"DETERMINATION OF RAINFALL/RUNOFF MODEL PARAMETERS"

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CERTIFICATION STATEMENT

I hereby declare that the content of this thesis does not comprise any work or material which I have previously submitted for a Degree or other similar award from any other Institute of Technology or University.

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Allan G Goyen B E. MIE. Aust.

ABSTRACT

"DETERMINATION OF RAINFALL/RUNOFF MODEL PARAMETERS"

KEY WORDS: Stochastic-Deterministic, Rainfall/Runoff Models. Joint Probability, Antecedence, Parameters-Field Measurements.

ABSTRACT: Runoff estimates both peaks and volumes are called for in design analysis for the sizing of a wide range of engineering structures. In many instances runoff records are very short or not available and it is necessary to use synthetic rainfall data and apply a rainfall/runoff model to estimate appropriate design hydrographs. This thesis addresses the particular portion of the rainfall/runoff process conversion dealing with the development of excess hyetographs prior to catchment routing and the estimation of the parameters affecting such development. Details are given on field based parameter estimating procedures as well as further model development to better reflect measurable input parameters. A joint probability model linking moisture deficiency criteria prior to an event, rainfall data and measured catchment parameters is developed and applied on Canberra data.

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LIST OF SYMBOLS

A	Subcatchment area in km^2.
A	Transition Probabilities Matrix.
A	Infiltration parameter (cm/min^1)$_2$
Ac	Cross-Sectional area of core (cm^2).
AO,A1	Redistribution Parameters.
API5	Five day antecedent prec. index.
B	Subarea coefficient.
B	Infiltration parameter (cm/min$^{3/2}$).
b_{jik}	Conditional probability of Qo_j given R_i. and M_k.
CAPIMP	Impervious store capacity.(mm).
CWI	Catchment Wetness Index.
C	Rational Method Runoff Coefficient.
DS	Pervious Depression storage.(mm).
DSC	Depression store capacity.(mm).
D	Diameter of soil core.(mm).
D(wet)	Wet density.(g/mm^3) and (g/cm^3).
D(dry)	Dry density.(g/mm^3) and (g/cm^3).
ER	Proportion of transpiration from US.
ECOR	Ratio of Pot. Evap. to A class pan.
f	Dimension of vector Qo.
FIMP	Proportion of catchment that is impervious.
GN	Variable rate groundwater recession factor.
GS	Groundwater storage.(mm).
H	Hydraulic head - dist. from base of core to pondage surface.(cm).
i	Cumulative infiltration.(cm).
ISC	Interception store capacity.(mm).
IAR	Proportion of rainfall intercepted by vegetation.
IDS	Impervious depression storage.(mm).
IS	Interception storage.(mm).
I	Rainfall intensity in mm/hr for a return period fy and duration Ta.
I	Infiltration rate.(mm/hr).
KG	Constant rate groundwater recession factor.
K	Subarea storage delay time in hours.
Ko	Saturated hydraulic conductivity.(cm/min).
L	Length of soil core.(cm).
LSC	Lower soil store capacity.(mm).
LH	Maxrate of water uptake from roots from lower soil store.(mm/day),
LDF	Lower soil drainage factor.
LS	Lower soil storage.(mm).
l	Dimension of vector R.
M_k	Particular value of parameter.
m_k	Probability of M_k.

m	Parameter value.
P(Q)	Peak flow prob. of exceedence.
$p(Q,T_i,R_j,I_k)$	Conditional probability of Q being exceeded given that T_i, r_j and I_k occur.
$p(T_i)$	Probability of T_i occuring.
$p(V_j)$	Probability of V_j occuring.
$p(I_k)$	Probability of I_k occuring.
Q	Instantaneous rate of runoff in m^3/s.
Qw	Volume of water discharged in time t.(cm^3).
Qo	Vector representing probability distribution of output.
qo_j	Probability of Qo_j.
Qo_j	Particular value of output.
qo	Output variable.
Q(fy)	Peak runoff for return period fy years.(m^3/s).
R	Vector representing probability distribution of input.
r_i	probability of R_i.
r	input variable.
R_i	Particular value of input.
S	Main channel slope in %.
S	Sorptivity ($cm/min^{1/2}$).
SO	Sorptivity at zero moisture level.
SMD	Soil moisture deficiency.
t	Time (min).
T	Time of concentration.
Ta	Rainfall intensity averaging time.
(1+U)	Urbanisation factor - equals fraction urbanised.
US	Initial moisture content in upper soil store (mm).
UH	Maxrate of water uptake from roots from upper soil store.
USC	Upper soil store capacity.(mm).
Vt	Total volume of soil sample.(mm^3).
V	Basin storage constant for an assumed linear reservoir.
Ww	Weight of water in soil sample (g).
Ws	Weight of dry soil in soil sample (g).
Wt	Total weight of soil sample (g).
W(Vol)	Moisture content by volume. (%).
W(Wt)	Moisture content by weight. (%).
X) Y).	values related to time in infiltration equ.

CHAPTER 1

INTRODUCTION

This thesis covers the particular area of the rainfall/runoff modelling process dealing with urban and rural runoff estimates used for engineering design purposes.

Rainfall/runoff models have been used extensively in Australia for the estimating of flow peaks and volumes to size hydraulic structures such as bridges, culverts, channels and piped stormwater systems. Methods employed have included simple empirical equations (such as the Rational Formula) , Unit Hydrograph procedures, regression analysis based on regional data and more recently runoff routing techniques based on conceptual catchment storages. The thesis has looked at the latter method and in particular the estimation of design or frequency based runoff magnitudes.

Based on extensive development and use of runoff routing models in a design environment over recent years, it had become apparent that the main inputs needed to correctly develop runoff estimates were the combination of parameters affecting the development of excess rainfall and in turn its appropriate routing through the catchment. Initial catchment wetness or antecedent wetness in urban design procedures had received little documented attention and the combined effects of design rainfall bursts and catchment wetness even less. The definition of appropriate design pre event catchment wetness for urban catchments incorporating different land types and covers as well as artificial watering, has formulated one of the main terms of reference for this thesis.

Although there were a large number of factors and parameters that could affect the runoff response from a given rainfall event, the current work was mainly centred around those affecting the volume of surface runoff and its initial distribution before catchment routing.

In recent years synthetic design storms based on dimensionless temporal patterns for a particular region have been used extensively for the estimation of design hydrographs using rainfall/runoff models. To improve the understanding and implications of this approach this thesis sought to test their general application.

Due to the increasing number of drainage works that have now incorporated artificial storages to promote peak attenuation, runoff volumes have taken on an even more important role requiring a greater emphasis on the proper estimation of those volumes.

The concentration on appropriate design rainfall excesses for use in urban drainage designs was thought to be more applicable in Canberra than some other areas of Australia, for example closer to the coast, due to its lower rainfall regime and higher summer temperatures. The Canberra region can be classed as semi-arid and often has potential for high infiltration rates due to extended dry periods. Inadequate data on appropriate rainfall losses to be applied to a particular frequency runoff event, could very easily lead to significant errors in estimated peak flow rates and volumes.

To extend practical interpretation of input parameters to analytical modelling, a field based data collection and analysis program was included. Several urban catchments were selected in Canberra to act as control and test areas. Long term soil moisture fluctuations and infiltration properties were monitored on a number of these catchments and over different land types and covers. Interfacing studies were carried out to merge the measured data with existing and proposed modelling algorithms.

The following chapters describe the collection of appropriate field data to supplement existing catchment data, and the development of a proposed frequency based excess rainfall model applicable to both urban and rural catchments. Application of the model is presented in a typical design environment.

In particular Chapter 2 discusses the background to this thesis and provides the basis for the terms of reference for the following chapters.

Chapter 3 details the results of field based data generation and discusses the practical application and difficulties associated with this work.

Chapter 4 describes the mechanics of proposed new modelling algorithms with respect to runoff supply and design peaks in urban areas and as well discusses a number of existing methodologies. Details of typical model applications are provided.

Chapter 5 summarises the general findings of the thesis and gives conclusions and recommendations in respect to those findings.

CHAPTER 2

BACKGROUND AND SCOPE OF THESIS

Over the last eight years the author with others (Goyen & Aitken(1976), Henkel & Goyen(1980)) has been responsible for the development and use , in practise , of a number of computer based urban stormwater drainage models. These have been applied in varied hydrologic and hydraulic projects throughout Australia and Papua New Guinea.

The evolutionary process involved in model development has necessitated constant inclusion of new algorithms to meet increased complexities in both analysis and design requirements.

One such rainfall/runoff model co-developed by the author entitled the Regional Stormwater Drainage Model (RSWM) has been used extensively, since its inception in 1974, in both the analysis and design of both urban and rural drainage systems. The RSWM has gained widespread use by a number of private consultants and government organisations in Eastern Australia on both minor and major drainage and flood mitigation projects and has now been developed into an efficient and versatile watershed model appropriate for both design and analysis of urbanised and rural drainage systems.

Through continued use of the RSWM several application shortcomings had come to the author's attention that could not be solved without indepth research and development. A major item related to the specifications of appropriate loss rates for design analyses , particularly when synthetic storms were to be applied. The RSWM in its present form, as with other rainfall/runoff models, requires rainfall losses to be input as raw data. These are entered as either initial and continuing loss rates or decay type loss functions based on input antecedent conditions. Because little data have been available on appropriate losses to be applied in varied design situations, this section of any runoff analysis, under certain circumstances, has placed the accuracy of some runoff estimates in serious jeopardy.

The scope of this thesis was therefore aimed at developing methods whereby appropriate losses could be estimated for particular design runoff events and the incorporation of these methods into models similar to the RSWM.

A brief synopsis of the RSWM as used prior to this thesis has been included below to further clarify the starting position of this thesis.

2.1 Description of RSWM. To design complex stormwater drainage systems, especially those which include flood storage, it is desirable to carry out the calculation by means of a rainfall/runoff model programmed for solution on a digital computer. This approach eliminates much of the repetitive calculations and allows the detailed investigation of many alternatives. The RSWM rainfall/runoff model described in this thesis was originally developed in 1974 to analyse catchments in a proposed new urban growth area near Darwin covering some 85 km^2 and was intended for use in the design and analysis of the trunk stormwater drainage systems. Since that time however the model has undergone extensive development and is now suitable for the analysis and design of urban and rural drainage systems with catchments varying upwards from 25 ha.

Details of the model have been presented by Goyen and Aitken (1976). Figure 2-1 shows a diagrammatic representation of the RSWM which consists of four modules:

(i) A library module which controls the overall operation of the program including most of the data input and the sequencing of calls to the other three modules. Given sufficient computer storage space, any conceivable arrangement of catchment areas, channels and stormwater retarding basins can be modelled.

(ii) A catchment hydrograph module which estimates the runoff hydrograph from a catchment, using Laurenson's non-linear runoff routing model (Laurenson, 1964). The module operates on a rainfall excess hyetograph which is derived from either an actual rainfall or a synthetic design storm hyetograph and losses calculated using initial and continuing units or Philip's (Philip, 1957) infiltration equation. The catchment storage delay parameter for Laurenson's equation may be calculated from the catchment area, catchment slope and degree of urbanisation using a regression equation derived by Aitken (1975).

(iii) A channel routing module which routes estimated runoff hydrographs along the channels using the Muskingum-Cunge procedure (Price, 1973) or, alternatively, simple lagging of the peak flow by translating the hydrograph in time. Lateral inflow to the channel is included in the procedure.

(iv) A reservoir routing module which routes an inflow hydrograph through a retarding basin or ornamental storage using a level pool routing procedure. The stage/discharge relationship may be calculated within the program by hydraulic equations for a circular pipe outlet and a high level spillway. The stage/storage relationship may be approximated by an exponential equation. Alternatively, either or both of these relationships may be input as a set of known points on a curve.

The hydrograph module of the RSWM utilises the following equations to estimate the storage delay time in the non-linear model:

$$K = BQ^{-0.285} \tag{2-1}$$

$$B = 0.285A^{0.520}(1.0+U)^{-1.972}S^{-0.499} \tag{2-2}$$

K = sub-area storage delay time in hours

Q = instantaneous rate of runoff in cubic metres per second at the headwater

B = the sub-area coefficient

A = subcatchment area in square kilometres

S = main channel slope in percent

(1.0+U) = an urbanisation factor.

The urbanisation factor "U" varies from zero for a rural catchment to unity for a fully urban catchment.

The output from the RSWM includes, for each subcatchment:

(i) A summary of subcatchment and rainfall data.

(ii) A summary of flow peaks, storage volumes and water levels.

(iii) The complete details of the outflow hydrographs and water levels in a retarding basin.

(iv) A graphical plot of all computed hydrographs.

Of the several modules making up the RSWM the most significant one likely to effect the outcome of a watershed analysis is the one controlling hydrograph generation.

As described above the hydrograph generation module of the RSWM uses Laurenson's runoff routing algorithms (Laurenson, 1964) with additional regression coefficients to allow for catchment urbanisation developed by Aitken (1975).

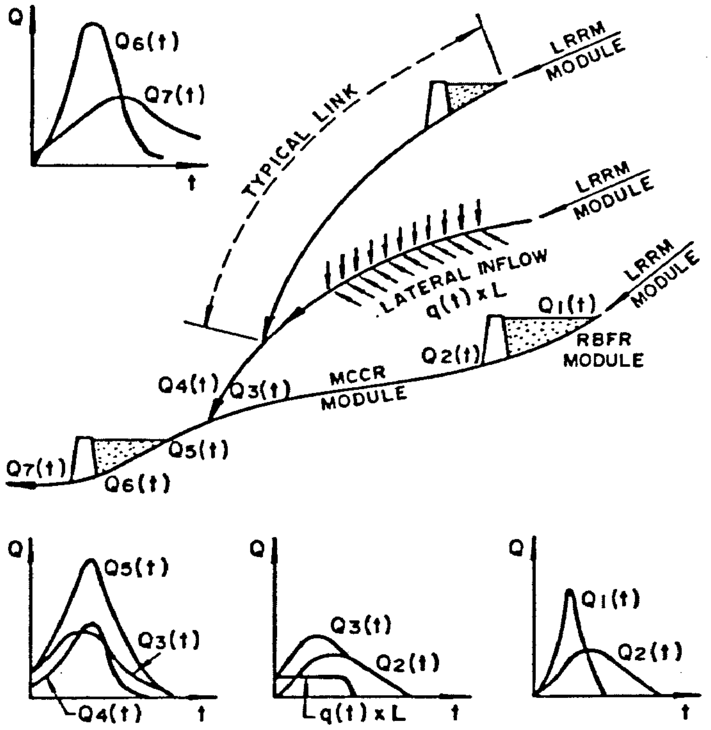

Q
Q6(t)
Q7(t)
t
TYPICAL LINK
LRRM MODULE
LRRM MODULE
LATERAL INFLOW
q(t)×L
Q1(t)
LRRM MODULE
RBFR MODULE
Q2(t)
MCCR MODULE
Q4(t)
Q3(t)
Q5(t)
Q7(t)
Q6(t)
Q
Q5(t)
Q3(t)
Q4(t)
t
Q
Q3(t)
Q2(t)
q(t)×L
t
Q
Q1(t)
Q2(t)
t

FIGURE 2-1. Diagrammatic Sketch of RSWM

Whether the RSWM is being used to analyse an historic event by simulation or to produce a design hydrograph using a synthetic storm, it first calls for the separation of excess rainfall from the total storm input. When analysing an historic event this can often be achieved by abstracting volume data from gauged rainfall and runoff charts. In a design mode, however, it is necessary to estimate appropriate loss rates for the type of storm under consideration and the particular catchment under study.

Unfortunately this often designated "simple" first step in the hydrograph generation process is far from simple. Depending on antecedent conditions and spatially averaged infiltration parameters , as well as the frequency of the storm, a poor estimate can very often influence the final peak and volume of the resulting hydrograph far more than any other subsequent step.

The continued development of this module particularly relating to catchment data for the development of rainfall excess is described in subsequent chapters of this thesis.

The Regional Stormwater Model (RSWM) is structured similarly to the Stanford Watershed Model described by Crawford and Lindsay (1966) and Larson (1965) in as much as it includes both land and channel phases. Figure 2-2 indicates a typical watershed breakup for analysis by the RSWM.

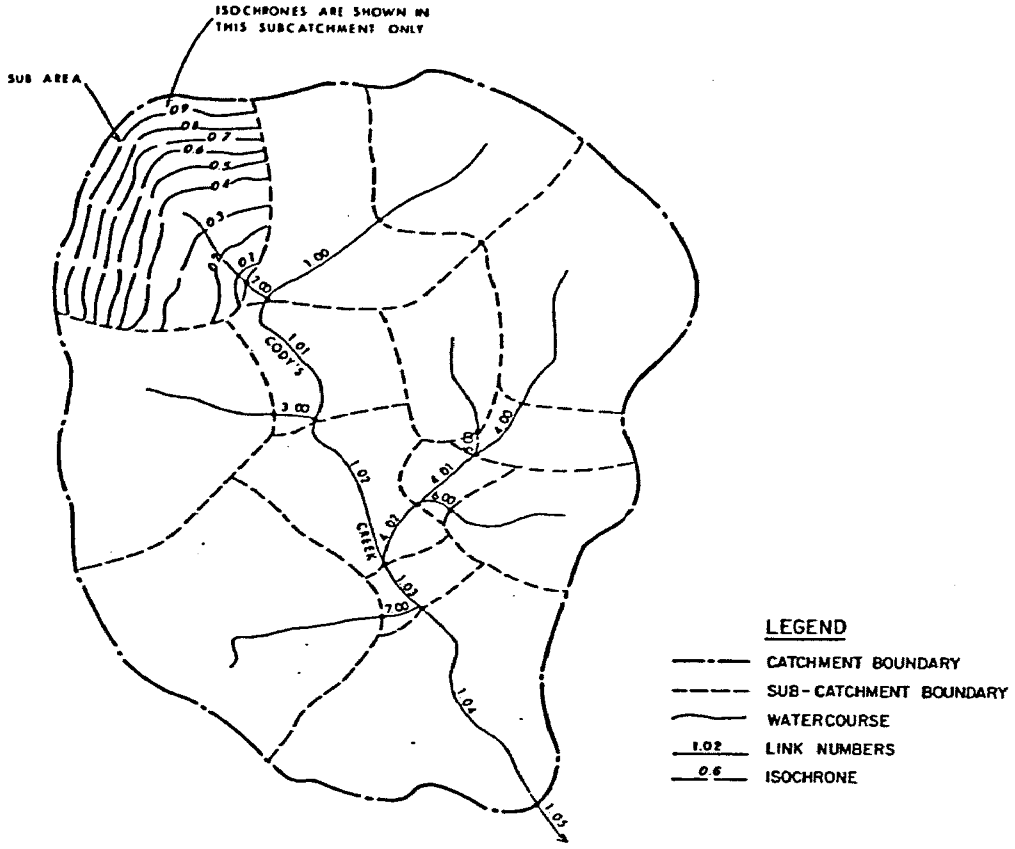

ISOCHRONES ARE SHOWN IN THIS SUBCATCHMENT ONLY
SUB AREA
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.00
2.00
1.01
CODY'S
3.00
1.02
CREEK
4.00
5.00
4.01
6.00
4.02
1.03
7.00
1.04
1.05
LEGEND
CATCHMENT BOUNDARY
SUB-CATCHMENT BOUNDARY
WATERCOURSE
1.02 LINK NUMBERS
0.6 ISOCHRONE

FIGURE 2-2. Typical Watershed Breakup for Analysis by RSWM

In principle the total study area is divided into subcatchments so that outlet nodes are located at points where flow estimates are required. Each subcatchment is then considered and analysed in isolation with outlet hydrographs transposed between nodes via appropriate main channel routing.

Subcatchment analysis, being the nucleus of the model, is approached as a two phase system. Firstly a land phase is included whereby rainfall excess or runoff supply is estimated then secondly a channel phase is applied for routing of rainfall excess through ten conceptual storages made up from isochronal areas to achieve a total runoff hydrograph at the outlet of the subcatchment.

The subcatchment channel phase therefore includes both overland flow and minor channel and pipe contributions. The total watershed analysis, considering the interconnection of the individual subcatchments, requires a second or major channel phase based on defined channel hydraulics.

It was proposed in this thesis to concentrate on the land phase of the RSWM in an urban environment principally at the subcatchment level.

It is well documented (Wittenburg, H.(1975)) that urban stormwater systems and rural runoff respond very differently to a similar storm event. In most modern day urban drainage systems there would appear to be broadly two separate runoff segments, ie. from the impervious areas and pervious areas respectively. These become fused together to provide the total runoff hydrograph at particular points in the system.

To take the analysis one step further however, it was also proposed to divide the land and minor channel phases into their pervious and impervious component parts, analyse separate hydrographs then superimpose these prior to any major channel phase to test the appropriateness of such actions.

The latter work was included to test the applicability or otherwise of using lumped models, usually associated with rural catchments, in an urban environment. Also it was necessary to ascertain the representative influences of both the impervious and pervious components of urban flows throughout the frequency range and urban land types.

The current edition of "Australian Rainfall and Runoff Flood Analysis and Design" (ARR, 1977), Chapter 8 contains a discussion on 'Initial and Continuing Losses'. In this, some discussion is provided on the selection of design values, however, apart from stating the various factors influencing them, it gives only general values for typical design situations. Initial losses are described as 'extremely variable, having a range from around zero to more than 50 mm'.

In urban stormwater drainage designs the normal range of storm events usually considered do not exceed two hours in duration.In Canberra, a total of 50 mm of rainfall corresponds to a once in 500+ year for a 15 minute storm or a once in 200+ year for a 30 minute storm or a once in 100 year for a 1 hour storm. As can be appreciated all of the stated storm bursts as well as variations in between fall beyond the normal range used in urban design analyses. With the vast extremes suggested for initial losses, without even considering continuing losses, it is not surprising that the generation of significant pervious runoff under a number of circumstances could be questioned. Conversely, a range of other meteorological and catchment circumstances could cause significant pervious runoff.

Added to the above discussion there was a very real problem of assigning appropriate losses to design storm bursts rather than total storms. Design storm bursts (design storms) are derived on a statistical basis from a long period of pluviograph record representative of a study area. Significant bursts of varying durations are accumulated from the record and mean dimensionless temporal patterns deduced. Such bursts can consist of the total storm or be imbedded within the event.

Assigning loss rates to design storms took on the added problem of assigning appropriate pre-storm burst wetness or average catchment antecedent wetness immediately prior to the start of the design burst. Chapter 3 in ARR 1977 gives typical temporal patterns of rainfall bursts for various locations in Australia based on long term continuous rainfall data. The use of such data has gained widespread acceptance in drainage design work and as such the question of appropriate losses needed urgent resolution.

Some Australian work has been carried out on this aspect notably by Laurenson & Pilgrim (1963), Pilgrim (1966), Cordery & Webb (1974) and Cordery (1970). Cordery studied 42 years and 32 years of rainfall records at Sydney and Griffith, N.S.W. respectively. He showed that antecedent wetness was an important factor in assigning initial losses to design storms particularly in areas where the mean annual rainfall was significantly less than 1200 mm.

Cordery developed a procedure to estimate a median antecedent precipitation index (API) prior to a design storm burst by relating the difference in catchment wetness occurring between the 9 a.m. estimate via normal API calculations using 24 hour rainfall data and the start of the design burst.

The API was then related to potential initial loss by an expression based on observed rainfall and runoff data for 14 rural catchments in eastern New South Wales.

The current thesis has carried on in a similar vein to Cordery's work making use of 45 years of continuous pluviograph record at Canberra in conjunction with a variable time water balance model to develop statistical antecedent relationships for several types of urban land domains.

To cover the significant factors that affect loss rate estimates on urban catchments the current thesis proposed to examine existing analytical estimating techniques with the view to adopting or developing suitable methods for use in urban design procedures. It was also proposed to review, adopt and devise suitable field data collection techniques to collect additional data for this thesis as well as provide data collecting guidelines for similar studies in other regions and land domains.

It was anticipated that relatively simple and rapid field data collection methods may be developed for adoption into regular stormwater drainage design exercises.

The following Chapter details the results of field based data generation and discusses the practical application and difficulties associated with this work.

CHAPTER 3

FIELD DATA COLLECTION AND ANALYSIS

3.1 Introduction

The original scope of the data collection and analysis program was not constrained by any predetermined ideas but ultimately because of funding and time constraints was limited to a number of specific experiments aimed at providing fundamental input data for loss rate determination on the catchments studied.

