720	59	21.5	363	2	7	720	.035	60	266
X2M39	A	1975	11	14	1140	10	29.3	393	2	14	1200	.024	300	428
	B	1976	2	1	1350	241	47.4	780	1	1	1350	.752	345	14285
	C	1977	1	24	60	9	26.4	273	1	24	60	.064	190	1187
	D	1978	12	31	1080	11	19.3	93	2	31	1140	.054	210	639
X2M42	A	1977	1	24	0	14	35.4	243	2	24	0	.059	60	493
	B	1978	11	12	1050	17	51.5	753	3	12	1050	.094	330	1953
	C	1980	11	20	780	16	64.9	303	2	20	780	.262	150	3637

TABLE A.6 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : DEPARTMENT OF FORESTRY

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
K4M03	A	1971	4	4	977	22	52.4	1000	1	4	960	28.955	1186	1277798
	B	1974	4	1	142	13	49.3	781	1	1	416	7.812	509	173874
	C	1972	2	5	1139	42	39.7	834	1	6	97	4.020	714	197237
	D	1970	2	15	712	31	63.9	1140	1	15	778	2.737	733	148867
Q9M21	A	1977	2	27	973	0	37.7	97	3	27	1038	.853	40	4284
	B	1977	2	28	923	38	28.5	432	3	28	1068	.839	9	7720
	C	1977	3	6	750	14	10.8	46	1	6	776	1.383	14	3850
	D	1977	5	7	1167	35	17.1	162	2	7	1250	1.217	101	14166

TABLE A.7 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : RHODES UNIVERSITY

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
W1M14	A	1981	12	7	890	0	60.3	74	1	7	898	1.669	84	12913
	B	1981	11	19	1370	7	58.2	284	1	19	1386	.522	120	7697
	C	1979	12	12	1120	32	38.3	286	1	12	1126	.430	179	5953
	D	1981	2	12	1381	28	29.2	382	1	12	1410	.272	177	6566
W1M15	A	1978	1	21	25	86	116.0	1071	2	21	96	52.322	601	921172
	B	1981	10	2	1355	24	41.1	364	3	3	20	25.673	98	206440
	C	1978	1	19	1186	0	81.8	317	2	19	1244	24.363	75	289861
	D	1977	11	9	987	4	40.6	73	3	9	976	18.021	84	133227
W1M16	A	1981	10	2	1375	22	46.4	1150	1	2	1375	4.322	166	52564
	B	1977	11	9	970	8	48.4	70	1	9	974	2.061	42	34475
	C	1978	1	19	1210	0	74.6	371	1	19	1222	1.657	270	46169
	D	1978	4	22	1108	18	75.1	973	1	22	1182	1.415	821	56014
W1M17	A	1977	2	7	80	196	49.7	495	1	7	86	4.141	199	20736
	B	1978	3	28	110	59	45.3	124	1	28	117	3.437	51	11797
	C	1977	11	9	960	8	49.4	112	1	9	963	1.956	47	7800
	D	1981	12	7	920	0	51.4	36	1	7	921	4.607	32	13911

TABLE A.8 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : UNIVERSITY OF ZULULAND

CATCHMENT	EVENT	YEAR	MONTH	RAINFALL						RUNOFF				
				DAY	START TIME min.	ANTECEDENT RAIN mm.	DEPTH OF RAIN mm.	DURATION min.	NO. OF GAUGES	DAY	START TIME min.	PEAK FLOW cu.m/sec	TIME TO PEAK min.	VOLUME cu.m.
2991M08	A	1983	11	27	1059	19	24.4	129	2	27	1134	16.776	10	74129
	B	1983	12	5	882	18	31.3	114	2	5	892	29.224	51	141453
	C	1983	12	31	936	37	1.5	27	2	31	1011	6.960	4	22706
	D	1984	3	21	960	6	33.3	120	4	21	1014	9.852	30	79422
2991M10	A	1979	1	24	1299	24	63.2	399	1	24	1342	28.413	271	86050
	B	1980	2	17	1071	36	16.1	54	1	17	1119	6.070	7	10216
	C	1983	1	10	951	13	8.1	102	2	10	1018	3.909	4	7883
	D	1983	1	11	1050	19	15.0	228	2	11	1082	6.592	34	20469

TABLE A.9 : SELECTED EVENT SUMMARY MONITORING ORGANIZATION : DEPARTMENT OF WATER AFFAIRS, S.W.A.

CATCHMENT - HBS01

M E T H O D	RAINFALL DISTR.	P E A K F L O W (cu.m/sec) A	B	C	D	V O L U M E (cu.m.) A	B	C	D
MEASURED		4.619	1.024	2.502	4.424	8506	1008	1913	6662
RATIONAL	CHICAGO	2.380	.860	1.010	2.700	-1	-1	-1	-1
	ACTUAL	2.030	.860	1.020	2.540	-1	-1	-1	-1
	SCS	2.760	.900	1.020	3.310	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	1.250	.000	.000	.240	2200	0	0	590
- SA VERSION		1.220	.010	.020	.690	3690	40	50	2460
- USA VERSION		.980	.000	.000	.200	2210	0	0	590
SCS - WASHMO	ACTUAL	1.460	.000	.000	.390	2200	0	0	590
- SA VERSION		1.290	.010	.020	.470	3690	40	60	2460
- USA VERSION		1.130	.000	.000	.300	2210	0	0	590
SCS - WASHMO	SCS	2.200	.000	.000	.420	2200	0	0	590
- SA VERSION		1.400	.010	.020	.850	3690	40	50	2460
- USA VERSION		1.340	.000	.000	.280	2210	0	0	590
ILLUDAS	CHICAGO	4.810	1.300	1.590	5.760	7321	1817	2085	9801
	ACTUAL	3.910	.930	1.930	5.150	7227	1840	2118	9853
	SCS	11.720	2.450	2.860	14.650	8303	1832	2106	10941
WITWAT	CHICAGO	3.593	.770	.956	4.060	7130	1470	1577	9362
	ACTUAL	3.204	.649	1.056	3.263	7032	1510	1670	9473
	SCS	4.775	1.150	1.378	5.602	7098	1507	1624	10876

CATCHMENT - MPS01

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		4.347	1.293	1.156	-1.000	53329	3926	6897	-1
RATIONAL	CHICAGO	4.220	2.180	3.050	-1.000	-1	-1	-1	-1
	ACTUAL	4.220	2.180	3.050	-1.000	-1	-1	-1	-1
	SCS	4.220	2.180	3.050	-1.000	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	1.400	.000	.000	-1.000	3900	0	0	-1
- SA VERSION		2.830	.001	.030	-1.000	11580	10	110	-1
- USA VERSION		1.180	.000	.000	-1.000	3910	0	0	-1
SCS - WASHMO	ACTUAL	1.490	.000	.000	-1.000	3900	0	0	-1
- SA VERSION		2.850	.001	.040	-1.000	11580	10	110	-1
- USA VERSION		1.210	.000	.000	-1.000	3910	0	0	-1
SCS - WASHMO	SCS	1.640	.000	.000	-1.000	3900	0	0	-1
- SA VERSION		2.890	.001	.030	-1.000	11580	10	110	-1
- USA VERSION		1.250	.000	.000	-1.000	3910	0	0	-1
ILLUDAS	CHICAGO	6.100	2.340	2.760	-1.000	11465	4730	6168	-1
	ACTUAL	7.100	2.550	2.810	-1.000	12816	4730	6168	-1
	SCS	11.950	2.830	4.020	-1.000	15654	4730	6168	-1
WITWAT	CHICAGO	2.791	1.161	1.457	-1.000	8796	3045	4305	-1
	ACTUAL	2.854	1.553	1.497	-1.000	9028	3957	4540	-1
	SCS	3.376	1.923	1.652	-1.000	9877	4291	4482	-1

CATCHMENT - PINE1

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		1.665	1.192	1.105	.931	1166	1259	726	411
RATIONAL	CHICAGO	.613	.519	.440	.340	-1	-1	-1	-1
	ACTUAL	.610	.722	.506	.383	-1	-1	-1	-1
	SCS	.839	.912	.602	.377	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.000	.001	.000	.000	0	10	0	0
- SA VERSION		.040	.050	.020	.001	140	240	50	10
- USA VERSION		.000	.001	.000	.000	0	10	0	0
SCS - WASHMO	ACTUAL	.000	.001	.000	.000	0	10	0	0
- SA VERSION		.050	.040	.020	.001	140	240	60	10
- USA VERSION		.000	.001	.000	.000	0	10	0	0
SCS - WASHMO	SCS	.000	.001	.000	.000	0	10	0	0
- SA VERSION		.040	.070	.020	.001	140	240	60	10
- USA VERSION		.000	.001	.000	.000	0	10	0	0
ILLUDAS	CHICAGO	.680	.630	.580	.490	1098	1415	770	380
	ACTUAL	.830	.760	.670	.610	1111	1423	771	460
	SCS	1.520	1.550	1.130	.660	1160	1486	813	397
WITWAT	CHICAGO	.079	.066	.054	.035	1092	1430	753	344
	ACTUAL	.120	.111	.077	.059	1137	1471	767	379
	SCS	.351	.387	.219	.086	1215	1701	826	384

CATCHMENT - CCCR03

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		5.556	7.292	6.023	8.802	100698	116815	95197	175470
RATIONAL	ACTUAL	17.780	24.820	24.440	20.560	-1	-1	-1	-1
	SCS	37.860	43.360	24.550	52.600	-1	-1	-1	-1
	HRU	22.270	28.330	10.950	25.440	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	3.180	4.490	.150	35.640	14680	25540	740	612580
- SA VERSION		8.530	11.810	4.350	36.750	91080	116140	39690	704310
- USA VERSION		3.680	5.350	.230	35.090	15030	25520	760	609690
SCS - WASHMO	SCS	1.940	3.600	.050	92.570	15690	26290	780	612670
- SA VERSION		11.360	14.830	4.420	82.690	92600	117060	39930	704580
- USA VERSION		1.980	3.830	.050	96.660	15630	26170	780	610700
SCS - WASHMO	HRU	1.260	2.300	.090	20.310	15540	26170	770	611670
- SA VERSION		5.000	7.500	1.310	24.770	92340	116880	39850	703850
- USA VERSION		1.410	2.620	.090	19.850	15450	25930	780	608900
HDYP01	ACTUAL	25.500	34.400	24.000	30.900	667000	740000	456000	980000
	SCS	39.200	44.600	26.700	57.100	665000	740000	455000	977000
	HRU	25.400	31.200	12.700	30.200	665000	742000	451000	984000

CATCHMENT - CCCR05

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		9.804	10.056	4.588	9.780	80605	181554	57349	83088
RATIONAL	ACTUAL	32.670	67.300	48.780	27.970	-1	-1	-1	-1
	SCS	32.670	86.470	48.900	28.000	-1	-1	-1	-1
	HRU	32.670	69.130	39.090	28.010	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	.000	4.980	.030	.000	0	49980	130	0
- SA VERSION		1.520	15.810	6.010	.430	14710	282350	65550	4830
- USA VERSION		.000	4.840	.020	.000	0	50070	130	0
SCS - WASHMO	SCS	.000	5.850	.020	.000	0	50050	130	0
- SA VERSION		1.440	21.930	5.250	.410	14730	282170	65590	4820
- USA VERSION		.000	4.630	.020	.000	0	50140	130	0
SCS - WASHMO	HRU	.000	3.120	.030	.000	0	50040	130	0
- SA VERSION		1.390	11.140	2.870	.410	14700	285830	65540	4820
- USA VERSION		.000	3.290	.020	.000	0	50130	130	0
HDYP01	ACTUAL	24.600	63.300	38.800	16.900	920000	2821000	1549000	671000
	SCS	25.300	75.900	42.200	18.500	918000	2811000	1558000	675000
	HRU	25.000	57.700	31.800	16.700	921000	2822000	1545000	668000

CATCHMENT - 101

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.611	.048	.006	.006	3779	162	70	60
RATIONAL	CHICAGO	1.159	.753	.368	.640	-1	-1	-1	-1
	ACTUAL	.860	.805	.281	.662	-1	-1	-1	-1
	SCS	2.204	1.353	.709	1.075	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.900	.303	.259	.159	2320	760	750	300
- SA VERSION		.793	.366	.243	.237	2580	990	850	480
- USA VERSION		1.185	.447	.358	.224	2370	780	770	310
SCS - WASHMO	ACTUAL	.947	.430	.239	.259	2330	760	750	300
- SA VERSION		.783	.417	.195	.277	2590	990	850	480
- USA VERSION		1.094	.507	.333	.356	2380	780	770	310
SCS - WASHMO	SCS	2.838	.835	.875	.399	2320	760	750	300
- SA VERSION		1.212	.532	.379	.306	2590	990	850	480
- USA VERSION		3.362	1.139	1.036	.457	2370	780	770	310
ILLUDAS	CHICAGO	1.870	1.210	.590	.150	2740	1626	666	58
	ACTUAL	1.360	4.280	.430	.500	2733	3223	659	214
	SCS	4.460	2.810	1.370	1.040	2774	1626	695	372
WITWAT	CHICAGO	1.522	.928	.560	.104	2457	1470	1242	61
	ACTUAL	1.295	1.118	.112	.225	2504	1509	415	122
	SCS	5.554	2.269	.285	1.154	2613	1534	280	349

CATCHMENT - 102

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.611	.069	.005	.016	2963	194	31	199
RATIONAL	CHICAGO	.995	.653	.320	.562	-1	-1	-1	-1
	ACTUAL	.809	.748	.251	.631	-1	-1	-1	-1
	SCS	1.692	1.052	.545	.821	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.728	.263	.220	.134	2320	760	750	300
- SA VERSION		.754	.347	.231	.225	2580	990	850	480
- USA VERSION		1.093	.406	.321	.209	2330	770	750	310
SCS - WASHMO	ACTUAL	.768	.327	.206	.195	2330	760	750	300
- SA VERSION		.760	.395	.184	.259	2590	990	850	480
- USA VERSION		1.013	.485	.306	.296	2340	770	760	310
SCS - WASHMO	SCS	1.695	.569	.523	.244	2320	760	750	300
- SA VERSION		1.126	.492	.352	.280	2590	990	850	480
- USA VERSION		2.597	.870	.801	.393	2330	770	750	310
ILLUDAS	CHICAGO	1.550	2.500	.490	.090	2740	3263	666	58
	ACTUAL	1.230	2.490	.380	.320	2733	3269	659	214
	SCS	2.820	2.500	.840	.570	2774	3263	695	372
WITWAT	CHICAGO	1.186	.753	.466	.060	2420	1432	1201	40
	ACTUAL	1.139	.848	.090	.148	2469	1469	397	87
	SCS	3.743	1.694	.210	.667	2532	1485	239	256

CATCHMENT - 103

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.835	.981	.009	.104	2385	1611	38	235
RATIONAL	CHICAGO	1.027	.674	.331	.580	-1	-1	-1	-1
	ACTUAL	.836	.772	.259	.652	-1	-1	-1	-1
	SCS	1.747	1.086	.562	.848	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.683	.232	.204	.119	2320	770	750	300
- SA VERSION		.751	.346	.230	.225	2580	990	850	480
- USA VERSION		1.109	.410	.330	.212	2330	770	760	310
SCS - WASHMO	ACTUAL	.742	.319	.188	.178	2330	770	750	300
- SA VERSION		.758	.392	.183	.257	2590	990	850	480
- USA VERSION		1.021	.488	.309	.296	2340	770	760	310
SCS - WASHMO	SCS	1.784	.533	.551	.269	2320	770	750	300
- SA VERSION		1.118	.489	.349	.278	2590	990	850	480
- USA VERSION		2.641	.874	.814	.408	2340	770	760	310
ILLUDAS	CHICAGO	1.610	2.750	.500	.100	2740	3273	666	58
	ACTUAL	1.220	2.740	.390	.360	2733	3279	659	214
	SCS	3.040	2.740	.900	.620	2774	3273	695	372
WITWAT	CHICAGO	1.213	.784	.475	.066	2426	1439	1208	43
	ACTUAL	1.166	.889	.093	.161	2474	1476	401	93
	SCS	4.003	1.787	.222	.729	2544	1493	246	270

CATCHMENT - 104

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		1.177	.994	.069	.148	4285	2588	536	739
RATIONAL	CHICAGO	1.364	.895	.439	.770	-1	-1	-1	-1
	ACTUAL	1.110	1.025	.344	.866	-1	-1	-1	-1
	SCS	2.320	1.442	.747	1.126	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.789	.251	.222	.122	2590	780	790	280
- SA VERSION		.822	.364	.242	.231	2980	1090	940	520
- USA VERSION		1.160	.381	.323	.183	2600	780	790	280
SCS - WASHMO	ACTUAL	.872	.334	.225	.179	2600	780	790	280
- SA VERSION		.862	.409	.199	.260	2990	1090	940	520
- USA VERSION		1.141	.496	.329	.271	2610	780	800	280
SCS - WASHMO	SCS	1.892	.569	.545	.202	2590	780	790	280
- SA VERSION		1.205	.502	.361	.278	2980	1090	940	520
- USA VERSION		2.796	.849	.807	.306	2600	780	790	280
ILLUDAS	CHICAGO	1.500	2.390	.480	.080	2740	3344	666	58
	ACTUAL	1.230	2.390	.370	.300	2733	3350	659	214
	SCS	2.640	2.390	.790	.520	2774	3344	695	372
WITWAT	CHICAGO	1.247	.914	.496	.009	2352	1661	1108	4
	ACTUAL	1.273	1.033	.070	.027	2462	1716	192	8
	SCS	4.250	2.073	.097	.722	2527	1732	58	224

CATCHMENT - C8M24

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		4.398	2.257	2.024	1.700	23170	32848	15398	15298
RATIONAL	CHICAGO	11.210	10.120	10.400	7.790	-1	-1	-1	-1
	ACTUAL	11.440	10.540	10.280	7.810	-1	-1	-1	-1
	SCS	11.280	9.350	9.830	7.790	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.000	1.450	.001	.240	0	21370	20	2380
- SA VERSION		2.350	6.590	2.300	3.160	15810	56700	19580	21860
- USA VERSION		.000	2.430	.001	.390	0	21220	20	2370
SCS - WASHMO	ACTUAL	.000	1.240	.001	.230	0	21380	20	2430
- SA VERSION		2.480	6.100	1.760	3.130	16690	56720	19570	21990
- USA VERSION		.000	2.060	.001	.360	0	21230	20	2410
SCS - WASHMO	SCS	.000	1.440	.001	.240	0	21390	20	2380
- SA VERSION		2.390	6.560	2.330	3.180	16080	56730	19580	21850
- USA VERSION		.000	2.400	.001	.390	0	21230	20	2360
ILLUDAS	CHICAGO	16.790	18.010	.000	9.680	34245	39728	0	21901
	ACTUAL	27.340	20.680	.000	15.530	59211	48075	0	32194
	SCS	30.650	19.070	.000	12.950	67856	44313	0	29801

CATCHMENT - C8M25

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		11.854	21.228	23.685	5.243	114573	475896	316673	112297
RATIONAL	ACTUAL	30.460	81.130	19.570	50.850	-1	-1	-1	-1
	SCS	30.400	48.850	19.520	50.900	-1	-1	-1	-1
	HRU	30.420	47.260	19.530	51.040	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	.000	.030	.000	.001	0	1230	0	140
- SA VERSION		2.830	10.320	4.150	10.180	50580	273800	66510	237980
- USA VERSION		.000	.070	.000	.010	0	1210	0	140
SCS - WASHMO	SCS	.000	.030	.000	.001	0	1200	0	130
- SA VERSION		2.960	12.010	4.220	11.720	48840	269790	64410	234970
- USA VERSION		.000	.080	.000	.010	0	1170	0	130
SCS - WASHMO	HRU	.000	.030	.000	.004	0	1220	0	140
- SA VERSION		2.820	8.630	4.040	9.695	49040	271060	64890	236850
- USA VERSION		.000	.080	.000	.010	0	1190	0	130
HDYP01	ACTUAL	13.700	32.100	5.000	28.500	191000	453000	71000	430000
	SCS	13.700	32.800	5.100	31.000	191000	457000	71000	432000
	HRU	13.600	32.600	5.400	31.000	190000	455000	75000	433000

CATCHMENT - G2M02

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.432	.356	.321	.264	15764	16917	4642	2001
RATIONAL	CHICAGO	20.676	19.032	26.126	12.743	-1	-1	-1	-1
	ACTUAL	2.680	4.020	13.400	3.404	-1	-1	-1	-1
	SCS	62.457	57.490	68.940	31.376	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	3.470	2.960	.110	.000	81960	70990	1970	0
- SA VERSION		9.520	8.360	2.570	.260	96930	85650	24130	2430
- USA VERSION		11.550	9.840	.170	.000	81350	70470	1950	0
SCS - WASHMO	ACTUAL	3.130	2.290	.130	.000	82060	71080	1970	0
- SA VERSION		4.370	4.540	4.010	.450	97040	85740	24130	2430
- USA VERSION		4.280	5.410	.340	.000	81450	70560	1950	0
SCS - WASHMO	SCS	5.670	4.870	.100	.000	81990	71050	1970	0
- SA VERSION		16.970	14.970	4.320	.410	96960	85710	24130	2430
- USA VERSION		25.960	22.310	.200	.000	81390	70520	1950	0
ILLUDAS	CHICAGO	.000	.000	20.400	2.770	0	0	30700	3137
	ACTUAL	.000	.000	18.700	.000	0	0	50892	0
	SCS	.000	.000	73.420	25.930	0	0	29329	28671

CATCHMENT - G2M03

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.091	.091	.048	.051	3696	1253	2037	276
RATIONAL	CHICAGO	1.076	.619	1.319	.268	-1	-1	-1	-1
	ACTUAL	.655	.481	.479	.133	-1	-1	-1	-1
	SCS	1.906	1.010	2.335	.424	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.020	.000	.000	.000	680	0	0	0
- SA VERSION		.430	.001	.180	.000	3670	50	1980	0
- USA VERSION		.020	.000	.000	.000	670	0	0	0
SCS - WASHMO	ACTUAL	.030	.000	.000	.000	680	0	0	0
- SA VERSION		.180	.010	.140	.000	3670	60	1980	0
- USA VERSION		.060	.000	.000	.000	670	0	0	0
SCS - WASHMO	SCS	.030	.000	.000	.000	680	0	0	0
- SA VERSION		1.000	.010	.480	.000	3670	60	1980	0
- USA VERSION		.080	.000	.000	.000	670	0	0	0
ILLUDAS	CHICAGO	1.590	.000	.000	.000	1639	0	0	0
	ACTUAL	.000	.000	.000	.000	0	0	0	0
	SCS	9.500	.000	6.520	.560	8728	0	6328	360
WITWAT	CHICAGO	.001	.001	.001	.001	94	52	94	42
	ACTUAL	.001	.001	.001	.001	94	52	94	42
	SCS	1.863	1.085	1.957	.012	764	288	798	44

CATCHMENT - G2M06

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.028	.022	.023	.011	608	762	427	274
RATIONAL	CHICAGO	2.107	1.898	.925	1.326	-1	-1	-1	-1
	ACTUAL	.326	.533	.305	.267	-1	-1	-1	-1
	SCS	6.064	5.512	2.686	3.743	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.060	.040	.030	.640	1090	790	480	3510
- SA VERSION		.450	.370	.200	.770	2890	2440	1290	4140
- USA VERSION		.080	.040	.030	.950	1080	780	480	3490
SCS - WASHMO	ACTUAL	.090	.050	.040	.170	1090	790	480	3510
- SA VERSION		.150	.220	.130	.220	2890	2440	1290	4150
- USA VERSION		.090	.060	.040	.190	1080	780	480	3490
SCS - WASHMO	SCS	.340	.200	.150	2.190	1090	790	480	3510
- SA VERSION		1.140	.950	.500	1.760	2890	2440	1290	4150
- USA VERSION		.560	.340	.240	3.380	1080	780	480	3490
ILLUDAS	CHICAGO	3.020	2.950	.250	1.360	2261	2552	127	993
	ACTUAL	.000	.400	.000	.000	0	1407	0	0
	SCS	14.800	14.270	5.130	8.460	5589	5543	1942	3224
WITWAT	CHICAGO	.047	.076	.003	.003	363	410	345	280
	ACTUAL	.003	.003	.003	.003	323	345	326	280
	SCS	10.069	8.900	1.033	4.448	5952	5303	977	2780

CATCHMENT - G2M07

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		2.357	2.266	1.617	1.310	49049	38821	30951	17293
RATIONAL	CHICAGO	12.380	14.493	10.574	3.366	-1	-1	-1	-1
	ACTUAL	6.228	4.237	2.754	1.695	-1	-1	-1	-1
	SCS	27.803	29.274	22.468	6.796	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	1.050	.000	.470	.000	16710	0	7530	0
- SA VERSION		3.140	.210	2.070	.090	29750	2390	18020	950
- USA VERSION		1.770	.000	.690	.000	16600	0	7480	0
SCS - WASHMO	ACTUAL	1.050	.000	.720	.000	16710	0	7530	0
- SA VERSION		2.610	.310	1.530	.210	29750	2390	18020	950
- USA VERSION		1.760	.000	.980	.000	16600	0	7480	0
SCS - WASHMO	SCS	3.340	.000	1.330	.000	16710	0	7530	0
- SA VERSION		5.850	.400	3.670	.170	29740	2390	18020	950
- USA VERSION		6.560	.000	2.590	.000	16590	0	7480	0
ILLUDAS	CHICAGO	.000	.550	.000	.000	0	477	0	0
	ACTUAL	.000	.000	.000	.000	0	0	0	0
	SCS	32.880	44.590	20.990	.000	28654	31462	19255	0