The major elements of the program in summary form included work;

(i) to measure long term variations in soil moisture occurring specifically in the top 300 mm profile in different Canberra urban land domains;

(ii) to define infiltration parameters for the land domains being studied;

(iii) to determine the make up of typical urban watersheds and the interaction of the various domains including the relative significance of impervious and pervious areas as the major subgroups of a catchment.

Canberra has several well gauged urban and rural catchments. Instrumentation includes pluviographs, stage recorders to monitor runoff, ancillary daily rainfall recorders and on one urban catchment water quality recorders.

The present gauging network was funded by the National Capital Development Commission and is maintained and operated by the Department of Housing & Construction and as such provides high quality data collected by skilled and dedicated hydrographers.

The catchments addressed in this thesis are at Giralang and Gungahlin in the town of Belconnen in the northwest sector of Canberra, at Mawson in the Woden Valley immediately south of Canberra City and the northern slopes of Black Mountain immediately adjacent to Canberra city.

The locations of these catchments are shown on Figure 3-1.

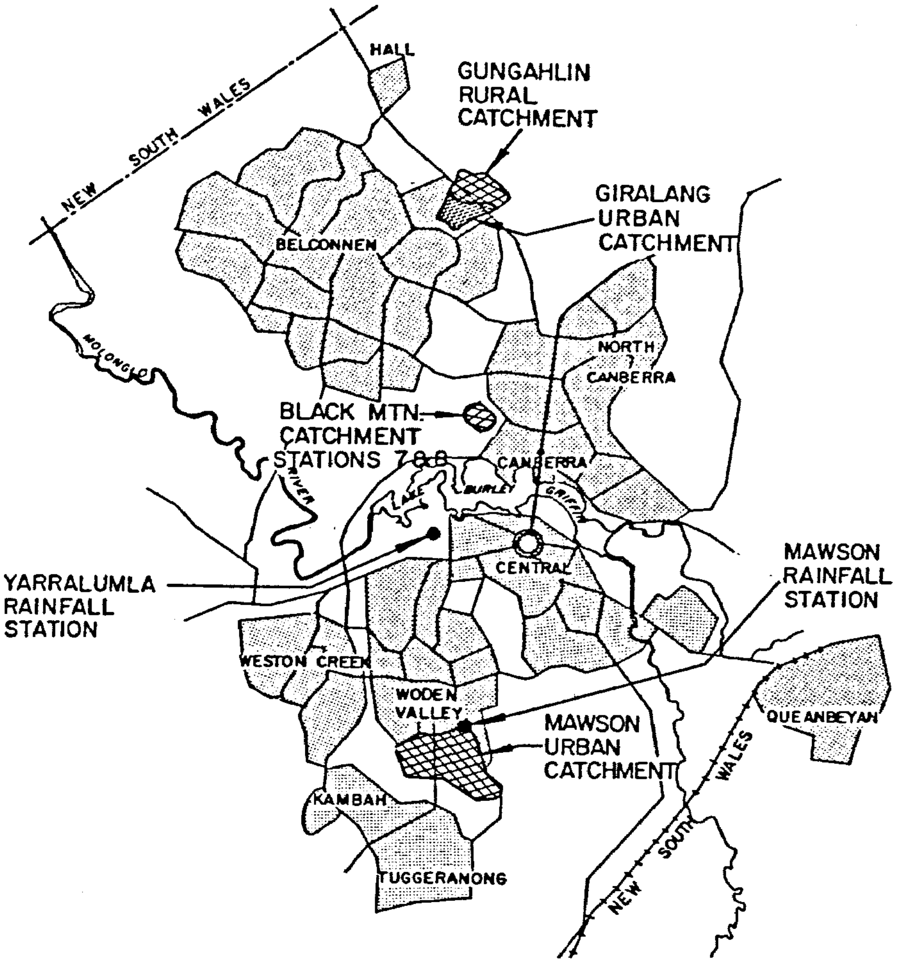

HALL
GUNGAHLIN RURAL CATCHMENT
NEW SOUTH WALES
GIRALANG URBAN CATCHMENT
BELCONNEN
NORTH CANBERRA
MOLONGLO
BLACK MTN. CATCHMENT STATIONS 7&8
CANBERRA
LAKE BURLEY GRIFFIN
RIVER
CENTRAL
MAWSON RAINFALL STATION
YARRALUMLA RAINFALL STATION
WESTON CREEK
WODEN VALLEY
QUEANBEYAN
MAWSON URBAN CATCHMENT
KAMBAH
TUGGERANONG
NEW SOUTH WALES

FIGURE 3-1. Location of Canberra Study Catchments.

Both the Giralang and Mawson catchments are for all practical purposes fully built up and represent typical Canberra type urban catchments. They have fully sealed roads with kerb and gutter, are fully sewered and have roof drainage directly connected to the piped drainage system. Planning and development in both areas occurred in close sympathy with the natural drainage lines and both a pipe drainage system to take flows up to about the once in 5 year level, together with an overland flow path over public land to protect private property from rarer flooding was provided.

Figures 3-2 and 3-3 indicate the two urban catchments. A description of the type of drainage systems (both minor and major) used and the general drainage policies adopted in Canberra have been given by Higgins & Mills (1975) and Henkel & Goyen (1980).

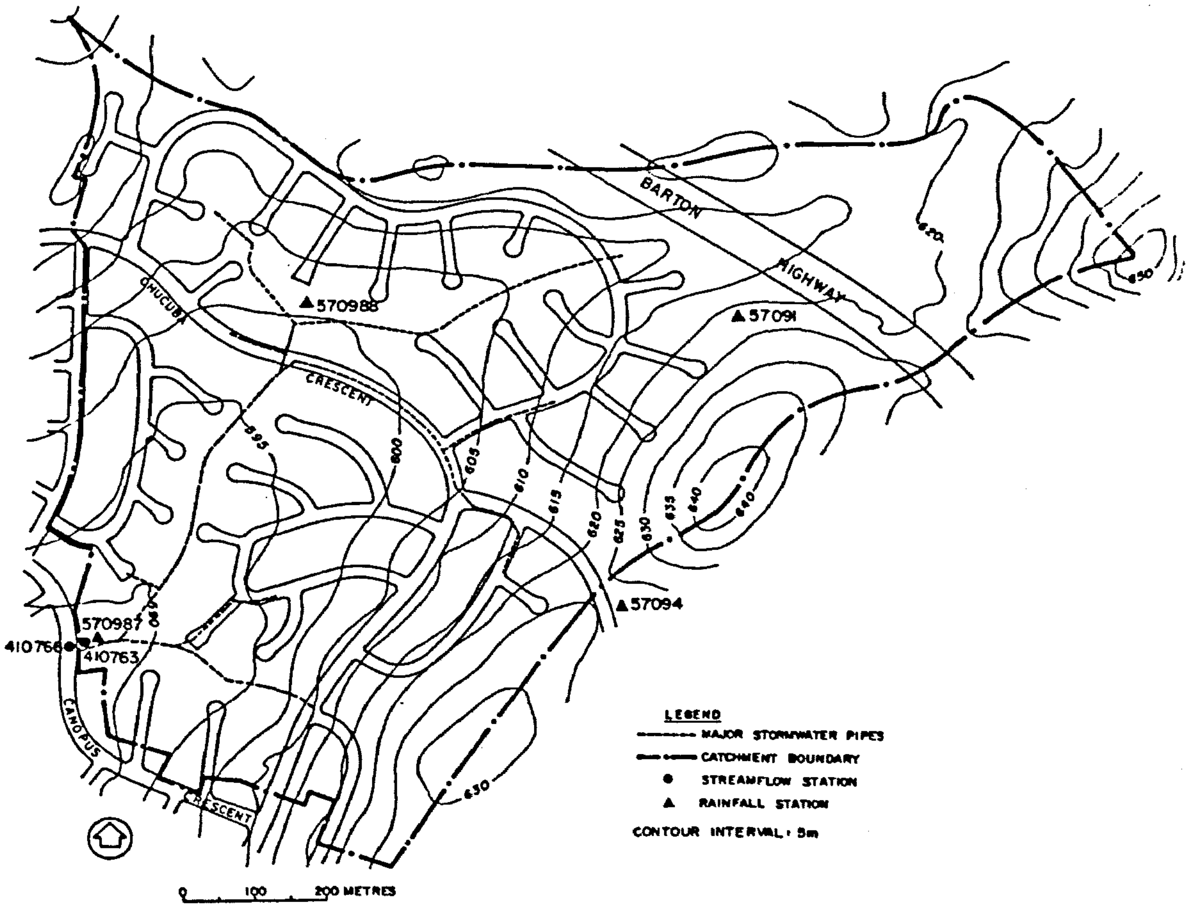

BARTON
HIGHWAY
CHUCUBA
CRESCENT
CANOPUS
CRESCENT
570988
57091
57094
570987
410766
410763
595
600
605
610
615
620
625
630
635
640
640
650
620
630
640
LEGEND
MAJOR STORMWATER PIPES
CATCHMENT BOUNDARY
● STREAMFLOW STATION
▲ RAINFALL STATION
CONTOUR INTERVAL: 5m
0
100
200 METRES

FIGURE 3-2. Giralang Urban Catchment.

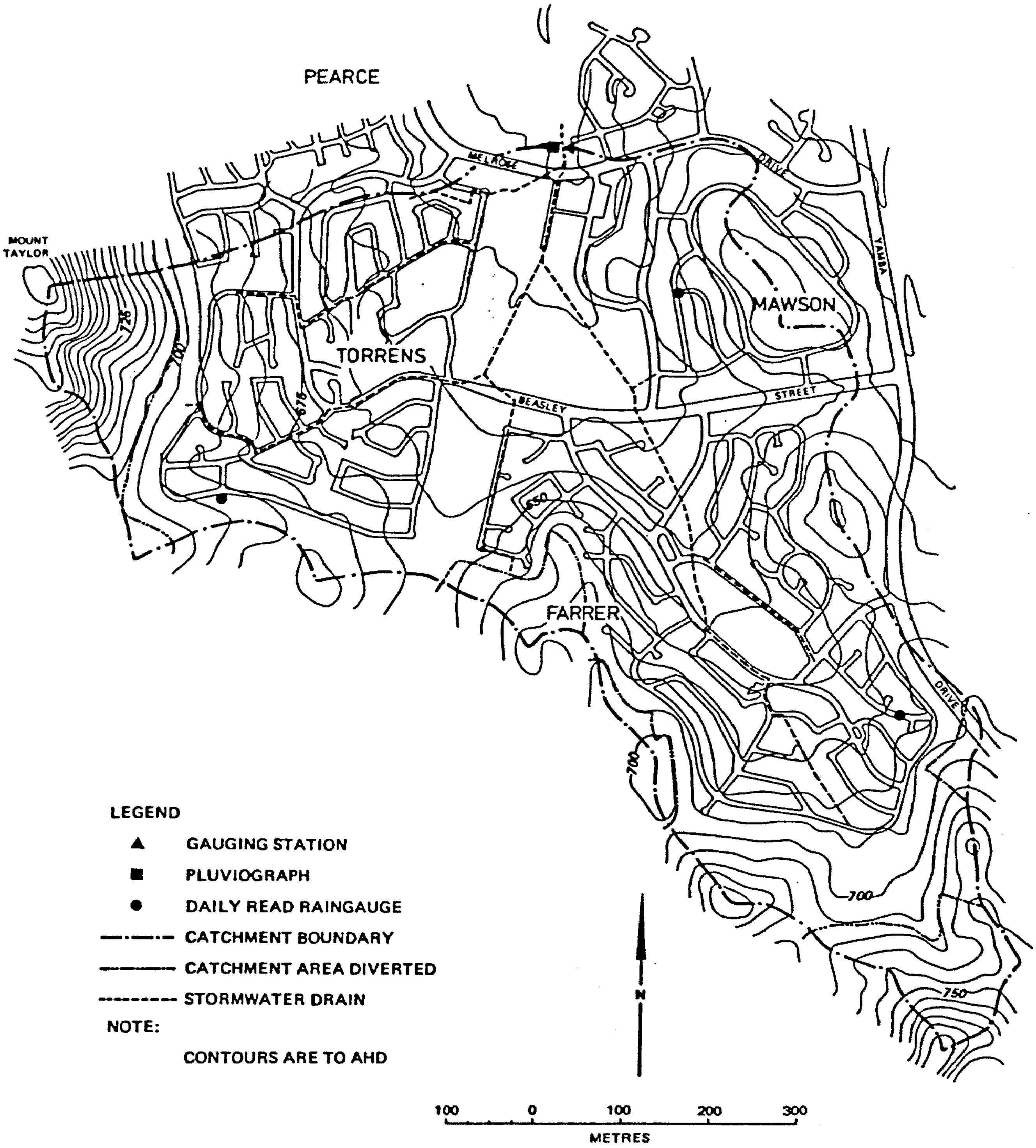

PEARCE
MOUNT TAYLOR
MELROSE
DRIVE
YAMBA
MAWSON
TORRENS
BEASLEY
STREET
FARRER
DRIVE
725
700
675
650
700
700
750
LEGEND
▲ GAUGING STATION
■ PLUVIOGRAPH
● DAILY READ RAINGAUGE
—·—·— CATCHMENT BOUNDARY
———— CATCHMENT AREA DIVERTED
-------- STORMWATER DRAIN
NOTE:
CONTOURS ARE TO AHD
N
100
0
100
200
300
METRES

FIGURE 3-3. Mawson Urban Catchment.

Additionally at Giralang a rural catchment adjacent to the urban catchment is gauged to provide additional data. A full description of the paired catchment gauging network is given in NCDC's Technical Report 29.(1980) This catchment is shown on figure 3-4.

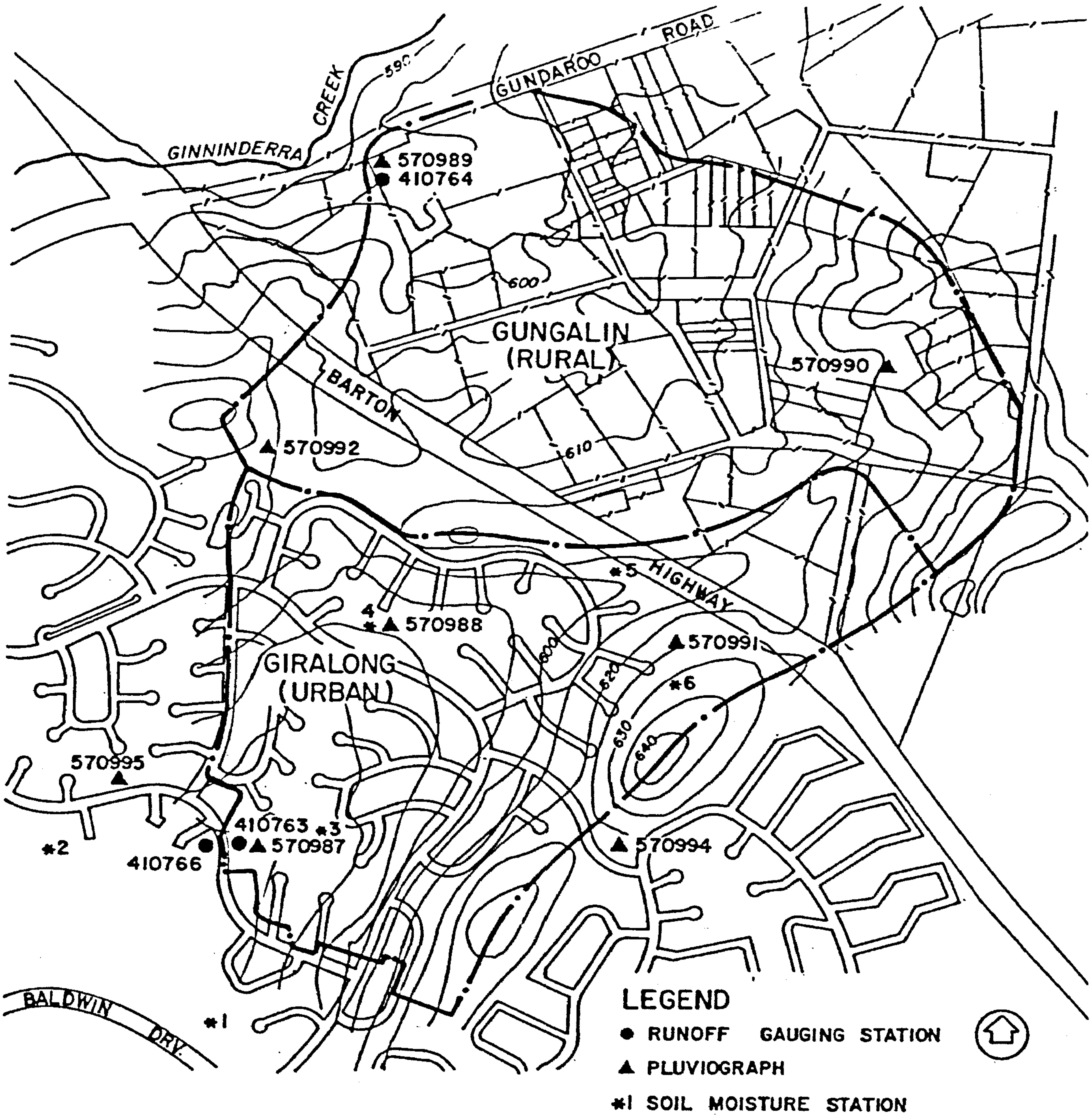

GINNINDERRA
CREEK
590
GUNDAROO
ROAD
▲ 570989
● 410764
600
GUNGALIN
(RURAL)
BARTON
HIGHWAY
570990 ▲
▲ 570992
610
*5
4
*▲ 570988
▲570991
GIRALONG
(URBAN)
600
620
*6
630
640
570995
▲
410763
*3
●▲ 570987
*2
●
410766
▲ 570994
BALDWIN
DRV.
*1
LEGEND
● RUNOFF GAUGING STATION
▲ PLUVIOGRAPH
*1 SOIL MOISTURE STATION

FIGURE 3-4. Giralang and Gungahlin Paired Catchments.

The main objective of the field work program was not only to provide input data to the current research but also to test the validity of expending additional funds on field measurements on other study catchments prior to hydrologic analyses or designs.

Specifically, the Giralang urban catchment was used as the base catchment where most field measurements were carried out. The Mawson catchment was used as a comparative test cachment on which to test the transferrability of data from the Giralang catchment to other typical urban catchments in the region.

Limited field data was also collected from the Black Mountain Reserve area to gather information on native forested areas which are fairly common on the surrounds of urban watersheds within the region.

The following briefly summarises the hydrologic data made available during the course of the thesis:

- Pluviograph data from the Yarralumla Forestry Research Station is shown on Figure 3-1 for the complete years 1933 through 1961 and 1966 through 1970.
- Pluviograph data at the outlet of the Giralang urban study catchment for years 1976 through 1979.
- Pluviograph data at the outlet of the Gungahlin rural study catchment for years 1976 through 1979.
- Pluviograph data at the city gauge adjacent to the Black Mountain soil moisture stations 7 and 8 for the years 1979 through 1980.
- Pluviograph data at the outlet of the Mawson creek catchment for the years 1972 through 1980. (Data not fully processed at the time of this Thesis.)
- Continuous runoff data at the Gungahlin rural catchment outlet for the complete years 1976 through 1979.
- Continuous runoff data at the outlet of the Mawson urban catchment for the complete years 1972 through 1980. (All data had not been processed at the time of this Thesis.)

3.2 Study Catchments

3.2.1 Giralang and Gungahlin.

The Giralang urban catchment indicated on Figures 3-2 and 3-4 formed the main study catchment used in this thesis. It has a total area of 94 hectares including 24 hectares of impervious surfaces and 32 hectares of predominantly indigenous soil unirrigated grassland. The residue 38 hectares consists of urban residential pervious areas made up of lawns and gardens with, predominantly, imported topsoils.

Indigenous areas have native grass cover similar to the sister Gungahlin rural catchment with some imported species, predominantly chewings fescue and ryes sown in the areas adjacent to residential lots.

Grasses common on residential lots are chewings fescue, couch, kentucky blue and various species of clover. Root depths are usually limited to less than 50 mm.

Native soil types consist basically of red podzolic on the upper slopes and yellow podzolics on the lower slopes of the catchment.

The 'A' horizon native topsoils or root zone consists mainly of sandy clay to clayey-sand of low plasticity which varies in thickness from virtually zero on some of the upper slopes where the weathered rock is exposed, to 400 mm at the bottom of the catchment close to ephemeral water courses.

Imported topsoils vary considerably in nature, from light sandy-clays to puggy organic clays depending on the area of procurement. Included in the appendix are engineering logs taken at six locations in the catchment as indicated on Figure 3-4. A detailed description of the Giralang gauging network is given in Technical Paper No. 29 published by the National Capital Development Commission, 1980.

Instrumentation, as described in the above document, consists of a runoff recording station at the outlet of the catchment consisting of a sloping crest crump weir to measure flows in the pipe system and an additional cut throat flume incorporated in a walkway underpass to measure excess overland flows up to at least the once in 100 year flow. Also included are five rainfall stations either in or just outside the catchment area consisting of various types of pluviographs capable of monitoring variations in storm patterns across the catchment. Additionally two rainfall stations are located within the adjacent rural Gungahlin catchment no more than 600 metres north of the Giralang catchment border. The location of all gauges are shown on Figure 3-4.

Urbanisation of the Giralang catchment was commenced in 1974 and was completed by late 1976. Tree planting was progressively implemented from early 1976 and was virtually complete by late 1977.

Rainfall and runoff data was made available for the years 1976, 1977, 1978 and 1979 on both the Gungahlin rural and Giralang urban catchments for use in this thesis.

The sister Gungahlin rural catchment as shown on Figure 3-4 has a total area of 112 hectares and is part of the CSIRO's experimental farm. As such its paddocks are better maintained than on the average grazing property in the region, hence the catchment probably relates to the dry grass areas in the adjacent urban area more than typical rural areas.

The Gungahlhn rural catchment was used principally to help isolate pervious and impervious runoff in the adjoining urban catchment and to help calibrate the water balance model parameters through rainfall/runoff simulation described in Chapter 4.

3.2.2 Mawson. The Mawson urban catchment indicated on Figure 3-3 formed the proving catchment in this thesis. It has an area of 445 hectares including 115 hectares of impervious surfaces, 320 hectares of dry grass and residential lawn area and 10 hectares of irrigated non-residential area.

The catchment's average slope is 2.5% and the general soils and grass covers appear to be reasonably similar to tie Giralang catchment with the geology of the area from the Upper Silurian period made up of the Deakin volcanics.

Instrumentation on this catchment started in 1971, and entails a runoff recording station at the outlet of the catchment consisting of a stage level recorder situated in a lined open channel, a rainfall recording station also at the outlet and several daily rainfall gauges situated within the catchment.

Urbanisation of the Mawson catchment commenced in the early 1960s and was predominantly completed by 1970. Some isolated infill areas have been developed on a progressive basis up to the present, however these would account for less than 5% of the total catchment area.

3.2.3 Black Mountain Reserve. Black Mountain is situated immediately adjacent and to the west of Canberra city, see Figure 3-1, and contains approximately 500 hectares of natural forest, predominantly eucalypts. The total area has been retained as a nature reserve and is typical of a number of the higher areas covering the upper portions of catchments with highly urbanised areas on the lower slopes.

The geology of the mountain is mainly from the middle to the Upper Ordovician and is classified as the Pittmen formation Action shale member.

This generally consists of shale, mudstone, sandstone, siltstone, radislarian cherts and some areas of black siliceous graptolitic slate.

Topsoils over the mountain are virtually non existent with mainly decomposed and broken rock combined with silty, sandy gravels mixed in the root zone for some 100 to 300 mm over more solid rock.

A thin layer of litter covers most of the surface, mainly twigs and leaves in various stages of decomposition and generally the top layers appear to be highly permeable.

3.3 Scope of Data Collection Program

From the apparent lack of published information on the general use of field based data as input to urban stormwater drainage models as well as procedural techniques it appeared that there was considerable scope to develop both measurement techniques and integration methods whereby additional field data would be used to improve runoff estimates.

Data was required in the form of spatial and temporal variations in soil moisture both short and long term; wetting front movement parameters including infiltration rates and upper soil storage capacities; depression storage; interception parameters by urban trees, shrubs, gardens and grasses; the significance of different land domains, their maintenance and connection with the overall drainage system (in particular the relationship between impervious and pervious areas) and the retardence factors affecting flow routing in typical urban catchments within the different domains.

The above lists a wide range of items requiring data acquisition, it is by no means complete, however it would represent the main parameters that could potentially affect the magnitude of runoff peaks and volumes occurring from a given rainfall event within an urban or rural area.