CATCHMENT - V1M21

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.026	.068	.039	.035	502	1675	286	266
RATIONAL	CHICAGO	3.352	1.772	2.842	1.556	-1	-1	-1	-1
	ACTUAL	.716	.563	2.955	2.041	-1	-1	-1	-1
	SCS	5.357	2.823	2.935	2.410	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.030	.000	.000	.260	570	0	0	2560
- SA VERSION		.820	.150	.240	1.000	3590	760	500	3750
- USA VERSION		.060	.000	.000	.910	560	0	0	2550
SCS - WASHMO	ACTUAL	.060	.000	.000	.230	570	0	0	2560
- SA VERSION		.410	.120	.250	1.000	3590	760	500	3750
- USA VERSION		.160	.000	.000	1.020	560	0	0	2550
SCS - WASHMO	SCS	.060	.000	.000	.400	560	0	0	2560
- SA VERSION		1.510	.300	.250	1.690	3590	760	500	3750
- USA VERSION		.270	.000	.000	2.300	560	0	0	2550
ILLUDAS	CHICAGO	1.350	2.860	5.060	2.210	1435	4195	6413	3183
	ACTUAL	.000	.680	4.790	3.120	0	3085	6512	3987
	SCS	12.050	6.620	6.610	5.250	11978	6631	6602	5248
WITWAT	CHICAGO	7.113	3.666	3.659	2.083	16259	9453	4716	4612
	ACTUAL	.343	.611	3.454	2.321	3701	4486	4247	4142
	SCS	.028	.180	7.400	6.418	157	602	5317	5742

CATCHMENT - X2M39

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.024	.752	.064	.054	429	14286	1187	640
RATIONAL	CHICAGO	6.935	10.189	6.610	5.948	-1	-1	-1	-1
	ACTUAL	4.782	4.829	3.827	4.377	-1	-1	-1	-1
	SCS	8.101	11.926	7.676	6.512	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.000	3.130	.000	.000	0	47720	0	0
- SA VERSION		.470	11.160	.360	.150	3120	61100	2200	600
- USA VERSION		.000	10.780	.000	.000	0	47370	0	0
SCS - WASHMO	ACTUAL	.000	2.570	.000	.000	0	47720	0	0
- SA VERSION		.260	6.330	.290	.170	3120	61090	2200	600
- USA VERSION		.000	5.790	.000	.000	0	47370	0	0
SCS - WASHMO	SCS	.000	3.900	.000	.000	0	47700	0	0
- SA VERSION		.640	14.460	.470	.160	3120	61080	2200	600
- USA VERSION		.000	16.070	.000	.000	0	47350	0	0
ILLUDAS	CHICAGO	.000	17.100	.000	.630	0	37205	0	600
	ACTUAL	.000	3.870	.000	.630	0	18119	0	600
	SCS	8.500	26.890	7.240	3.840	15079	54372	12690	7806

CATCHMENT - X2M42

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.059	.094	.262	-1.000	493	1953	3637	-1
RATIONAL	CHICAGO	13.813	17.014	24.437	-1.000	-1	-1	-1	-1
	ACTUAL	11.330	2.013	7.818	-1.000	-1	-1	-1	-1
	SCS	22.568	28.090	40.137	-1.000	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.000	.001	.090	-1.000	0	20	1080	-1
- SA VERSION		.640	1.480	3.160	-1.000	3050	8250	14180	-1
- USA VERSION		.000	.001	.130	-1.000	0	20	1070	-1
SCS - WASHMO	ACTUAL	.000	.001	.110	-1.000	0	20	1080	-1
- SA VERSION		.900	.540	1.240	-1.000	3050	8260	14180	-1
- USA VERSION		.000	.001	.180	-1.000	0	20	1070	-1
SCS - WASHMO	SCS	.000	.001	.090	-1.000	0	20	1080	-1
- SA VERSION		.890	2.170	4.410	-1.000	3050	8250	14180	-1
- USA VERSION		.000	.001	.160	-1.000	0	20	1070	-1
ILLUDAS	CHICAGO	5.820	10.640	26.480	-1.000	5725	14825	34837	-1
	ACTUAL	7.550	.000	3.310	-1.000	7304	0	14994	-1
	SCS	22.840	26.930	57.020	-1.000	20706	29946	50572	-1

CATCHMENT - Q9M21

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		.853	.839	1.383	1.217	4284	7721	3851	14167
RATIONAL	ACTUAL	34.618	12.461	11.262	16.185	-1	-1	-1	-1
	SCS	29.875	12.613	11.164	11.094	-1	-1	-1	-1
	HRU	26.077	7.689	11.151	8.496	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	.000	.000	.000	.000	0	0	0	0
- SA VERSION		1.730	1.640	.000	.000	8820	20060	0	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
SCS - WASHMO	SCS	.000	.000	.000	.000	0	0	0	0
- SA VERSION		1.760	2.100	.000	.000	8690	20060	0	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
SCS - WASHMO	HRU	.000	.000	.000	.000	0	0	0	0
- SA VERSION		1.720	1.100	.000	.000	8700	20050	0	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
HDYP01	ACTUAL	9.400	5.800	1.300	3.400	43000	26400	6100	15600
	SCS	9.500	5.800	1.200	3.500	43000	26300	5400	3500
	HRU	9.500	5.700	1.200	3.500	43000	26500	5300	15800

CATCHMENT - W1M14

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		1.669	.522	.430	.272	12914	7697	5954	6567
RATIONAL	CHICAGO	9.840	20.130	4.020	2.820	-1	-1	-1	-1
	ACTUAL	8.880	5.810	2.200	2.180	-1	-1	-1	-1
	SCS	14.000	9.640	6.330	4.490	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.000	.000	.000	.000	0	0	0	0
- SA VERSION		.360	.180	.030	.000	1930	1750	210	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
SCS - WASHMO	ACTUAL	.000	.000	.000	.000	0	0	0	0
- SA VERSION		.370	.190	.020	.000	2000	1760	220	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
SCS - WASHMO	SCS	.000	.000	.000	.000	0	0	0	0
- SA VERSION		.360	.200	.030	.000	1950	1750	210	0
- USA VERSION		.000	.000	.000	.000	0	0	0	0
ILLUDAS	CHICAGO	.000	.000	1.140	.000	0	0	3015	0
	ACTUAL	6.040	.000	.000	.000	17038	0	0	0
	SCS	6.630	4.180	3.840	1.460	16455	10662	10044	3866

CATCHMENT - W1M15

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		52.322	25.673	24.363	18.021	921172	206440	289861	133227
RATIONAL	ACTUAL	48.815	32.308	75.391	64.142	-1	-1	-1	-1
	SCS	93.052	43.228	89.082	63.923	-1	-1	-1	-1
	HRU	36.894	24.946	54.063	63.800	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	48.480	.050	5.900	.030	1157359	520	105040	350
- SA VERSION		65.750	4.790	20.110	7.530	1211859	61310	265900	59510
- USA VERSION		70.720	.100	8.560	.070	1148728	510	104260	340
SCS - WASHMO	SCS	73.240	.050	7.210	.030	1157069	500	105940	310
- SA VERSION		97.530	5.940	27.740	7.550	1211609	61170	267180	59020
- USA VERSION		138.690	.090	14.020	.070	1148329	500	105160	300
SCS - WASHMO	HRU	22.020	.050	6.370	.030	1156759	500	105840	280
- SA VERSION		29.070	3.670	16.990	7.320	1211329	61170	267050	58750
- USA VERSION		28.010	.090	9.290	.060	1148000	500	105060	280
HDYP01	ACTUAL	36.900	12.300	40.700	13.500	321000	55700	185000	61200
	SCS	70.200	12.300	40.700	13.600	311000	56100	186000	61700
	HRU	34.800	12.400	34.700	13.600	318000	56200	185000	61900

CATCHMENT - W1M16

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		4.322	2.061	1.657	1.415	52565	34476	46170	56015
RATIONAL	CHICAGO	9.310	22.730	20.500	15.770	-1	-1	-1	-1
	ACTUAL	12.460	24.130	16.370	7.600	-1	-1	-1	-1
	SCS	11.100	23.370	23.700	18.730	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	.030	.180	.930	.480	750	1090	15010	15510
- SA VERSION		1.170	3.360	5.110	3.830	17660	19240	49280	50080
- USA VERSION		.030	.450	1.470	.740	740	1090	14900	15390
SCS - WASHMO	ACTUAL	.060	.170	1.150	1.140	750	1150	15120	15520
- SA VERSION		.820	3.390	4.170	3.460	17690	19480	49450	50100
- USA VERSION		.100	.400	1.650	2.000	750	1140	15010	15410
SCS - WASHMO	SCS	.030	.180	1.080	.680	740	1110	15020	15510
- SA VERSION		1.610	3.440	6.200	5.020	17650	19320	49290	50080
- USA VERSION		.030	.430	2.170	1.380	740	1100	14910	15390
ILLUDAS	CHICAGO	.000	.000	.000	9.310	0	0	0	15602
	ACTUAL	.960	.000	.000	.000	2329	0	0	0
	SCS	5.210	31.860	22.940	34.640	9060	37167	28081	46229

CATCHMENT - W1M17

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		4.141	3.437	1.956	4.607	20737	11797	7801	13912
RATIONAL	CHICAGO	4.840	6.750	7.580	12.300	-1	-1	-1	-1
	ACTUAL	5.040	6.380	9.330	13.010	-1	-1	-1	-1
	SCS	8.460	10.950	12.250	16.990	-1	-1	-1	-1
SCS - WASHMO	CHICAGO	1.410	1.830	.000	.000	12980	10840	0	0
- SA VERSION		1.860	2.410	.570	.760	16290	14030	3180	3530
- USA VERSION		2.550	3.320	.000	.000	12890	10750	0	0
SCS - WASHMO	ACTUAL	1.600	2.260	.000	.000	12990	10890	0	0
- SA VERSION		1.900	2.610	.620	.770	16290	14090	3200	3530
- USA VERSION		2.950	4.290	.000	.000	12890	10810	0	0
SCS - WASHMO	SCS	2.080	2.290	.000	.000	12980	10850	0	0
- SA VERSION		2.310	2.670	.610	.770	16290	14040	3180	3530
- USA VERSION		4.150	4.600	.000	.000	12890	10770	0	0
ILLUDAS	CHICAGO	1.920	5.830	.000	1.080	2046	6371	0	506
	ACTUAL	4.620	8.750	.000	10.490	5961	10846	0	8480
	SCS	8.810	13.130	8.090	7.380	7024	10829	6065	6567
WITWAT	CHICAGO	.813	6.920	.668	1.536	1100	10255	529	1026
	ACTUAL	1.366	9.371	2.240	21.270	1839	14423	2735	7597
	SCS	6.683	22.093	15.015	15.908	4037	11259	6727	9414

CATCHMENT - 2991M08

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		16.776	29.224	6.960	9.852	74130	141453	22706	79422
RATIONAL	ACTUAL	25.728	33.004	2.733	35.113	-1	-1	-1	-1
	SCS	25.729	33.004	2.733	35.115	-1	-1	-1	-1
	HRU	25.728	33.002	2.733	35.111	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	.310	1.100	.000	1.400	13950	47980	0	61120
- SA VERSION		10.080	20.470	.000	22.250	91950	154440	0	174760
- USA VERSION		1.220	4.630	.000	5.840	14020	48290	0	61430
SCS - WASHMO	SCS	.320	1.090	.000	1.390	13950	47970	0	61120
- SA VERSION		11.540	19.840	.000	22.300	91960	154440	0	174780
- USA VERSION		1.290	4.480	.000	5.660	14030	48290	0	61450
SCS - WASHMO	HRU	.320	1.090	.000	1.380	13940	47950	0	61090
- SA VERSION		9.560	16.750	.000	18.550	91950	154420	0	174740
- USA VERSION		1.300	4.400	.000	5.500	14020	48280	0	61420
HDYP01	ACTUAL	10.200	13.300	.460	18.500	64100	82900	3900	115700
	SCS	10.300	13.400	.460	13.200	64500	83800	3900	116800
	HRU	10.400	13.400	.460	18.500	64900	83900	3900	116100

CATCHMENT - 2991M10

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		28.413	6.070	3.909	6.592	86050	10217	7883	20470
RATIONAL	ACTUAL	82.724	37.816	19.023	33.125	-1	-1	-1	-1
	SCS	113.707	37.813	19.021	31.070	-1	-1	-1	-1
	HRU	96.042	37.813	19.023	29.459	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	36.370	5.590	.000	.000	687350	72000	0	0
- SA VERSION		75.590	11.810	.800	4.880	1000450	84200	3710	48750
- USA VERSION		62.360	3.640	.000	.000	629360	25450	0	0
SCS - WASHMO	SCS	38.240	5.510	.000	.000	687000	71730	0	0
- SA VERSION		97.270	11.710	.750	4.740	995380	78580	3820	41660
- USA VERSION		84.120	3.140	.000	.000	627490	24910	0	0
SCS - WASHMO	HRU	26.480	5.360	.000	.000	687730	71680	0	0
- SA VERSION		57.580	10.210	.640	4.050	999790	81110	3910	43650
- USA VERSION		39.300	3.220	.000	.000	632500	25090	0	0
HDYP01	ACTUAL	52.000	7.400	2.000	6.400	533000	52700	14200	45700
	SCS	74.900	7.400	1.800	6.700	536000	52700	13100	47700
	HRU	74.700	7.400	1.900	6.400	534000	52700	13900	45500

CATCHMENT - K4M03

METHOD	RAINFALL DISTR.	PEAK FLOW (cu.m/sec) A	B	C	D	VOLUME (cu.m.) A	B	C	D
MEASURED		28.955	7.812	4.020	2.737	1277794	173874	197237	148868
RATIONAL	ACTUAL	63.207	39.774	64.593	55.325	-1	-1	-1	-1
	SCS	83.015	86.016	67.498	96.196	-1	-1	-1	-1
	HRU	58.097	63.341	49.048	65.526	-1	-1	-1	-1
SCS - WASHMO	ACTUAL	.000	.000	.920	.070	0	0	60970	5070
- SA VERSION		12.390	9.120	12.270	10.570	284410	241650	452870	468360
- USA VERSION		.000	.000	3.830	.360	0	0	73750	6310
SCS - WASHMO	SCS	.000	.000	.910	.070	0	0	61050	5070
- SA VERSION		10.210	9.710	18.860	16.470	283910	241280	453090	468370
- USA VERSION		.000	.000	3.010	.420	0	0	73850	6310
SCS - WASHMO	HRU	.000	.000	.900	.070	0	0	61060	5070
- SA VERSION		6.520	7.040	11.370	9.140	284040	241300	453100	468350
- USA VERSION		.000	.000	2.920	.400	0	0	73850	6310
HDYP01	ACTUAL	11.400	7.800	8.900	18.300	511000	473000	339000	811000
	SCS	13.600	12.800	8.900	21.600	516000	486000	339000	820000
	HRU	12.900	12.500	8.700	19.900	507000	481000	335000	804000

APPENDIX C

STATISTICS AND SCATTER DIAGRAMS

ACTUAL RAINFALL DISTRIBUTION

METHOD	STATISTIC	LAND-USE				CATCHMENT SIZE			REGION				ALL
		URBAN	AGRIC	FOREST	VELD	0-1	1-10	10-100	H/VELD	NATAL	W.CAPE	SWA	
SCS - WASHMO	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.24	3.23	1.02	1.08	2.66	.58	.64	.22	2.28	1.00	2.04	1.41
	STD DEVIATION	.77	6.16	2.28	2.65	5.35	1.33	1.80	.70	5.12	2.47	3.18	3.71
	STD ERROR	1.08	6.55	2.28	2.65	5.60	1.40	1.84	1.04	5.28	2.47	3.35	3.74
SCS - SA VERSION	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.57	4.21	2.70	2.35	3.70	2.08	1.57	1.74	3.13	2.13	3.41	2.54
	STD DEVIATION	.92	6.87	3.32	3.32	6.18	2.22	2.32	2.06	5.94	2.91	3.93	4.36
	STD ERROR	1.02	7.58	3.73	3.58	6.74	2.47	2.39	2.18	6.31	3.12	4.61	4.62
SCS - USA VERSION	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.24	3.28	1.02	.93	2.69	.57	.50	.22	2.31	.99	1.39	1.37
	STD DEVIATION	.77	6.25	2.27	2.40	5.41	1.32	1.37	.69	5.19	2.46	2.37	3.70
	STD ERROR	1.08	6.66	2.27	2.40	5.67	1.39	1.46	1.04	5.36	2.46	2.40	3.72
ILLUDAS	NO OF CATCHMENTS	3	5	5	5	10	7	1	5	9	4	0	18
	NO OF EVENTS	11	20	20	19	40	27	3	18	36	16	0	70
	MEAN	1.08	5.24	2.70	1.19	3.78	1.47	.78	1.94	4.05	.80	.00	2.76
	STD DEVIATION	.37	7.11	6.02	3.36	6.59	3.42	.40	3.29	6.89	2.66	.00	5.54
	STD ERROR	.38	8.28	6.26	3.36	7.15	3.45	.46	3.42	7.54	2.67	.00	5.82
WITWAT	NO OF CATCHMENTS	3	4	2	2	10	0	1	2	7	2	0	11
	NO OF EVENTS	11	16	8	8	40	0	3	7	28	8	0	43
	MEAN	.96	3.38	5.09	.62	2.71	.00	.61	.92	3.60	.38	.00	2.57
	STD DEVIATION	.34	4.18	6.30	.34	4.20	.00	.34	.42	4.74	.35	.00	4.09
	STD ERROR	.35	4.81	7.51	.51	4.54	.00	.52	.43	5.41	.71	.00	4.38
HDYP01	NO OF CATCHMENTS	2	1	1	4	0	0	8	1	1	4	2	8
	NO OF EVENTS	8	4	4	16	0	0	32	4	4	16	8	32
	MEAN	10.67	1.67	2.57	2.27	.00	.00	4.33	1.67	.43	6.99	2.31	4.33
	STD DEVIATION	7.01	1.35	1.85	2.63	.00	.00	5.47	1.35	.14	6.52	2.06	5.47
	STD ERROR	11.95	1.50	2.43	2.92	.00	.00	6.40	1.50	.59	8.85	2.44	6.40

TABLE C.1 : VOLUME ANALYSIS (ACTUAL RAINFALL DISTRIBUTION)

METHOD	STATISTIC	LAND-USE				CATCHMENT SIZE			REGION				ALL
		URBAN	AGRIC	FOREST	VELD	0-1	1-10	10-100	H/VELD	NATAL	W.CAPE	SWA	
RATIONAL	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	2.42	15.03	28.62	13.60	15.25	27.62	6.10	28.69	14.44	10.47	3.21	15.39
	STD DEVIATION	2.54	24.62	42.53	31.99	23.53	50.99	7.54	56.49	23.44	10.13	1.95	31.53
	STD ERROR	2.91	28.33	50.71	34.38	27.51	57.52	9.10	62.91	27.02	13.87	2.95	34.66
SCS - WASHMO	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.34	7.62	1.12	.86	5.39	.78	.28	.24	4.87	1.38	.30	2.42
	STD DEVIATION	.90	13.63	2.27	2.60	11.18	1.84	.72	.71	11.13	3.11	.47	7.47
	STD ERROR	1.11	15.16	2.28	2.61	12.01	1.85	1.02	1.04	11.79	3.13	.84	7.61
SCS - SA VERSION	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.65	7.80	5.44	2.67	6.98	3.91	1.11	2.84	6.07	3.41	1.14	4.15
	STD DEVIATION	1.02	12.75	6.70	4.29	11.27	4.50	1.09	3.96	11.18	4.64	.94	7.87
	STD ERROR	1.08	14.45	8.04	4.61	12.76	5.36	1.10	4.37	12.28	5.23	.95	8.48
SCS - USA VERSION	NO OF CATCHMENTS	5	6	6	9	10	7	9	6	10	8	2	26
	NO OF EVENTS	19	24	24	35	40	27	35	22	40	32	8	102
	MEAN	.34	10.99	2.95	1.05	8.14	1.47	.36	.46	7.60	1.88	.45	3.71
	STD DEVIATION	.89	19.55	6.67	2.90	16.30	3.53	.78	1.60	16.32	4.17	.70	10.98
	STD ERROR	1.11	21.96	6.95	2.90	17.80	3.56	1.01	1.69	17.60	4.26	.89	11.31
ILLUDAS	NO OF CATCHMENTS	3	5	5	5	10	7	1	5	9	4	0	18
	NO OF EVENTS	11	20	20	19	40	27	3	18	36	16	0	70
	MEAN	1.10	23.34	15.03	8.68	17.36	9.04	2.01	10.65	18.79	4.78	.00	13.49
	STD DEVIATION	.61	30.63	33.30	28.51	31.97	25.90	.33	28.75	33.29	14.49	.00	29.40
	STD ERROR	.62	37.91	36.14	29.53	35.91	27.11	1.06	30.33	37.75	14.97	.00	31.95
WITWAT	NO OF CATCHMENTS	3	4	2	2	10	0	1	2	7	2	0	11
	NO OF EVENTS	11	16	8	8	40	0	3	7	28	8	0	43
	MEAN	.54	8.78	22.14	1.18	8.25	.00	1.05	.81	11.67	.09	.00	7.74
	STD DEVIATION	.42	10.45	32.74	1.54	17.88	.00	.28	.30	20.44	.09	.00	17.34
	STD ERROR	.63	13.03	38.97	1.56	19.29	.00	.29	.35	23.05	.92	.00	18.61
HDYP01	NO OF CATCHMENTS	2	1	1	4	0	0	8	1	1	4	2	8
	NO OF EVENTS	8	4	4	16	0	0	32	4	4	16	8	32
	MEAN	4.47	2.08	2.57	2.05	.00	.00	2.73	2.08	.90	4.23	.94	2.73
	STD DEVIATION	1.99	2.00	2.46	2.79	.00	.00	2.68	2.00	.46	2.89	.62	2.68
	STD ERROR	4.01	2.27	2.92	2.98	.00	.00	3.19	2.27	.47	4.34	.62	3.19

TABLE C.2 : PEAK FLOW ANALYSIS (ACTUAL RAINFALL DISTRIBUTION)

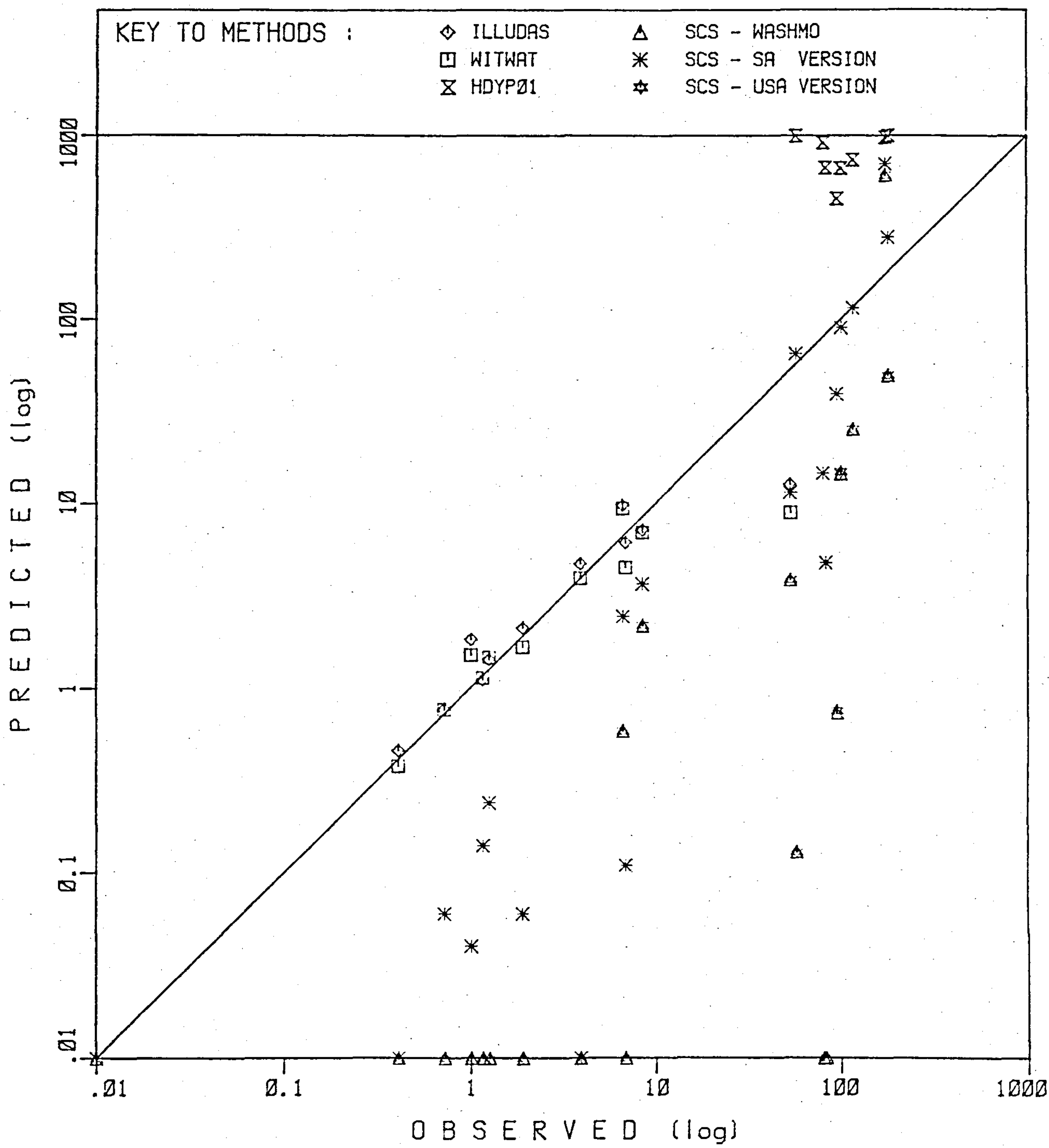

FIG. C 1 : VOLUME (cu.mx10^3) : URBAN

ALL EVENTS

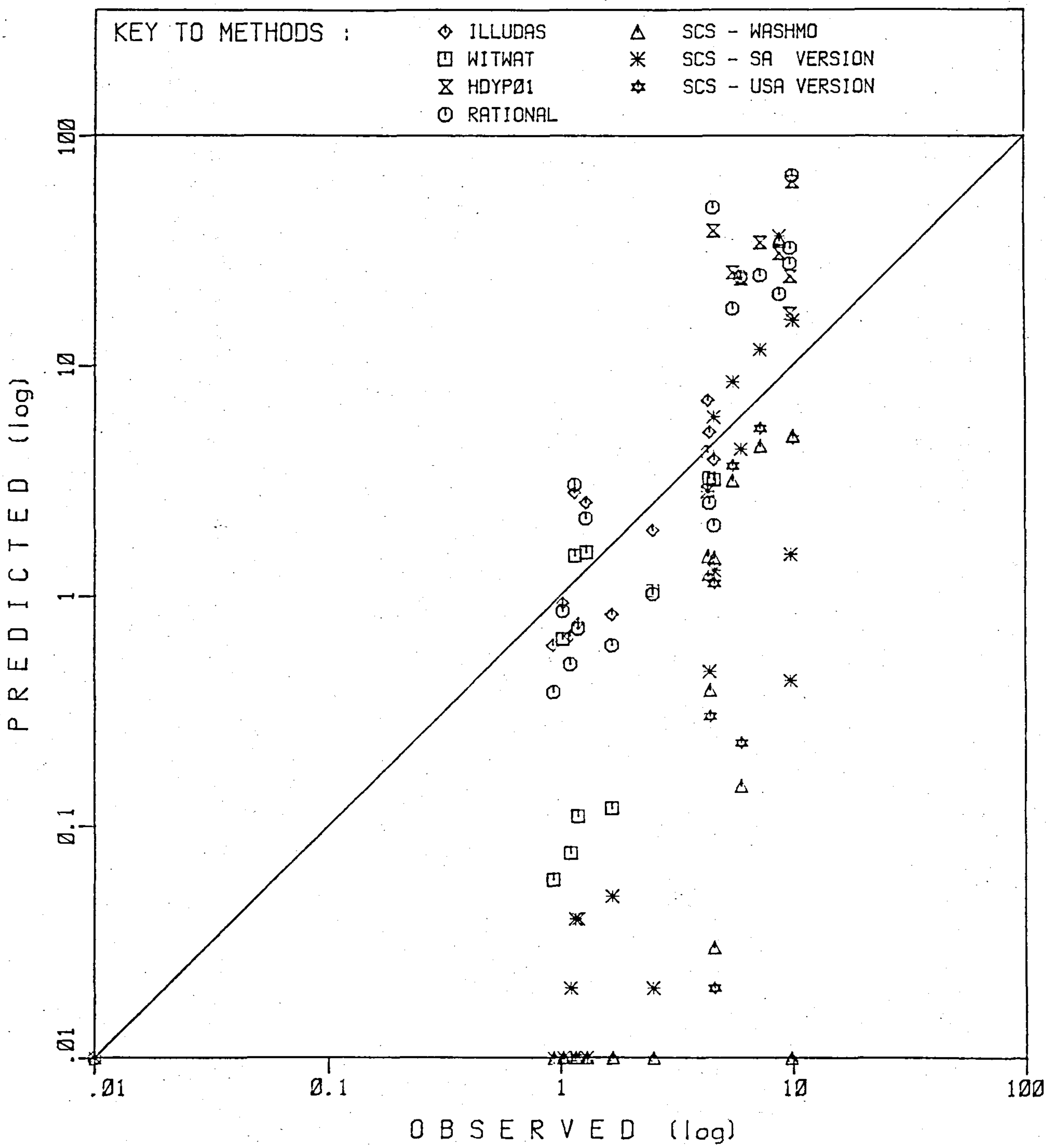

FIG. C 2 : PEAK FLOW (cu.m/s) : URBAN

ALL EVENTS

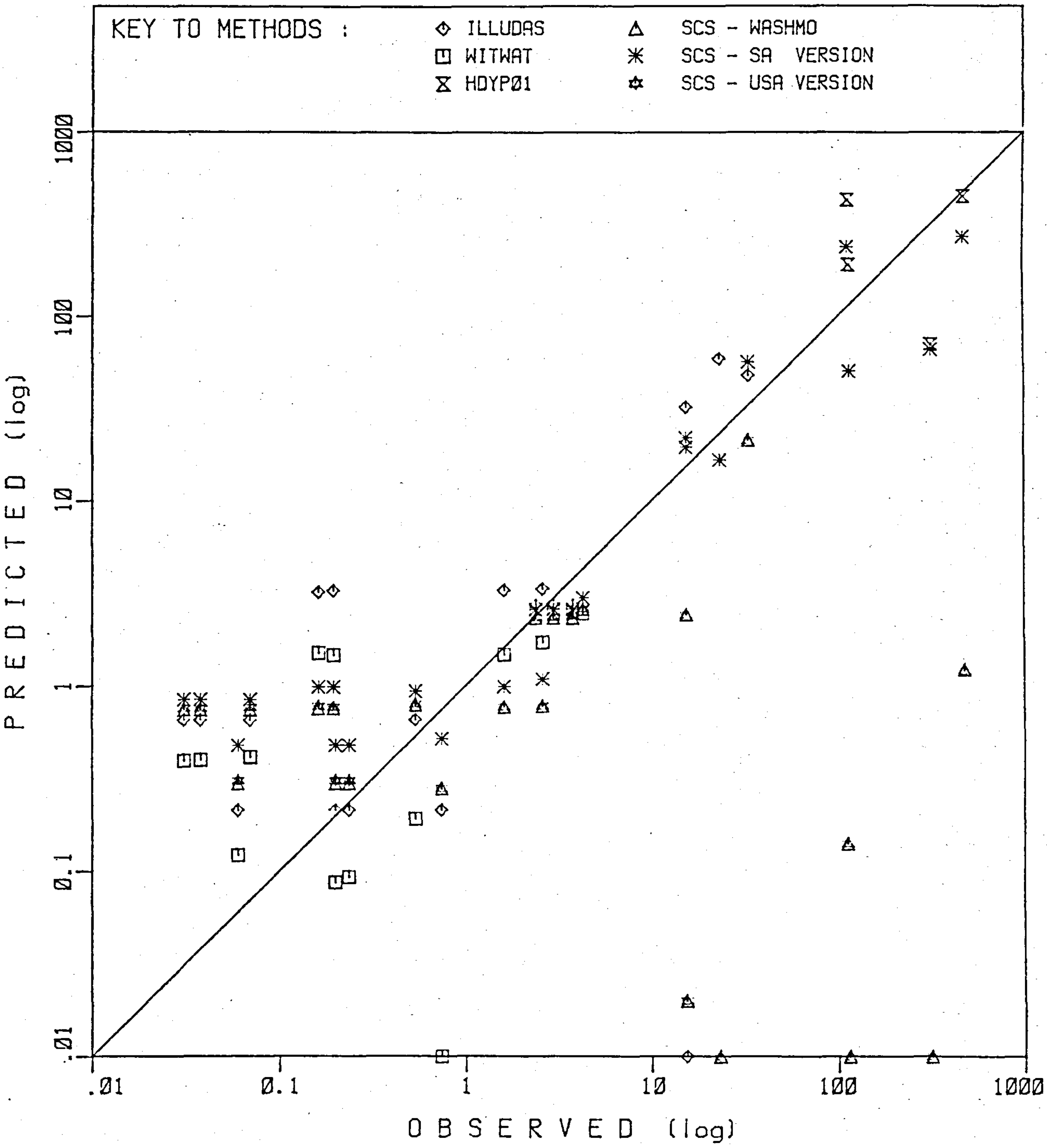

FIG. C 3 : VOLUME (cu.mx10^3) : AGRICULTURE

ALL EVENTS

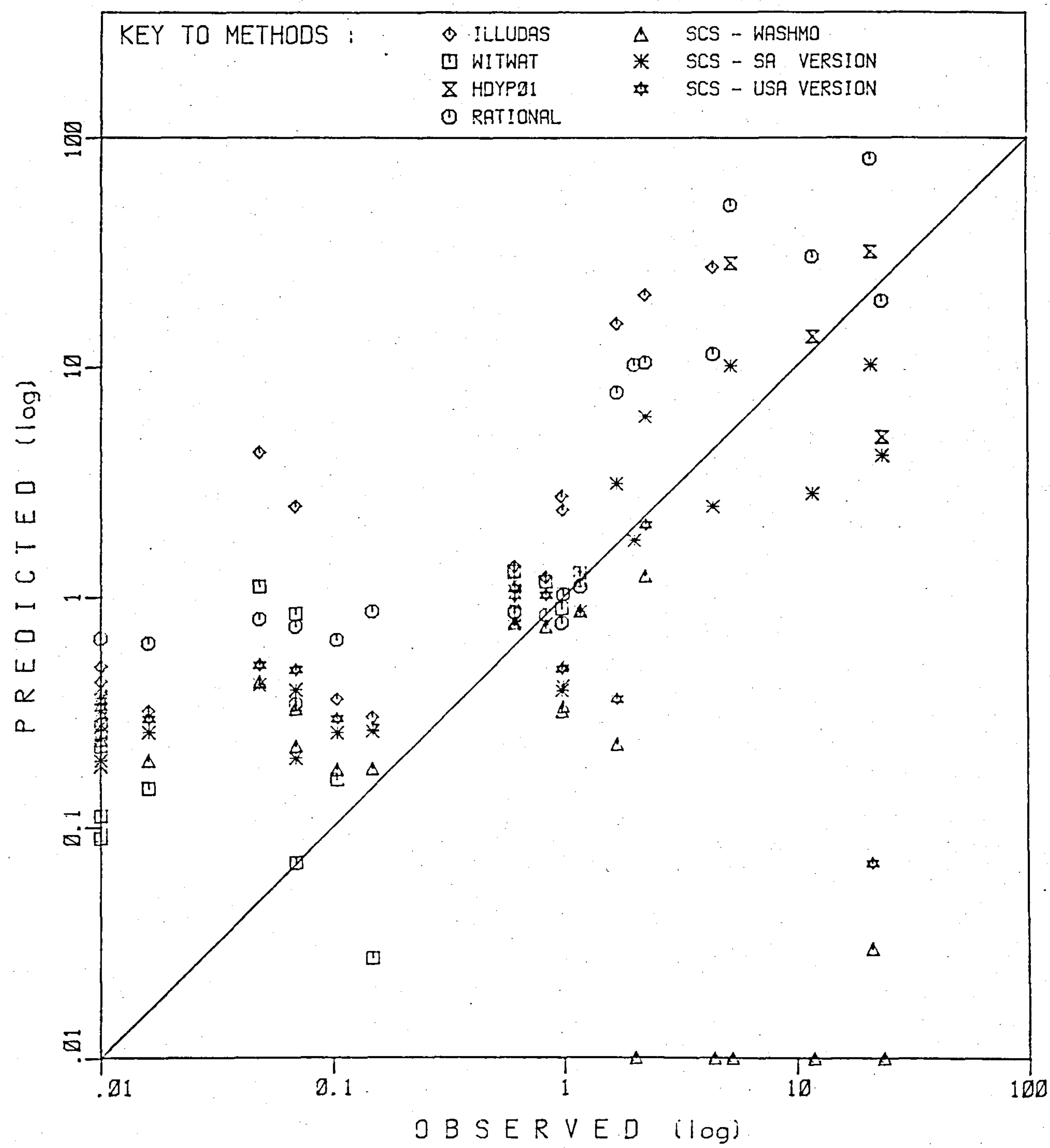

FIG. C 4 : PEAK FLOW (cu.m/s) : AGRICULTURE

ALL EVENTS

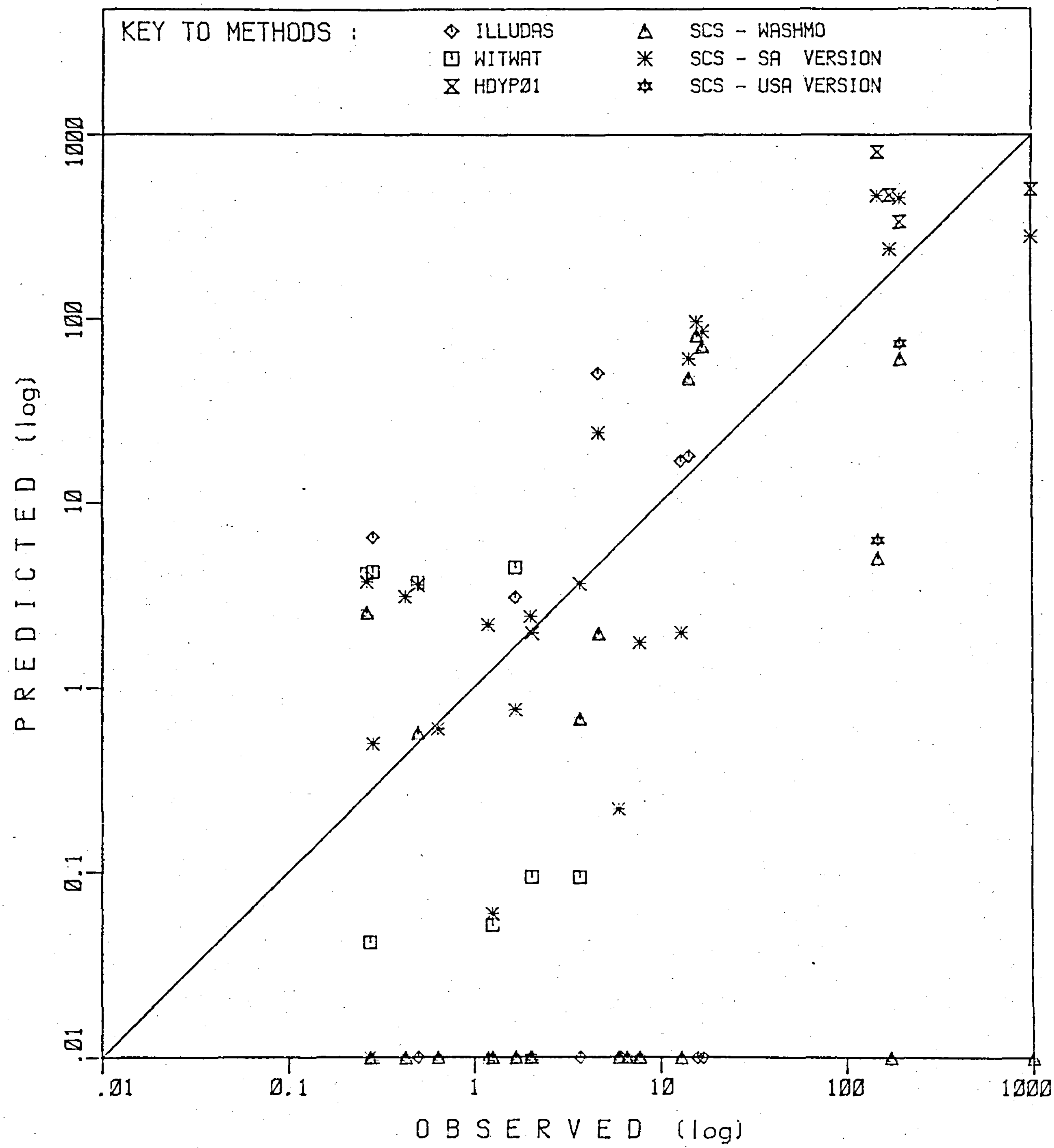

FIG. C 5 : VOLUME (cu.mx1Ø^3) : AFFORESTATION

ALL EVENTS

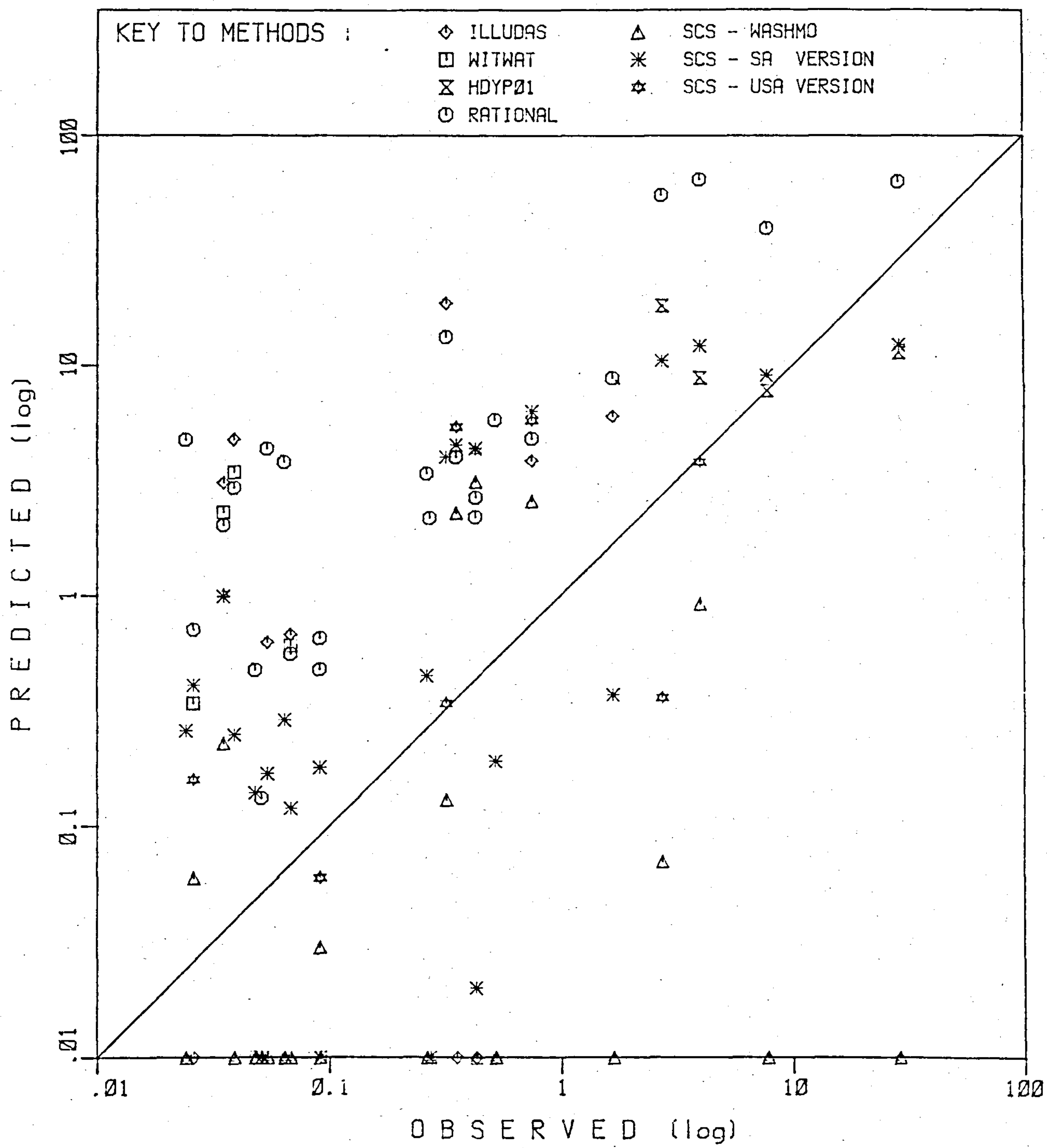

FIG. C 6 : PEAK FLOW (cu.m/s) : AFFORESTATION

ALL EVENTS

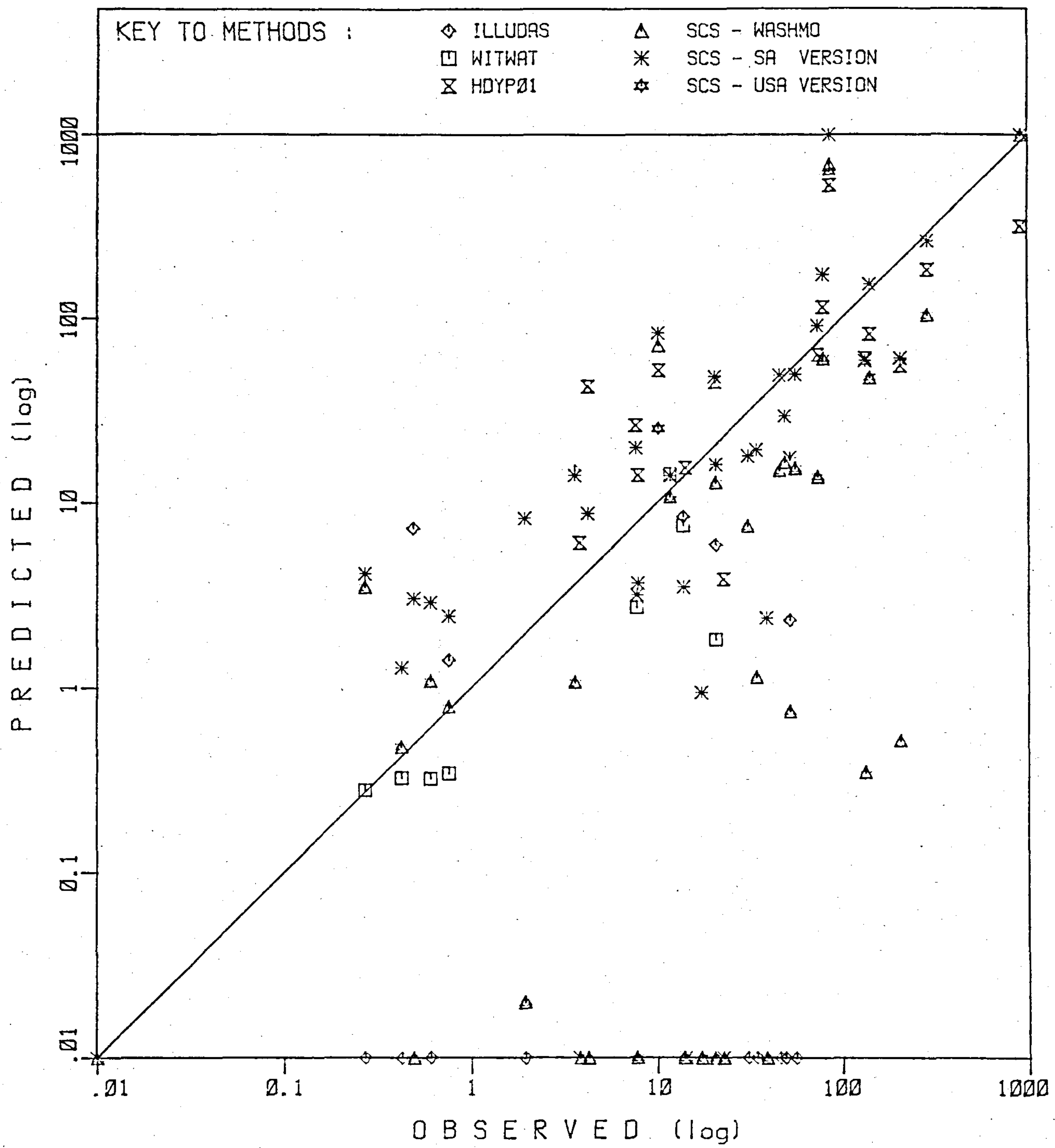

FIG. C 7 : VOLUME (cu.m×1Ø^3) : VELD

ALL EVENTS

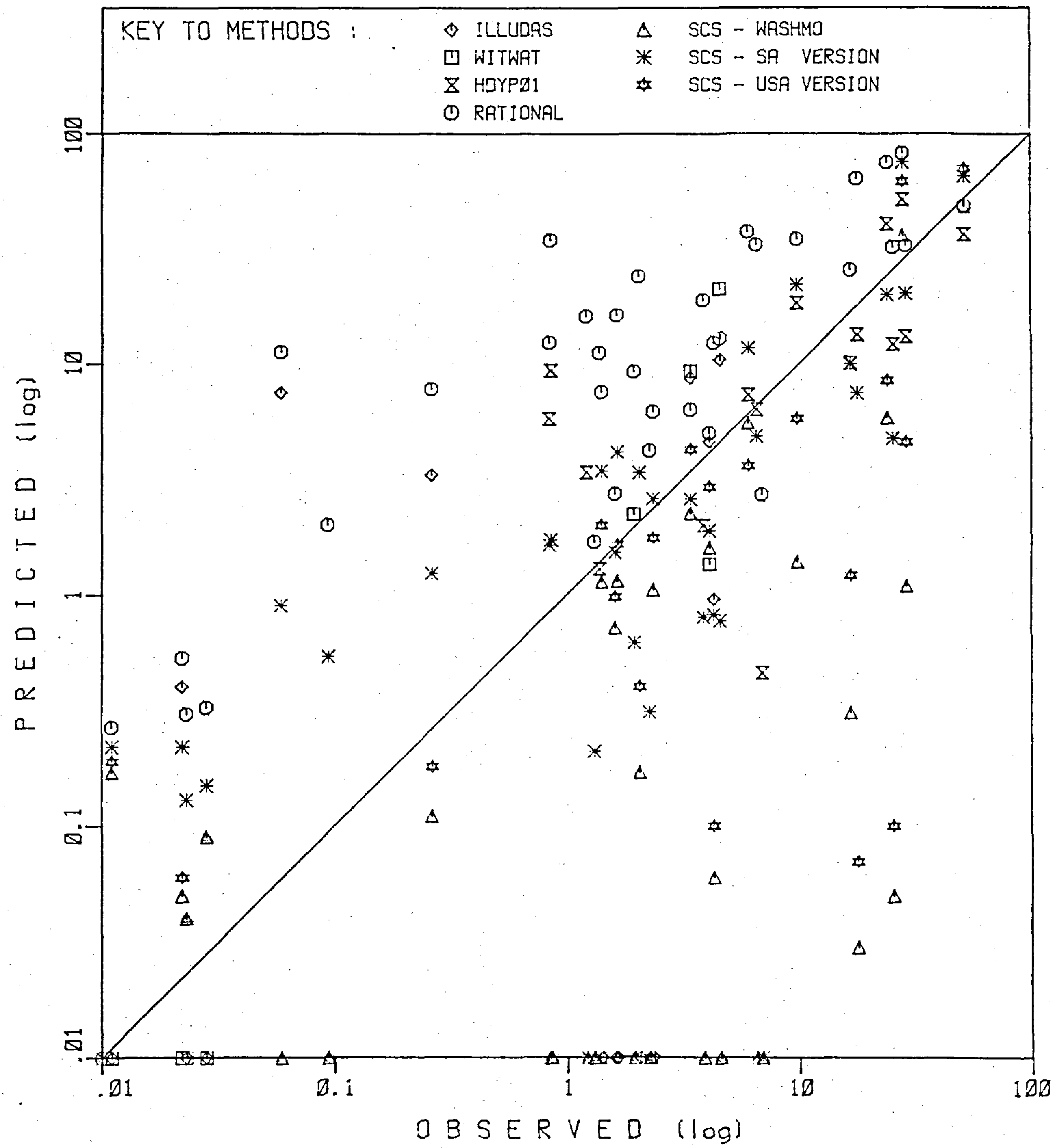

FIG. C 8 : PEAK FLOW (cu.m/s) : VELD

ALL EVENTS

METHOD	STATISTIC	PEAK FLOW (cu.m/sec.) URBAN	AGRIC	FOREST	VELD	VOLUME (thou. cu.m.) URBAN	AGRIC	FOREST	VELD
RATIONAL	NO OF CATCHMENTS	5	6	6	9				
	NO OF EVENTS	19	24	24	35				
	REGRESSION : A	-5.19	2.37	7.22	9.86				
	: B	4.42	2.25	2.40	1.33				
	: R**2	.59	.57	.49	.53				
	STD ERROR	19.24	16.15	19.37	19.40				
SCS - WASHMO (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	19	24	24	35	19	24	24	35
	REGRESSION : A	-1.76	.39	.42	-1.85	-28.54	1.85	11.64	-15.67
	: B	.99	-.02	-.01	.65	1.28	-.00	-.00	1.15
	: R**2	.16	.13	.01	.57	.31	.00	.00	.69
	STD ERROR	7.46	7.09	6.24	8.80	115.23	121.17	267.01	124.15
SCS - SA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	19	24	24	35	19	24	24	35
	REGRESSION : A	-2.19	1.01	1.87	-1.08	-37.40	8.37	50.96	11.34
	: B	1.53	.30	.46	1.18	2.10	.50	.27	1.27
	: R**2	.32	.43	.43	.66	.57	.64	.26	.62
	STD ERROR	7.43	5.12	4.50	9.85	126.78	71.88	221.08	166.34
SCS - USA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	19	24	24	35	19	24	24	35