Due to the limited resources available, data collection in this thesis mainly concentrated on changes in soil moisture and infiltration parameters affecting pervious runoff. Additionally the effects of catchment structure and the relative importance of various land domains occurring was considered.

A number of primary data measurement stations were selected including six (6) at Giralang and two (2) on Black Mountain to provide permanently located data collection sites representative of different urban and non-urban land types.

The selection of individual sites took into consideration the soil type and its depth and structure, type of cover (dry grass, irrigated grass, gardens, residential lawns, etc), its elevation in catchment, site slope, proximity to watercourses and drainage pipes, depressions, humps and trees.

Six of the eight (8) primary stations are located as shown on Figure 3-4. At each of the stations full engineering investigations were carried out including logging and density profiling. The other two (2) station locations are shown on Figure 3-1.

Additionally, by adopting a random selection technique (dividing the total Giralang watershed into 1000 half allotment parcels), secondary temporary stations were selected to describe moisture changes within residential allotments . Twenty (20) individual allotment measurements, based on random number generation selection, were taken in any one recording session to represent an average catchment wide wetness.

Additionally, using the same random selection techniques, limited representative infiltration and soil storage data was obtained for a number of the land domains within the catchment. These were carried out employing insitu infiltrometer rings to derive soil conductivity and sorptivity values using methods described by Talsma (1969). Samples were also collected to obtain soil/water storage capacities.

Soil moisture/density readings were made using several methods including neutron scatter and gamma ray absorption techniques, conventional sampling techniques combined with oven drying methods and the installation and monitoring of thermocouples using a psychrometer.

Measurements were taken regularly over a period of approximately 10 months between July 1979 and April 1980, roughly at monthly intervals, with additional readings taken on an event basis.

Two additional runoff gauging stations were installed in the form of maximum stage boards to monitor peak pervious runoff from discrete land domains. These were located immediately upstream of Antares Crescent and at the underpass under Chuculba Crescent in Giralang. The additional stations were used to measure the significance of pervious runoff from these areas in small to moderate events.

3.4 Description of Sampling Stations

Station No 1. This station is situated just outside the Giralang study catchment adjacent to Ginninderra Creek as shown on Figure 3-4. Station 1 was chosen to reflect changes in soil moisture in a typical dry grass area with a good grass cover close to an emphemeral stream to monitor possible interflow affects in the lower portion of the catchment. See photos 3-1 and 3-2.

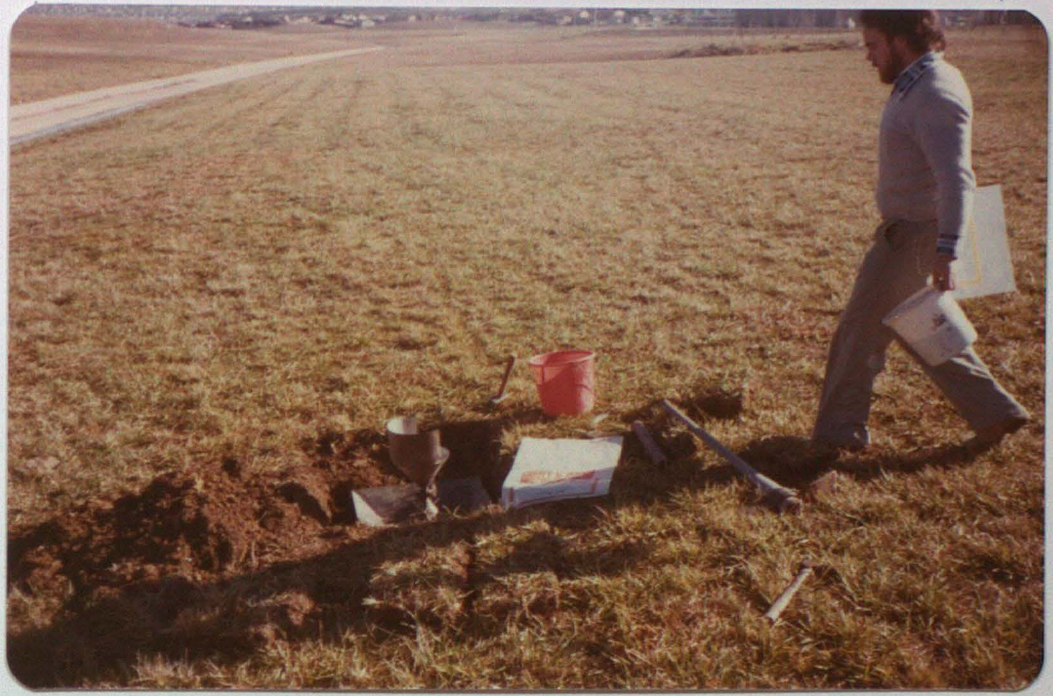


Photo 3-1. Giralang-Station No 1. General View.

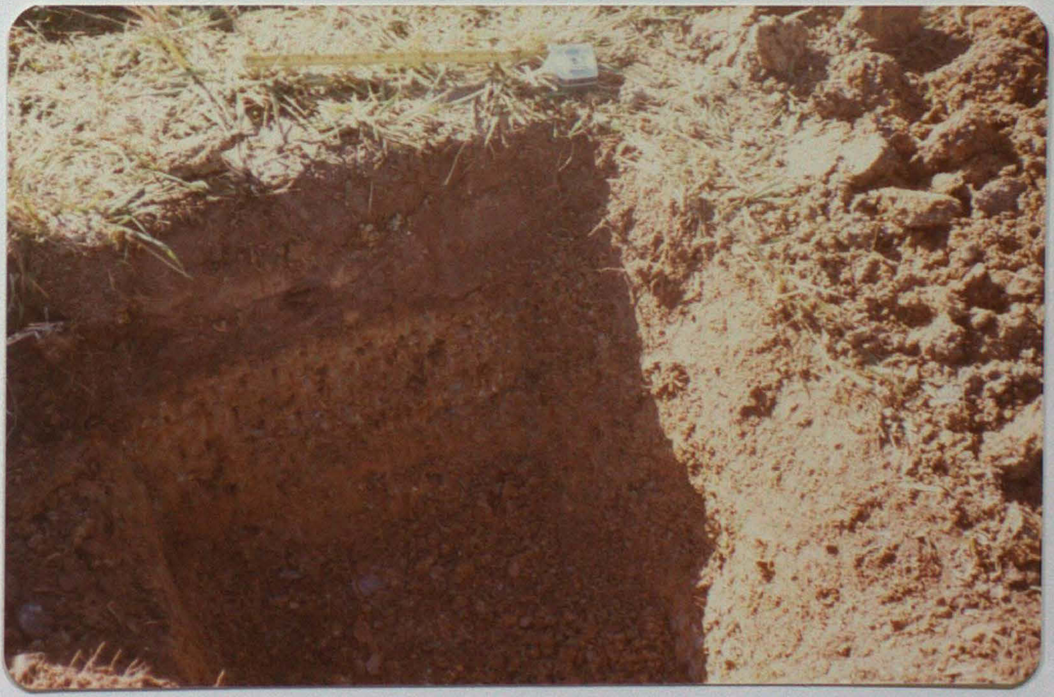


Photo 3-2. Giralang-Station No 1. Strata Details.

Station No 2. Indicated on Figure 3-4, is situated on the edge of a formalised playing field immediately to the west of the Giralang catchment in an area encompassed by an automatic irrigation system. The site contains mainly natural soils which are considerably denser and more clayey than the imported topsoils immediately adjacent and covering the fields themselves. See photos 3-3 and 3-4.

Photo 3-3. Giralang. Station No 2. General View.

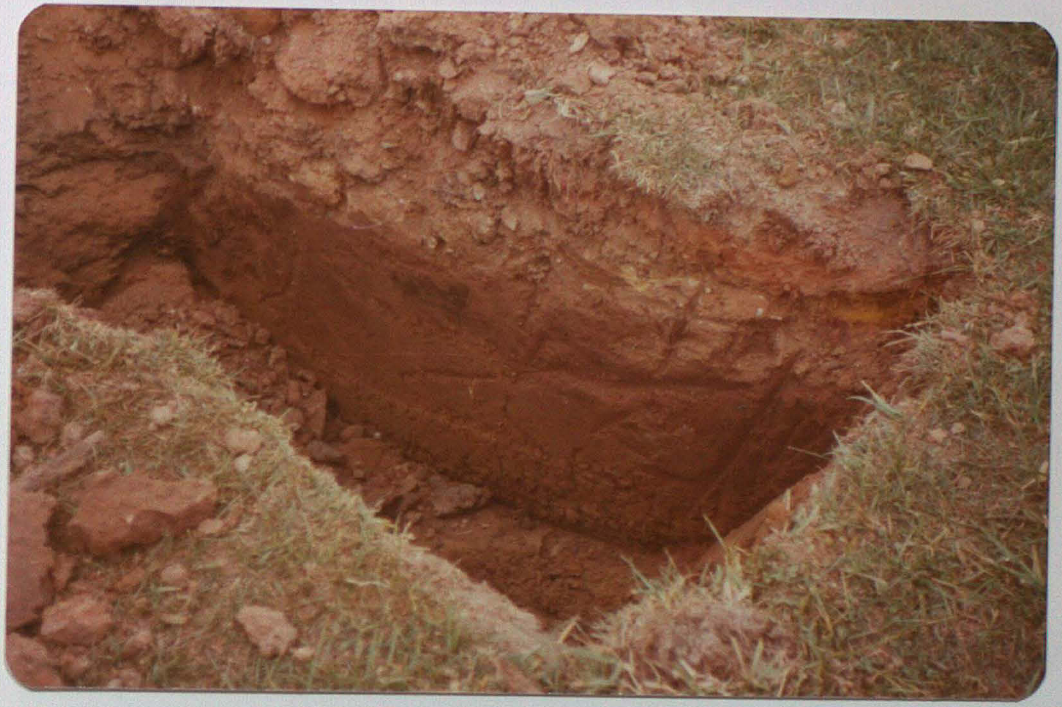


Photo 3-4. Giralang. Station No 2. Strata Details.

This station was chosen to test the effects of irrigation on an otherwise dry grass area.

Random sampling on the adjacent playing fields was also carried out over the course of the monitoring period to compare moisture changes.

Stations Nos 3 and 4. Both stations are situated in dry grass areas in the middle portions of the catchment as shown on Figure 3-4 with Station 3 being somewhat lower than Station 4. See photos 3-5 and 3-6.

Photo 3-5. Giralang. Station No 3. General View.

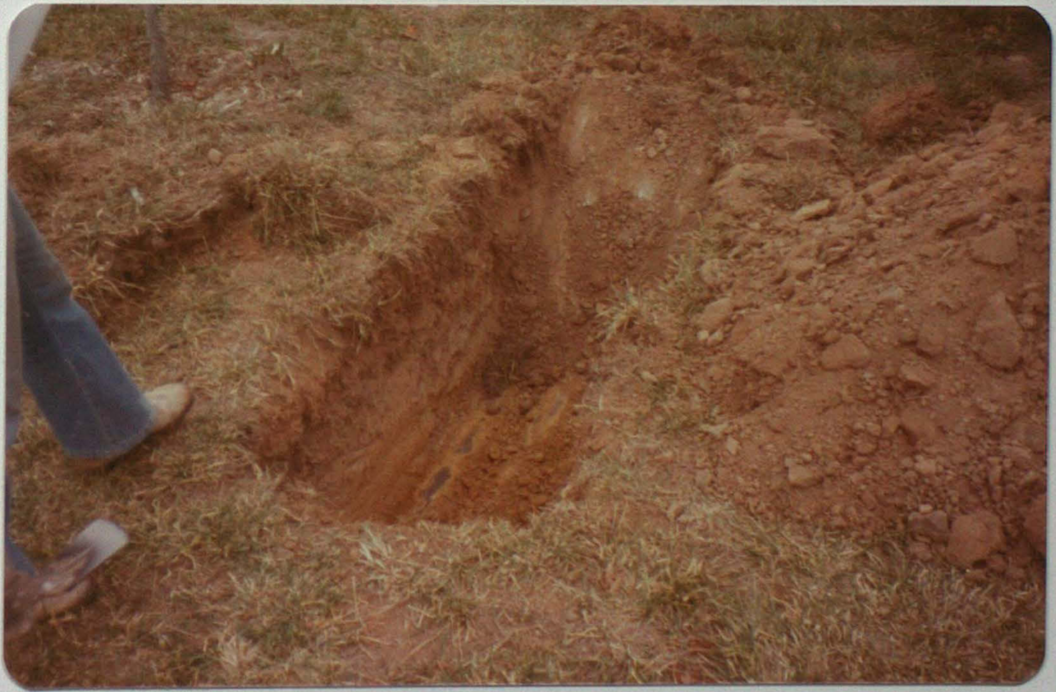


Photo 3-6. Giralang. Station No 3. Strata Details.

Both station areas contain poor to fair (but typical) grass cover with significant bare areas visible at most times of the year.

Stations Nos 5 and 6. Stations 5 and 6 are typical of the top portion of the study catchment above the urban areas (see Figure 3-4) where, although some minor modification to the land surface has occurred, it has been predominantly left in its rural form. Cover consists mainly of native grasses which in wetter weather can grow to a height in excess of 400 mm. Infrequent mowing is carried out on this portion of the catchment to minimise grass fires and vermen. See photos 3-7 , 3-8 , 3-9 and 3-10

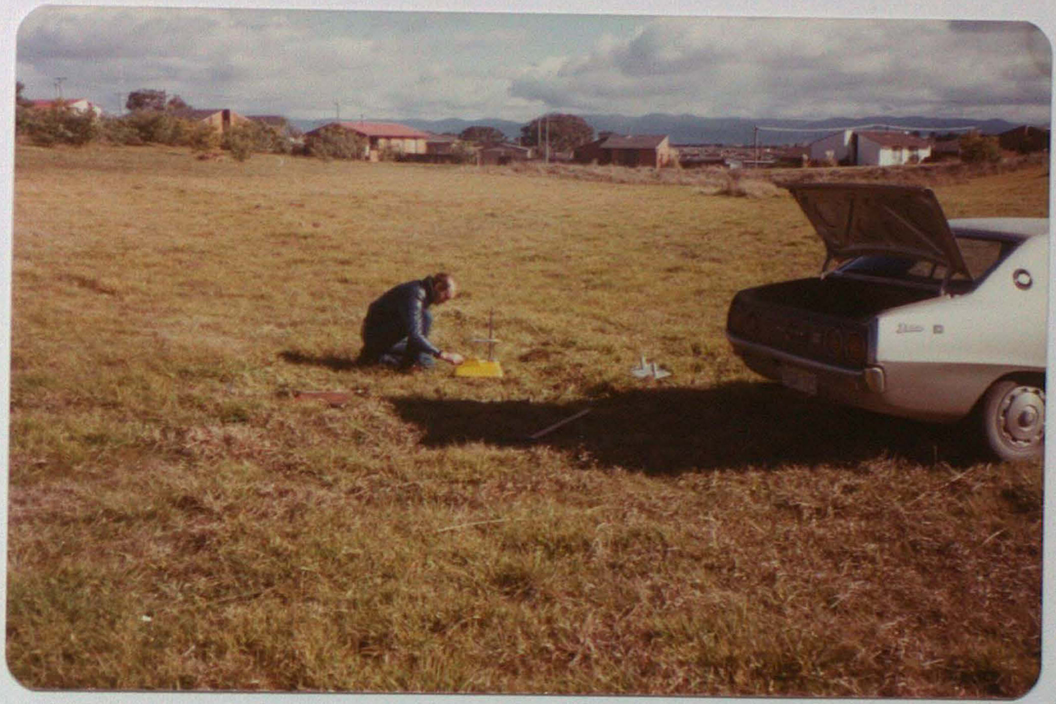


Photo 3-7 Giralang Station No 5. General View.

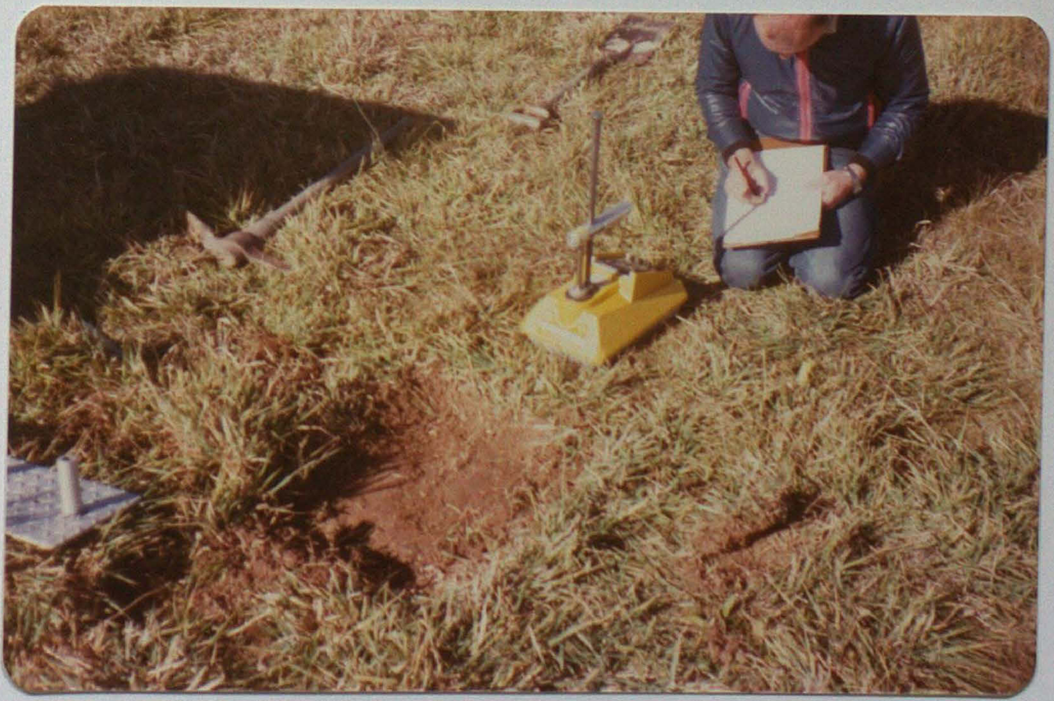


Photo 3-8 Giralang Station No 5. Showing Initial Nuclear Gauging.

Photo 3-9 Giralang Station No 6. General View.

Photo 3-10 Giralang Station No 6. General View.

Station 5 is approximately on the floor of the main valley of the catchment. Considerable depths of topsoil exceeding 300 mm were common around the site.

Station 6, which is close to the top of the northeast boundary of the catchment, contains only a thin layer of topsoil with rock outcrops occurring either at or just below the surface in a number of locations adjacent to the site.

Stations Nos 7 and 8. Stations 7 and 8 are located on the north face of Black Mountain about midway up the slope from Barry Drive and situated approximately 500 metres apart. Both represent similar, typical areas on the mountain and are included together to check for consistency in their response characteristics. Apart from a thin layer of decomposed as well as fresh litter the areas generally have poor topsoils. Because of the decomposed nature of the shallow rock however and the significant amounts of tree roots the area would appear to be quite permeable and contain significant storage capacity. The sites were chosen so as not to be adversely affected by tree canopy, yet not too exposed to reflect a non-typical area. See photos 3-11 and 3-12.

Photo 3-11 Black Mountain. Station No 8. General View.

Photo 3-12 Black Mountain. Station No 8
Detailed Surface View.

Random Sampling Stations. To expand the monitoring network to include residential lawn readings and as mentioned in the section on Station No 2, additional irrigated grass readings, it was necessary to use a random selection technique to provide representative area sampling to take into account spatial variability.

To this end the total number of residential allotments were sequentially numbered to provide nearly 1,000 half allotments for testing.

Using a random number generator, up to 20 areas were selected for any one monitoring session. At each selected area a sample was taken from or a reading made at a point as close as possible to the centre of the area described.

The playing field was similarly divided into areas from which a number of sampling points were randomly selected.

The samples from the random stations for any one land domain were accumulated and the mean value was derived by dividing by the total number of samples or readings taken.

3.5 Sampling Methods

3.5.1 Soil Moisture Profiles. The measurement of soil moisture profiles was carried out by two methods, namely by taking cores and weighing before and after oven drying and by making direct measurements using nuclear scatter methods.

As the depth of influence, corresponding to shorter duration storms adopted in urban drainage design, is usually limited to significantly less than 300 mm it was decided to limit moisture profile measurements to this level. This decision was also based on the measurement techniques proposed and described below. It was realised that monitoring of a deeper profile could assist in overall water balance analysis as described in Section 3.6.1.

Additionally, special interest was taken to accurately define the profile over the top 100 mm as in most cases this depth would be expected to control storm infiltration response.

The pervious land domains for which soil moisture measurements were undertaken consisted of residential lawns, reconstituted dry grass areas, natural dry grass areas, irrigated grass areas and natural forest.

A brief description of the measurement techniques adopted is given below to familiarise the reader with the equipment used.

(i) Conventional Oven Drying - Soil Moisture Measurements. Using a spoon tube soil sampler with a 15.0 mm internal diameter, soil cores were extracted and divided into the following sectional lengths: surface to 25 mm, 25 to 50 mm, 50 to 100 mm and where appropriate 100 to 200 mm.

The sectioned core samples were directly placed into separately labelled containers with screw top lids. When a sufficient number of samples had been collected to provide a representative sample set, the containers were weighed. Conventional oven drying and reweighing of the samples in the containers was then carried out and the following information calculated:

		Units	
Moisture Content	$Wwt = Ww/Ws \times 100$	%	(3-1)
Wet Density	$Dwet = Wt/Vt$	g/mm^3	(3-2)
Dry Density	$Ddry = Ws/Vt$	g/mm^3	(3-3)
Equiv. Water Level	$= (Ww \times 4000)/(L \times D^2 \times N)$	mm	(3-4)

where:

All weights in grams (g)
All volumes in millimetres cubed (mm^3)

(ii) Nuclear Soil Moisture and Density Measurements. Soil moisture profiles were obtained using nuclear techniques with a Troxler Model 3411B Surface Moisture/Density Meter. Initially nuclear measurements were, where possible, sup-

plemented by conventional moisture measurements via oven drying of collected samples. Additionally, sand replacement densities were taken to help verify gamma ray wet density readings.

The instrument in operation is shown in Photograph 3-7 and diagrammatically in Figure 3-5.

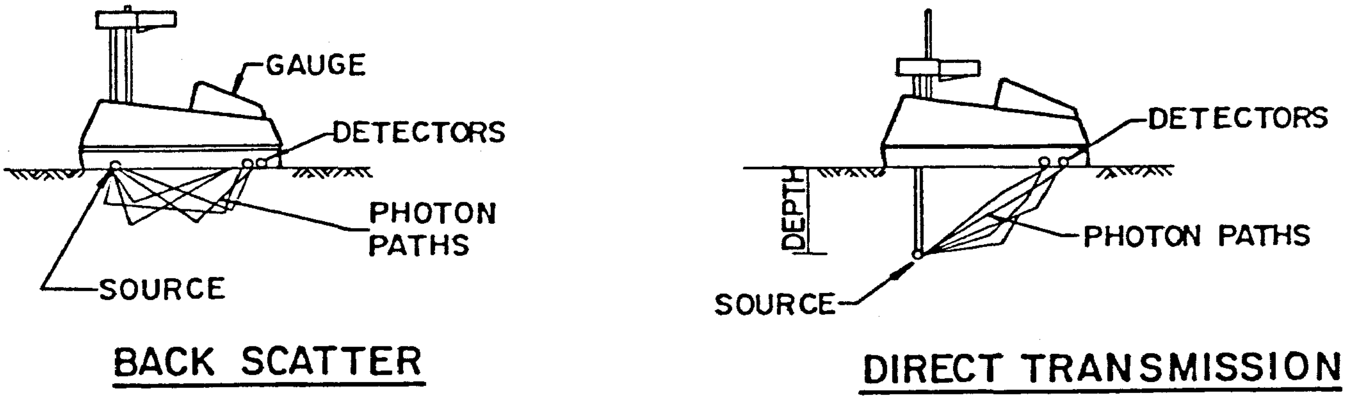


Figure 3-5 Troxler Surface Moisture/Density Meter

As indicated above the instrument can be used in both backscatter or direct transmission mode. In the latter mode, density readings only were possible.

The instrument contains both a gamma and neutron source to measure density and moisture content respectively.

The position of the sources is shown above with the gamma source at the lower extremity of the probe and the neutron sources at the base of the main body of the instrument.

(a) Neutron Approach. Soil moisture content could, unfortunately, only be measured in the backscatter mode as the instrument is only calibrated to the source/detector geometry in that position. In the direct transmission mode (with the probe lowered to a set depth) moisture readings although displayed referred to repeated backscatter scans only.