	REGRESSION : A	-1.75	.55	.93	-2.73	-28.42	1.85	12.08	-18.48
	: B	.99	-.03	-.02	1.01	1.28	-.00	-.00	1.15
	: R**2	.17	.12	.01	.57	.31	.00	.00	.72
	STD ERROR	7.35	7.08	6.37	10.36	114.64	121.17	266.71	115.36
ILLUDAS	NO OF CATCHMENTS	3	5	5	5	3	5	5	5
	NO OF EVENTS	11	20	20	19	11	20	20	19
	REGRESSION : A	-.17	-.50	1.02	.28	2.75	-.46	3.15	4.08
	: B	1.20	5.82	3.09	.97	.21	1.65	.38	-.07
	: R**2	.72	.71	.07	.20	.62	.78	.03	.09
	STD ERROR	1.15	7.39	4.47	2.97	12.27	10.20	12.09	27.76
WITWAT	NO OF CATCHMENTS	3	4	2	2	3	4	2	2
	NO OF EVENTS	11	16	8	8	11	16	8	8
	REGRESSION : A	-.35	.28	2.29	-.63	2.60	.40	3.18	1.19
	: B	.76	.91	-25.78	2.76	.14	.57	-.86	.33
	: R**2	.80	.58	.24	.55	.43	.72	.22	.25
	STD ERROR	1.10	.41	1.47	6.33	13.41	.81	2.90	7.33
HDYP01	NO OF CATCHMENTS	2	1	1	4	2	1	1	4
	NO OF EVENTS	8	4	4	16	8	4	4	16
	REGRESSION : A	25.06	28.18	12.28	3.33	156.42	241.09	551.32	63.08
	: B	.94	-.54	-.06	.78	8.48	.18	-.04	.30
	: R**2	.02	.13	.03	.54	.25	.03	.01	.25
	STD ERROR	27.88	15.90	11.98	10.55	1210.80	204.73	532.91	195.00

TABLE C.3 : REGRESSION STATISTICS (ALL EVENTS)

APPENDIX D

STATISTICS AND SCATTER DIAGRAMS

ACTUAL RAINFALL DISTRIBUTION DESIGN STORMS

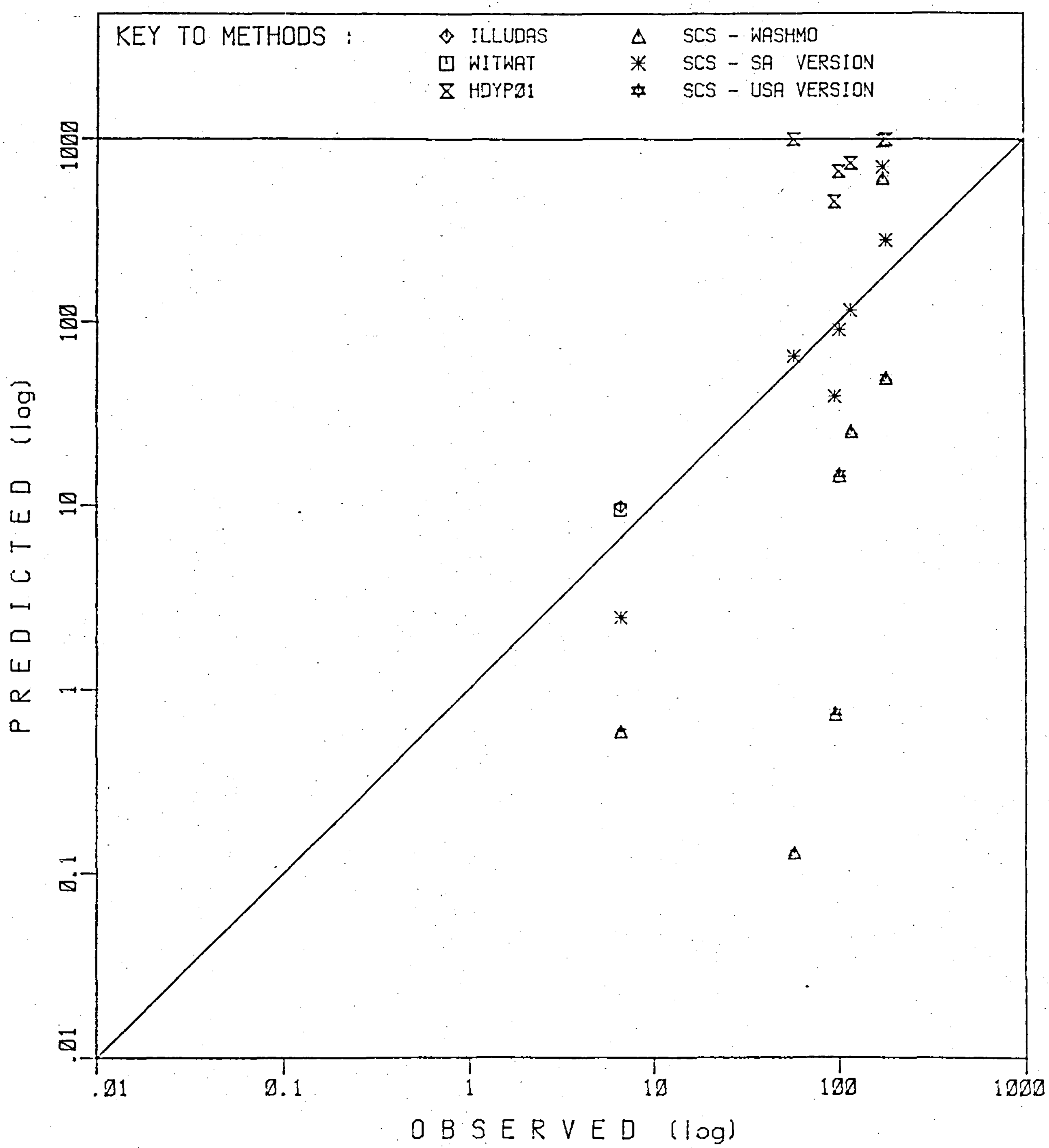

FIG. D 1 : VOLUME (cu.mx1Ø^3) : URBAN

EVENTS WITH RAINFALL > 2Ø mm.

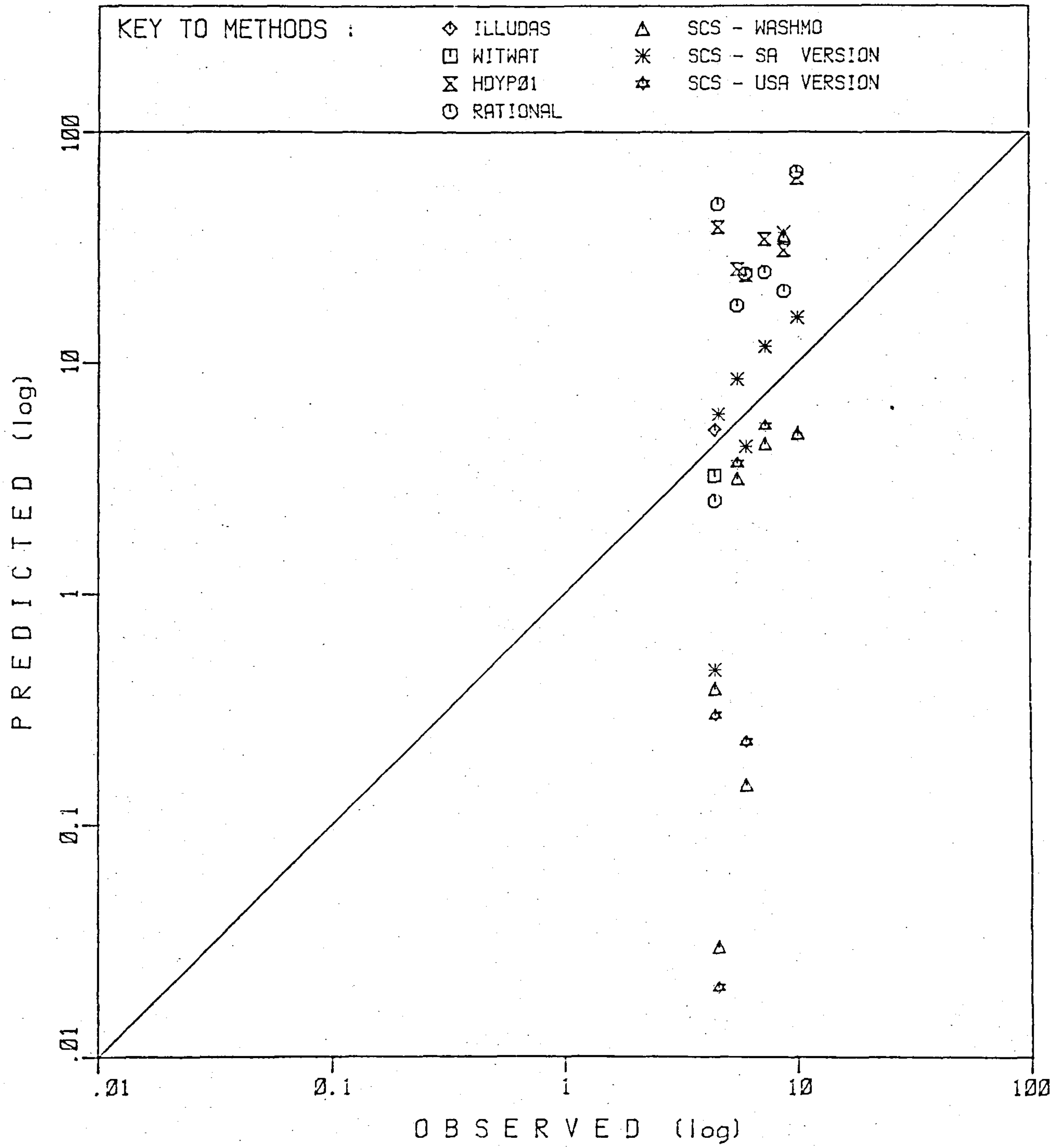

FIG. D 2 : PEAK FLOW (cu.m/s) : URBAN
EVENTS WITH RAINFALL > 20 mm.

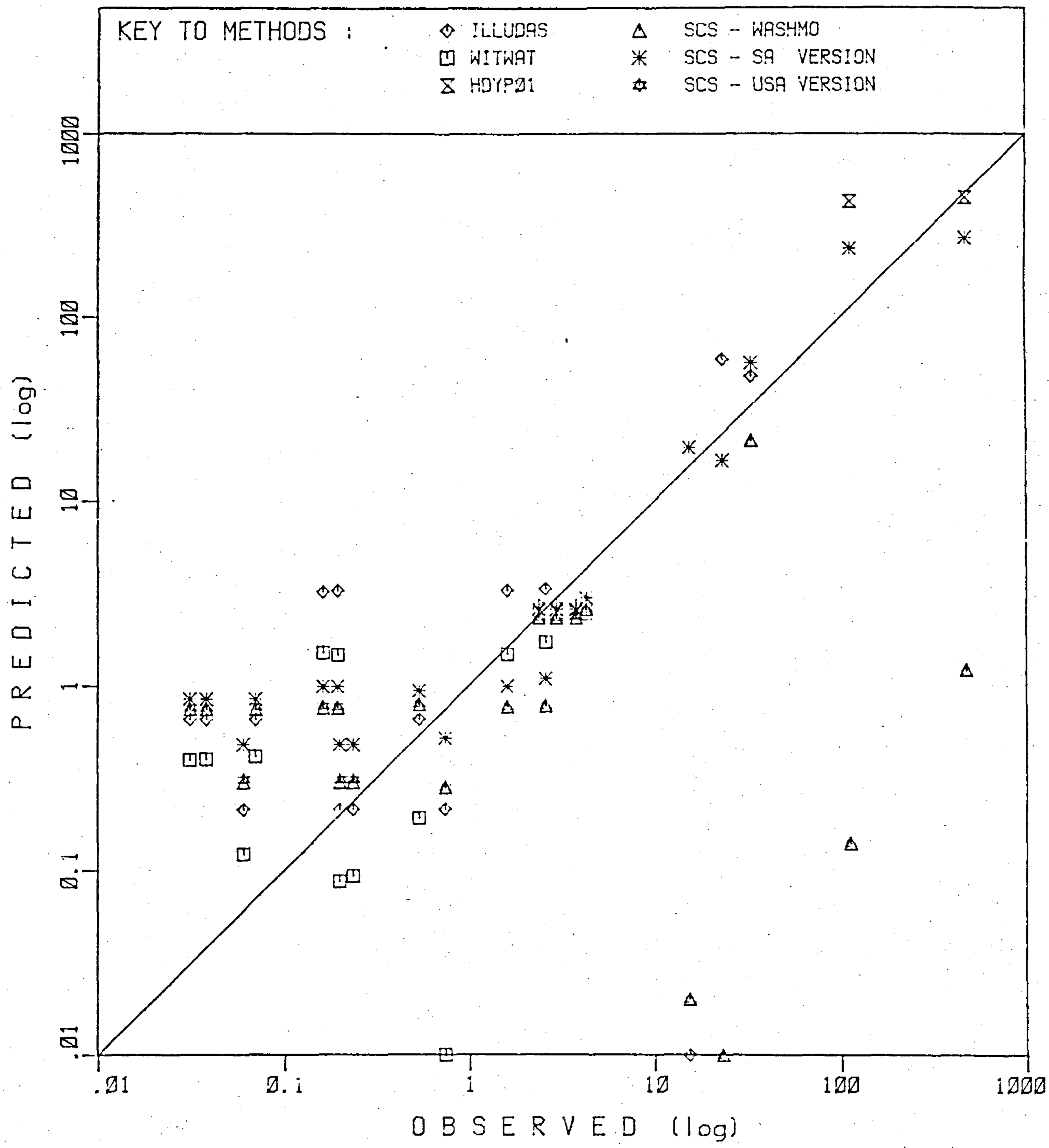

FIG. D 3 : VOLUME (cu.mx1Ø^3) : AGRICULTURE
EVENTS WITH RAINFALL > 2Ø mm.

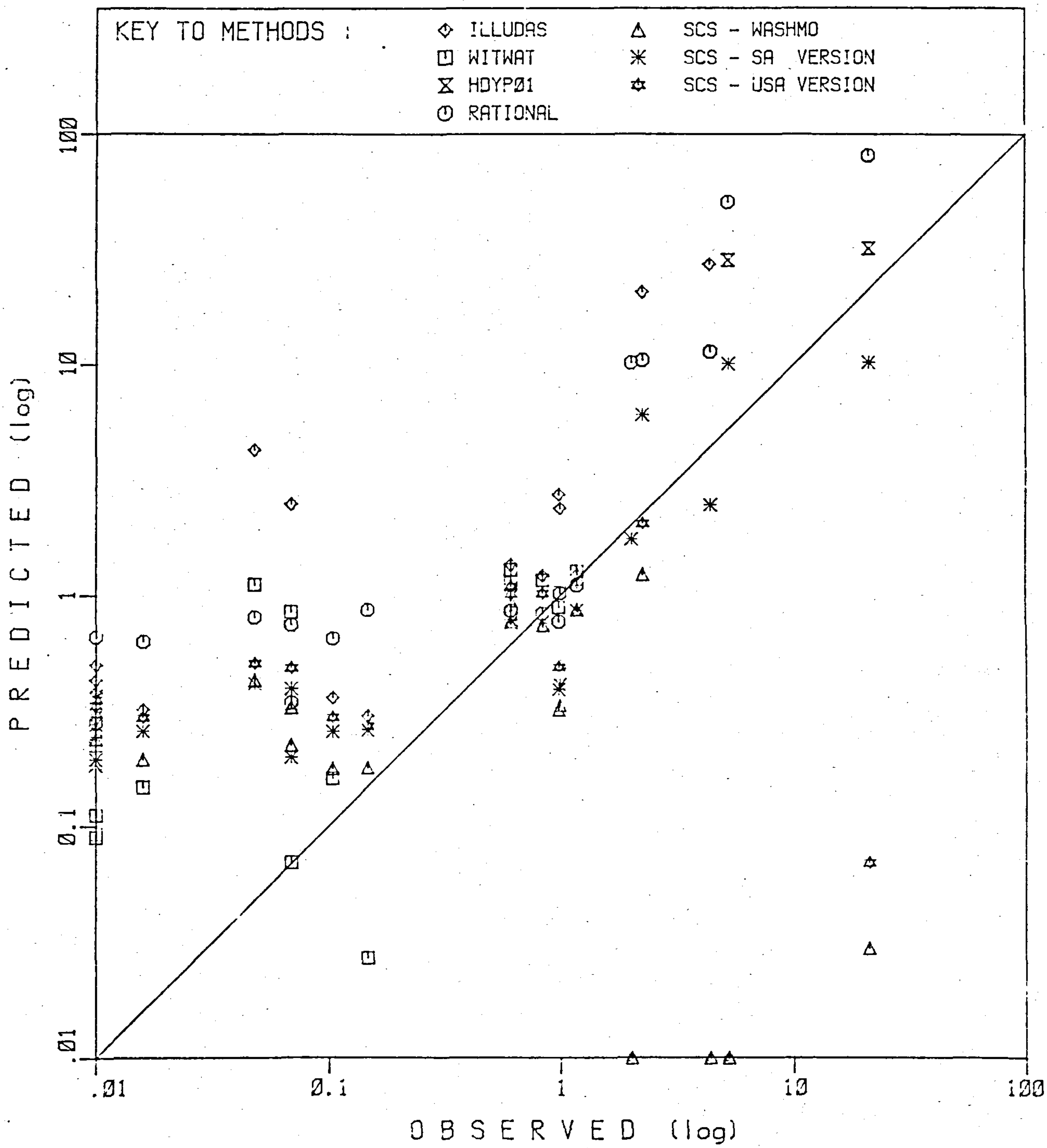

FIG. D 4 : PEAK FLOW (cu.m/s) : AGRICULTURE

EVENTS WITH RAINFALL > 2Ø mm.

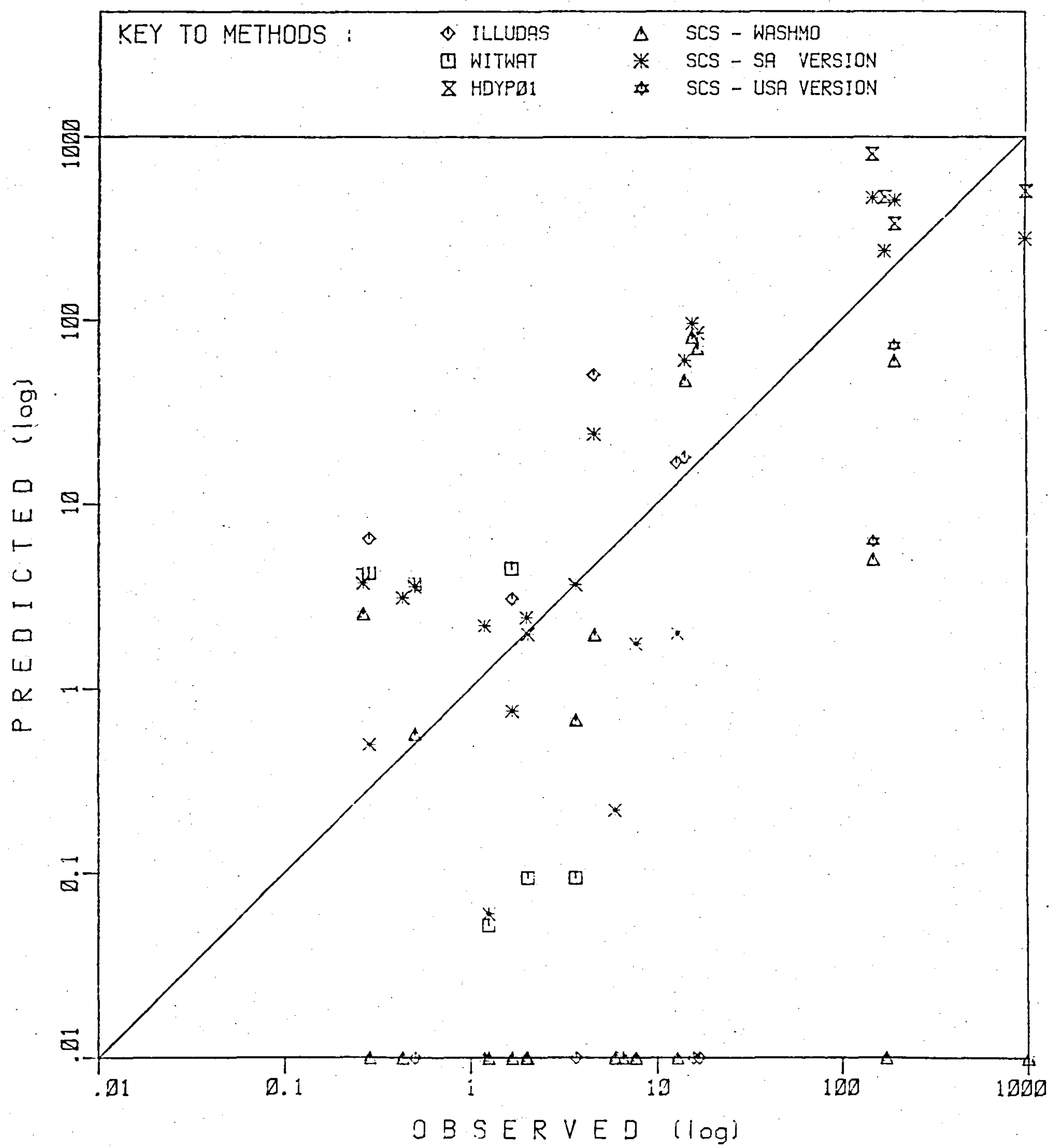

FIG. D 5 : VOLUME (cu.mx1Ø^3) : AFFORESTATION EVENTS WITH RAINFALL > 2Ø mm.

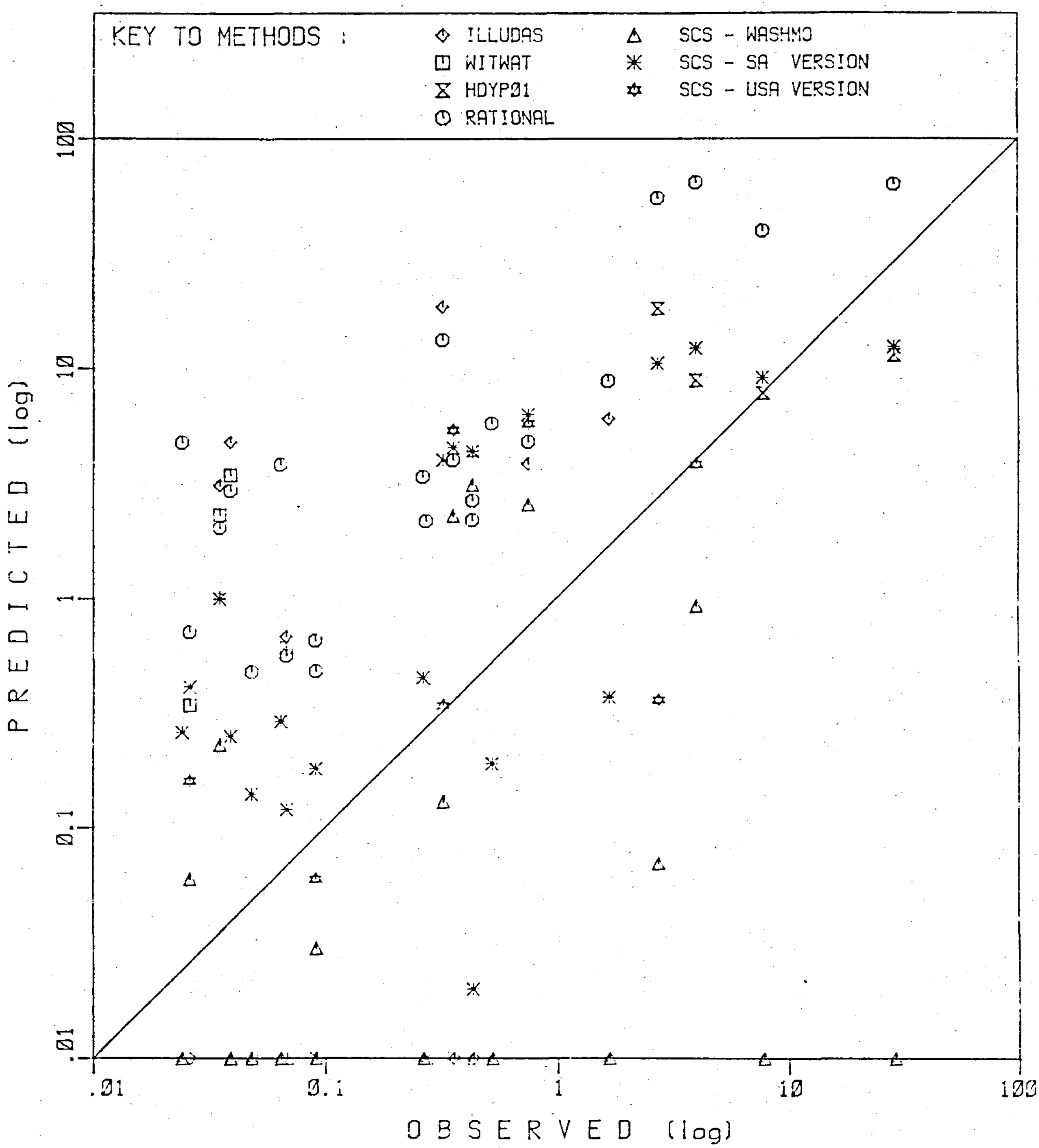

FIG. D 6 : PEAK FLOW (cu.m/s) : AFFORESTATION
EVENTS WITH RAINFALL > 20 mm.

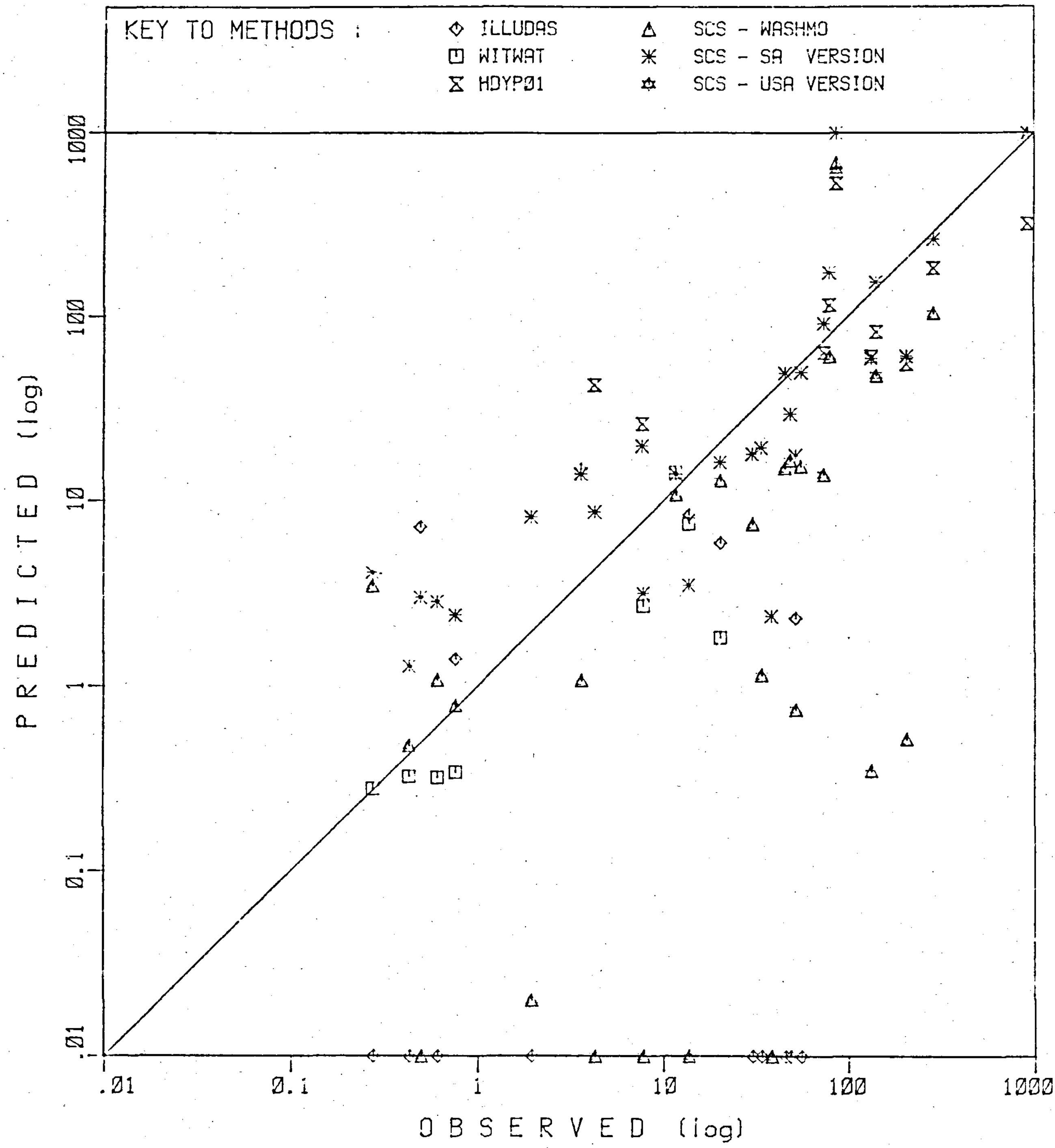

FIG. D 7 : VOLUME (cu.m×10^3) : VELD

EVENTS WITH RAINFALL > 20 mm.

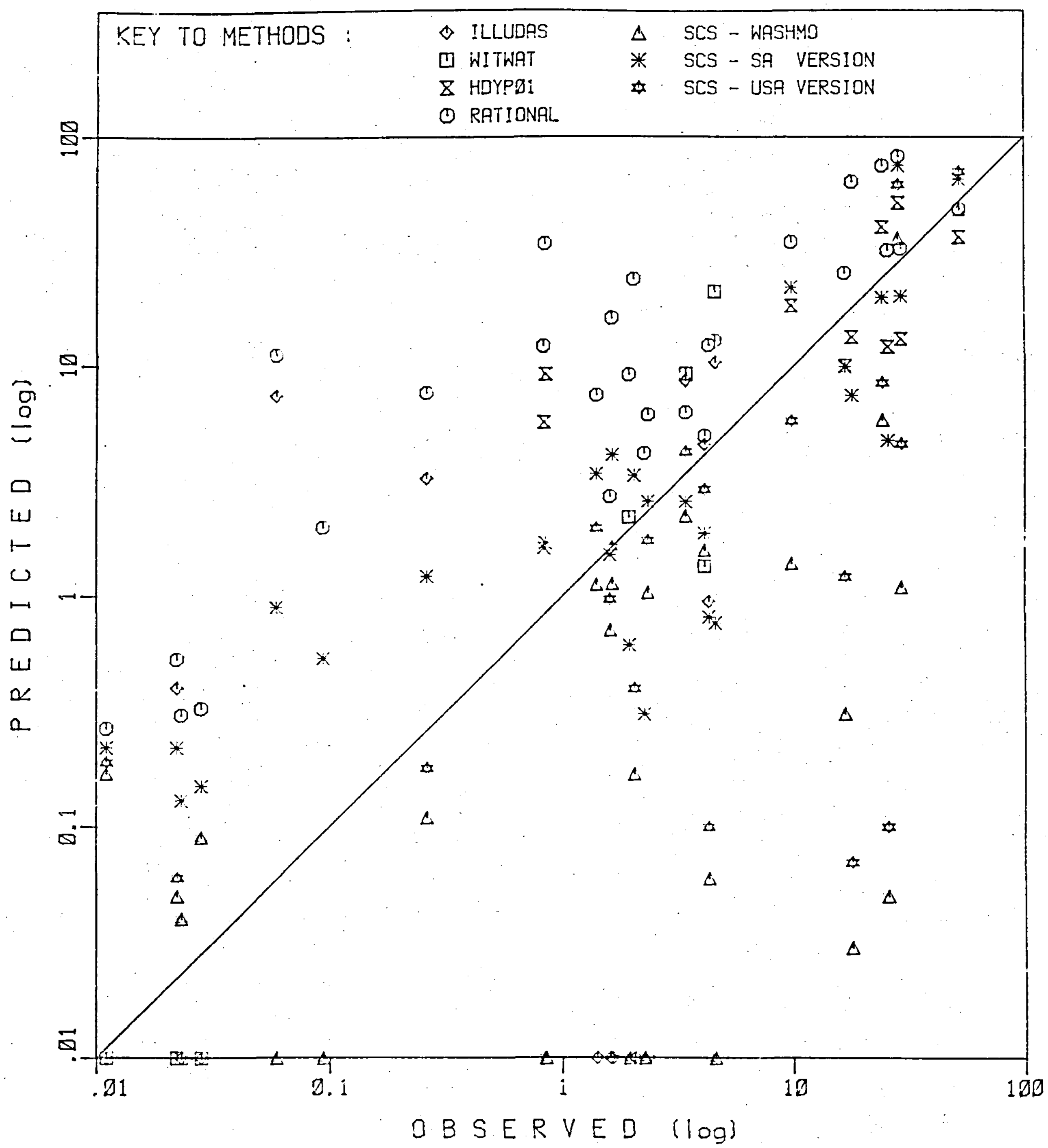

FIG. D 8 : PEAK FLOW (cu.m/s) : VELD

EVENTS WITH RAINFALL > 20 mm.

METHOD	STATISTIC	PEAK FLOW (cu.m/sec.)				VOLUME (thou. cu.m.)			
		URBAN	AGRIC	FOREST	VELD	URBAN	AGRIC	FOREST	VELD
RATIONAL	NO OF CATCHMENTS	5	6	6	9				
	NO OF EVENTS	7	21	22	28				
	REGRESSION : A	-5.29	.47	7.74	9.22				
	: B	5.20	4.05	2.38	1.34				
	: R**2	.27	.88	.49	.56				
	STD ERROR	29.68	16.70	20.21	19.73				
SCS - WASHMO (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	7	21	22	28	7	21	22	28
	REGRESSION : A	-15.10	.40	.46	-1.90	-114.70	1.88	12.81	-18.70
	: B	3.31	-.02	-.02	.66	2.05	.00	-.00	1.16
	: R**2	.30	.06	.01	.57	.32	.00	.00	.69
	STD ERROR	10.90	4.89	6.52	9.63	183.75	106.64	278.88	138.12
SCS - SA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	7	21	22	28	7	21	22	28
	REGRESSION : A	-15.48	.74	2.05	-.79	-126.89	9.17	56.06	14.02
	: B	4.11	.54	.45	1.17	2.98	.64	.27	1.26
	: R**2	.53	.64	.43	.66	.57	.76	.25	.61
	STD ERROR	11.11	2.79	4.70	10.86	204.62	52.23	230.91	185.27
SCS - USA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	7	21	22	28	7	21	22	28
	REGRESSION : A	-14.64	.56	1.03	-2.57	-114.15	1.88	13.29	-20.38
	: B	3.25	-.02	-.03	1.01	2.05	.00	-.00	1.15
	: R**2	.31	.05	.01	.57	.32	.00	.00	.72
	STD ERROR	10.67	4.88	6.66	11.39	182.73	106.64	278.57	128.74
ILLUDAS	NO OF CATCHMENTS	3	5	5	5	3	5	5	5
	NO OF EVENTS	1	19	18	18	1	19	18	18
	REGRESSION : A	-.00	-.63	1.17	.39	.00	-.59	3.78	4.27
	: B	.00	5.56	2.93	.96	.00	1.60	.32	-.07
	: R**2	.00	.71	.07	.20	.00	.76	.02	.10
	STD ERROR	.73	6.89	4.71	3.04	3.19	9.72	12.74	28.23
WITWAT	NO OF CATCHMENTS	3	4	2	2	3	4	2	2
	NO OF EVENTS	1	16	7	8	1	16	7	8
	REGRESSION : A	-.00	.28	2.50	-.63	.00	.40	4.09	1.19
	: B	.00	.91	-27.11	2.76	.00	.57	-1.21	.33
	: R**2	.00	.58	.28	.55	.00	.72	.47	.25
	STD ERROR	1.16	.41	1.57	6.33	2.81	.81	3.09	7.33
HDYP01	NO OF CATCHMENTS	2	1	1	4	2	1	1	4
	NO OF EVENTS	6	2	4	10	6	2	4	10
	REGRESSION : A	5.38	27.32	12.28	8.21	215.67	422.90	551.32	103.75
	: B	4.36	.23	-.06	.63	8.14	.06	-.04	.23
	: R**2	.40	1.00	.03	.37	.20	1.00	.01	.15
	STD ERROR	31.49	18.15	11.98	13.15	1334.05	225.23	532.91	246.08

TABLE D.1 : REGRESSION STATISTICS (EVENTS WITH RAINFALL > 20 mm.)