Soil moisture content is deduced by counting the number of thermal or slow neutrons detected after fast neutrons collide with hydrogen atoms in the material. This number is then compared with a reference number in the instrument's memory deduced from a calibration block supplied with the instrument which has a known moisture content and density.

The moisture content displayed is expressed as a percentage representing the average water content over the depth of influence. Unfortunately this depth is variable and dependent on the moisture content itself. The following relationship is cited in the manual for the instrument operating in the backscatter mode:

Depth of influence* (cm) = 28-27 Dwet (3-5)

* source Troxler operating manual.

where:

Dwet = Moisture content (g/cm^3)
Depth refers to depth over which reading averaged

When trying to relate changes in the near surface moisture profile, specifically between 0 and 300 mm, this situation was far from satisfactory as variations in the profile were undetectable. It would appear at this stage that for the purposes of this thesis a better profile definition measuring technique employing the instrument was needed if it was to be used to gather meaningful data.

The backscatter reading however could be useful as a rapid index measurement. Unfortunately this possibility has not been developed in this thesis mainly through lack of time. It may have been possible, through regression analysis, to link this index with the overall moisture/runoff response based on the sensitivity of results obtained in the analysis section of this thesis described in Chapter 4. It would appear that there is considerable scope to develop this form of rapid surface measuring technique because of its inherent repeatability characteristics over conventional extraction techniques.

(b) Gamma Ray Approach. An alternative method was developed using the same instrument to obtain soil moisture content over incremental depths up to 300 mm adopting the direct transmission mode to indirectly deduce soil moisture via density measurements. On the assumption that dry density was relatively constant within the increment it was only necessary to either measure soil moisture once by conventional means to obtain by deduction a dry density profile for the site or take readings over extended dry periods to obtain dry density when moisture content was near zero. Subsequent moisture readings were then taken by measuring wet density and relating this to the station dry density profile. Within the measuring period there were significant dry periods where soil moisture was very low. hence in the majority of cases it was possible to deduce from these dry density profiles.

Alternatively, conventional samples were extracted using a soil core sampler with an external diameter equal to the solid drill supplied with the Troxler. The collected core was divided into 50 mm increments between 0 and 300 mm and conventional oven dryed moisture content obtained. The tube sampler had the added advantage of minimising density effects within the area surrounding the probe hole. The same hole was subsequently used to take the nuclear meter's gamma source probe.

From the readings taken the following results were deduced:

	Units	
Wet Density - direct reading	g/cm^3	(3-6)
Dry Density - direct reading	g/cm^3	(3-7)
Moisture Content - $W_{vol} = \frac{(D_{wet}-D_{dry})}{D_{dry}} \times 100$	%	(3-8)

As can be seen from the above list, nuclear based moisture content measurements are given in volumetric units, whereas oven dry values are expressed as a percent of dry weight.

The different modes of expressing moisture content adopted by the two methods presented some difficulties when comparisons were required however, provided wet density was obtainable the following expression allowed one to be converted to the other:

$$W_{vol} = (W_{wt\%} \times D_{wet})/(W_{wt\%} + 100) \qquad (3\text{-}9)$$

A number of comparison runs , using the nuclear techniques described above were carried out to test the applicability of the method, against conventional oven dryed moisture measurements, as a suitable rapid non destructive method for determining moisture data. The results from a series of comparative readings using conventional and nuclear methods are shown on Figure 3-6.

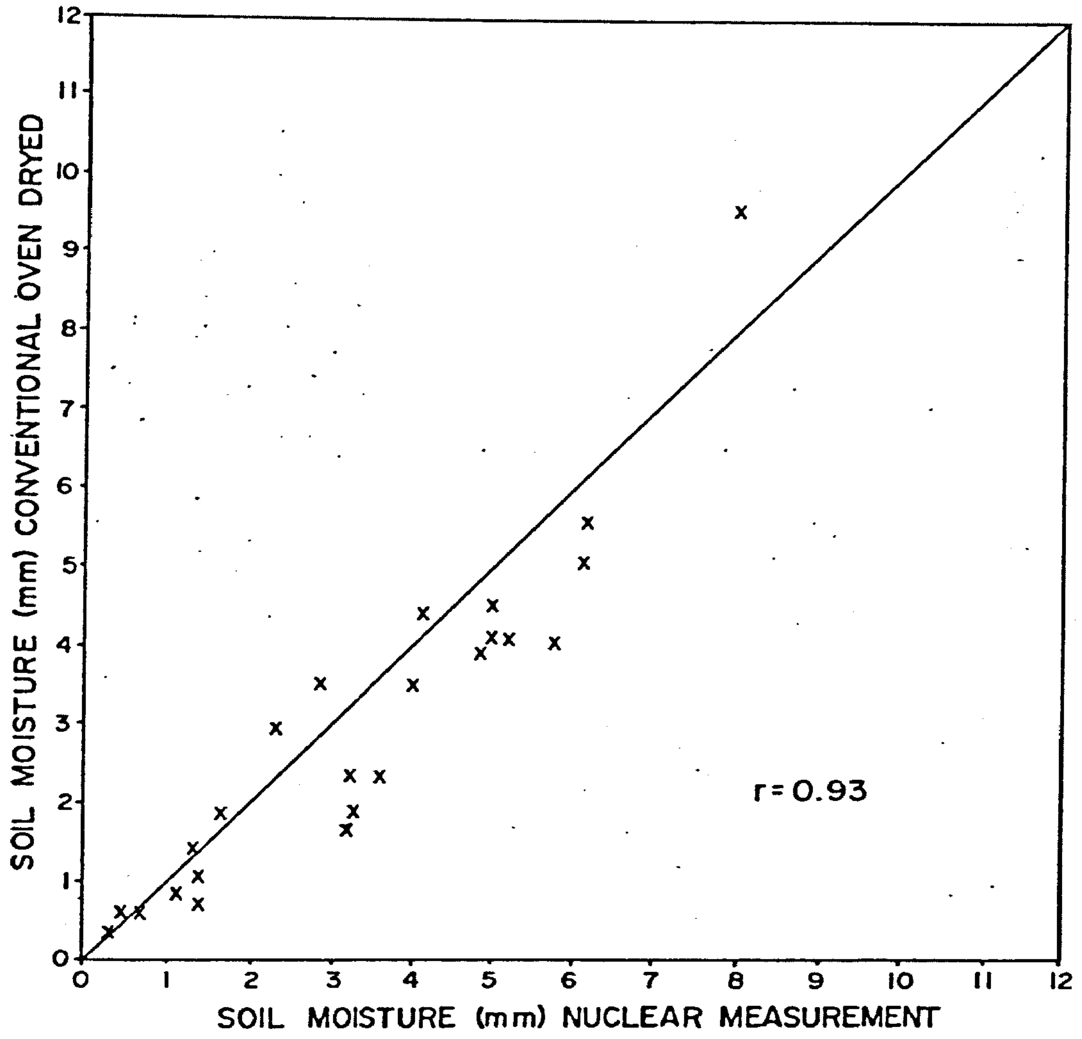


FIGURE 3-6 Scatter Diagram Comparing Nuclear and Conventional Soil Moisture Readings

(iii) Psychrometer - Thermocouples Moisture Measurements. As an additional method to measure long term fluctuations in moisture content over shallow soil profiles, thermocouples were installed at defined incremental depths at each of the six permanent stations at Giralang. These were to be monitored using a portable psychrometer.

It was intended that this technique would also monitor any hysteresis effects in long term wetting and drying cycles of the soils as well as soil moisture changes deeper than 300 mm.

It was also intended to assess and comment on the general suitability of this type of apparatus.

Two thermocouples were placed at each of Stations 1, 3, 4, 5 and 6 at depths of 150 and 300 mm and five at Station 2 at depths ranging down to 500 mm.

Typical installation of these units is shown on Photographs 3-13 and 3-14 at Station No. 1.

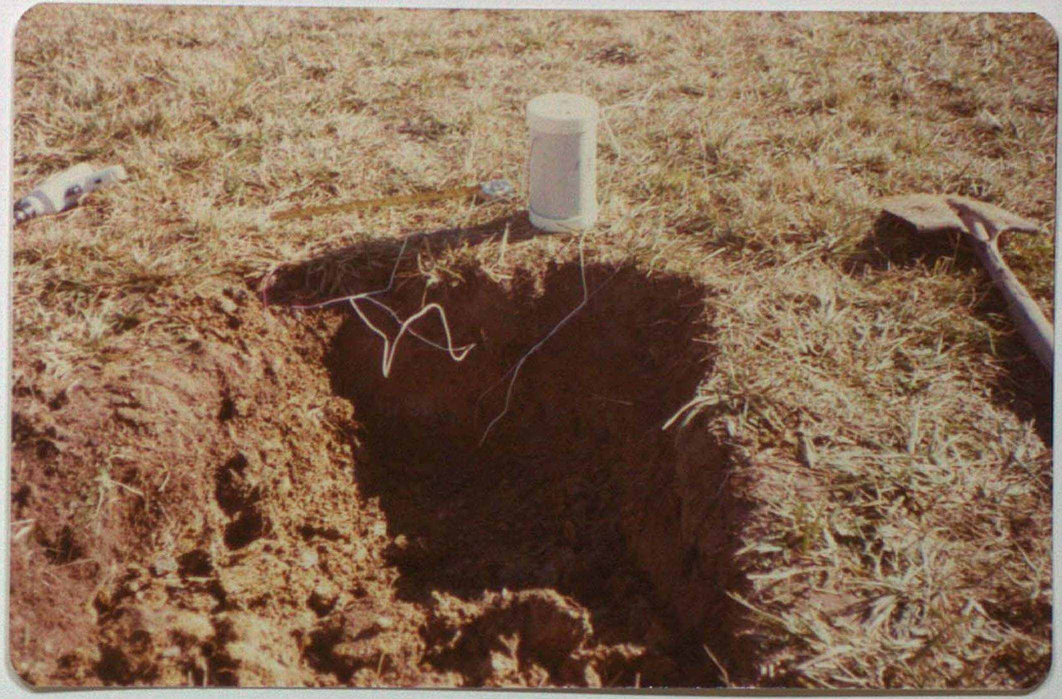


Photo 3-13 Installation of Thermocouples - Station No 1

Photo 3-14 Completed Installation of Thermocouples
Station No 1

Core samples were taken from as close as possible to the thermocouples and taken to the laboratory to obtain reference soil moisture/soil suction (pF) relationships for both wetting and drying cycles. pF readings from the psychrometer field measurements were then to be related to laboratory reference graphs to obtain representative soil moisture values.

3.5.2 Infiltration Parameters.

(a) Sorptivity. In this thesis the main theoretical infiltration algorithms adopted in Chapter 4 were based on the work carried out by Philip (1957) when he showed that cumulative absorption or desorption into or out of a horizontal column of soil of uniform properties and initial moisture content was proportional to the square root of time. Philip also showed that for shorter times of (t), vertical one - dimensional infiltration could be described by a rapidly converging power series in $t^{1/2}$. The coefficient of the leading term of the series (bracketed below) was termed sorptivity. Talsma (1969) proposed methods of measuring sorptivity in the field on undisturbed soil, for subsequent use in analytical applications.

$$i = (S)t^{1/2} + At + Bt^{3/2} \ldots\ldots \qquad (3\text{-}10)$$

where:

i = cumulative infiltration (cm)
t = time (min)
S = sorptivity (cm/min$^{1/2}$)
A, B, are parameters of the second and third terms (cm/min^{1}, cm/min$^{3/2}$).

Philip (1957) and again Talsma (1969) pointed out that sorptivity depended on initial moisture content and on the depth of water over the soil. Talsma varied these parameters in a series of field based experiments to test their effect on sorptivity values. Measurements of sorptivity were made by Talsma on large samples enclosed with 300 mm diameter, 150 mm high, infiltrometer rings pushed 100 mm into the soil.

Water was rapidly ponded in the rings to a depth of about 30 mm and the subsequent drop in water level was noted at regular time increments of 10 to 15 seconds after ponding.

Sorptivities were calculated from the linear portions of initial inflow against the square root of time. Samples of soil for initial and final moisture content were taken close to and inside the rings.

Based on the work by Talsma (1969) the method relied on the reasonable assumptions (a) that during the short time of measurement (1-2 minutes) water flow would remain vertical within the ring infiltrometer, and (b) that the first term of the infiltration equation (Philip, 1957) accounted for nearly all of the flow.

The first condition was found, within the accuracies of experimental technique, to be easily verified, however the second depended on the magnitude of A relative to S. Talsma found that plots of i against $t^{1/2}$ remained essentially linear at least to 1 minute and showed that for the wide range of different textured and structured soils studied the drop in head during the measuring process was not significant. He concluded that the accuracy of the ring infiltrometer method of measuring S insitu was quite acceptable even in soils with high saturated hydraulic conductivity relative to sorptivity. He also concluded that neither the diameter nor shape of the ring affected the results.

In the work carried out on the Giralang catchment perspex rings were used where possible in preference to steel ones to provide a visual check on the wall/soil interface as well as allowing direct head drop measurements through the wall.

Sorptivities were measured at a number of random sites over the Giralang catchment to add data to the work of Talsma in the Canberra region.

(b) Hydraulic Conductivity. Hydraulic conductivity, a measurement of the ability of a section of soil profile to conduct water, is reflected in the second term in the infiltration equation by Philip (1957) $i = St^{1/2} + At$ ...

Talsma (1969) showed that for a wide range of soils, A could be expressed as follows:

$$A = Ko/2.8 \qquad (3\text{-}11)$$

where Ko equaled the saturated hydraulic conductivity.

Ko therefore is the ability of a soil profile to transmit water when the soil is fully saturated. Ko is therefore only a special case of general hydraulic conductivity.

To apply Philip's infiltration equation it was therefore necessary to obtain measurements of Ko as well as sorptivity for each of the land domains.

Subsequent to reviewing the above equations 3-10 and 3-11, a modified equation eliminating the need for equation 3-11 was cited in a paper by Chong and Green (1979).

In this publication work was described by Talsma and Parlange (1972) and Parlange (1971,1975,1977) where the following equations were developed:

$$X = Y - 1 + \exp(-X) \qquad (3\text{-}12)$$

where X and Y were related to time, t, and accumulative infiltration, i, by the series expansion of equation 3-10 and

the substitution of equation 3-13 and 3-14 in the result, with rearrangement and truncation after the $t^{3/2}$ term.
where:

$$X = 2 \times Ko^2 \times t/S^2 \qquad (3\text{-}13)$$

and:

$$Y = 2 \times Ko \times I/S^2 \qquad (3\text{-}14)$$

The new equation termed the "Talsma-Parlange Equation" was therefore shown as follows:

$$i = St^{1/2} + (1/3 \times Ko) + (1/9 \times Ko^2/S \times t^{3/2}) \qquad (3\text{-}15)$$

in which i was the cumulative infiltration, S the sorptivity at a specified antecedent soil moisture content, and Ko the hydraulic conductivity at water saturation.

Equation 3-15 was subsequently adopted in place of equations 3-10 and 3-11.

The method of measurement adopted for Ko followed a similar procedure to measuring sorptivity, only on this occasion the undisturbed core sample held by the infiltrometer ring was removed from the surrounding soil and placed on a wire grid raised above ground level. A 100 cm length of core was adopted for all Ko and S measurements.

In this way zero moisture potential at the base of the core was assured. Water was then ponded on top of the soil until a steady outflow was observed. This flow was then measured at constant head and the saturated hydraulic conductivity calculated as follows:

$$Ko = Qw \times L/(H \times Ac \times t) \qquad (3\text{-}16)$$

where:

Ko = Saturated hydraulic conductivity (cm/min)
Qw = volume of water discharged in time t (cm^3)
t = time (min)
L = length of soil core (cm)
H = hydraulic head
= dist. from base of core to pondage surface (cm)
Ac = cross-sectional area of core (cm^2)

(c) Storage Capacity. The same samples used for the determination of saturated hydraulic conductivity were used to measure water storage capacity in the depth of sample.

To achieve this the sample was first weighed then oven dryed and reweighed to deduce moisture content.

In both the hydraulic conductivity and storage capacity sampling procedure two rings were used, one to obtain the sample and an additional ring containing an imported sample to reinstate the sampling area.

Upper Soil Storage Capacity (USC), defined below, was an important parameter in the infiltration process using the Australian Representative Basins Model (ARBM) described in Chapter 4 to relate sorptivities of varying initial moisture contents. The following relationship was given by Black and Aitken (1977):

$$S = SO \times (1 - US(init)/USC) \qquad (3\text{-}17)$$

where:

S = sorptivity
SO = sorptivity at zero moisture content
US(init) = initial moist. content in upper soil store (mm)
USC = maximum moist. content of upper soil store (mm)

3.6 Results from Gauging Program

3.6.1 Long Term Soil Moisture Fluctuations. Soil moisture monitoring via both nuclear and conventional means on an event basis was carried out at the stations shown on Figure 3-4 on the Giralang catchment as well as Black Mountain.

Figure 3-7 shows in graphical form a summary of the results from this work.

It would appear that the Troxler neutron-gamma probe was a particularly suitable device for carrying out the type of rapid repeat measurements necessary for this type of analysis.

The measurement tolerances of the Troxler were specified by the manufacturers at ± 2 to 4 percent of absolute values.

In carrying out repetitive measurements at the same location with the probe left in position between measurements, both moisture and wet density readings remainded fairly constant with a typical standard deviation from the mean, expressed as a coefficient of variation of .20.

As for the absolute accuracy of soil moisture readings, Figure 3-6 shows the scatter of conventional oven dryed samples compared with the values deduced frofm the Troxler probe. As can be seen from the figure the correlation is fair with a correlation coefficient r = 0.93. There appeared to be a general tendency for the Troxler to predict values on the high side of those decuded using conventional oven drying methods.

Based on an upper soil moisture saturation level of 12.5 mm, being roughly the top 25 mm of the soil profile, up to a 2 mm error in soil moisture at the start of a storm event would not unduly effect the resulting runoff peak using the procedures described in Chapter 4. Based on computer runs this difference would account for less than a 5% change in peak.

As a 2 mm error in reading would account for a 16% tolerance in field estimation it is contended that the Troxler would be most valuable in providing long term data for model calibration. From Figure 3-7 it is shown that the differences in soil moisture between stations of similar description presents a far more challenging problem to contend with.

Serious problems were encountered with the thermocouple-psychometer techniques and as a consequence no reliable readings were forthcoming during the period of this thesis.

The main problems tended to be with the thermocouples themselves including their fragility and problems involved in obtaining a satisfactory contact between the soil and the porous thermocouple. Unfortunately the resources available for this thesis precluded detailed study into improving the thermocouple technique. Considerable scope does however exist for continued work in this field as the use of these instruments in conjunction with soil moisture readings was seen to offer definite advantages in estimating the distribution of soil moisture going to evapotranspiration and groundwater respectively.

Vachaud et al (1973) and Kovacs (1979 and 1981), proposed to simultaneously measure, over the soil profile, both soil tension and soil moisture (see Figure 3-8).

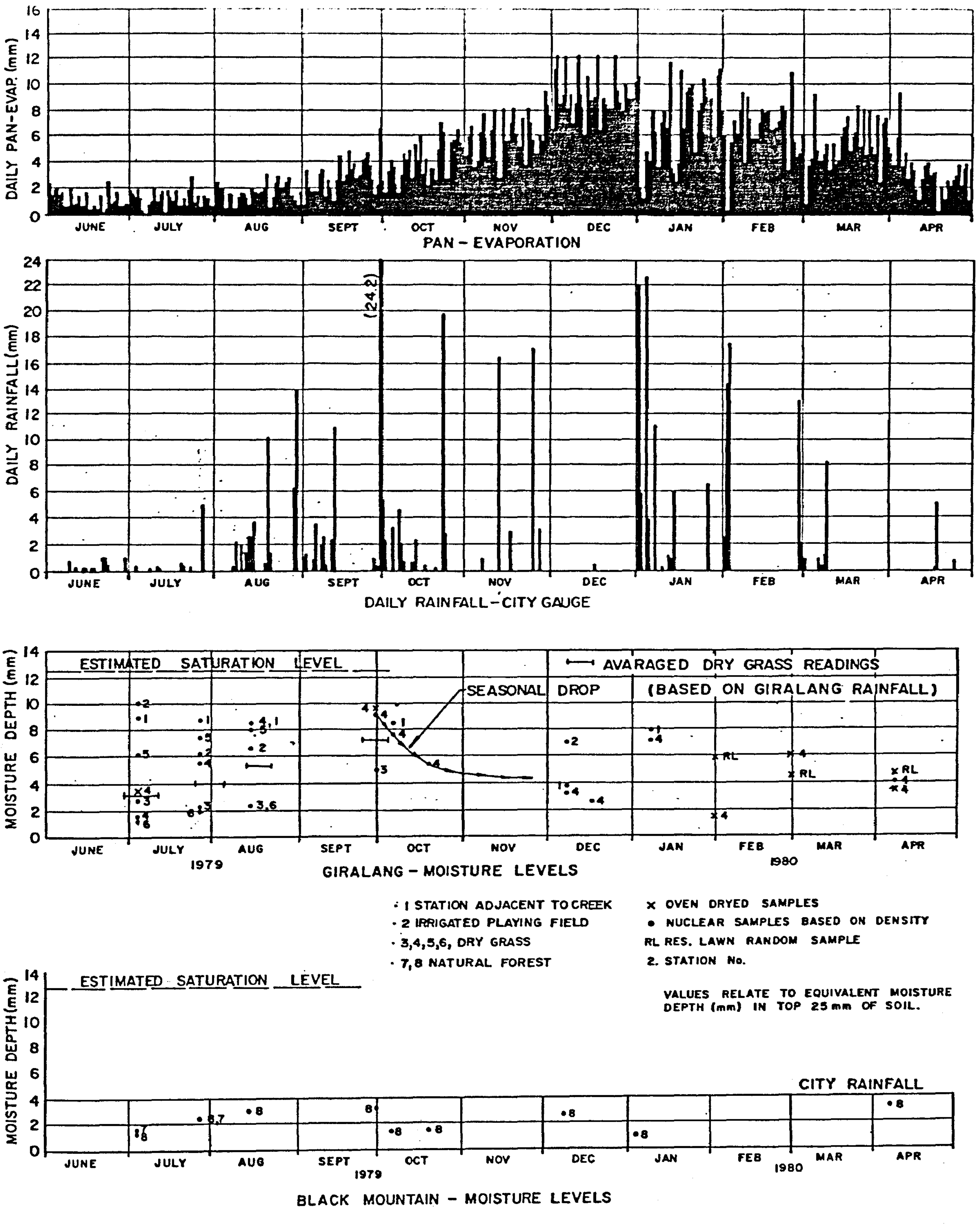
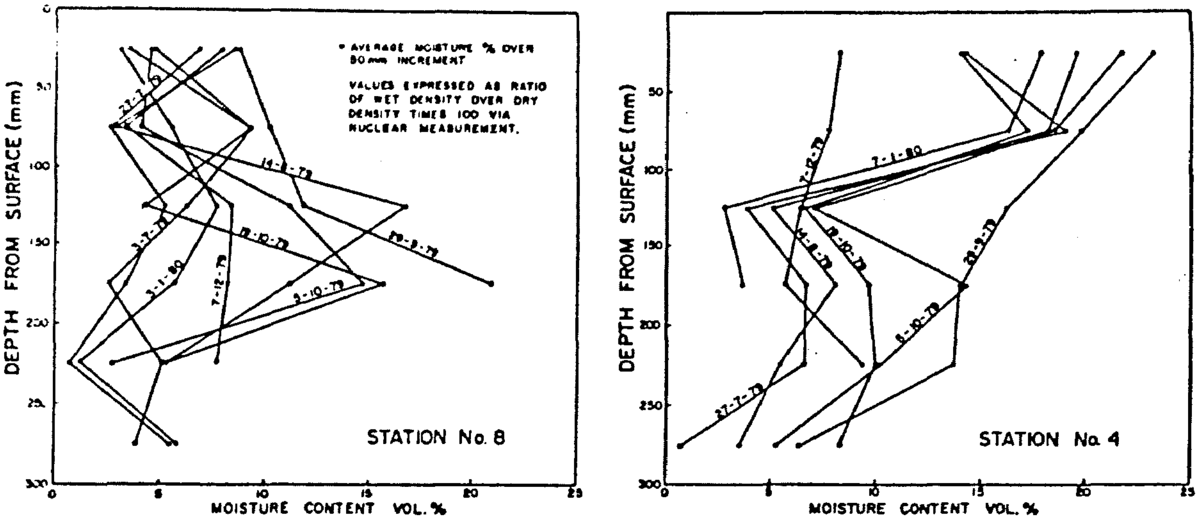
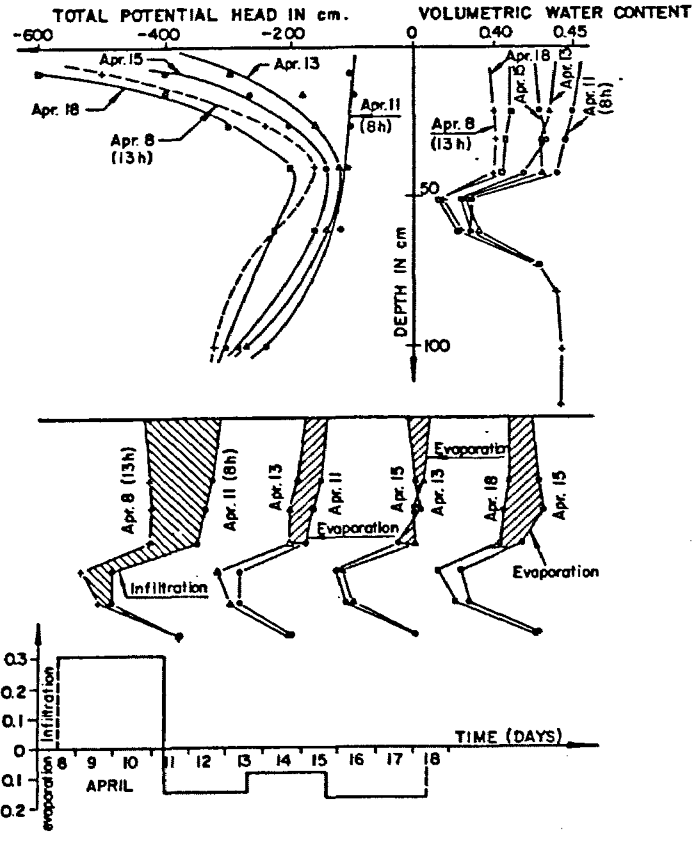


FIGURE 3-7 Shallow Soil Moisture Readings During the 1979,80 Period





CALCULATION OF EVAPOTRANSPIRATION BY COMBINING THE MEASURED VALUES OF TENSION AND WATER CONTENT.
(SOURCE, VACHAUD ET AL 1973)

FIGURE 3-8 Profile Summaries

The installation of the thermocouples at Giralang was aimed at establishing such a procedure, however, because of the lack of reliable readings this has not been possible.

Kovacs (1981) described how, by recording the tension values along a profile, the vertical distribution of total potential could be easily constructed (see Figure 3-8). The potential versus the depth curve has a maximum point, (the vertical gradient is zero); ie, flow does not develop through this horizontal section. As the gradient is directed upwards above this depth one can measure the water drained by evapotranspiration.

The profile below this critical depth allows the estimation of the water transported into the gravitational groundwater space.

Provided the thermocouple techniques could be made to work satisfactorily the above method of interpreting soil moisture movement between successive readings could help in further narrowing the gap between physical measurements and the various conceptual components of typical rainfall/ runoff models.

Results from the nuclear gauging plus the conventional monitoring, however did give some results that could help in assessing profile - depth development for use in assigning upper soil, lower soil and grounwater moisture movements. See Figure 3-8.

A brief review of the soil moisture readings taken and general observation during storm events at Giralang and Black Mountain indicated some interesting (if not unexpected) results:

- Over the period between June 1979 and April 1980 no significant runoff from the pervious area was observed.
- Large variations in upper soil water content, over extended periods, were observed between the stations being monitored pointing to the need for characterising the different land domains being monitored in respect to potential infiltration magnitudes. The differences, between Black Mountain stations(7, 8) and the unirrigated stations (3, 4, 5, 6) at Giralang, as well as the irrigated playing field station (2) and residential lawns (RL) are clearly shown on Figure 3-7.
- The majority of observed rainfall events produced moisture penetration, into the unirrigated areas, of only a few centimetres.
- The recession of soil moisture, after a rainfall event, in the upper 300 mm was fairly rapid even

during the winter period.

This fact can be seen in Figure 3-7 (Station 4) taking for example the 35 mm rainfall event in late September 1979. An apparent seasonal moisture equilibrium was reached in only 20 days after that event, even with intervening lesser rainfalls in that period. In that period the rapid increase in evapotranspiration typical of the commencement of Spring/Summer had an overriding effect on the upper soil store.

- There was a very rapid decrease in dry grass soil moisture over the top 30 cm after November 1979 in line with the higher temperatures and stronger winds.

- Figure 3-7, showing the results from the ten months monitoring program, indicates the typical variations in soil moisture at a point in time at the different locations measured. The measurements are representative of approximately the top 25 mm of the soil profile and as such are very sensitive to the amount of grass cover and drainage available.

Throughout this thesis the upper soil store has been considered as the thin band of the soil profile forming the root zone. For the type of grass found in Canberra this is limited to approximately the first 25 to 50 mm. The typical clay soils found in Canberra have soil saturation capacities of approximately 50% by volume. Based on the aim of this thesis to be able to estimate flood peaks resulting from short storm durations, it was decided at this stage to fix the upper soil storage at 12.5 mm. In this manner a relatively fixed 25 mm band was adopted as the physical upper soil profile. This was further based on the observed shallow penetration of short burst storm water as stated above.

As can be seen the dry grass readings (Station Nos 3, 4, 5 and 6), particularly in the Winter months, vary significantly.

The irrigated playing field (Station No. 2) was predominantly wetter than the dry grass stations although on two occasions at least one of the dry grass stations was wetter. Station No. 1 adjacent to the Giralang Creek was consistently wetter than all the other dry grass stations.

The random residential lawn samples were consistently above the representative dry grass Station No. 4 although the difference was not as great as would have been expected based on observation of individual lawns.

Station Nos 7 and 8 representing the forest area on Black Mountain consistently showed very low soil moisture readings.

The differences in moisture levels between, in particular, the dry grass stations appeared to be at least partly due to the difference in grass cover at the various locations. This did not however account for all the differences and these require a lot more work to further quantify the differences.

The results from the short measurement program carried out confirmed the need for assessing factors such as land type, cover and surface maintenance on the production of runoff from pervious portions of urban catchments. Chapter 4 studies the absolute effects of various domain changes and consequental differences in soil moisture, by modelling the effects of the changes on the flood peak and volume results.

- The difference in soil moisture profiles at any one time, between individual land units was most marked between Black Mountain readings and irrigated grassed areas as would be expected. The difference between residential lawn areas and dry grass areas was significant, however this was not as much as expected when the random selection of residential sites was considered. Individual variations in residential lawn areas caused by lawn watering was greatly offset by the overall averaged affect caused by the significant number of poorly watered sites within the catchment as a whole.

- Because of the lack of apparent runoff from pervious areas in Canberra, it is considered that the measurements described in this chapter are particularly relevant in obtaining additional rainfall/runoff response data over and above total catchment outlet rainfall/runoff data. Gauged catchment outlet flow data provide the accumulated flows from both pervious and impervious areas. In most cases in semi-arid areas, such as Canberra, this only includes impervious runoff. Any model parameter calibration using only total catchment rainfall/runoff data could be in serious error when analyses are extrapolated to more significant events where pervious runoff may be significant. The problems of non-homogeneity of urban runoff, because of pervious and impervious areas , is dealt with in Chapter 4. It would appear that the majority of present catchment outlet gauged data in urban areas gives little, if any, information on the mechanisms and responses from pervious areas. The paired catchment at Giralang and Gungahlin respectively representing similar urban and rural catchments seeked to partially overcome this problem by allowing correlation between the adjoining pervious areas.

3.6.2 Sorptivity and Hydraulic Conductivity. Table 3-1 lists averaged sorptivity and saturated hydraulic conductivity values for the typical land domains studied. The values relate approximately to the top 100 mm of soil profile. Because of lack of time and resources it was not possible to carry out extensive measurements on all the domains. Some measurements, however, were taken on residential lawns and dry grass areas. Other data was abstracted from Talsma's results. This was deemed appropriate as those measurements were representative of the region under study.

Table 3-1
Average Sorptivity and Hydraulic Conductivities

Land Domain	Hydraulic Conductivity Ko (cm/min)	Moist Cont(by wt) Initial %/100	Final %/100	Sorptivity (cm/min$^{1/2}$)
				** ***
Residential Lawns, Giralang	0.140(.40)[10]	0.22	0.37	1.4(.50)[10]
Urban Dry Grass Area Medium Grass Cover, Giralang	0.200(.30)[12]	0.15	0.40	.45(.40)[12]
Pialligo Sand*				
Dry	0.424(.13)	0.04	0.40	3.08(.12)
Moist		0.11	0.40	2.16(.9)
Wet		0.20	0.40	1.04(.28)
Ginnindera Silty Clay Loam*	0.184(.29)	0.11	0.46	0.90(.28)
Ginnindera Clay Loam*	0.120(.55)	0.04	0.38	0.45(.18)

* Values taken from Table 1, Talsma (1969).

** Figures in brackets are standard deviations from the means expressed as coefficients of variation.

*** Number of samples shown in square brackets.

3.7 Discussion on Results

Substantial differences were found in the results obtained from the relatively simple data collection program over the Giralang study catchment as well as limited work in the forested area on Black Mountain.

The differences in long term fluctuations in soil moisture occurring in the upper soil profile for the different land domains indicated in a quantitative way one of the most significant factors affecting the production of runoff, that was point variations in moisture content at any point in time.

The combined effects of variations in prevailing moisture content shown in Figure 3-7 and the variations in infiltration parameters indicated in Table 3-1 indicate the probable reasons for the experienced differences in runoff produced from different pervious urban land domains.

The effects of residential lawn planting, watering and topsoil development can significantly increase sorptivity and possibly hydraulic conductivity values to a smaller degree over and above average dry grass areas (See Table 3-1). The results for sorptivity measured on the residential lawns compared with the dry grass areas indicated a statistical difference at the 0.01% level. Saturated hydraulic conductivity values between the two domains were not found to be statistically different at the 0.10% of level. Additionally, persistent soil moisture can be higher than for dry grass areas. Similarly irrigated areas have high persistent moisture profiles combined with high sorptivity and hydraulic conductivity. The actual magnitude of potential infiltration is dependent on the total effects of the three parameters measured (Moisture Content, Sorptivity, Hydraulic Conductivity). The sensitivity of the individual parameters is treated in Chapter 4.

The gauging program described in this Chapter must be described as a feasibility program rather than a rigidly controlled field data collection program.

Over the limited time that the program was carried out it was only possible to carry out preliminary assessments on the various measurement techniques described to indicate if, individually, they showed promise to be included in future analysis and design situations.

The general results from the program were most encouraging and provided valuable model calibration aids for the methods described in Chapter 4. There is, however, considerable work still to be carried out in the further development of the methods described as well as additional techniques still to be found.

The following Chapter considers how the data collected as part of this Chapter can be best utilized in rainfall/runoff modelling techniques. Existing models are discussed and new modelling techniques developed.

CHAPTER 4

THEORETICAL RAINFALL/RUNOFF MODEL DEVELOPMENT

4.1 Discussion on Current Techniques

The general objective of this chapter was to establish improved analytical methods for deterministic rainfall/runoff modelling in a design environment.

To date methods employed to estimate design runoff events have largely been dependent on empirical parameters for which physical correlation has often been difficult. Probably the best known and widely used analytical design tool for estimating runoff peaks in Australia has been the Rational Formula. This method first attributed to Mulvaney in 1850 is a very simplistic model requiring the estimation of only two parameters. These are a runoff coefficient "C" and a time of concentration.

The "C" value has been very difficult to define with any degree of certainty. Unfortunately embedded in the parameter "C" are all the factors determining the ratio between rainfall and runoff rates. These include catchment wetness, infiltration parameters, the effects of non-uniform rainfall and catchment routing characteristics to name a few.

Over a number of years the Rational Method, as a deterministic model, has come under heavy criticism by many researchers and users, most notably French et al (1974), Watkins (1962), Aitken (1975) and Schaake et al (1967), for its poor general performance.

Despite the present uncertainties in parameter estimates the Rational Method still attracts widespread use and is by far the predominant method used by Australian practising engineers to estimate both urban and rural flow peaks for the sizing of drainage structures. Its general acceptance is further encouraged by the fact that the method is currently recommended in the Institution of Engineers publication 'Australian Rainfall and Runoff - Flood Analysis and Design' (ARR 1977) for the sizing of structures with catchments up to 25 km^2.

The main difference however between the Rational Method recommended (ARR 1977) over the deterministic form discussed above is that it is expressed in its statistical form. Design runoff peaks of a defined frequency are calculated from the same frequency rainfall intensity appropriate to a storm duration equal to the catchment time of concentration. Intensities are usually selected from intensity duration frequency curves derived for a particular region.

There are strong grounds for the use of the rational formula for day to day urban drainage design work as its simplicity and ease of application allows very rapid estimates of design runoff peaks of designated return periods provided appropriate times of concentration and coefficient of runoff can be estimated.

Urban drainage design work is usually split into two levels; the first relating to the design of minor systems usually pipelines and smaller channels while the second usually refers to larger systems where catchment storage, both natural and artificial, needs to be taken into account as well as the need to assess separate subarea contributions resulting from significantly different subcatchment make up and size.

The latter type usually demands the estimation and manipulation of runoff hydrographs throughout the watershed.

One of the objectives of this thesis was to develop methods whereby both levels of drainage analyses could be improved.

Aitken (1975) described in detail a procedure to estimate runoff coefficients for the rational formula using rainfall and runoff frequency distributions for a particular catchment. In Schaake's et al (1967) work on urban catchments they used similar frequency analysis of rainfall and runoff records to estimate "C" values. They then related "C" values using regression analysis with the impervious area and catchment slope as the independent variables.

Aitken (1975), when applying Schaake's regression equation on several catchments in Melbourne, found that the values , when compared to those from a frequency analysis were considerably higher. Aitken observed that Schaake's formula did not contain either a rainfall intensity or a soil type variable, and stated that in his opinion it would be unwise to use it in areas where pervious runoff frequently occurred.

Aitken concluded that the problem of obtaining reasonable lengths of runoff records to base runoff coefficient estimation could be overcome by the application of catchment simulation models of the rainfall/runoff process. He stated that the model would need to be verified over a short period of record, say 2 to 3 years, then a longer period could be synthetically produced using available rainfall and evaporation data as input to the model. This longer period could then be used as the basis for frequency studies.

The procedures described above have been taken up in this thesis to deduce rational formula runoff coefficients for use in the more minor flow peak analysis based on the development of frequency curves described later in this chapter.

In recent years a number of more complex deterministic design orientated rainfall/runoff models have been developed in an attempt to better quantify the imbedded factors included in the rational formula runoff coefficient.

Two models widely applied in Australia are 'RORB' developed by Laurenson & Mein (1978) and the 'RSWM' - 'Regional Stormwater Drainage Model' - developed by Goyen & Aitken (1976) briefly described in Chapter 2. Both models employ catchment routing techniques, channel routing and allow for variations in rainfall loss rates, catchment storage parameters and storm patterns over the catchment to allow complete watershed analysis.

A non linear catchment storage runoff routing model (LRRM) developed by Laureson (1964) has been adopted in both the RSWM and RORB. The LRRM was developed for use on rural catchments and as such was modified by Aitken (1975) to include its application on urban and urbanising catchments. In Aitken's work the storage delay coefficient operating within different catchments was related to catchment characteristics including area, main channel, slope and urbanisation content using regression analysis.

Since the inception of the RSWM in late 1974 significant work has been carried out and is continuing to further refine appropriate storage delay coefficients appropriate for the LRRM based on measurable or estimated catchment parameters. Although this development phase of the total catchment modelling process is far from exhausted it has been the aim of this current thesis to concentrate predominantly on the estimation of excess rainfall and with particular reference to design events rather than catchment routing.

The estimation of excess rainfall is made difficult because of the fact that in most day to day design exercises using deterministic models a design storm approach is employed rather than historical events. Appropriate design losses in this instance have to be compatible on a statistical basis with that of the design rainfall. This necessarily has to take into account the factors affecting the chance of certain rainfall events occurring with varying loss rates to produce catchment runoff. One of the main factors affecting this is the uncertainty of catchment wetness prior to a design event due to the short as well as longer term time-dependent fluctuations in catchment wetness.

It was at the relationships between catchment wetness, design rainfalls and the deterministic processes involved in loss rate estimation that the model development described in Chapter 4.2 was directed.

4.2 Development of a Combined Stochastic-Deterministic Rainfall/Runoff Model

4.2.1 General. In the development of suitable analytical tools capable of responding to the parameters affecting the conversion of rainfall to runoff it was first necessary to define the scope of the processes occurring and the parameters likely to be significant.

The current work was aimed at design procedures for both rural and urban catchments and consequently analytical tools would need to respond to the various land domains and their corresponding parameters existing in an urban as well as rural environment. Such domains would necessarily include residential lawns, dry grass areas, irrigated grassed areas, natural forested fringe areas and impervious areas as well as adjacent rural catchments.

The following is a brief description of the methods used at present to estimate excess rainfall with deterministic rainfall/runoff models, based on the RSWM as a typical model.

The RSWM accepts either an estimated initial plus continuing loss rate or infiltration parameters and an estimated prestorm catchment wetness in conjunction with Philip's Infiltration Equation, Philip (1957). The losses to infiltration are then subtracted from the total design storm to deduce an excess rainfall hyetograph.

In the majority of day to day cases the initial loss-continuing loss estimates have been used in preference to the more complex infiltration equations as the calculation or estimation of an appropriate prestorm catchment wetness or moisture deficiency has not been possible or practical.

Initial and continuing loss rates generally applied with design storms up to date have been taken from the literature where appropriate design values dependent on various catchment parameters or soil types have been recommended. As indicated in Chapter 2 however the values stated have often been misleading or vague and therefore could lead to significant errors when improperly interpreted.

Table 4-1 summarises some of the typical values quoted and applied to Australian urban and rural stormwater analyses.

TABLE 4-1

Summary of Typically Recommended Initial and Continuing Loss Rates for Australian Conditions

Type of Catchment Surface	Initial Loss (mm)	Continuing Loss (mm/hr)
Impervious areas		
Roofs of houses, factories and commercial buildings, road surfaces etc.	1.5	0.0
Pervious areas		
(i) Sandy, open structured soils	5.0-20*	10-25*
(ii) Loam soils	5.0-20*	3.0-10*
(iii) Clays, dense Structured soils	5.0-20*	0.5-3.0*
(iv) Clays subject to high shrinkage and in a cracked state at the start of rain	25-35*	4.0-6.0*
(v) ARR (1977)	0-50	-

* Values taken from an unpublished report by Aitken (1974) based on various textbook values.

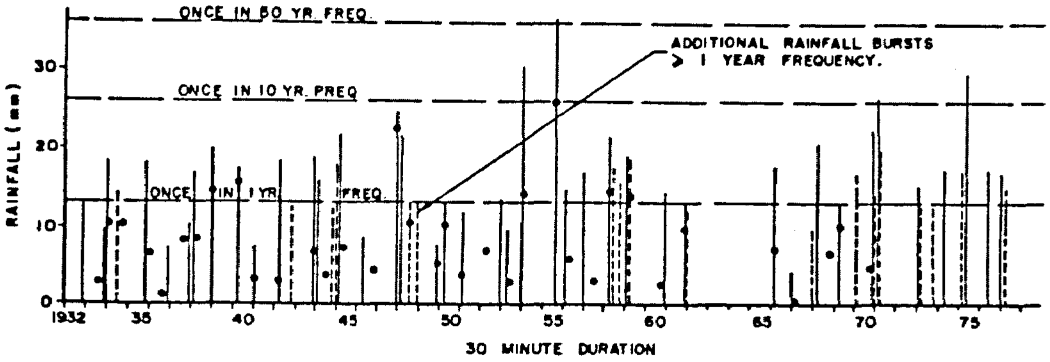
As stated above the problem of loss estimation is complicated by the fact that the design storm approach in urban drainage design infers the use of rainfall bursts rather than complete storm events. Consequently design storm loss rates need to reflect the possibilities of pre-burst catchment wetting. Depending on historical sequences of storms and the statistical interpretation of catchment parameters, the design storm loss rates could vary greatly from those associated with complete storm analyses. As mentioned in Chapter 2, Cordery (1970) carried out work on two New South Wales catchments in Sydney and Griffith respectively to test the effects of the problems described.

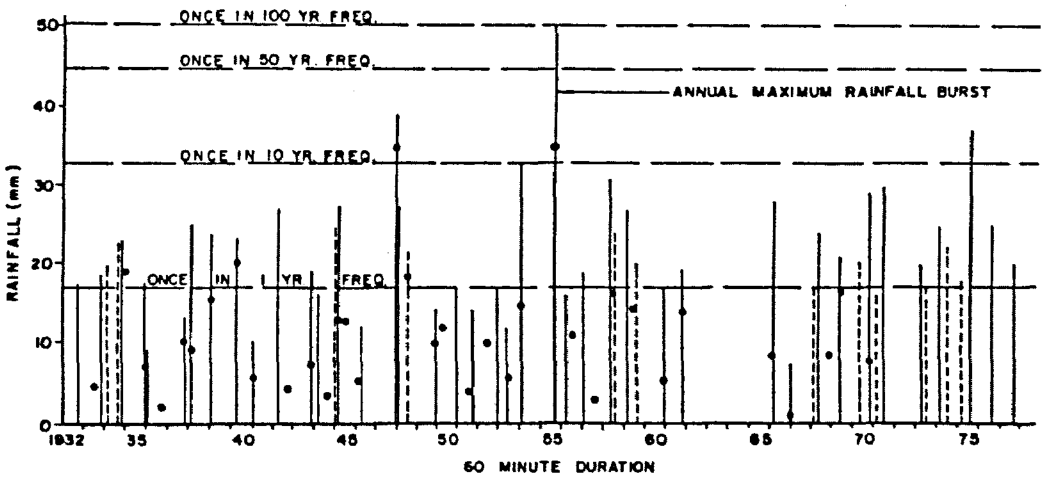
The values given in Table 4-1 and in the majority of the literature would unfortunately appear to be directed towards complete storms and therefore could be quite inapplicable for urban design modelling based on design storm bursts.

Based on the historical rainfall record in the Canberra region, it would appear that the average values quoted may well be low taking into account the semi-arid nature of the region and the long term timing of events.

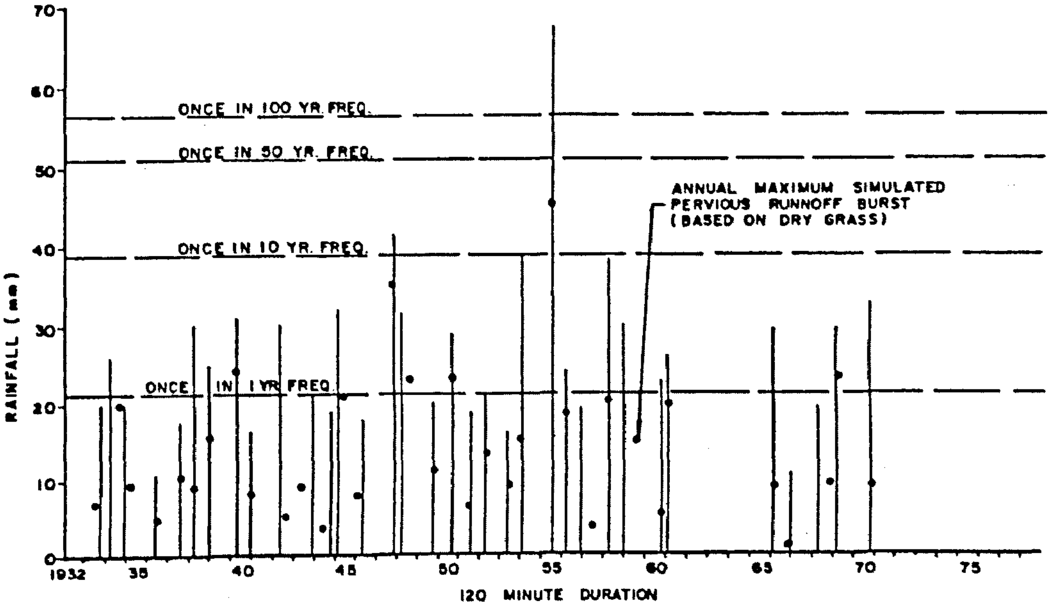
Figures 4-1 to 4-3 reinforce this opinion by the predominance of short duration historical events occurring in the high evaporation summer periods and then in the latter part of the day after potentially high catchment drying. To take this hypothesis a step further it was necessary for a detailed assessment of the time sequence of all rainfall events be made to ascertain, in real time, fluctuations in runoff producing catchment parameters. To achieve this aim a long term continuous water balance model was employed to simulate the catchment response over the period of rainfall record available. The development and application of the water balance model selected is described below.