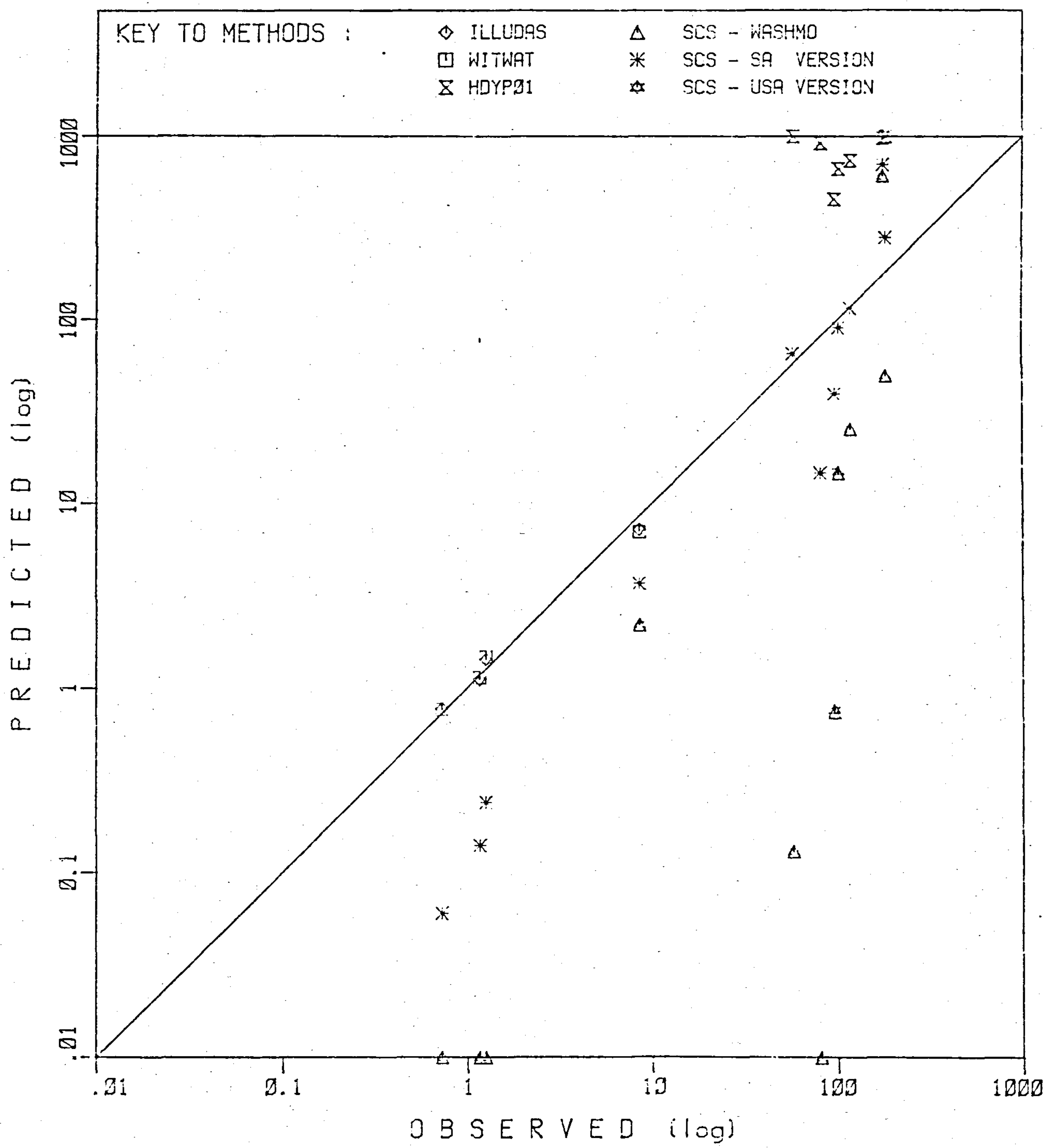

FIG. D 9 : VOLUME (cu.mx1Ø^3) : URBAN
EVENTS WITH RELEVANT R.I. RAINFALL

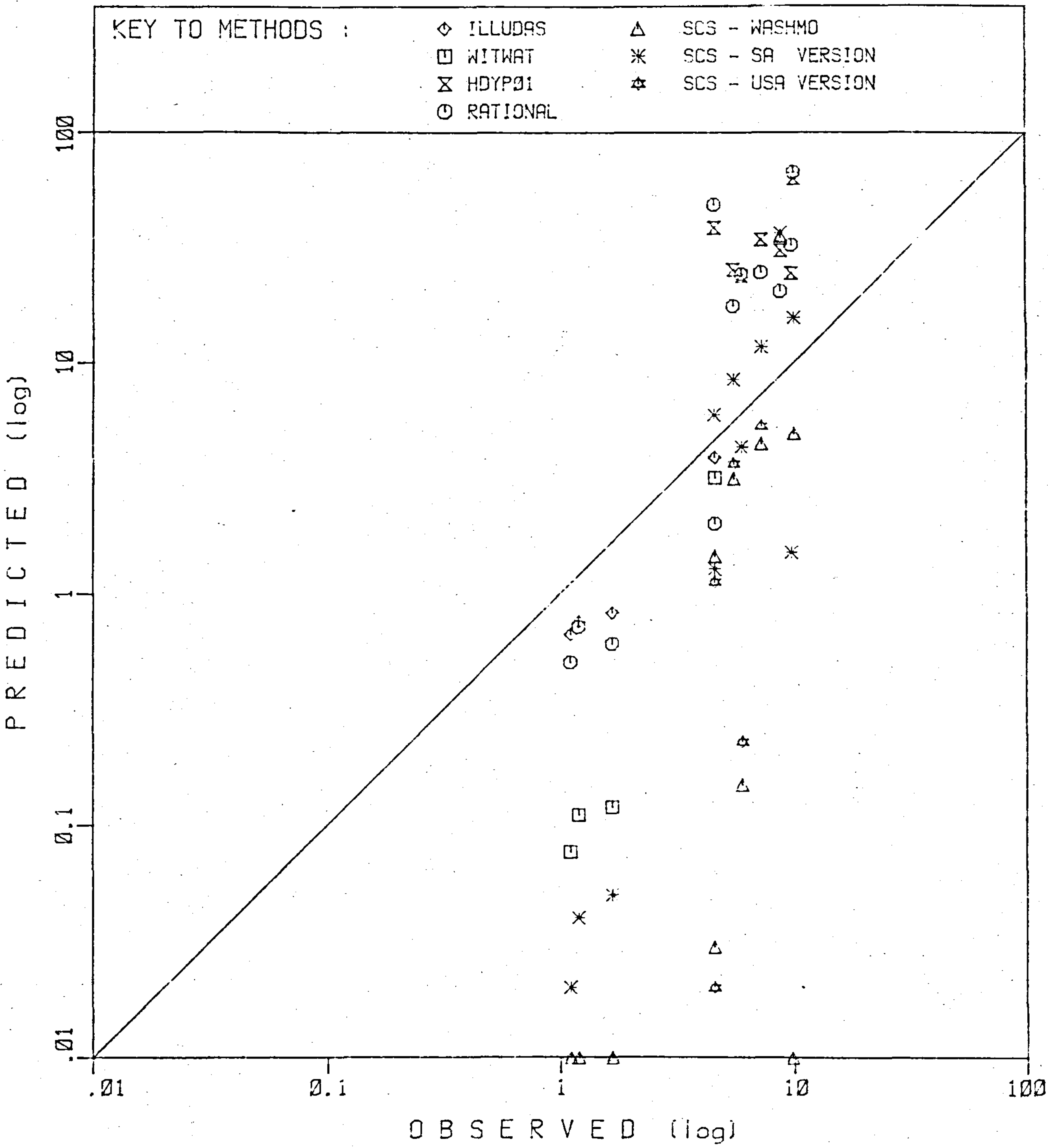

FIG. D 10 : PEAK FLOW (cu.m/s) : URBAN
EVENTS WITH RELEVANT R.I. RAINFALL

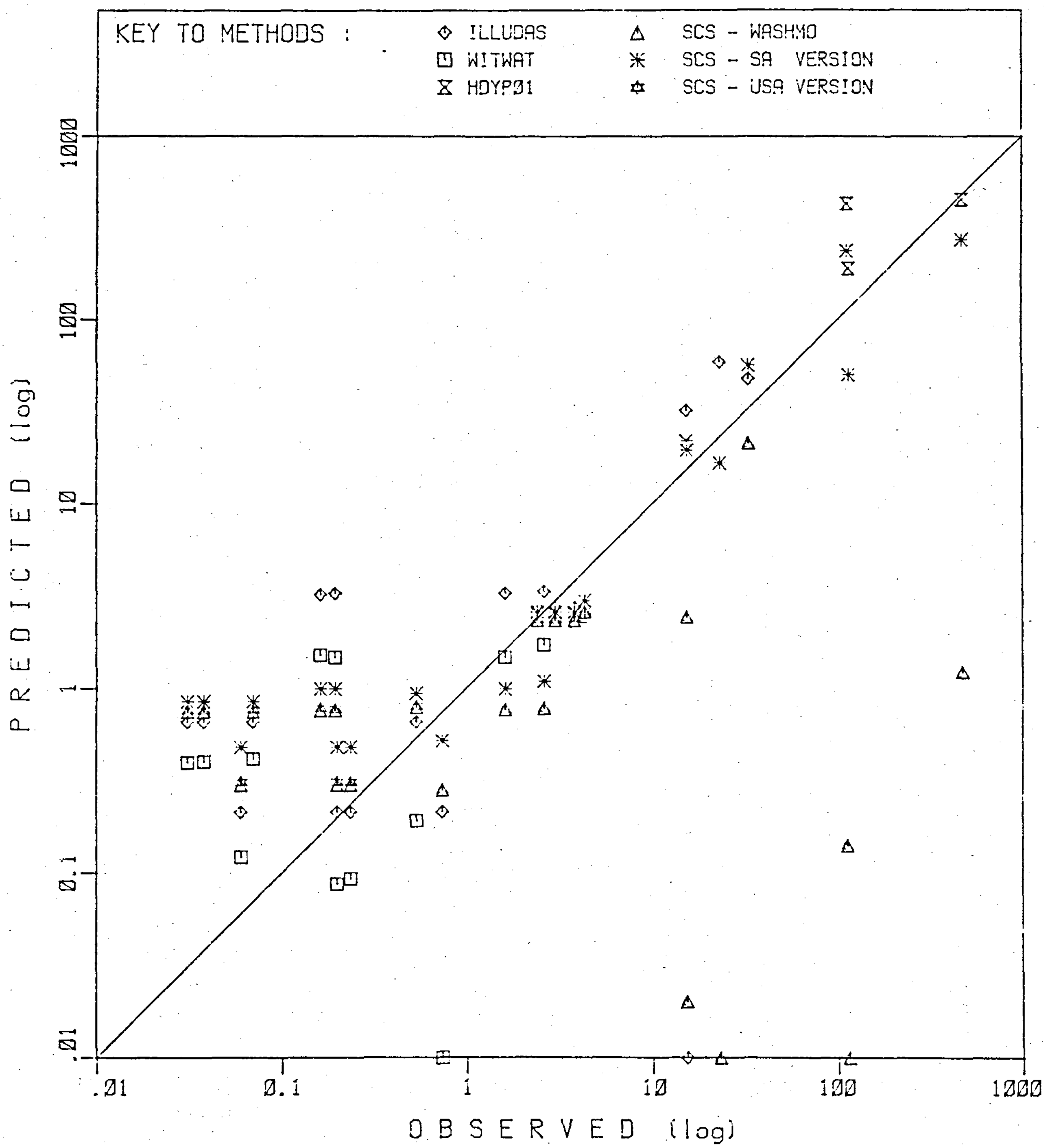

FIG. D 11 : VOLUME (cu.mx10^3) : AGRICULTURE
EVENTS WITH RELEVANT R.I. RAINFALL

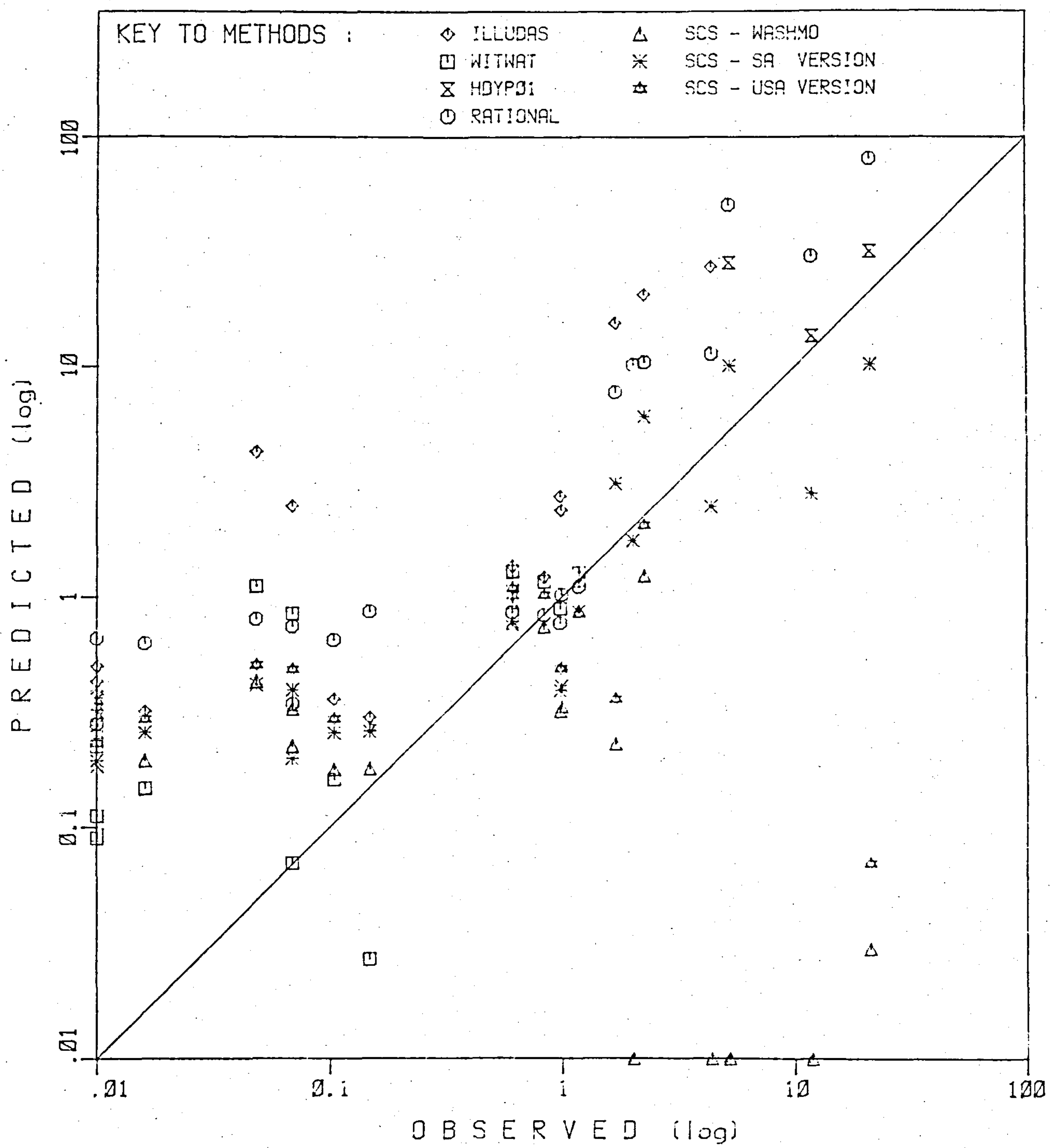

FIG. D 12 : PEAK FLOW (cu.m/s) : AGRICULTURE
EVENTS WITH RELEVANT R.I. RAINFALL

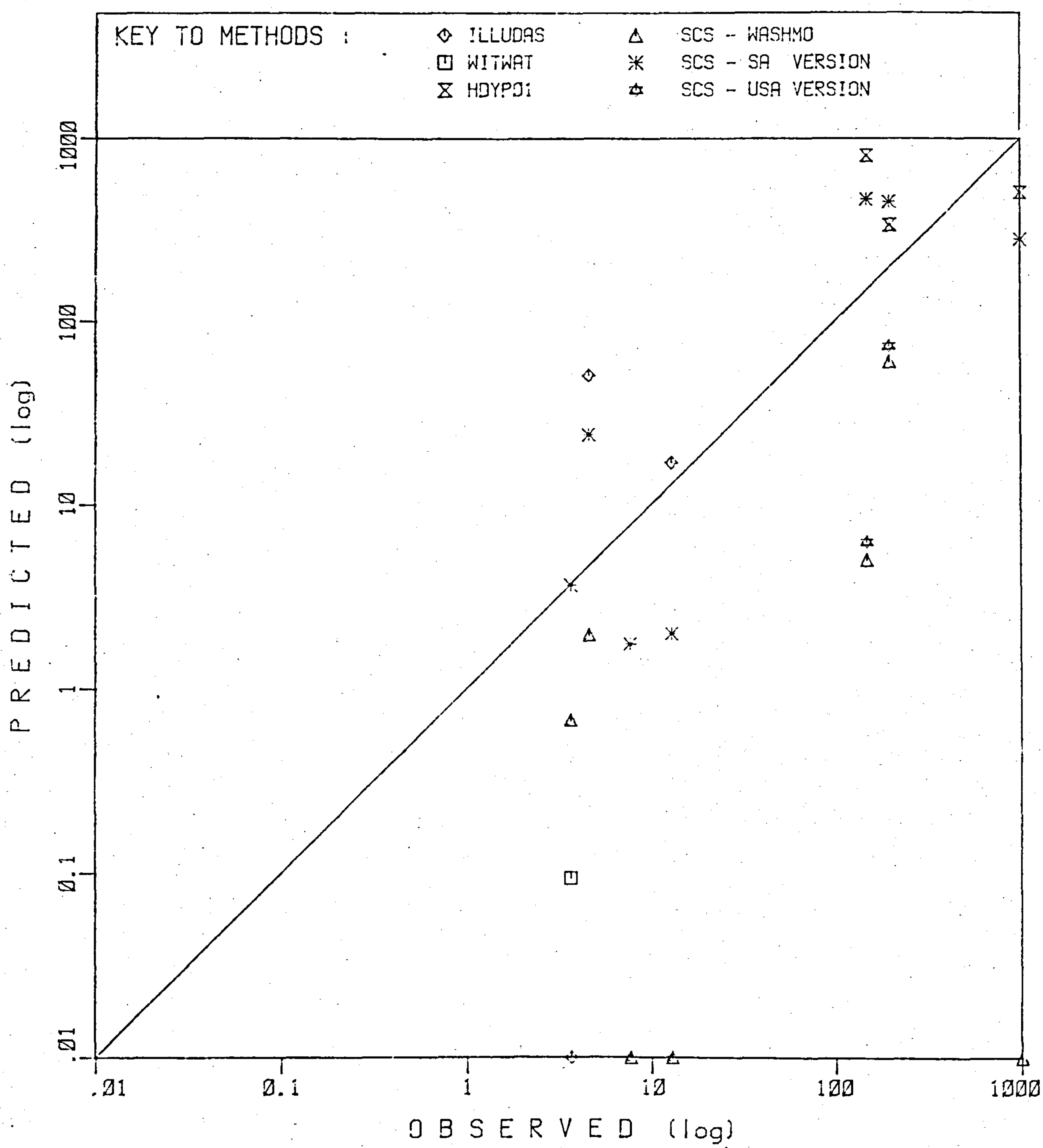

FIG. D 13 : VOLUME (cu.mx10^3) : AFFORESTATION
EVENTS WITH RELEVANT R.I. RAINFALL

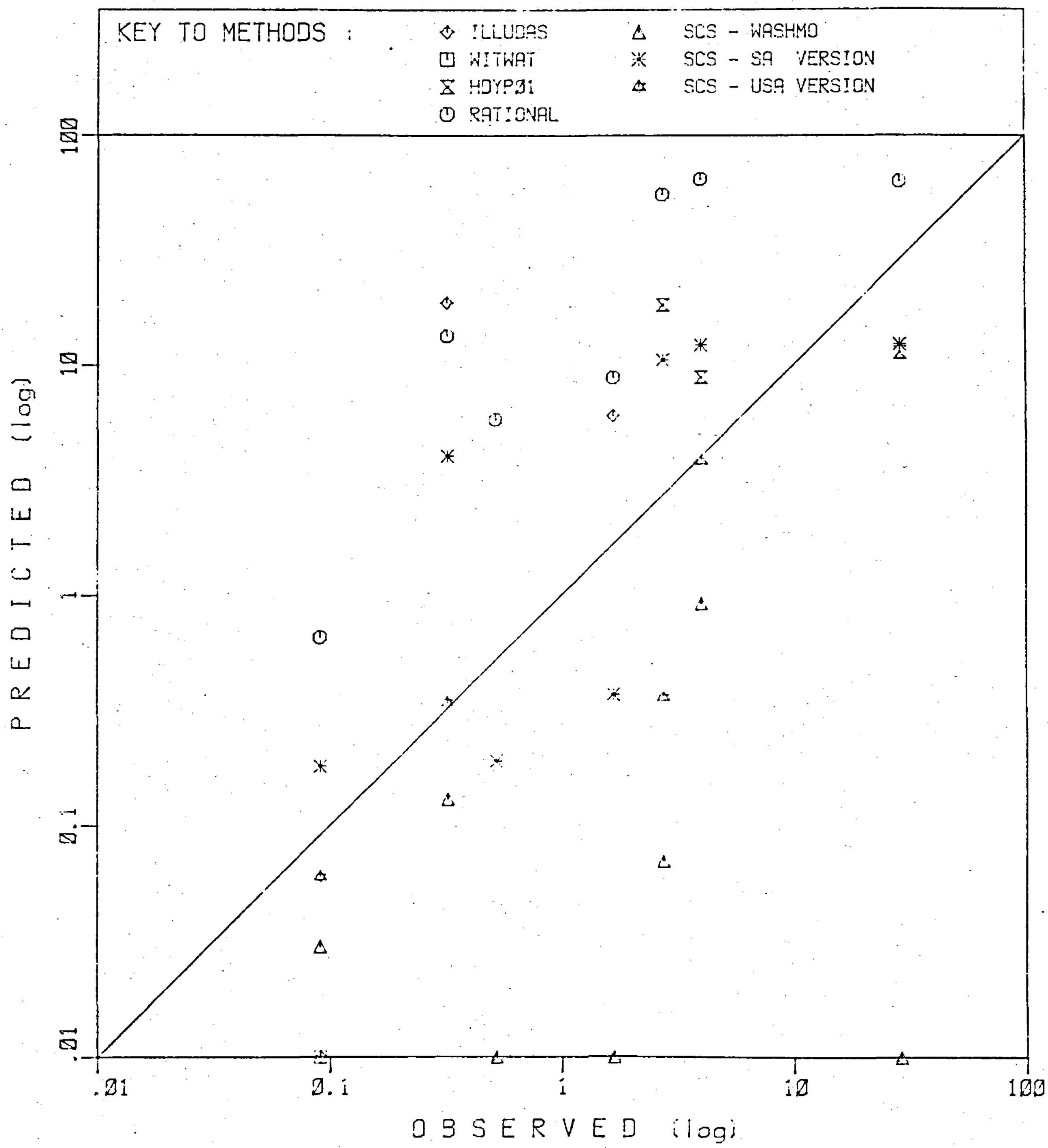

FIG. D 14 : PEAK FLOW (cu.m/s) : AFFORESTATION
EVENTS WITH RELEVANT R.I. RAINFALL

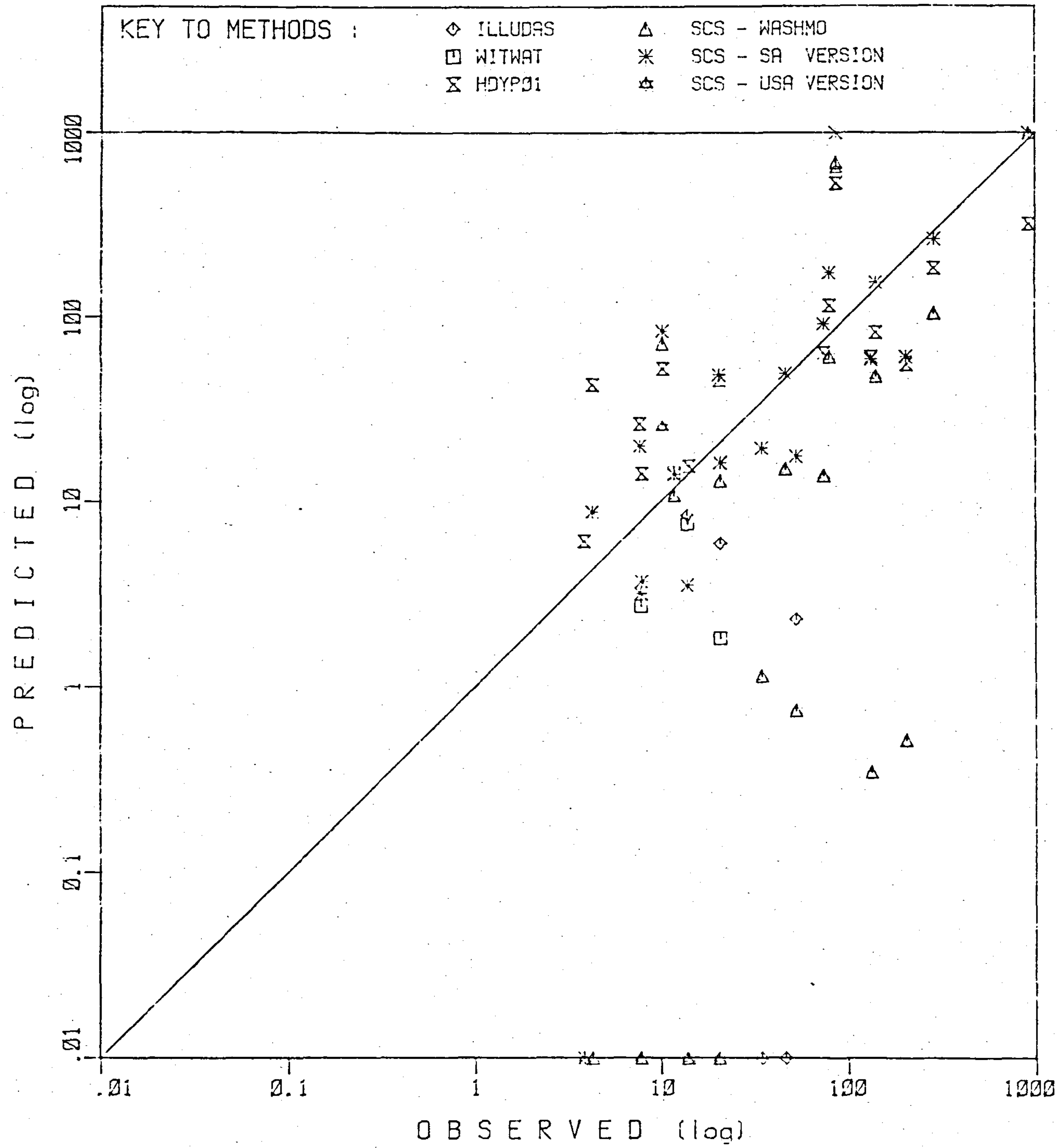

FIG. D 15 : VOLUME (cu.mx10^3) : VELD
EVENTS WITH RELEVANT R.I. RAINFALL

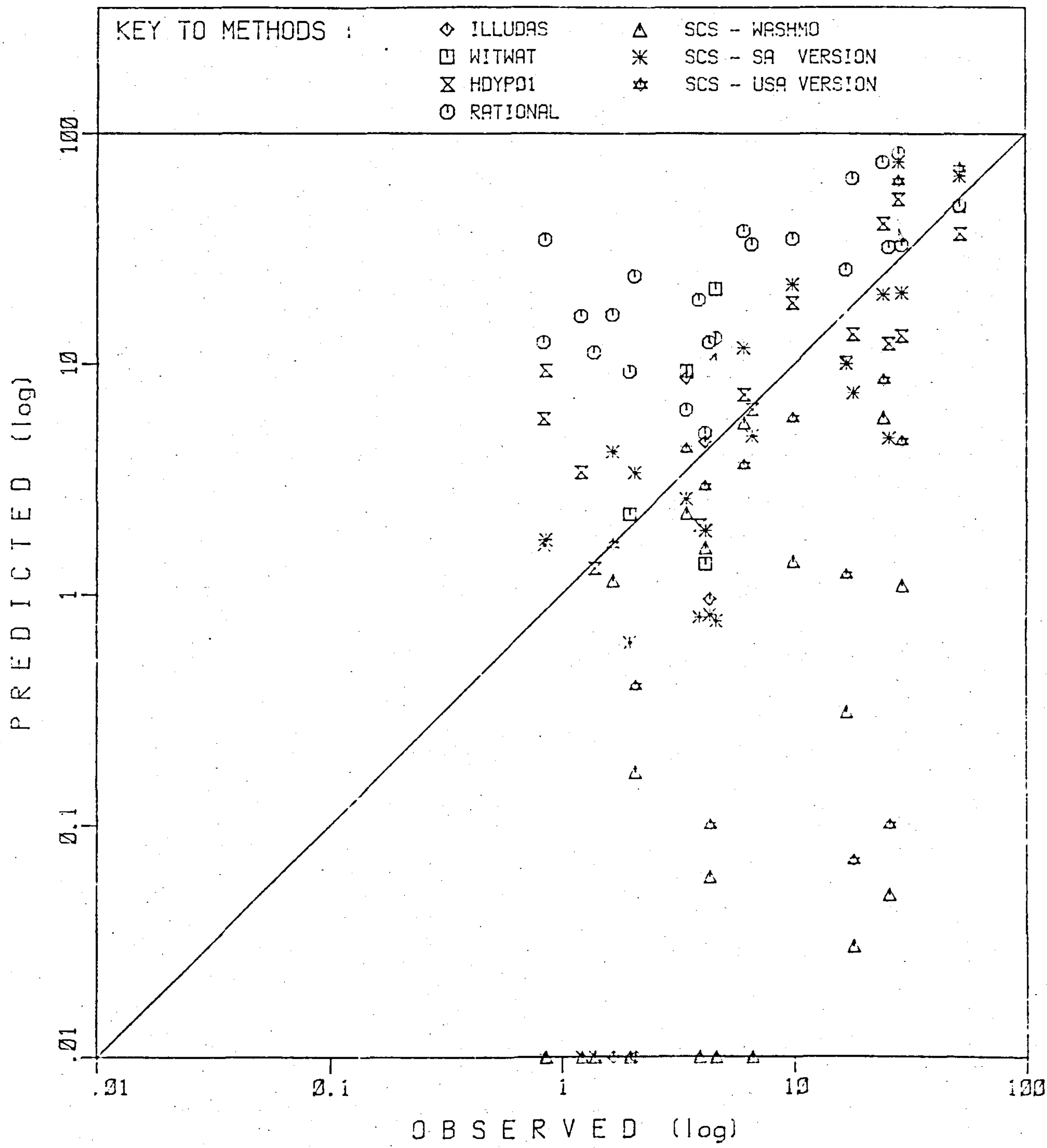

FIG. D 16 : PEAK FLOW (cu.m/s) : VELD
EVENTS WITH RELEVANT R.I. RAINFALL

METHOD	STATISTIC	PEAK FLOW (cu.m/sec.) URBAN	AGRIC	FOREST	VELD	VOLUME (thou. cu.m.) URBAN	AGRIC	FOREST	VELD
RATIONAL	NO OF CATCHMENTS	5	6	6	9				
	NO OF EVENTS	11	23	7	22				
	REGRESSION : A	-4.51	.48	21.05	17.40				
	: B	4.77	3.72	1.68	1.07				
	: R**2	.52	.85	.36	.44				
	STD ERROR	24.67	16.47	33.51	24.22				
SCS - WASHMO (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	11	23	7	22	11	23	7	22
	REGRESSION : A	-2.95	.40	.18	-3.19	-48.21	1.85	10.43	-15.85
	: B	1.36	-.02	-.00	.71	1.51	-.00	-.00	1.16
	: R**2	.18	.10	.01	.57	.31	.00	.00	.68
	STD ERROR	9.18	5.30	11.07	10.98	148.58	104.69	488.77	155.79
SCS - SA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	11	23	7	22	11	23	7	22
	REGRESSION : A	-3.17	.81	3.87	-1.70	-57.53	8.33	135.00	27.08
	: B	2.00	.46	.34	1.21	2.38	.63	.18	1.24
	: R**2	.36	.56	.36	.63	.58	.75	.14	.60
	STD ERROR	9.21	3.28	7.74	12.32	164.44	51.68	406.16	209.50
SCS - USA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	5	6	6	9	5	6	6	9
	NO OF EVENTS	11	23	7	22	11	23	7	22
	REGRESSION : A	-2.89	.56	.73	-4.68	-47.98	1.85	12.54	-20.74
	: B	1.35	-.03	-.01	1.09	1.50	-.00	-.00	1.16
	: R**2	.18	.08	.01	.57	.31	.00	.00	.71
	STD ERROR	9.01	5.29	11.00	12.96	147.78	104.70	488.23	144.63
ILLUDAS	NO OF CATCHMENTS	3	5	5	5	3	5	5	5
	NO OF EVENTS	4	20	4	7	4	20	4	7
	REGRESSION : A	-.48	-.50	6.19	-4.22	.24	-.46	21.93	7.46
	: B	.94	5.82	-.01	2.45	.82	1.65	-.68	-.13
	: R**2	.99	.71	.00	.47	1.00	.78	.01	.27
	STD ERROR	.63	7.39	9.45	3.49	.65	10.20	23.61	29.65
WITWAT	NO OF CATCHMENTS	3	4	2	2	3	4	2	2
	NO OF EVENTS	4	16	1	4	4	16	1	4
	REGRESSION : A	-1.10	.28	.00	-8.30	.29	.40	.00	10.56
	: B	.92	.91	.00	4.77	.79	.57	.00	-.29
	: R**2	.98	.58	.00	.36	1.00	.72	.00	.07
	STD ERROR	1.29	.41	.09	8.95	.75	.81	3.60	10.36
HDYP01	NO OF CATCHMENTS	2	1	1	4	2	1	1	4
	NO OF EVENTS	7	3	3	15	7	3	3	15
	REGRESSION : A	16.78	20.40	14.05	4.21	237.19	266.63	592.56	68.76
	: B	2.38	.34	-.10	.75	8.01	.39	-.07	.30
	: R**2	.14	.08	.09	.53	.22	.32	.04	.23
	STD ERROR	29.69	14.86	13.83	10.77	1275.19	189.12	590.62	201.34

TABLE D.2 : REGRESSION STATISTICS (EVENTS WITH RELEVANT R.I. RAINFALL)