In particular the analysis was intended to include the definition of moisture deficiencies, over extended periods, on different urban land types and the role of these in producing runoff of varying magnitudes.





NOTE: RAINFALL DATA TAKEN
FROM YARRALUMLA
FOREST RESEARCH STATION.



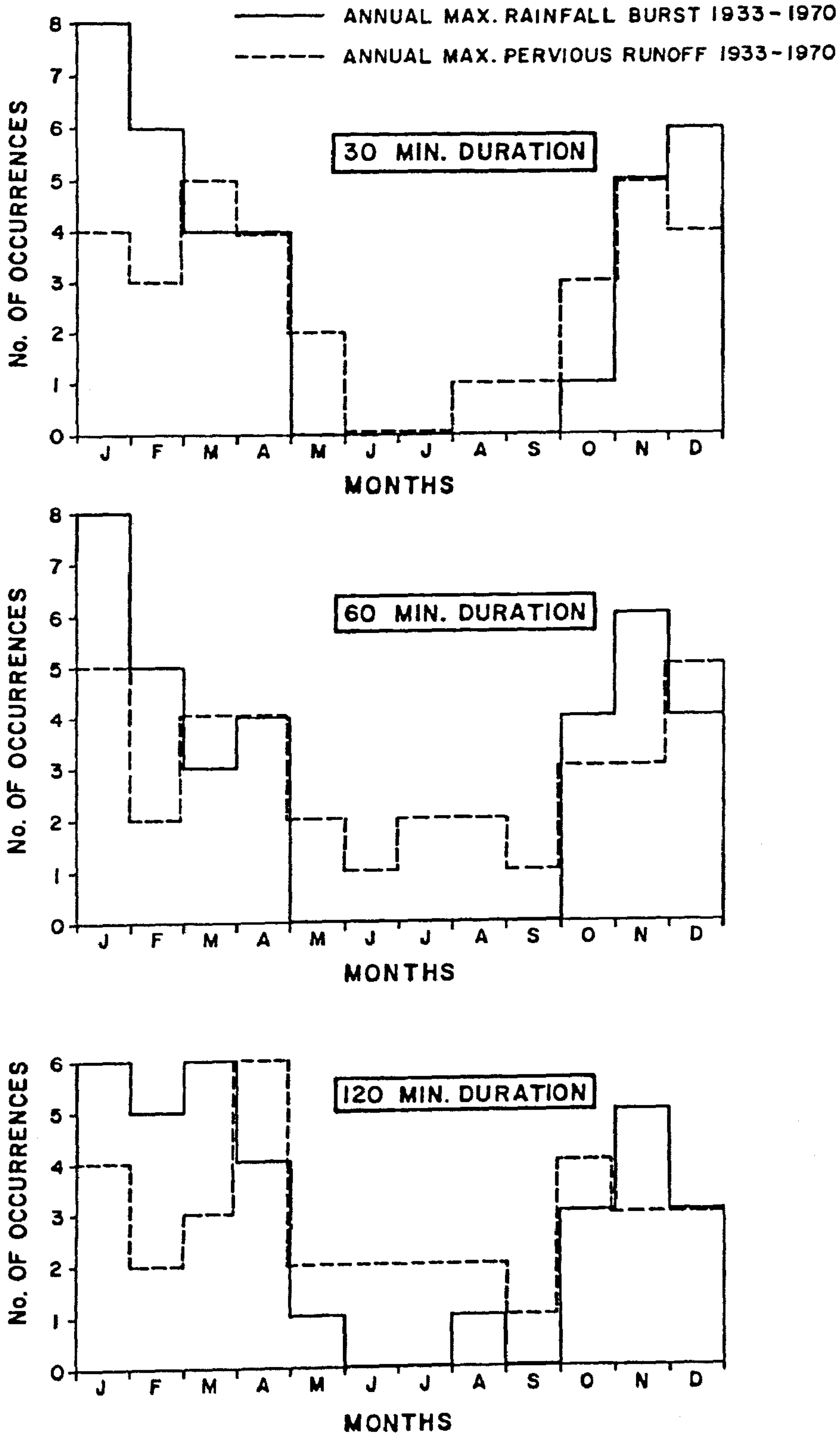
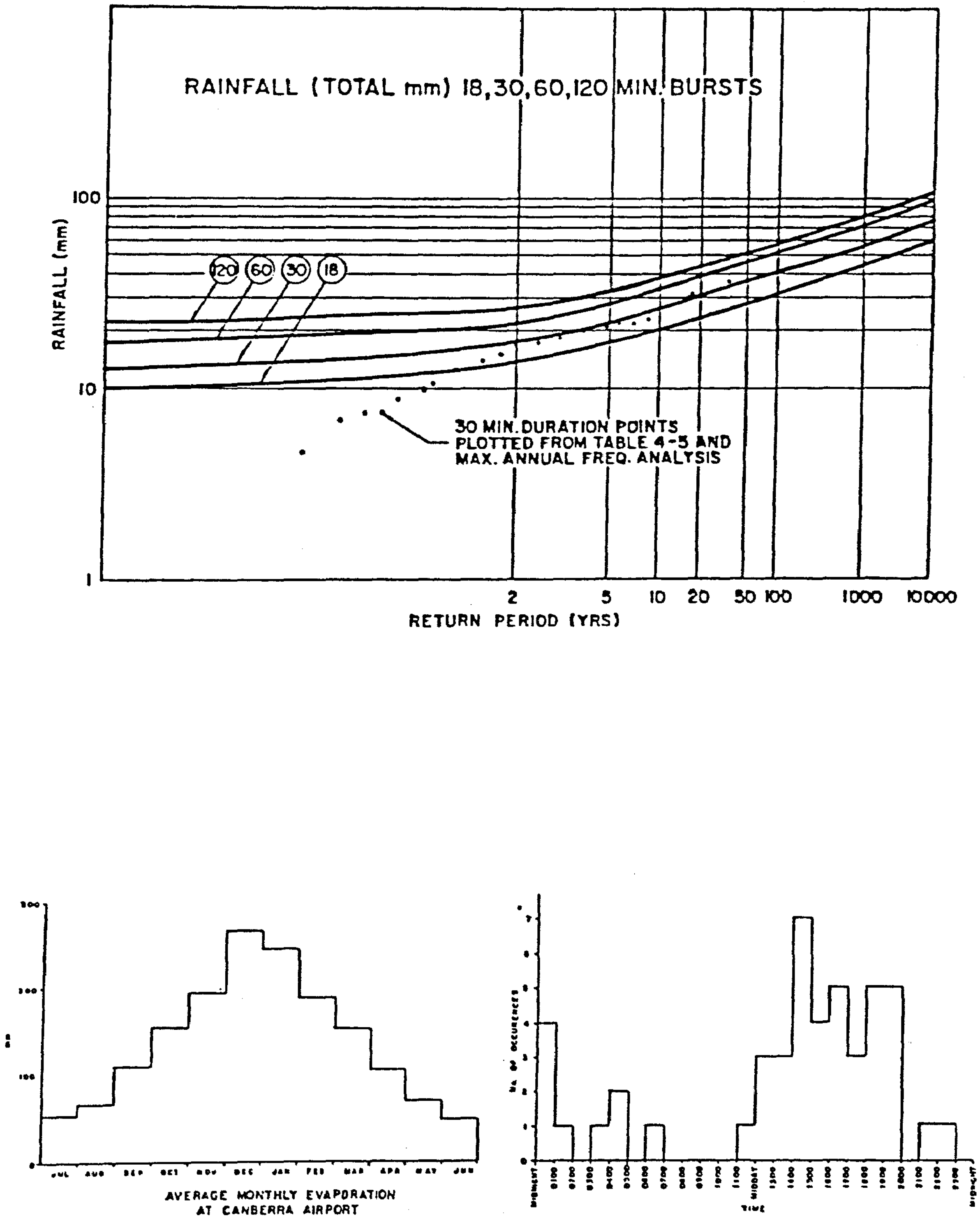


FIGURE 4-2 Seasonal Distribution of Annual Maximum 30, 60 and 120 Minute Rainfall Bursts



AVERAGE MONTHLY EVAPORATION AT CANBERRA AIRPORT

TIME OF OCCURENCE STORMS ≥ 1 YR FREQ.

FIGURE 4-3 Canberra Intensity-Frequency Duration, Pan Evaporation and Daily Rainfall Distribution

4.2.2 Continuous Water Balance Model Development.

After careful consideration of the models available for continuous rainfall/runoff simulation, the Australian Representative Basins Model (ARBM) originally developed by Chapman (1968,1970) and further modified by Black & Aitken (1977) was chosen for the following reasons:

(1) The model structure provided for detailed sensitivity analysis of a large number of catchment parameters.

(2) The model allowed infinitely variable time steps thus allowing direct input from existing Australian Water Resources Council standard format digitised pluviograph and runoff records.

(3) The combination of both pervious and impervious areas were allowed for.

(4) In its simplist form the model provided an economical tool capable of analysing very long records within a limited budget.

(5) As the model is currently being examined and used in a research environment by several organisations throughout Australia, further research into the operation of the ARBM and required modifications could only help to strengthen the basis for the model's use in Australian conditions.

Other similar models such as the Hydrocomp Simulation Model (Stanford Model) developed in the USA were considered but rejected on the basis of their unnecessary complexity and consequent cost to run. The basis for this assessment was further detailed by Black & Aitken (1977). Figure 4-4 gives a diagrammatic representation of the ARBM as described by Black & Aitken (1977).

The basic structure of the ARBM, described by Black & Aitken, was retained in this thesis. Some changes were made to data input, output provisions, allowances for the acceptance of variable time step computations and the way time steps were interpreted and modelling algorithms applied.

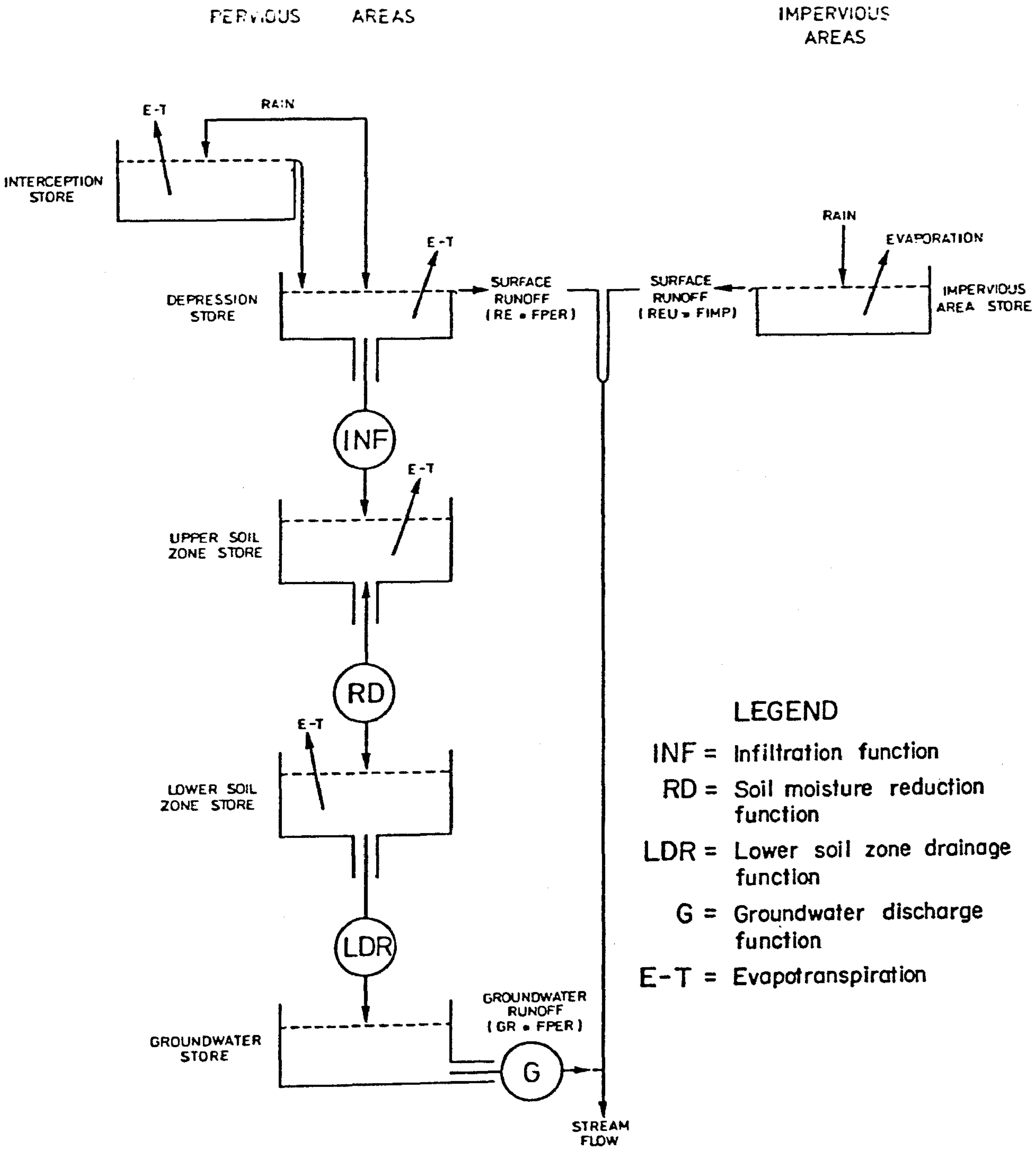

PERVIOUS AREAS
IMPERVIOUS AREAS
E-T
RAIN
INTERCEPTION STORE
E-T
DEPRESSION STORE
SURFACE RUNOFF (RE • FPER)
SURFACE RUNOFF (REU • FIMP)
RAIN
EVAPORATION
IMPERVIOUS AREA STORE
INF
E-T
UPPER SOIL ZONE STORE
RD
E-T
LOWER SOIL ZONE STORE
LDR
GROUNDWATER RUNOFF (GR • FPER)
GROUNDWATER STORE
G
STREAM FLOW
LEGEND
INF = Infiltration function
RD = Soil moisture reduction function
LDR = Lower soil zone drainage function
G = Groundwater discharge function
E-T = Evapotranspiration

FIGURE 4-4 Diagrammatic Sketch of the ARBM source (Black and Aitken 1977)

In the form described by Black & Aitken the model operated in predetermined time increments depending on prevailing weather conditions.

If the day was dry and the depression storage empty, then the time interval used was one day. If there was rain during the day, or the depression storage was not empty at the beginning of aky day, then an hourly time step was used. If there was rain during any given hour then a shorter time step was used during that hour. Six minutes was usually recommended for smaller urban catchments.

Unfortunately the use of the model in the above format required the search, backtrack and interpretation of intermediate data from the pluviograph record resulting in high running costs.

The model was modified to receive data directly from the digitised pluviograph record. Intermediate time step data was interpreted, only as required, to maintain stable model operation.

As a first step, catchment parameters needed to execute the ARBM were taken directly from data suggested by Black & Aitken (1977) appropriate for the Giralang urban catchment described in Chapter 3. The initial parameter set in fact closely resembled the data set for Yarralumla Creek catchment described by Black & Aitken.

Table 4-2 lists this initial set of parameters designated the reference set. The variables were adopted as the 'standard textbook set' from which all variations were compared in the subsequent proving and sensitivity analysis.

The term 'standard textbook set' was used to indicate the typical model parameters one might obtain from readily available reference material (eg, Black & Aitken (1977), Chapman (1970), Eagleson (1970), Talsma (1969)) without, apart from rudimentary catchment examination necessary to assess literature data, going to detailed rainfall/runoff simulation runs or the inclusion of field measured values.

Model Calibration

The major objective of this thesis was clearly to establish if additional simple field measurements could be included in the course of hydrologic studies to allow more relevant input to the mathematical models now used to predict runoff events, and in particular, urban events of short duration.

Over the last decade much has been published (Mein & Brown (1978), Johnstone & Pilgrim (1973), Fleming & Black (1974)) in regard to the complex calibration processes available for continuous water balance models such as the

ARBM.

As stated in the work by Johnstone & Pilgrim (1973) "A true optimum set of values was not found in over two years of full-time work". This was based on the study of a single study catchment with well documented rainfall runoff and soil moisture data. The above declaration indicated the inappropriateness of such complex machine optimisation processes for day to day design exercises for all but the largest projects.

As this thesis was aimed at everyday trunk drainage systems of small to medium scale it was decided to test the appropriateness of the much simpler process put forward by the Australian Water Resources Council's Technical Report No. 26 (Black & Aitken, 1977).

This document proposed that a set of parameters based on a number of published works be selected . Additionally where data could be measured it be so included in place of the more generalised published data.

To test the accuracy of such a procedure, in lieu of the more tedious optimisation methods, the results (ie, runoff peaks) would need to be compared with gauged data. This point is taken up in Chapter 4 using Mawson data.

TABLE 4-2

ARBM PARAMETERS
REFERENCE SET

Parameter	Description	Value	Unit
CAPIMP	Impervious store capacity	.5	mm
ISC	Interception store capacity	1.0	mm
DSC	Depression store capacity	5.0	mm
USC	Upper soil store capacity	12.5	mm
LSC	Lower soil store capacity	200.0	mm
UH	(Maxrate of water uptake from roots	10.0	mm/day
LH	(for upper and lower soil stores	10.0	mm/day
ER	Proportion of transpiration from US	.7	-
FIMP	Proportion of catchment that is impervious	.25	-
GN	Variable rate groundwater recession factor	1.0	-
KG	Constant rate groundwater recession factor	.94	-
SO	Sorptivity	7.0	$mm/min^{1/2}$
A	Function of soil conductivity	.5	mm/min
AO	(Redistribution	57.0	-
A1	(Parameters	.063	-
LDF	Lower soil drainage factor	.05	-
ECOR	Ratio of Potential Evaporation to A class pan	.7	-
IAR	Proportion of rainfall intercepted by vegetation	.7	-

Output variables defining the status of the various storage components of the ARBM at the end of any time increment were as follows:

(1) IDS - Impervious depression storage (mm)

(2) IS - Interception storage (mm)

(3) DS - Pervious depression storage (mm)

(4) US - Upper soil storage (mm)

(5) LS - Lower soil storage (mm)

(6) GS - Groundwater storage (mm).

A sensitivity analysis was carried out on the 1977 set of rainfall data to test model output responses to changes in individual and combinations of the more sensitive input parameters defined in Table 4-2.

Figure 4-5 summarises the sensitivity of the maximum value of US for 1977 to changes in individual parameters from the reference set.

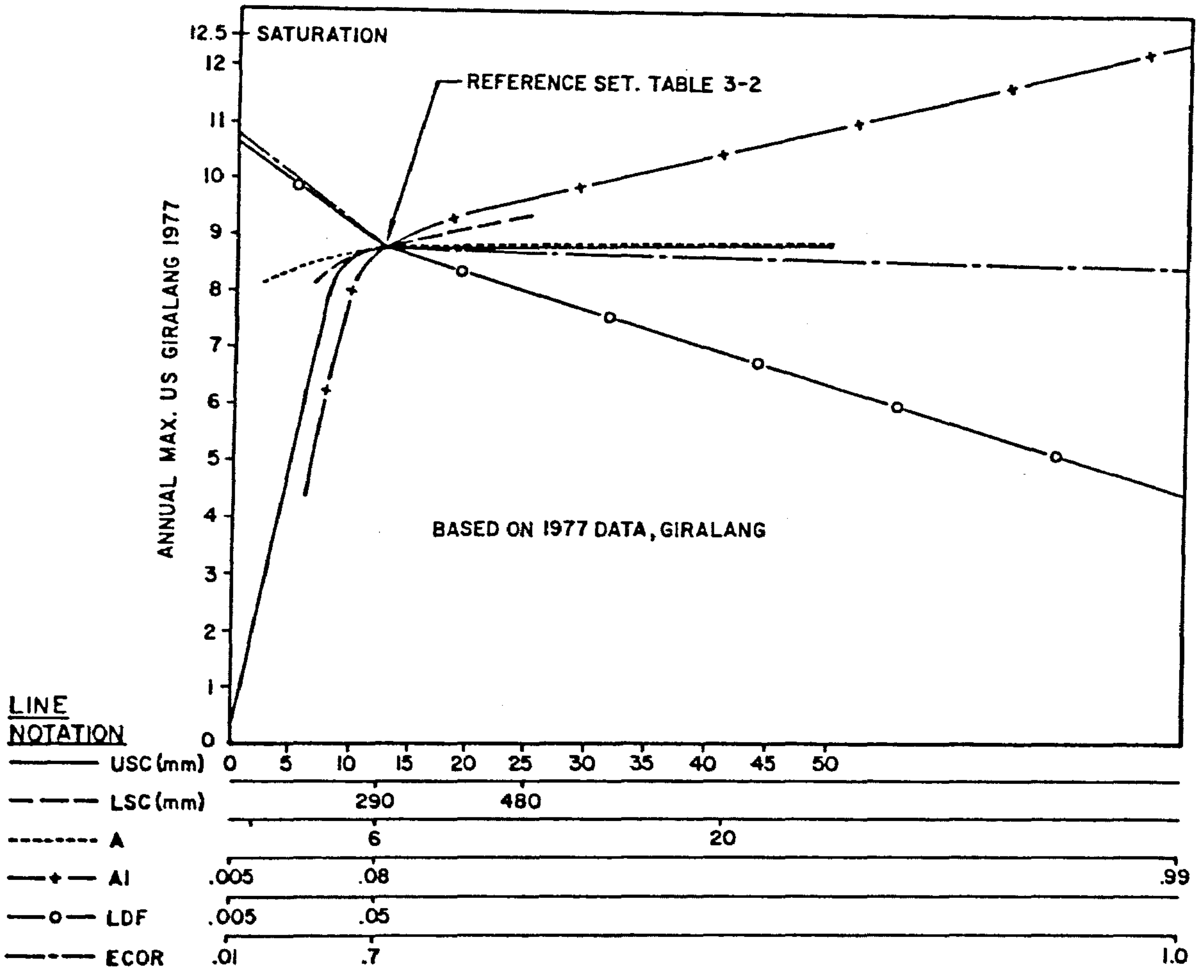


FIGURE 4-5 Sensitivity of ARBM Model Parameters

As indicated on Figure 4-5, the sensitivity of the maximum annual upper soil storage content (US) to moderate changes in the more sensitive input parameters was significant. As this output variable was potentially one of the most important in the prediction of infiltration, it showed that the most accurate definition of the more sensitive parameters was essential if accurate simulation was to be achieved.

Similarly it was found that changes to model parameters significantly affected upper soil moisture responses both in short term fluctuations and base magnitudes over extended periods.

The parameters directly affecting runoff volumes of short term storm events were sorptivity (S), hydraulic conductivity parameter (A) and the redistribution parameters (A0,A1). Sorptivity however is directly related to the prestorm burst soil moisture and most significantly the upper soil storage content (US).

As the percentage of moisture residing in the upper store at any time related not only to infiltration into it but also redistribution between it and the lower storage, the parameters affecting this later soil movement, including redistribution parameters and the defined upper and lower soil moisture capacities, were equally important.

The following provides a brief synopsis of a number of important aspects of ARBM operations borne out during initial use and testing.

- In Canberra, based on rainfall and evaporation data between 1933 and 1942, the total amount of pervious runoff simulated using the reference set was insignificant. As a percentage of the total rainfall this amounted to only .002% with flows occurring in only two of the 10 years simulated.

- Based on recorded rainfall/runoff data accrued at the outlet of the Giralang urban catchment for the years 1976, 1977 and 1978 it was impossible to separate the contributions of pervious, impervious and artificial baseflow from the total gauged flow. It was found that during the three years examined that the total annual baseflows were of the same order as the total impervious flow and that it was not possible to assess the pervious flow at all.

- In consequence to the above findings it was shown that significant changes to the majority of input parameters relating to pervious areas, ie, S0, Ko, USC, LSC, A0, A1, LDF, and ECOR had little or no effect on predicted runoff amounts. Total catchment runoff monitoring on urban catchments with pervious areas would therfore not appear to be appropriate for the calibrating of the above parameters unless the separate contribution from the pervious and impervious components could be resolved.