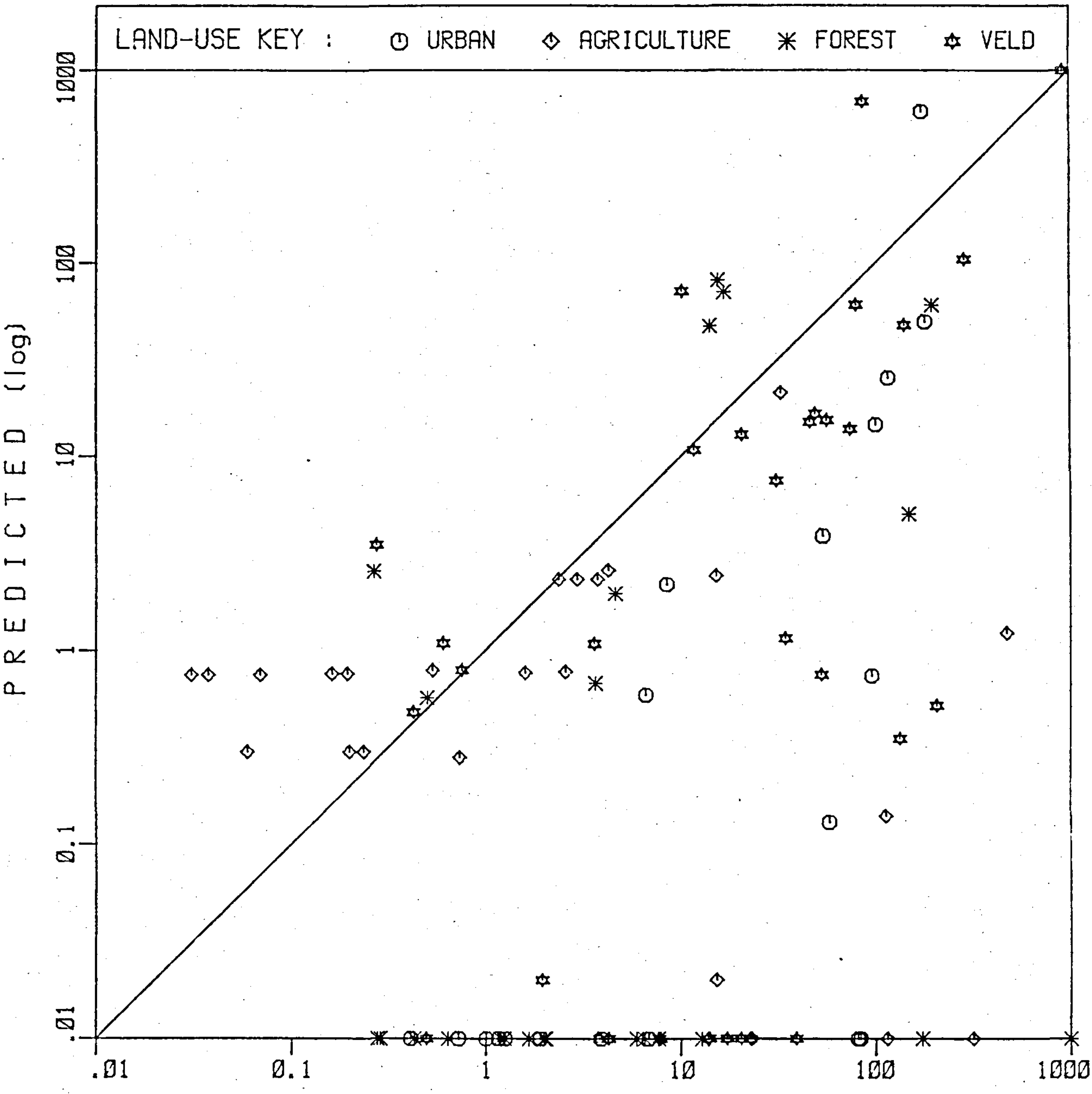

FIG. E 1 : VOLUME (cu.mx10^3) : SCS - WASHMO

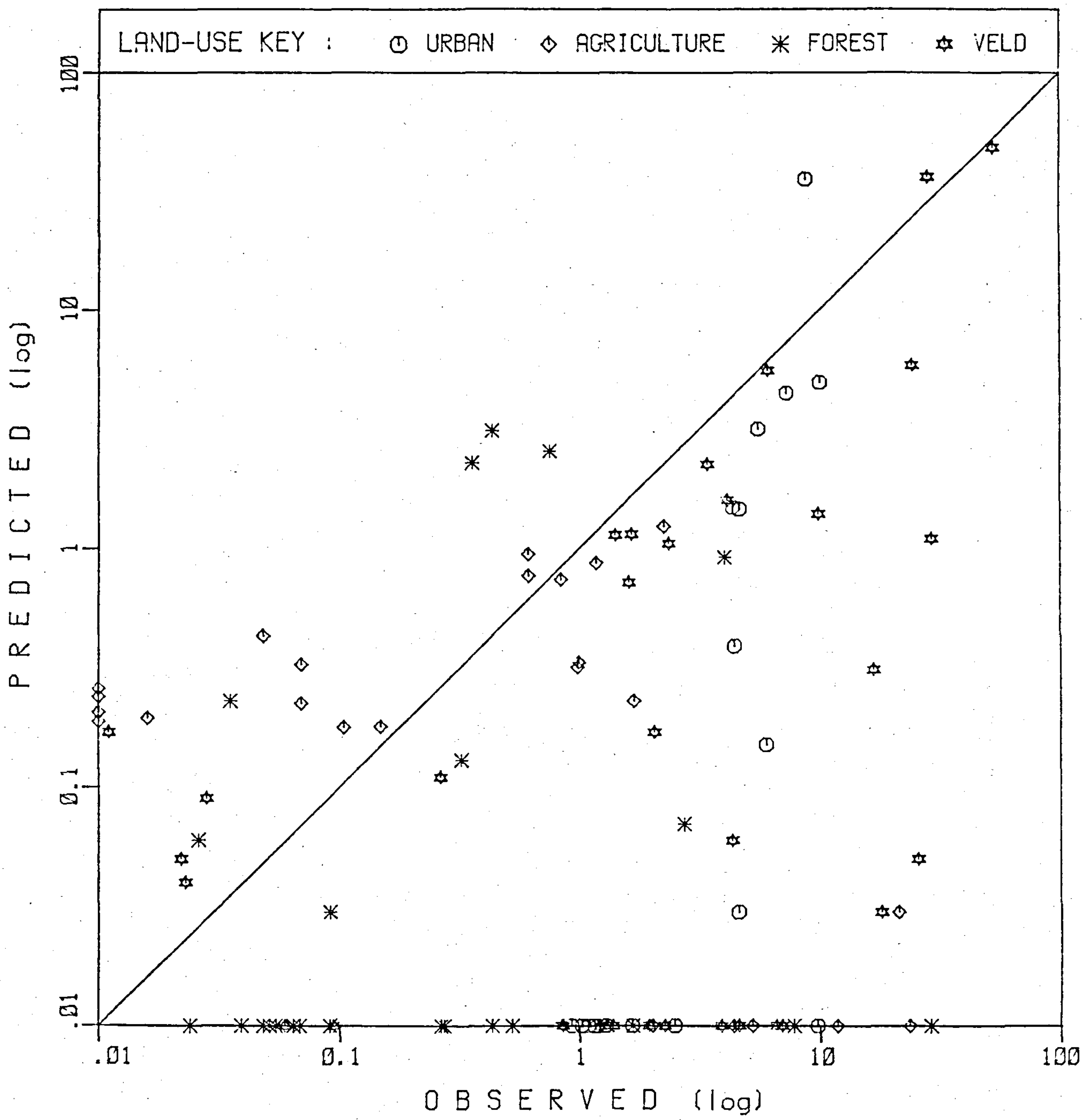

FIG. E 2 : PEAK FLOW (cu.m/s) : SCS - WASHMO

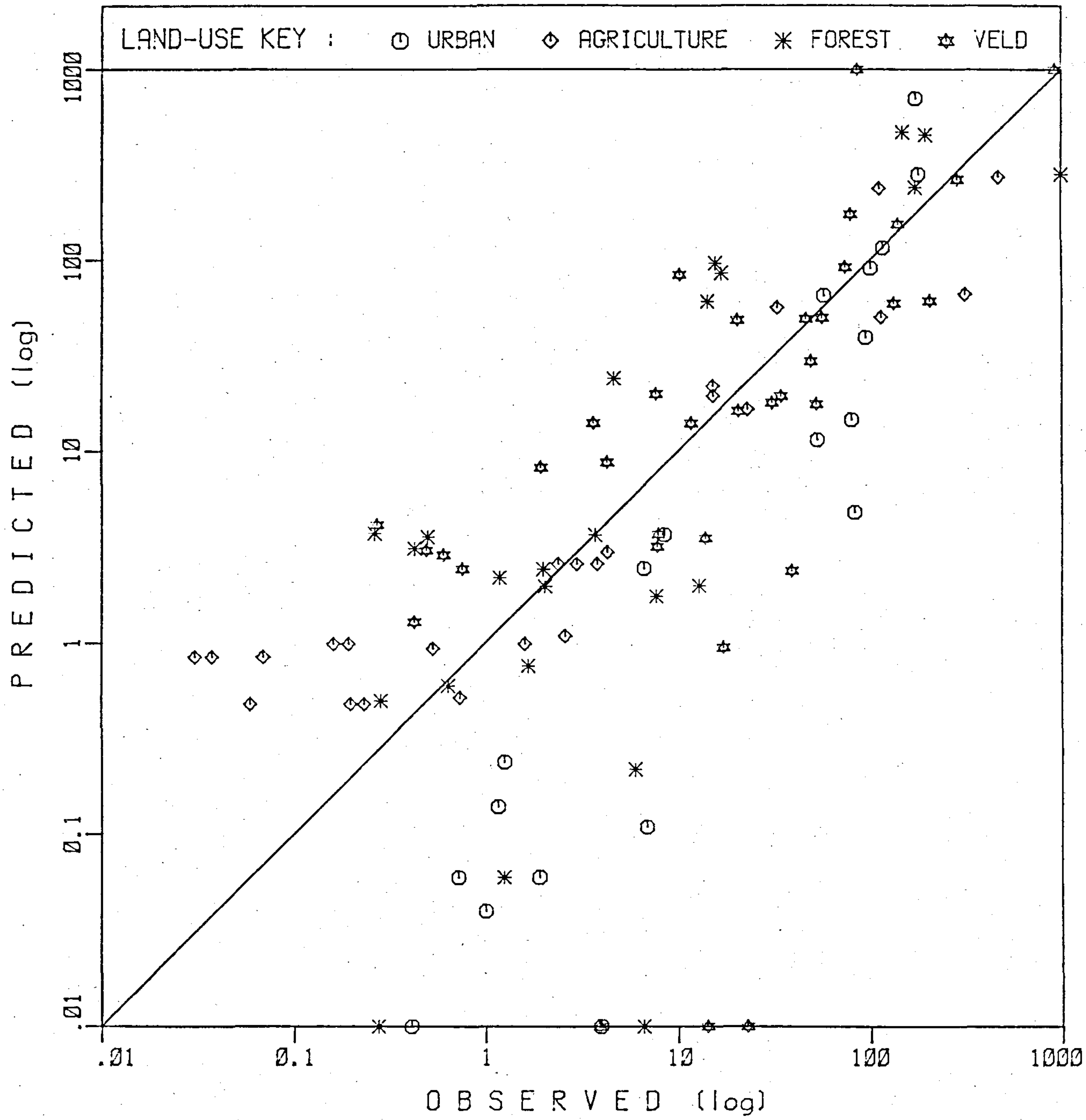

FIG. E 3 : VOLUME (cu.m×1Ø^3) : SCS - SA VERSION

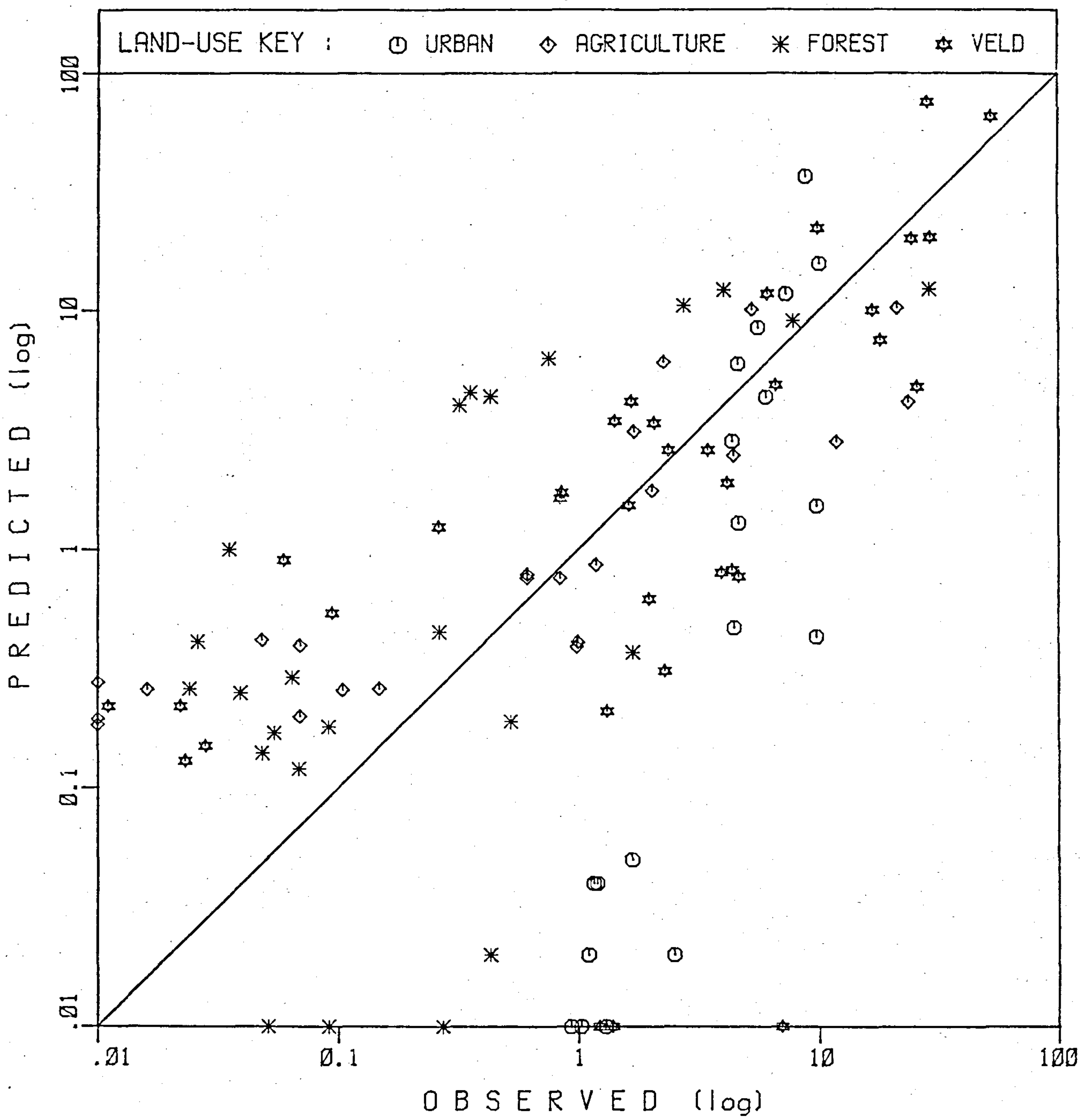

FIG. E 4 : PEAK FLOW (cu.m/s) : SCS - SA VERSION

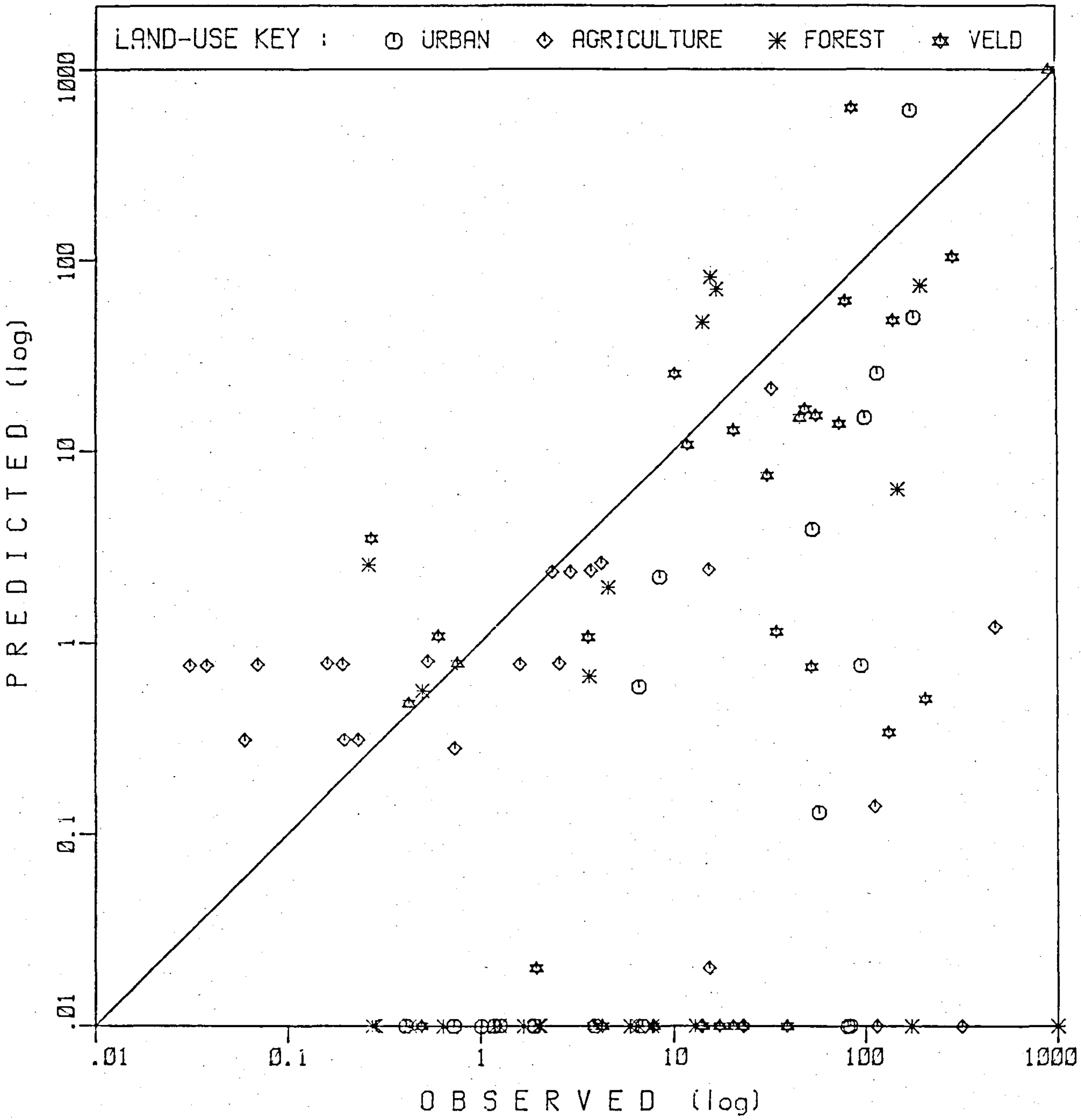

FIG. E 5 : VOLUME (cu.mx10^3) : SCS - USA VERSION

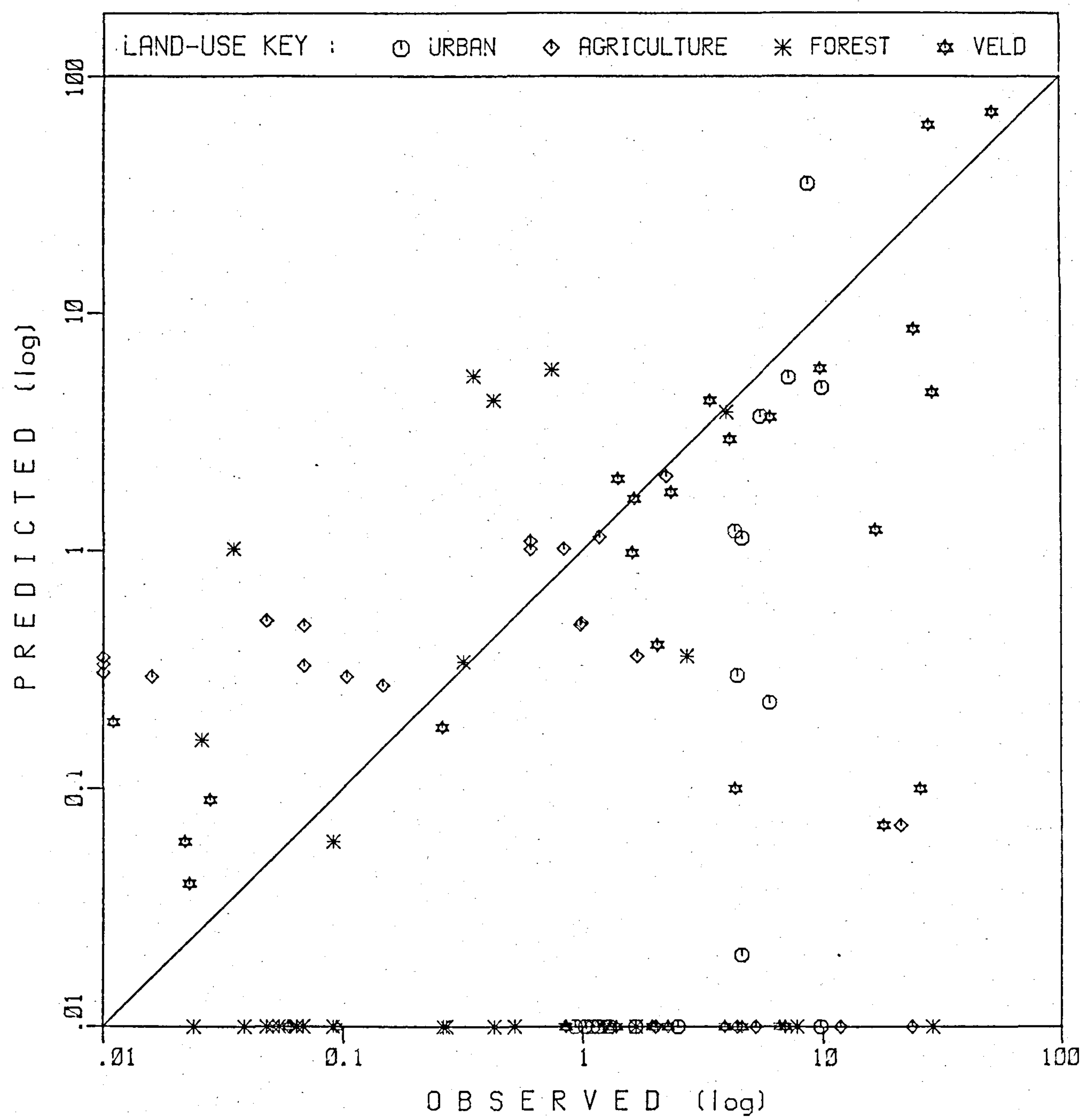

FIG. E 6 : PEAK FLOW (cu.m/s) : SCS - USA VERSION

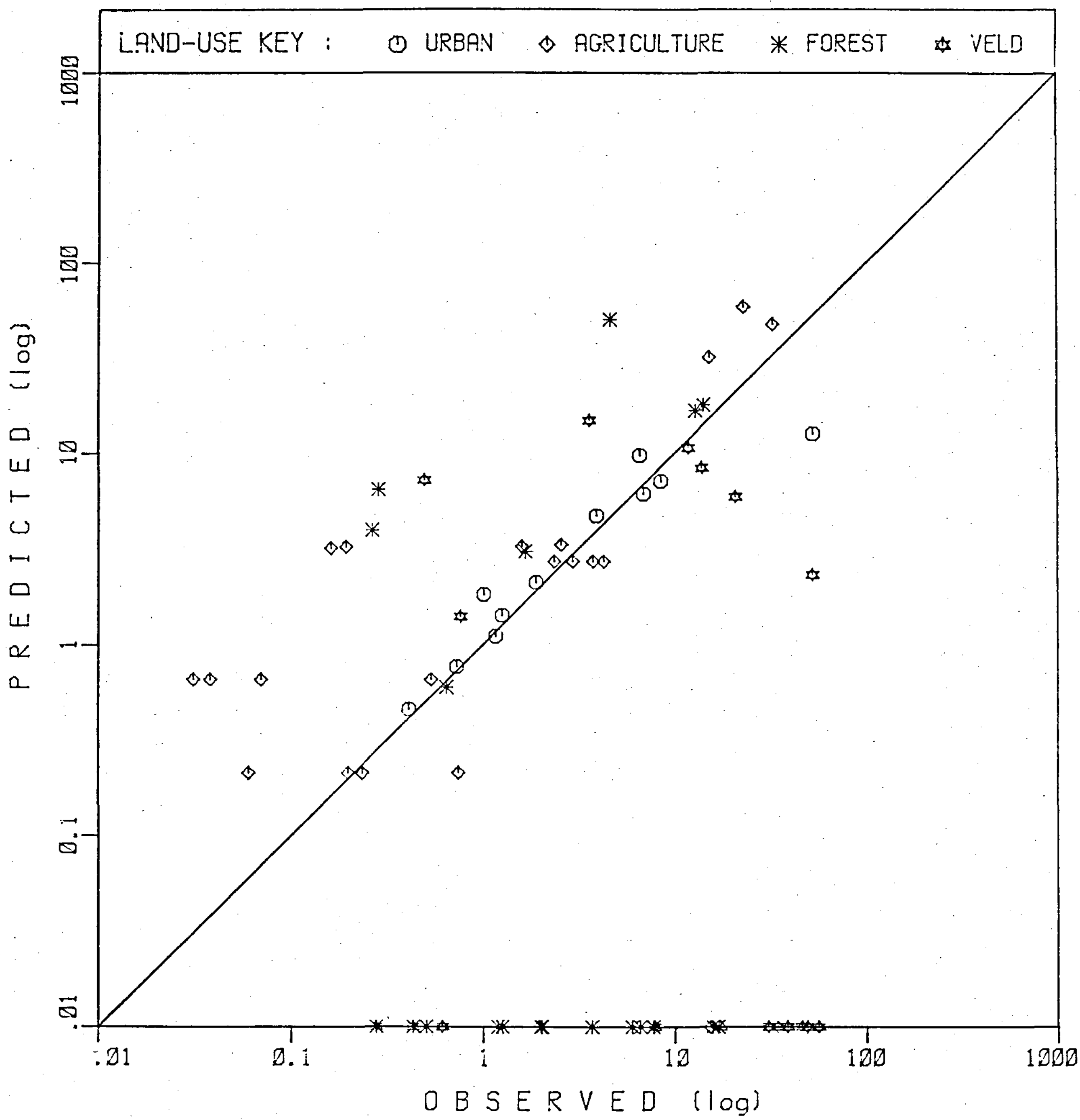

FIG. E 7 : VOLUME (cu.mx10^3) : ILLUDAS

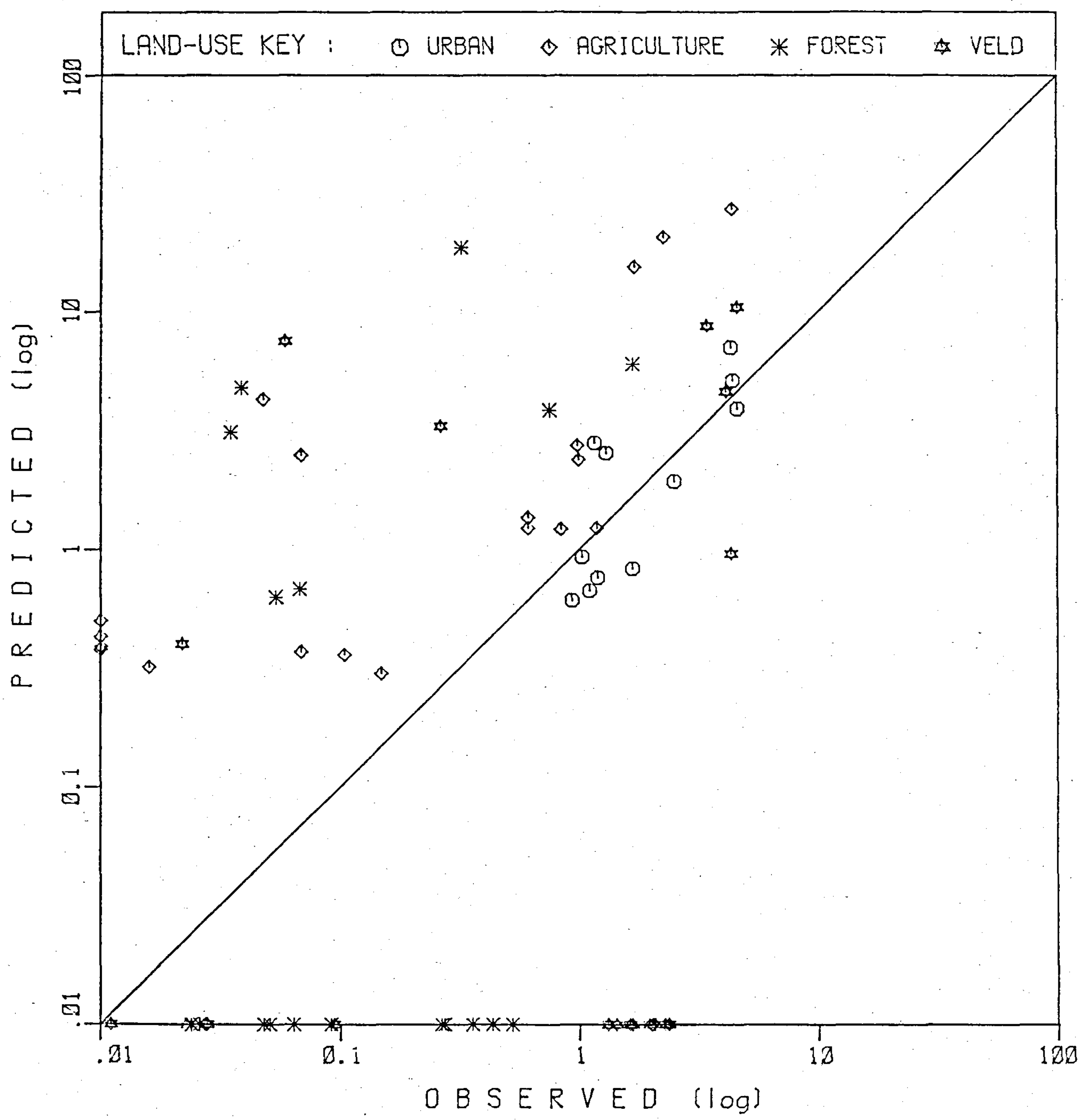

FIG. E 8 : PEAK FLOW (cu.m/s) : ILLUDAS

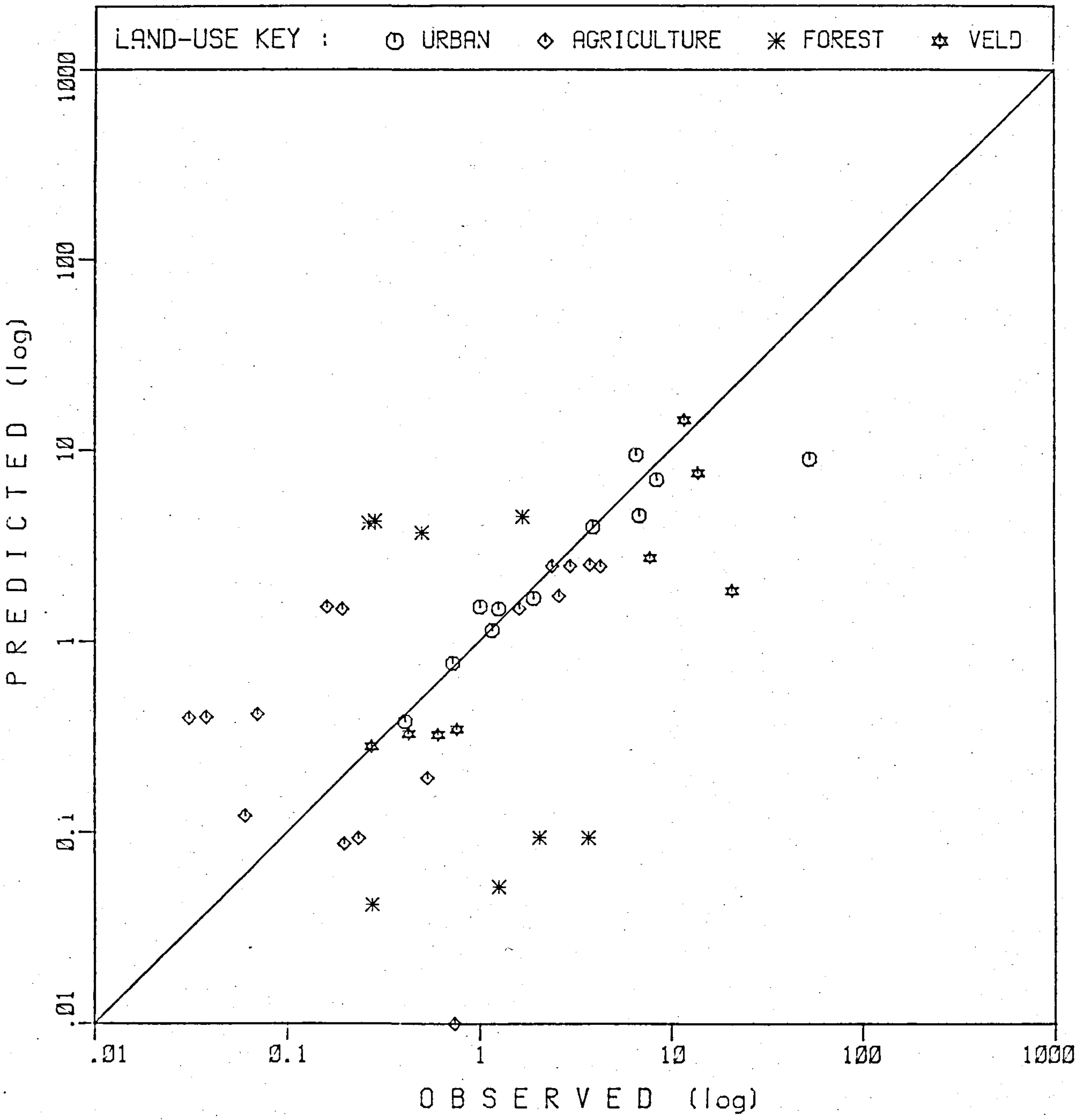

FIG. E 9 : VOLUME (cu.m×10^3) : WITWAT

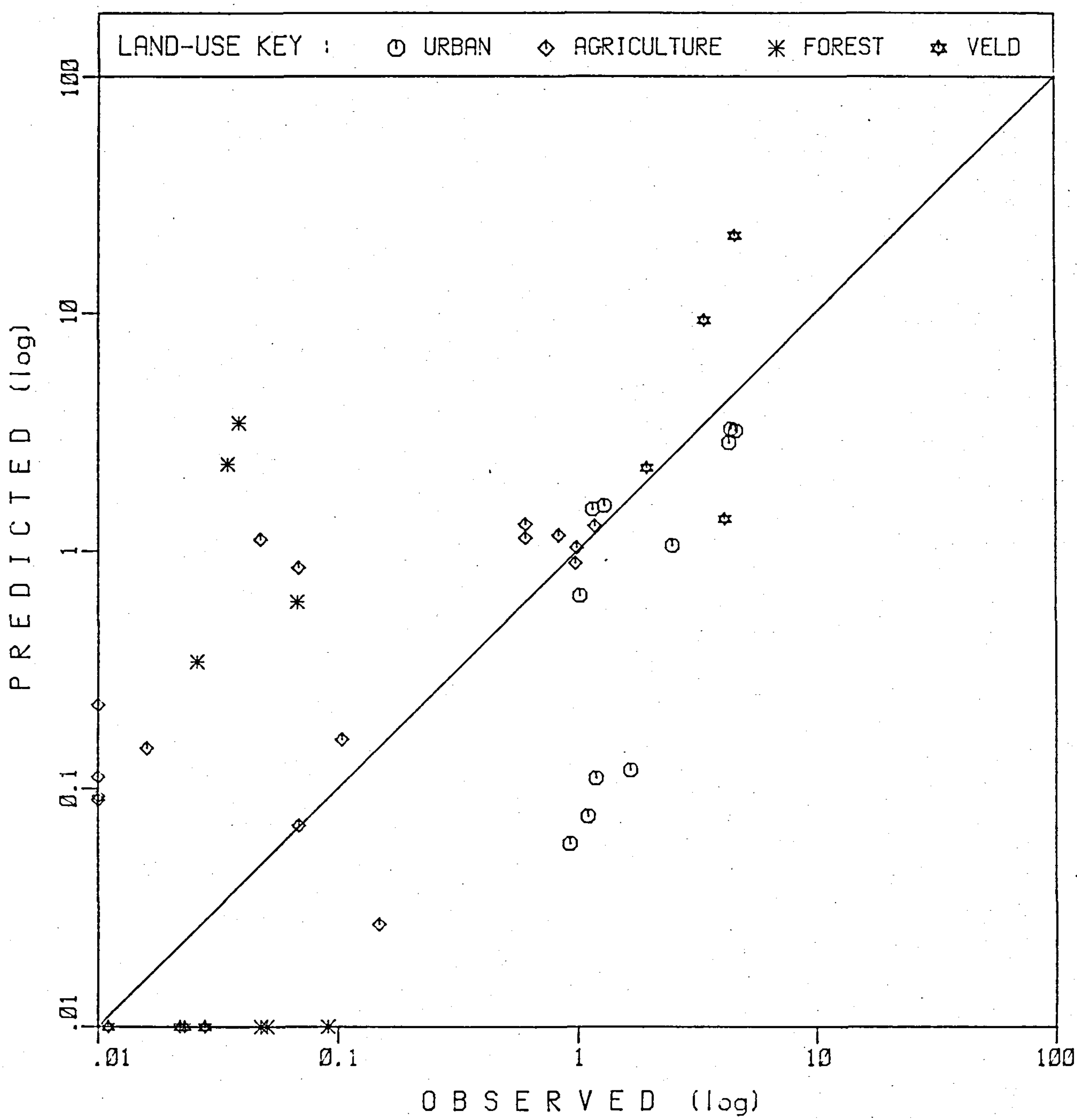

FIG. E 10 : PEAK FLOW (cu.m/s) : WITWAT

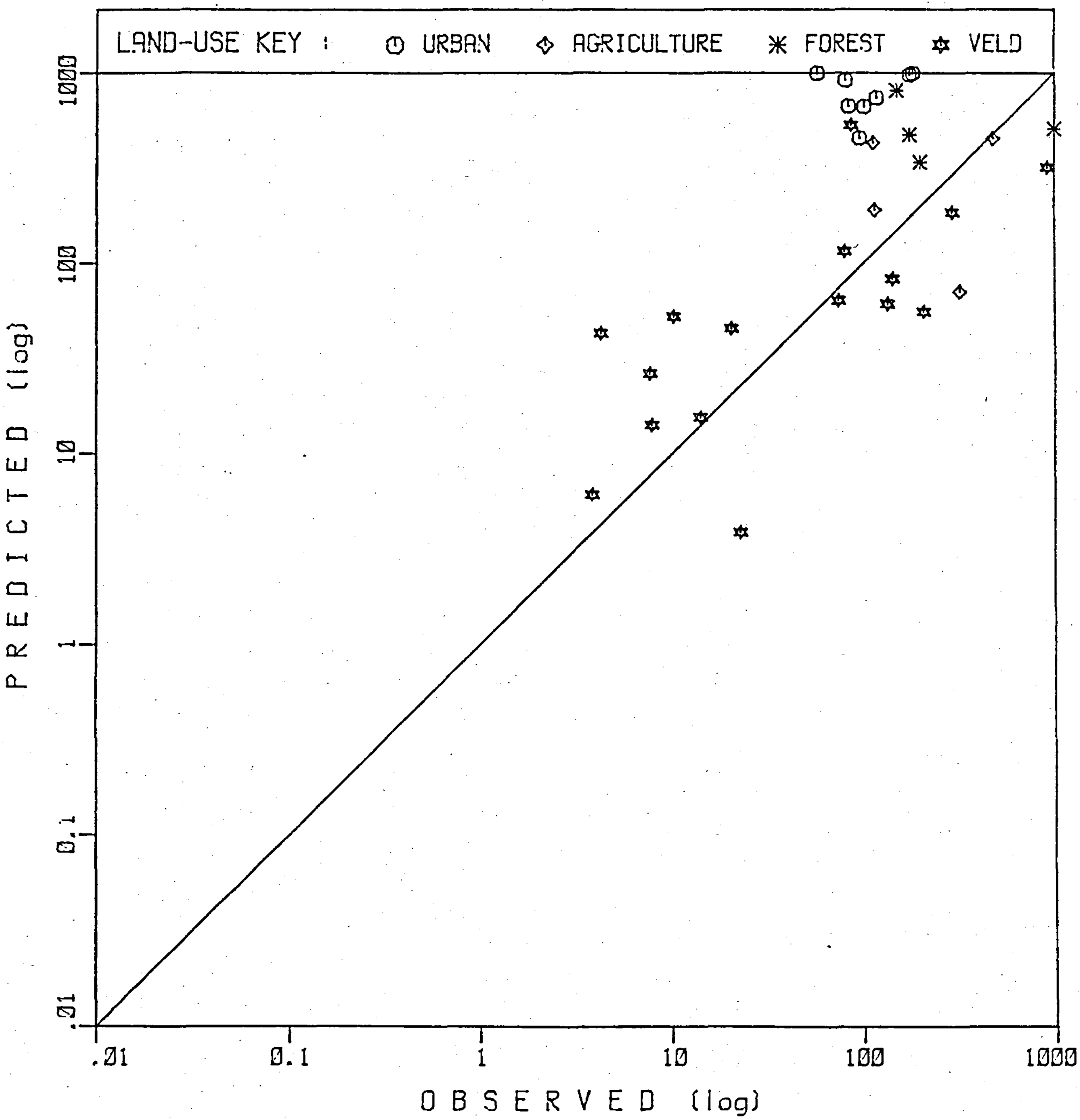

FIG. E 11 : VOLUME (cu.mx10^3) : HDYP01

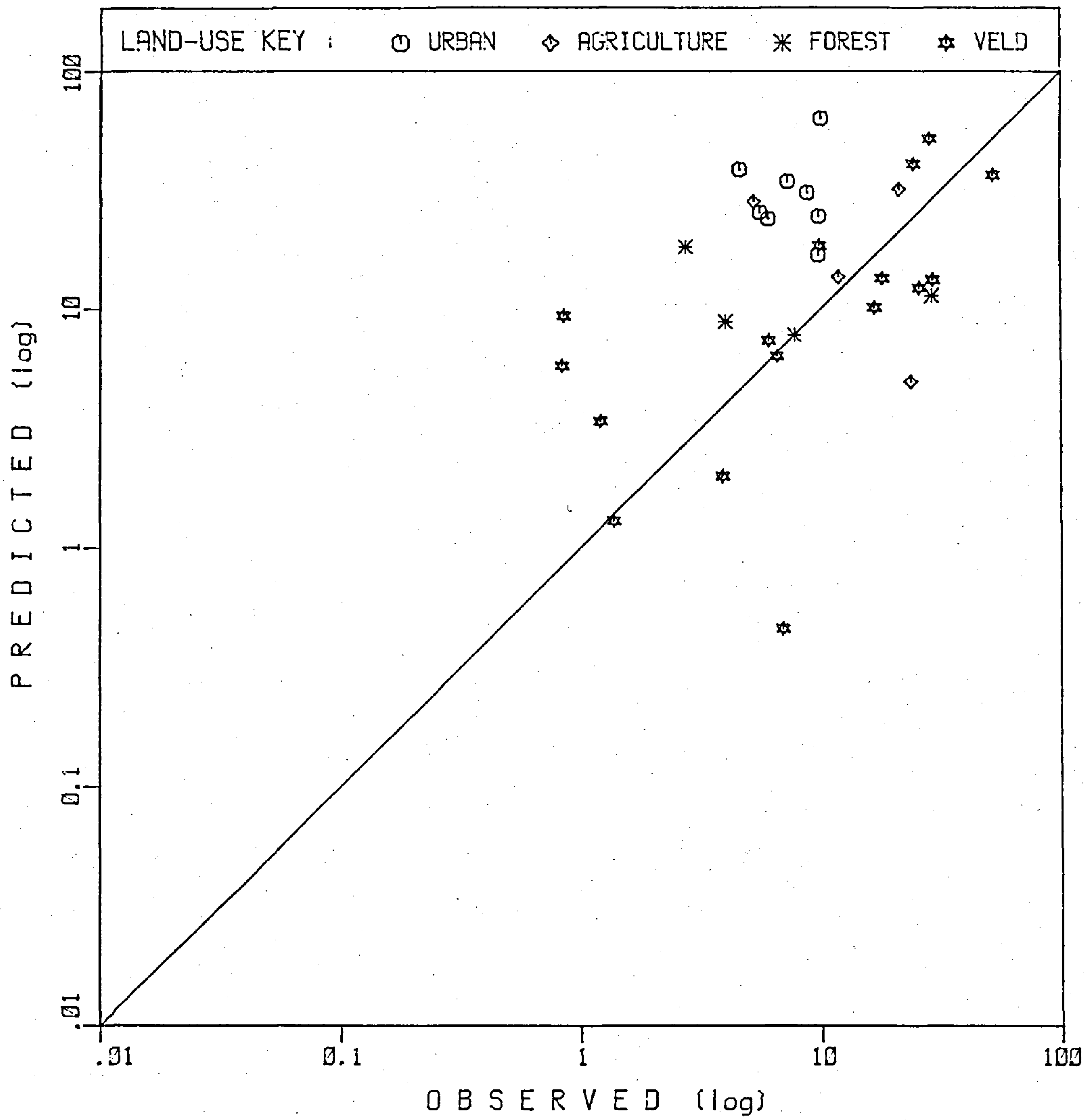

FIG. E 12 : PEAK FLOW (cu.m/s) : HDYP01

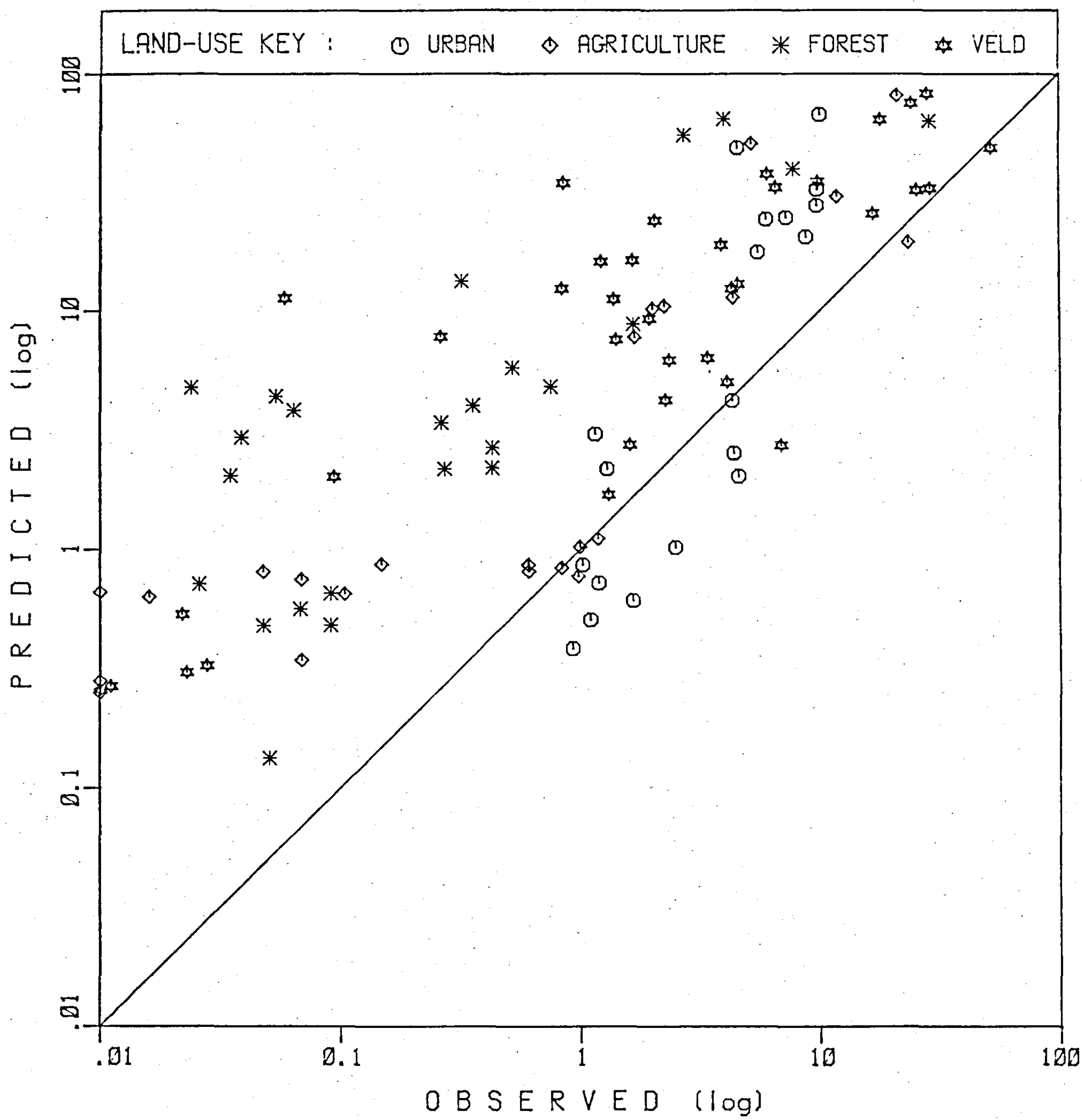

FIG. E 13 : PEAK FLOW (cu.m/s) : RATIONAL