- The most sensitive input parameters and variables affecting the production of pervious runoff from a given rainfall event were S0, Ko, US, USC and LSC with US being the most critical after the field establishment of S0 and Ko and model calibration runs to fit USC and LSC.

- Particularly during dry spells , the accuracy of the potential evaporation input was insensitive with respect to model output ; as the maximum water uptake parameter from plant roots nearly always controlled the transpiration rate.

- During marginal runoff events the infiltration routine, employing Philip's equation, could give false results due to the trigger mechanism in setting new sorptivity values at the beginning of a storm burst based on the criteria of the depression storage being empty.

- During initial model runs using data directly from the record it was found that runoff from pervious areas was predicted from long duration time steps with low rainfall. This was primarily caused by rainfall exceeding the upper soil store within the time step before it could be dissipated to the lower stores.

The ARBM model is a one dimensional water balance model working in discrete time steps. It describes water volumes in terms of depth in all designated stores at the end of each time period.

As shown on Figure 4-4 the main soil stores are represented by the upper zone, lower zone and groundwater sections. These must necessarily define the status of the complete soil moisture profile at any point in time.

As can be well appreciated this is very simplistic and in some cases can cause significant soil moisture profile distribution errors.

To model profile development it was necessary to take account of all redistribution movements between the upper and lower soil stores as well as infiltration and evapotranspiration movements into and out of the soil strata. The mechanisms for this in the ARBM , as reported , are fairly limited , particularly in respect to probable hystersis effects throughout the wetting and drying cycles of the profile.

The ARBM model provided for runoff only when the upper store was full and overtopping occurred.This, in some cases, led to false runoff simulation when the additional constraint of rainfall rate exceeding infiltration rate was not met. Even when the ground surface was completely saturated, water still infiltrated at a rate equal to the saturated hydraulic conductivity level provided no barrier below the upper soil zone existed to cause backwater effects.

The model as described unfortunately did not account for this occurrence. It was necessary therefore to alter the modelling algorithms in this area to allow additional infiltration, provided redistribution to the lower store was sufficient to offset the increase to the upper store due to the rainfall infiltration in the incremental time period. This philosophy was further expanded to provide for the changing status of the upper store (US) during the time step caused by inflows and outflows due to transpiration, evaporation and redistribution between the depression storage and the ground storage. It was assumed that flow rates would act as a linear function over the time increment. In this fashion the model was in pseudo fashion changed from an incremental model to a continuous one.

The rate of moisture movement through the upper and lower soil stores was modelled for a number of historic runoff producing events by varying the lower soil storage capacity and redistribution parameters with a fixed upper storage capacity until gauged and simulated runoff volumes agreed. To isolate pervious and impervious runoff, gauged data was used from the rural Gungahlin catchment immediately adjacent to the Giralang urban catchment. The calibrated parameter set for the Gunghalin catchment was then used to compare with the reference set and to provide a base for additional sensitivity analysis.

The complexities of soil moisture profiles, particularly over a catchment with wide variations in soil characteristics, made it necessary to test the limitations of a lumped model such as the ARBM in providing acceptable runoff simulation. This facet of the thesis is taken up later in this chapter.

Using 33 years of pluviograph record between 1933 and 1970 from the Yarralumla Forest Research Station, Canberra, and the ARBM modified as described, long term soil profile movements and runoff simulation were carried out to examine fluctuation patterns and possible trends.

Following is a condensed listing of the ARBM as adopted in analysis work for this thesis together with the input data for the single year 1977 on the Giralang urban catchment and a part of the output and the summarised annual statistical data.

ARBM - PROGRAM LISTING

```
      PROGRAM ARBM2(INPUT,OUTPUT,TAPE1=OUTPUT,TAPE10=INPUT)
C     SIMPLIFIED VERSION OF AUSTRALIAN REPRESENTATIVE BASINS MODEL PROGRAM
C     FOR THE DETERMINATION OF EXCESS RAINFALL
      REAL IAR,ISC,LSC,LM,LDF,KG,IS,INF,LE,LS,LDR,LEC
      REAL IDS
      DIMENSION INTZ(4000),IDAY(4000),ATZX(2)
      DIMENSION XRUN(4000),INCCT(4)
      DIMENSION XISNT(4,2),IAND(4,2),ISDA(4,7),CI(4,2)
      DIMENSION NIS(16),NIF(16),DPER(4000),RNTD(4000)
      DIMENSION TITLE(40),PP(4000),P(4000),T(4000)
      DIMENSION AR(200),GPMR(200),PPI(200),DURL(4)
      DIMENSION BDUR(4),XBURST(4),INDXS(4),INDXF(4),BACKS(4),BACKF(4),
     1BPRECS(4),BPRECF(4),CLKPOS(4),IANTI(6,4),ACCR(100,4),IIS(4),
     2STORS(100,4,6),ATIM(100,4),DATI(100,4),IDTI(100,4),INDA(100,4)
      DATA DAT/3HDAT/
      DATA HRS/3HHRS/
      DATA XMIN/3HMIN/
      DATA XJAN/3HJAN/
      DATA FEB/3HFEB/
      DATA XMAR/3HMAR/
      DATA APR/3HAPR/
      DATA XMAY/3HMAY/
      DATA XJUN/3HJUN/
      DATA XJUL/3HJUL/
      DATA AUG/3HAUG/
      DATA SEP/3HSEP/
      DATA OCT/3HOCT/
      DATA XNOV/3HNOV/
      DATA DEC/3HDEC/
      DATA ATZX(1)/3HRES/
      DATA ATZX(2)/3HIRR/
C                    CATCHMENT   CHARACTERISTICS
C     DEPRESSION STORAGE CAPACITY IN (MM)                         DSC
C     INTERCEPTION STORAGE CAPACITY IN (MM)                       ISC
C     UPPER SOIL ZONE STORAGE CAPACITY IN (MM)                    USC
C     LOWER SOIL ZONE STORAGE CAPACITY IN (MM)                    LSC
C     MAX EVAPOTRANSPIRATION FROM USZ IN (MM/DAY)                 UM
C     MAX EVAPOTRANSPIRATION FROM LSZ IN (MM/DAY)                 UM
C     PROPORTION OF EVAPOTRANSPIRATION FROM USZ                   ER
C     SORPTIVITY OF DRY SOIL IN USZ IN (MM/MIN 1/2)               SO
C     CONTINUING INFILTRATION RATE IN (MM/MIN)                    A
C     SOIL MOISTURE REDISTRIBUTION CONSTANTS                      A0
C                                                                 A1
C     IMPERVIOUS DEPRESSION STORAGE IN (MM)                       IDS
C     LOWER SOIL ZONE DRAINAGE FACTOR                             LDF
C     GROUNDWATER DEPLETION CONSTANT                              KG
C     PROPORTION OF RAIN INTERCEPTED BY VEGETATION                IAR
C     RATIO OF EVAPORATION FROM PAN TO EST. POT. EVAPOT.          ECOR
C     PROPORTION OF CATCH. AREA THAT IS IMPERVIOUS                FIMP
C     STORAGE CAPACITY OF IMPERVIOUS AREA IN (MM)                 CAPIMP
C     GROUNDWATER ROUTING CONSTANT                                GS
      READ(10,1499) NJOBSS
      DO 7001 BJS=1,NJOBSS
      NCCT=1
      ACSRUN=0
      ACSP=0
      ACSI=0
      ACRUN=0
      ACP=0
      ACI=0
      READ(10,1500)TITLE
      WRITE(1,2500)TITLE
 2500 FORMAT(1H1,40A2)
 1500 FORMAT(40A2)
      READ(10,1501)CAPIMP,ISC,DSC,USC,LSC,UM,LM,ER
      WRITE(1,7779)CAPIMP,ISC,DSC,USC,LSC,UM,LM,ER
 7779 FORMAT(1H ,8F10.4)
      READ(10,1501)IDS,FIMP,IS,DS,US,LS,GS,GM
      WRITE(1,7779)IDS,FIMP,IS,DS,US,LS,GS,GM
      XIDSX=IDS
      XISX=IS
      XDSX=DS
      XUSX=US
      XLSX=LS
      XGSX=GS
      XGMX=GM
      READ(10,1501)SO,A,A0,A1,LDF,KG,ECOR,IAR
      WRITE(1,7779)SO,A,A0,A1,LDF,KG,ECOR,IAR
 1501 FORMAT(8F10.0)
      XAX=A
      READ(10,1499)N
 1499 FORMAT(I10)
      READ(10,1508)NNN,NNN
 1508 FORMAT(2I10)
      READ(10,5001)IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,ACAT,CRN,BFLO
     1W,ARPN,IRCT
 5001 FORMAT(7I2,F6.0,3F5.0,I1)
      WRITE(1,8913)ARPN,ATZX(IRCT+1)
      IF (CRN.EQ.0.) GO TO 4999
 8913 FORMAT(1H ,"    INCLUDES ",F5.2,"MM/HR   ",A3," LAWN WATERING")
      WRITE(1,8914)BFLOW
 8914 FORMAT(1H ,"   GAUGED BASEFLOW ADJUSTED TO ",F5.2)
      LTN=INT(USC/CRN)
 4999     IF(IOP2.EQ.0) GO TO 7060
      READ(10,5003)(NIS(J),NIF(J),J=1,IOP3)
 5003 FORMAT(16I5)
 7060     IF(IOP7.EQ.0) GO TO 5000
      READ(10,7030)(BDUR(J),J=1,IOP7)
 7030 FORMAT(4F5.0)
 5000 IF(IOP4.EQ.0) GO TO 5002
      READ(10,1591)(IX,P(I),T(I),PE(I),INTZ(I),IDAY(I),I=1,N)
 1591 FORMAT(1X,I9,3F20.3,5X,A3,5X,I8)
      GO TO 1590
 5002 READ(10,1507)(IX,P(I),T(I),PE(I),INTZ(I),IDAY(I),XRUN(I),I=1,N)
 1507 FORMAT(I6,3X,3F12.3,2X,A3,I4,3X,F7.3)
 1590 CONTINUE
C     ROUTINE TO INTERROGATE PTE FILE TO LOCATE ANNUAL MAXIMUM
C     HISTORICAL STORM BURSTS OF DEFINED DURATION
      LAA=1
      IF(IOP7.EQ.0) GO TO 7031
 3705 DO 7032 IAZ=1,IOP7
      DI=1
      DJ=DI+BDUR(IAZ)
      XBURST(IAZ)=0.0
      NST=1
      NFT=1
 7034 CONTINUE
      IF(DJ.GT.T(NNN)) GO TO 7033
      GO TO (3051,3052,3053),LAA
 3051 CALL INTRP(T,P,5000,DI,SS,1,NST,TBS,PBS)
      CALL INTRP(T,P,5000,DJ,FS,1,NFT,TBF,PBF)
      GO TO 3091
 3052 CALL INTRP(T,DPER,5000,DI,SS,1,NST,TBS,PBS)
      CALL INTRP(T,DPER,5000,DJ,FS,1,NFT,TBF,PBF)
      GO TO 3091
 3053 CALL INTRP(T,RNTD,5000,DI,SS,1,NST,TBS,PBS)
      CALL INTRP(T,RNTD,5000,DJ,FS,1,NFT,TBF,PBF)
 3091 CONTINUE
      IF(NFT.NE.NST) GO TO 3333
      IF(NFT.EQ.1) GO TO 3393
      IF((T(NFT)-T(NFT-1)).LT.60.) GO TO 3333
      DJ=T(NFT)+1
      DI=DJ-BDUR(IAZ)
      GO TO 3334
 3393 IF(T(NFT).LT.60.) GO TO 3333
      DJ=T(NFT)+1
      DI=DJ-BDUR(IAZ)
      GO TO 3334
 3333 DI=DI+5
      DJ=DI+BDUR(IAZ)
 3334 CONTINUE
      TBURST=FS-SS
      IF(IOP4.EQ.1.AND.LAA.EQ.1) TBURST=TBURST/10.0
      IF(TBURST.LE.XBURST(IAZ)) GO TO 7034
      XBURST(IAZ)=TBURST
      INDXS(IAZ)=NST
      INDXF(IAZ)=NFT
      XR=SS
      IF(LAA.NE.1) XR=P(NST)-(BACKS(IAZ)*(P(NST)-P(NST-1))/(T(NST)
     1-T(NST-1)))
      BACKS(IAZ)=TBS
      BACKF(IAZ)=TBF
      BPRECS(IAZ)=PBS
      BPRECF(IAZ)=PBF
      CLOCKS=T(NST)-BACKS(IAZ)
      IC=CLOCKS/24.0
      CLKPOS(IAZ)=CLOCKS - IC*24.0
       GO TO 7034
 7033 CONTINUE
       WRITE(1,8876)XBURST(IAZ),INDXS(IAZ),INDXF(IAZ),SS,BACKS(IAZ),
     1BACKF(IAZ),BPRECS(IAZ),BPRECF(IAZ),CLKPOS(IAZ)
 8876 FORMAT(1H ,F10.2,2I10,F20.1,5F10.1)
C     SEARCH FOR PRE STORM RAINFALLS-30DAYS,-5DAYS,-1DAY,-12HRS,-1HR,
C     -30MIN
      NST=1
      DO 7035 IDK=1,6
      GO TO (7036,7037,7038,7039,7040,7041),IDK
 7036 ATIME=CLOCKS -30*24*60
      GO TO 7042
 7037 ATIME=CLOCKS - 5*24*60
      GO TO 7042
 7038 ATIME=CLOCKS - 24*60
      GO TO 7042
 7039 ATIME=CLOCKS - 12*60
      GO TO 7042
 7040 ATIME= CLOCKS - 60
      GO TO 7042
 7041 ATIME = CLOCKS - 30
 7042 CALL INTRP(T,P,5000,ATIME,SR,1,NST,TBS,PBS)
      IF(PBS.LT.0.00001) GO TO 7043
      IANTI(IDK,IAZ) = NST-1
      ACCR(IDK,IAZ)=XR-SR
      IF(IOP4.EQ.1) ACCR(IDK,IAZ)=ACCR(IDK,IAZ)/10.0
      GO TO 7035
 7043 IANTI(IDK,IAZ) = NST
      ACCR(IDK,IAZ)=XR-SR
      IF(IOP4.EQ.1) ACCR(IDK,IAZ)=ACCR(IDK,IAZ)/10.0
 7035 CONTINUE
 7032 CONTINUE
 7031 CONTINUE
      A2=0
      IAL=0
      A3=0
      RDC=0.0
      LEC=0.0
      IDS=XIDSX
      IS=XISX
      DS=XDSX
      US=XUSX
      LS=XLSX
      GS=XGSX
      GM=XGMX
      A=XAX
      S=SO*(1.-US/USC)
      CGR=0.0
      UEC=0.0
      CINF=0.0
      CLDR=0.0
      TS=0.0
      INS=0.0
C     START SIMULATION OF INTERFACE PROCESS
      IF(IOP1.EQ.0) GO TO 5005
      IF(LAA.NE.1) GO TO 5005
      WRITE(1,6000)
 6000 FORMAT(1H ,45X,"DATA , STORES AND EXCESS RAINFALL SUMMARY"/)
      WRITE(1,6001)
 6001 FORMAT(1H ,"INDEX MTH DAY INC HR RATE POTEVAP INTER S  DEP S   UPP
     1ER S   LOWER S   GRNDW S   MINF    INF    RDIST   GRNDR  RUNOFF PRU
     2NOFF I FLOWPTE" /1H ,"***** *** *** ****** **** ******* *******
     3 *****   *******   *******   *******   ****   ***   *****   *****
     4 ******** ******** ********")
 5005     JJJ=0
      DURA=0.0
      DJ=0.0
      TTS=IS+DS+US+LS+GS
      EXPI=0.0
      EXI=0.0
      EXN=0.0
      DO 1234 KMM=1,4
      INCCT(KMM)=INDXS(KMM)-1
      IF(BACKS(KMM).LT.0.00001) INCCT(KMM)=INDXS(KMM)
      IF(INCCT(KMM).LT.1) INCCT(KMM)=1
 1234 IIS(KMM)=6
      IF(IOP1.EQ.0) GO TO 5006
      IF(LAA.NE.1) GO TO 5006
      WRITE(1,6002)JJJ,AZ,IAL,DURA,DJ,DJ,IS,DS,US,LS,GS
 5006     DO 100 JJJ=NNN,NNN
      IF(JJJ.EQ.1) GO TO 7500
      PP=P(JJJ)-P(JJJ-1)
      TT=(T(JJJ)-T(JJJ-1))/60.
      PEE=PE(JJJ)-PE(JJJ-1)
      GO TO 7501
 7500 PP=P(JJJ)
      TT=T(JJJ)/60.
      PEE=PE(JJJ)
 7501 CONTINUE
      TI=TT     *60.
      DURA=TT
      TF=DURA/24.0
      PEJ=PEE     *ECOR
      PEC=PEJ
      EMAX=0.7
      IF(IOP4.EQ.1) PP=PP/10
      PIP=PP
      IF(INTZ(JJJ).EQ.XMAY.OR.INTZ(JJJ).EQ.XJUN) GO TO 8551
      IF(INTZ(JJJ).EQ.XJUL.OR.INTZ(JJJ).EQ.AUG) GO TO 8551
      IF(INTZ(JJJ).EQ.SEP)  GO TO 8551
      IF(IRCT.EQ.1) GO TO 8555
      IF(TT.GT.1.0) PP=PP+ARPN*TT
      GO TO 8552
 8555 PP=PP+ARPN*TT
      GO TO 8552
 8551 IF(IRCT.NE.1) GO TO 8552
      PP=PP+ARPN*TT/2.0
 8552 CONTINUE
      PIIP=PP-PIP
      XIP=PP
      XIT=TT
      VPI=0
      XP=PP
      JSTN=0
 3316 NI=0
 3311 NI=NI+1
      XP=XP/NI
      PP=XP
      TT=TT/NI
      PEJ=PEJ/NI
      DURA=TT
      PEE=PEE/NI
      PIIP=PIIP/NI
      PEC=PEJ
      TF=TF/NI
      TI=TI/NI
      AOIA=(ISC-IS)
      QUS=US
      QLS=LS
      IF((PP*IAR)-AOIA)813,813,814
  813 QIS=IS+PP*IAR
      QDS=DS
      QUS=US
      GO TO 6510
  814 QIS=ISC
      QDS=0
      QUS=US+DS+PP-AOIA
 6510 IF(PEJ.EQ.0) GO TO 6500
      IF(PEJ.GT.QIS) GO TO 6501
      QIS=QIS-PEJ
      GO TO 6500
 6501 PET=PEJ-QIS
      QIS=0
      IF(PET.GE.QDS) GO TO 6502
      QDS=QDS-PET
      GO TO 6500
 6502 PET=PET-QDS
      QDS=0.
      FU=QUS*(1.-EXP(-TF*UM/USC))
      FL=QLS*(1.-EXP(-TF*LM/LSC))
      IF(PET.GE.FU) GO TO 6503
      QIN=ER*PET
      GO TO 6504
 6503 QIN=ER*FU
 6504 QUS=QUS-QIN
      IF(PET.LT.FL) GO TO 6517
      LE=(1.-ER)*FL
      GO TO 6518
 6517 LE=(1.-ER)*PET
 6518 QLS=QLS-LE
      GO TO 6505
 6500 LF=0.
      QIN=LE
 6505 ROT=TI*A0*(1+A1)*EXP(A)*LS)
      IF(ROT.GT.20.0) ROT=20.0
      RDT=(QUS-A1*QLS-A2)*(1-EXP(-ROT))/(1.+A1)
      IF(TF.LE.1.0) GO TO 4449
      STORE=(ISC-IS)+(DSC-DS)+(USC-US) +QIN+RDT
      IF(TF.GT.10.0) GO TO 3311
      IF(XP.LT.0.0001) GO TO 4449
      IF(STORE.LT.XP) GO TO 3311
 4449 VPI=VPI+TT
      JSTN=JSTN+1
C     SIMULATION OF CATCHMENT WETTING
C
 2020 PIN=PP     *IAR
      IF(PIN.GT.ISC-IS) GO TO 2070
      IS=IS+PIN
      PT=PP     -PIN
      GO TO 2090
 2070 PT=PP-ISC+IS
C
C     MODIFIED PHILLIPS EQUATION
C
      IS=ISC
 2090 INF=S*(SQRT(TS+TI)-SQRT(TS))+.33*A*TI+1/8*TS*A*TI*FI.5/A
      INF=INF
      IF(INF.GT.PT+DS) INF=PT+DS
      IF(RDT.LE.0.0) RDT=0.0
      IF(TF.LT.0.5) DIM=0.0
      AI=(USC-US)+RDT+DIM
      IF(INF.LT.AI) GO TO 2160
      INF=AI
 2160 CINF=CINF+INF
      US=US+INF
      DS=DS+PT-INF
      IF(DS.LE.0.) GO TO 2260
      TS=TS+TI
      IF(DS.LE.DSC) GO TO 2280
      RE=DS-DSC
      DS=DSC
      GO TO 2290
 2260 TS=0.
      S=SO*(1.-US/USC)
 2280 RE=0.
C
C      SIMULATION OF CATCHMENT DRYING
C
 2290 IF(PEJ.EQ.0.) GO TO 2560
      IF(PEJ.GT.IS) GO TO 2340
      IS=IS-PEJ
      GO TO 2560
 2340 PET=PEJ-IS
      IS=0.
      IF(PET.GE.DS) GO TO 2390
      DS=DS-PET
      GO TO 2560
 2390 PET=PET-DS
      DS=0.
      FU=US*(1.-EXP(-TF*UN/USC))
      FL=LS*(1.-EXP(-TF*LN/LSC))
      IF(PET.GE.FU) GO TO 2460
      UE=ER*PET
      GO TO 2470
 2460 UE=ER*FU
 2470 UEC=UEC+UE
      US=US-UE
      IF(PET.LT.FL) GO TO 2520
      LE=(1.-ER)*FL
      GO TO 2530
 2520 LE=(1.-ER)*PET
 2530 LEC=LEC+LE
      LS=LS-LE
      GO TO 2570
 2560 LE=0.
      UE=LE
C
C      SIMULATION OF SOIL MOISTURE REDISTRIBUTION
C      RD.GT.0 = FLOW FROM UPPER TO LOWER SOIL ZONE
C      RD.LT.0 = FLOW FROM LOWER TO UPPER SOIL ZONE
C
 2570 RO=TI*AO*(1.+A1)*EXP(A3*LS)
      IF(RO.GT.20.0) RO=20.0
      RD=(US-A1*LS-A2)*(1.-EXP(-RO))/(1.+A1)
      RDC=RDC+RD
      IF(RD.LE.0.0) GO TO 2660
      IF(RD.LE.US) GO TO 2710
      LS=LS+US
      US=0.
      GO TO 2770
 2660 IF(-RD.LE.LS) GO TO 2710
      US=US+LS
      LS=0.
      GO TO 2730
 2710 LS=LS+RD
      US=US-RD
 2730 IF(US.LE.USC) GO TO 2770
      LS=LS+(US-USC)
      US=USC
C
C      SIMULATION OF GROUNDWATER RECHARGE AND RUNOFF
C
 2770 IF(DS.GT.0) GO TO 9770
      TS=0.
      S=SO*(1-US/USC)
 9770 LDR=LS*(1.-EXP(-TF*LDP*SQRT(LS/LSC)))
      IF(LS-LDR.GT.LSC) LDR=LS-LSC
      LS=LS-LDR
      CLDR=CLDR+LDR
      GS=GS+LDR
      GR=0.
      RCOR=SQRT(TF+2.*GM*KG**(GM-1)*TF)-SQRT(TF)
      IF(GS.GT.0) GR=GS/GM*RCOR
      IF(GR.GT.GS) GR=GS
      GS=GS-GR
      CGR=CGR+GR
C
C      END MAIN LOOP OF MODEL
C
      IF(IOP5.EQ.0) GO TO 9771
      RN=CRN
      L=1
 7000 IF(US.GT.RN) GO TO 7001
      HR(L)=HR(L) + DURA
      GO TO 7002
 7001 RN=RN + CRN
      IF(RN.GT.LIM) GO TO 7002
      L= L+1
      GO TO 7000
 7002 CONTINUE
 9771      TTS=IS+DS+US+LS+GS
C      IMPERVIOUS AND PERVIOUS RUNOFF
      EXI=0.0
      REU=0.0
      IF(FIMP.EQ.0) GO TO 171
      CAP1=IDS
      CAP=IDS+PP-PIIP
      IF(CAP.GT.CAPINP) GO TO 131
      IDS=CAP-PEE
      IF(IDS.LT.0.0) IDS=0.0
      EII=0.0
      EIPI=0.0
      REU=0.0
      GO TO 172
  131 IF((CAP-CAPINP).LT.PEE) GO TO 771
      REU=(CAP-CAPINP)-PEE
      IDS=CAPINP
      EXI=FIMP*REU
      GO TO 171
  771 REU=0.0
      EII=0.0
      IDS=CAP-PEE
      IF(IDS.LT.0.0) IDS=0.0
  171 EIPI=RE*(1-FIMP)
  172 CONTINUE
      EIW=EII+EIPI
      IF(IOP7.EQ.0) GO TO 7044
C      SEARCH AND STORE APPROPRIATE ARDM WATER BALANCE DATA
C      PRE STORM ARDM DATA SEARCH
      DO 7045 KAF=1,IOP7
      DO 7046 KAD=1,6
      IF(JJJ.NE.IANTI(KAD,KAF)) GO TO 7046
      STORS(KAD,KAF,1)=IS
      STORS(KAD,KAF,2)=DS
      STORS(KAD,KAF,3)=US
      STORS(KAD,KAF,4)=LS
      STORS(KAD,KAF,5)=0.
      STORS(KAD,KAF,6)=0.
 7046 CONTINUE
 7045 CONTINUE
C       STORM BURST ARDM DATA SEARCH
      DO 7047 IAZ=1,IOP7
      IF(INCCT(IAZ).GT.INDIF(IAZ)) GO TO 7047
      IF(JJJ.NE.INCCT(IAZ)) GO TO 7047
      INCCT(IAZ)=INCCT(IAZ)+1
      IES(IAZ)=IES(IAZ)+1
      N=IES(IAZ)
      INDA(N,IAZ)=JJJ
      STORS(N,IAZ,1)=IS
      STORS(N,IAZ,2)=DS
      STORS(N,IAZ,3)=US
      STORS(N,IAZ,4)=LS
      STORS(N,IAZ,5)=RE
      STORS(N,IAZ,6)=REU
      DATI(N,IAZ)=XNTI(JJJ)
      IOYT(N,IAZ)=IDOY(JJJ)
C      INCREMENTAL STORM DATA
      IF(N.EQ.7) GO TO 7049
      IF(N.NE.8) GO TO 7050
      IF(BACKS(IAZ).LT.0.00001) GO TO 7050
      ACCR(8,IAZ)=BPRECS(IAZ)
      IF(IOP6.EQ.1) ACCR(8,IAZ)=BPRECS(IAZ)/10.0
      ATIN(8,IAZ)=BACKS(IAZ)
      STORS(N,IAZ,5)=RE*ATIN(8,IAZ)/(DURA*60.)
      STORS(N,IAZ,6)=REU*ATIN(8,IAZ)/(DURA*60.)
      DURL(IAZ)=DURA
      GO TO 7047
 7049 ACCR(7,IAZ) =0.0
      ATIN(7,IAZ)=0.0
      STORS(N,IAZ,5)=0.0
      STORS(N,IAZ,6)=0.0
      GO TO 7047
 7050 ACCR(N,IAZ)=ACCR(N-1,IAZ)+PP
      ATIN(N,IAZ)=ATIN(N-1,IAZ) + DURA*60.
      DURL(IAZ)=DURA
 7047 CONTINUE
C      CORRECTION TO LAST ITEM WHEN BACKF GT 0
 7044 CONTINUE
      IF(IOP6.EQ.0) GO TO 7052
      IF(DURA.GT.24.0.AND.PP.LT.3.0) XRUN(JJJ)=BFLOW
 7052 CONTINUE
      SPER(JJJ)=SPER(JJJ-1)+RE
      SWTD(JJJ)=SWTD(JJJ-1)+EIW
      IF(IOP1.EQ.0) GO TO 5007
      IF(LAA.NE.1) GO TO 5007
      WRITE(1,6002)JJJ,XNTI(JJJ),IDOY(JJJ),DURA,PP,PEE,IS,DS,US,LS,GS,
     1INF,INF,RD,CGR,RE,REU,XRUN(JJJ)
 6002 FORMAT(1H ,I4,2X,A3,I3,F8.3,F6.2,F7.2,F7.2,F8.2,F9.2,F10.2,F10.2,
     1F8.2,F7.2,F7.2,"*",F7.2,F7.2,F8.2,F10.2)
C      INDIVIDUAL STORM SUMMARY
 5007 IF(IOP2.EQ.0) GO TO 5099
      IF(NCCT.GT.IOP2) GO TO 5099
      IF(LAA.NE.1) GO TO 100
      NJJS=NIS(NCCT)
      NJF=NIF(NCCT)
      IF(JJJ.LT.NJJS) GO TO 5099
      IF(JJJ.GT.NJF) GO TO 5055
      IF(JJJ.GT.1) GO TO 5043
      IF(JSTM.GT.1) GO TO 5044
      ACSRUN=ACSRUN+XRUN(JJJ)*DURA*3600
      GO TO 5044
 5043 IF(JSTM.GT.1) GO TO 5044
      ACSRUN=ACSRUN+(XRUN(JJJ)+XRUN(JJJ-1))/2.0*DURA*3600
 5044 ACSP=ACSP + RE*ACAT*(1-FIMP)*10.
      ACSI=ACSI + REU*ACAT*FIMP*10.
      GO TO 5099
C   WRITE STORM SUMMARY
 5055 NCCT=NCCT+1
      WRITE(1,5063) NJJS,NJF
 5063 FORMAT(1H ,30X,"STORM SUMMARY - NODE",I5," TO NODE",I5/)
      WRITE(1,5027)
      ACSIP=ACSP+ACSI
      WRITE(1,5028)P(NNN),PE(NNN), ACSRUN,ACSI,ACSP,ACSIP
      ACSRUN=0
      ACSP=0
      ACSI=0
 5099 IF(JJJ.GT.1) GO TO 5010
      IF(JSTM.GT.1) GO TO 5011
      ACRUN=ACRUN+XRUN(JJJ)*DURA*3600.
      GO TO 5011
 5010 IF(JSTM.GT.1) GO TO 5011
      ACRUN=ACRUN + (XRUN(JJJ) + XRUN(JJJ-1))/2.0*DURA*3600.
 5011 ACP=ACP+RE/1000.*ACAT*(1-FIMP)*10000.
      ACI=ACI+REU*ACAT*FIMP*10.
      IF(IS.LE.C1) GO TO 5015
      XISM=IS
      C1=IS
      IISNUM=JJJ
      XISMTH=XNTI(JJJ)
      IISDY=IDOY(JJJ)
 5015 IF(DS.LE.C2) GO TO 5016
      XDSM=DS
      C2=DS
      IDSNUM=JJJ
      XDSMTH=XNTI(JJJ)
      IDSDY=IDOY(JJJ)
 5016 IF(US.LE.C3) GO TO 5017
      XUSM=US
      C3=US
      IUSNUM=JJJ
      XUSMTH=XNTI(JJJ)
      IUSDY=IDOY(JJJ)
 5017 IF(LS.LE.C4) GO TO 5018
      XLSM=LS
      C4=LS
      ILSNUM=JJJ
      XLSMTH=XNTI(JJJ)
      ILSDY=IDOY(JJJ)
 5018 CONTINUE
      J=1
      IF(XNTI(JJJ).EQ.XNOV.OR.XNTI(JJJ).EQ.DEC) J=2
      IF(XNTI(JJJ).EQ.XJAN.OR.XNTI(JJJ).EQ.FEB) J=2
      IF(XNTI(JJJ).EQ.XMAR.OR.XNTI(JJJ).EQ.APR) J=2
      IF(IS.LE.CI(1,J)) GO TO 5019
      CI(1,J)= IS
      ISNO(1,J)= JJJ
      XISMT(1,J) = XNTI(JJJ)
      ISDA(1,J)= IDOY(JJJ)
 5019 IF(DS.LE.CI(2,J)) GO TO 5020
      CI(2,J) = DS
      ISNO(2,J)= JJJ
      XISMT(2,J)= XNTI(JJJ)
      ISDA(2,J)=IDOY(JJJ)
 5020 IF(US.LE.CI(3,J)) GO TO 5021
      CI(3,J)=US
      ISNO(3,J) = JJJ
      XISMT(3,J)= XNTI(JJJ)
      ISDA(3,J)= IDOY(JJJ)
 5021 IF(LS.LE.CI(4,J)) GO TO 5022
      CI(4,J)=LS
      ISNO(4,J)=JJJ
      XISMT(4,J)= XNTI(JJJ)
      ISDA(4,J)= IDOY(JJJ)
 5022 CONTINUE
      IF((TPI+.000001).LT.XIT) GO TO 3316
  100 CONTINUE
      IF(IOP3.EQ.0) GO TO 1001
      IF(LAA.NE.1) GO TO 3050
C     OUTPUT SUMMARY
      WRITE(1,5025)
 5025 FORMAT(1H ,20X,"OUTPUT SUMMARY - FULL RUN"/)
      WRITE(1,5027)
 5027 FORMAT(1H ," TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL
     1. PER  SIMUL. TOT "/1H ,4X,"MM",10X,"MM",10X,"M**3",5X,"FLW-M**3",
     24X,"FLW-M**3",4X,"FLW-M**3")
      ATIP=ACI+ACP
      PXXX=P(NNN)
      IF(IOP4.EQ.1) PXXX=PXXX/10.
      WRITE(1,5028)PXXX,PE(NNN), ACRUN,ACI,ACP,ATIP
 5028 FORMAT(1H ,6(F9.1,3X)/)
      WRITE(1,5029)
 5029 FORMAT(1H ,10X,"MAXIMUM STORAGE DEPTH SUMMARY"/)
      WRITE(1,5030)
 5030 FORMAT(1H ,11X,"INT STOR/CAP    DEP STOR/CAP    UPPER STOR/CAP
     1LOWER STOR/CAP")
      WRITE(1,5031) XISM,XDSM,XUSM,XLSM
 5031 FORMAT(1H ,"DEPTH(MM) ",F10.3,6X,F10.3,6X,F10.3,8X,F10.3)
      WRITE(1,5032)IISNUM,IDSNUM,IUSNUM,ILSNUM
 5032 FORMAT(1H ,"INDEX",6X,I6,10X,I6,10X,I6,12X,I6)
      WRITE(1,5033)IISDY,IDSDY,IUSDY,ILSDY
 5033 FORMAT(1H ,"DAY",13X,I2,14X,I2,14X,I2,16X,I2)
      WRITE(1,5034)XISMTH,XDSMTH,XUSMTH,XLSMTH
 5034 FORMAT(1H ,"MONTH",8X,A3,13X,A3,13X,A3,15X,A3//)
      DO 5070 K=1,2
      IF(K.EQ.2) GO TO 5049
      WRITE(1,5050)
      GO TO 5052
 5049 WRITE(1,5051)
 5050 FORMAT(1H ,10X,"MAX SUMMER STORAGE DEPTH SUMMARY"/)
 5051 FORMAT(1H ,10X,"MAX WINTER STORAGE DEPTH SUMMARY"/)
 5052 WRITE(1,5030)
      WRITE(1,5031)(CI(N,K),N=1,4)
      WRITE(1,5032)(ISNO(N,K),N=1,4)
      WRITE(1,5033)(ISDA(N,K),N=1,4)
      WRITE(1,5034)(XISMT(N,K),N=1,4)
 5070 CONTINUE
      IF(IOP5.EQ.0) GO TO 7020
      HRTOT=0
      DO 7003 I=1,LIM
      HRTOT=HRTOT + HR(I)
 7003 CONTINUE
      GENR(1)=HRTOT
      PEX(1)=100.
      DO 7004 I=2,LIM
      GENR(I)=GENR(I-1) - HR(I-1)
      PEX(I)=GENR(I)/HRTOT*100.
 7004 CONTINUE
      WRITE(1,7009)
 7009 FORMAT("       ANNUAL SUMMARY PERCENTAGE TIME UPPER SOIL STORAGE
     1LEVELS"/)
      WRITE(1,7006)
 7006 FORMAT(1H ,"PARTITION INCREMENT    TOTAL HRS    SUM >= PREV. INCS
     1  PROB OF EXCEEDANCE %")
      RN=CRN
      WRITE(1,7007)CRN,HR(1),GENR(1),PEX(1)
 7007 FORMAT(1H ," 0.000 - ",F6.3,10X,F7.2,10X,F7.2,10X,F6.2)
      DO 7005 I=2,LIM
      WRITE(1,7008)RN,RN+CRN,NR(I),GENR(I),PEE(I)
      RN=RN+CRN
 7008 FORMAT(1H ,F6.3," - ",F6.3,10X,F7.2,10X,F7.2,10X,F6.2)
 7009 CONTINUE
      WRITE(1,7010)
 7010 FORMAT(//)
 7020      WRITE(1,6002)NNN,INTI(NNN),IDDY(NNN),DURA,PP,PEE,TS,DS,US,LS,GS,
     1SNF,INF,RD,CGR,RE,REU,RRUN(NNN)
C     OUTPUT OF BURST STATISTICS
      IF(IOP7.EQ.0) GO TO 7053
 3058 DO 7066 J=1,IOP7
      GO TO (3701,3702,3703),LAA
 3701 WRITE(1,7067) BDUR(J),FIMP
 7067 FORMAT(//1H ,14X,"ANNUAL MAXIMUM",F6.1," MIN  BURST STATISTICS
     1"      /1H, " MAX RAINFALL - IMPERV RUNOFF - IMP FRACT = ",F5.2)
      GO TO 3704
 3702 WRITE(1,7071)BDUR(J),FIMP
 7071 FORMAT(//1H ,14X,"ANNUAL MAXIMUM",F6.1," MIN  BURST STATISTICS
     1"/1H ," MAX PERVIOUS RUNOFF - IMP FRACT = ",F5.2)
      GO TO 3704
 3703 WRITE(1,7072)BDUR(J),FIMP
 7072 FORMAT(//1H ,14X,"ANNUAL MAXIMUM",F6.1," MIN  BURST STATISTICS
     1"/1H ," MAX WEIGHTED RUNOFF - IMP FRACT = ",F5.2)
 3704 CONTINUE
      WRITE(1,7054)
 7054 FORMAT(1H ,"DATE   CLOCK   DATA  ACCUM    ACCUM *              SI
     1MULATED DATA"/1H ," OR      TIME   INDEX  TIME    RAIN   *   IS
     2DS    US      LS     PERV  IMPERV"/1H ,"TIME   (HRS)            (MIN)
     3   (MM)   *  (MM)  (MM)  (MM)    (MM)   RNOFF RNOFF")
      DO 7055 I=1,6
      GO TO (7056,7057,7058,7059,7060,7061)I
 7056 A=DAY
      IT=-30
      CT=CLKPOS(J)
      GO TO 7062
 7057 A=DAY
      IT=-5
      CT=CLKPOS(J)
      GO TO 7062
 7058 A=DAY
      IT=-1
      CT=CLKPOS(J)
      GO TO 7062
 7059 A=HRS
      IT=-12
      CT=CLKPOS(J)+12.0
      IF(CT.GT.24.0) CT=CT-24.0
      GO TO 7062
 7060 A=HRS
      IT=-1
      CT=CLKPOS(J) -1
      IF(CT.LT.0.0) CT=24.0+CT
      GO TO 7062
 7061 A=MIN
      IT=-30
      CT=CLKPOS(J)-0.5
      IF(CT.LT.0.0) CT=24.0+CT
 7062 IIANT=IANTI(I,J)+1
      WRITE(1,7063) A,IT,CT,IIANT,ACCR(I,J),(STORS(I,J,L),L=1,4)
 7063 FORMAT(1H ,A3,I3,F8.3,I5,9X,F9.2,"*",2F6.2,F8.4,F8.3)
 7055 CONTINUE
      L=IES(J)
      BPR=BPRECP(J)
      IF(IOP4.EQ.1) BPR=BPRECP(J)/10.0
      ACCR(L,J)=ACCR(L,J)-BPR
      ATIM(L,J)=ATIM(L,J)-BACKF(J)
      STORS(L,J,5)=STORS(L,J,5)*(ATIM(L,J)-ATIM(L-1,J))/(DURL(J)*60.)
      STORS(L,J,6)=STORS(L,J,6)*(ATIM(L,J)-ATIM(L-1,J))/(DURL(J)*60.)
      AREN=0
      AREUN=0
      AWTRN=0
      DO 7064 I=7,L
      INND=INDA(I,J)
      WRITE(1,7065)DATE(I,J),IDTT(I,J),INND,ATIM(I,J),ACCR(I,J),
     1(STORS(I,J,K),K=1,6)
 7065 FORMAT(1H ,A3,I3,8X,I5,F9.2,F9.2,"*",2F6.2,F8.4,F8.3,2F6.2)
      AREN=AREN+STORS(I,J,5)
      AREUN=AREUN+STORS(I,J,6)
      AWTRN=AWTRN+FIMP*STORS(I,J,6)+(1.-FIMP)*STORS(I,J,5)
 7064 CONTINUE
      WRITE(1,7777)AREN,AREUN,AWTRN
 7777 FORMAT(1H ,66X,3F7.2)
 7066 CONTINUE
      LAA=LAA+1
      IF(LAA.LT.4) GO TO 3058
 7053 CONTINUE
 1001 CONTINUE
99999 STOP
      END
```

```
      SUBROUTINE INTRP(SF,OF,NF,WF,OFI,NSG,NST,BACKT,PBACK)
      DIMENSION SF(NF),OF(NF)
      IF(NSG.NE.1) GO TO 300
      DO 1212 I=NST,NF
      IF(SF(I)-WF)1212,2,3
    2 OFI=OF(I)
      BACKT=0.0
      PBACK=0.0
      GO TO 100
    3 IF(I.EQ.1) GO TO 400
      OFI=OF(I)-(SF(I)-WF)/(SF(I)-SF(I-1))*(OF(I)-OF(I-1))
      BACKT=SF(I)-WF
      PBACK=OF(I)-OFI
      GO TO 100
  400 IF(WF.GT.0.0) GO TO 222
      OFI=0.0
      BACKT=0.0
      PBACK=0.0
      GO TO 100
  222 OFI=OF(I)-(SF(I)-WF)/SF(I)*OF(I)
       BACKT=SF(I)-WF
       PBACK=OF(I)-OFI
      GO TO 100
 1212 CONTINUE
      OFI=OF(I-1)
       BACKT=0.0
       PBACK=0.0
      GO TO 100
  300 DO 1313 I=NST,NF
      IF(SF(I)-WF)8,6,1313
    6 OFI=OF(I)
      BACKT=0.0
      PBACK=0.0
      GO TO 100
    8 OFI=OF(I)-(WF-SF(I))/(SF(I-1)-SF(I))*(OF(I)-OF(I-1))
      BACKT=WF-SF(I)
      PBACK=OF(I)-OFI
      GO TO 100
 1313 CONTINUE
      OFX=OF(I-1)
      BACKT=0.0
      PBACK=0.0
      NST=I-1
      GO TO 1001
  100 NST=I
 1001 RETURN
      END
```