METHOD	STATISTIC	PEAK FLOW (cu.m/sec.)	VOLUME (thou. cu.m.)
RATIONAL	NO OF CATCHMENTS	26	
	NO OF EVENTS	102	
	REGRESSION : A	6.81	
	: B	1.69	
	: R**2	.48	
	STD ERROR	18.65	
SCS - WASHMO (AMC ADJUSTED CN)	NO OF CATCHMENTS	26	26
	NO OF EVENTS	102	102
	REGRESSION : A	-.53	7.48
	: B	.48	.39
	: R**2	.35	.20
	STD ERROR	7.61	167.31
SCS - SA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	26	26
	NO OF EVENTS	102	102
	REGRESSION : A	.13	30.37
	: B	.97	.65
	: R**2	.55	.35
	STD ERROR	7.38	158.76
SCS - USA VERSION (AMC ADJUSTED CN)	NO OF CATCHMENTS	26	26
	NO OF EVENTS	102	102
	REGRESSION : A	-.94	6.57
	: B	.74	.39
	: R**2	.39	.21
	STD ERROR	8.26	164.94
ILLUDAS	NO OF CATCHMENTS	18	18
	NO OF EVENTS	70	70
	REGRESSION : A	.83	3.88
	: B	1.63	.14
	: R**2	.19	.03
	STD ERROR	4.89	17.44
WITWAT	NO OF CATCHMENTS	11	11
	NO OF EVENTS	43	43
	REGRESSION : A	.02	1.62
	: B	1.44	.20
	: R**2	.36	.31
	STD ERROR	2.87	7.60
HDYP01	NO OF CATCHMENTS	8	8
	NO OF EVENTS	32	32
	REGRESSION : A	14.09	402.45
	: B	.42	.14
	: R**2	.10	.00
	STD ERROR	17.31	652.89

TABLE E.1 : REGRESSION STATISTICS (MODELS)

A P P E N D I X   F

STATISTICS - SYNTHETIC RAINFALL DISTRIBUTION