INPUT DATA

```
                1
     1979   SIRALANG RURAL CALIBRATION RUN
  .50      1.0      1.0       12.5     12.50    10.      10.     0.7
  .0       0.01     0.0       0.0      2.50      2.50    5.      1.0
  4.5      0.15    17.280     1.00     0.05     0.94     0.7     0.7
          297
           1       297
  0 0 1 1 1 1 2    94.    .5    .0    00
   30.   40.   120.
```

} CATCHMENT PARAMETER SET

No. OF FOLLOWING RAINFALL, PAN EVAP. DATA INCR

OUTPUT OPTIONS

NO ΣRAIN STIME ΣEVAP DATE GAUGED DATA

```
   2      .831    9642.635     59.711  JAN   7   .003
   3     1.062    9679.923     61.000  JAN   7   .003
   4     1.592    9919.470     61.000  JAN   7   .003
   5     2.123   10879.072     66.944  JAN   8   .003
   6     2.654   24259.722    162.200  JAN  17   .007
   7     3.185   24338.957    162.200  JAN  17   .007
   8     4.777   49498.339    287.073  FEB   4   .014
   9     5.308   49537.953    287.711  FEB   4   .014
  10     7.166   87738.314    483.000  MAR   3   .025
  11     7.696   88074.987    483.000  MAR   3   .025
  12     8.227   88154.220    483.800  MAR   3   .025
  13     9.023   88590.052    485.209  MAR   3   .025
  14     9.556   88620.672    485.353  MAR   3   .025
  15    10.350   88847.984    486.110  MAR   3   .025
  16    11.147   88887.304    486.283  MAR   3   .025
  17    13.270   88907.414    486.383  MAR   3   .025
  18    15.393   88926.875    486.400  MAR   3   .025
  19    16.189   88964.448    486.400  MAR   3   .025
  20    16.720   88986.255    486.400  MAR   3   .025
  21    17.781   89806.045    486.400  MAR   3   .025
  22    18.312   89075.076    486.400  MAR   3   .025
  23    18.843   89045.086    486.400  MAR   3   .025
  24    19.374   89144.547    486.400  MAR   3   .025
  25    20.170   89184.357    486.400  MAR   3   .025
  26    20.701   89204.167    486.400  MAR   3   .025
  27    21.762   89223.977    486.400  MAR   3   .025
  28    22.558   89323.028    486.400  MAR   4   .025
  29    23.089   89362.838    486.400  MAR   4   .025
  30    23.620   89382.459    486.400  MAR   4   .025
  31    24.151   89481.510    486.400  MAR   4   .025
  32    24.947   89600.371    486.400  MAR   4   .025
  33    25.743   89639.991    486.400  MAR   4   .025
  34    26.539   89659.805    486.483  MAR   4   .025
  35    27.070   89679.611    486.561  MAR   4   .025
  36    27.601   89838.093    487.225  MAR   4   .025
  37    28.132   90590.880    489.400  MAR   4   .029
  38    28.662  103984.070    539.200  MAR  14   .029
  39    29.459  104093.237    539.984  MAR  14   .029
  40    29.989  104232.312    540.517  MAR  14   .029
  41    30.520  104262.077    540.804  MAR  14   .029
  42    31.051  104381.173    541.444  MAR  14   .029
  43    31.582  104391.102    541.736  MAR  14   .029
  44    33.174  104420.888    541.951  MAR  14   .029
  45    36.890  104430.817    542.023  MAR  14   .029
  46    40.605  104440.746    542.094  MAR  14   .029
  47    42.994  104450.675    542.166  MAR  14   .029
  48    44.321  104470.532    542.309  MAR  14   .029
  49    45.648  104480.461    542.381  MAR  14   .029
  50    46.975  104490.390    542.453  MAR  14   .029
  51    47.505  104500.319    542.835  MAR  14   .029
  52    48.301  105086.120    544.400  MAR  14   .029
  53    49.628  105205.266    544.400  MAR  15   .029
  54    50.955  105215.195    544.400  MAR  15   .029
  55    52.813  105225.124    544.400  MAR  15   .029
  56    55.202  105235.053    544.400  MAR  15   .029
  57    56.263  105244.981    544.400  MAR  15   .029
  58    56.794  105254.910    544.400  MAR  15   .029
  59    57.325  105264.839    544.400  MAR  15   .029
  60    57.856  105284.697    544.400  MAR  15   .029
  61    58.652  105294.625    544.400  MAR  15   .029
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  62    61.040  105304.554    544.400  MAR  15   .029
  63    63.960  105314.483    544.400  MAR  15   .029
  64    66.206  105324.412    544.400  MAR  15   .029
  65    69.798  105334.341    544.400  MAR  15   .029
  66    70.860  105344.270    544.400  MAR  15   .098
  67    71.656  105354.199    544.400  MAR  15   .151
  68    72.452  105374.056    544.400  MAR  15   .094
  69    72.983  105393.914    544.400  MAR  15   .063
  70    74.045  105830.702    544.985  MAR  15   .001
  71    74.575  105910.213    545.117  MAR  15   .001
  72    75.106  106426.512    545.600  MAR  15   .001
  73    75.902  106446.369    545.600  MAR  15   .001
  74    77.229  106466.227    545.600  MAR  15   .001
  75    78.356  106486.084    545.600  MAR  15   .001
  76    79.087  107141.387    546.461  MAR  16   .001
  77    79.618  107359.021    547.319  MAR  16   .001
  78    80.679  108968.291    550.090  MAR  17   .001
  79    81.210  109027.846    550.255  MAR  17   .001
  80    82.006  110378.184    555.210  MAR  18   .001
  81    83.333  110398.042    555.364  MAR  18   .001
  82    83.864  114721.235    565.058  MAR  21   .001
  83    84.926  116813.231    572.600  MAR  23   .001
  84    85.722  116902.610    572.600  MAR  23   .001
  85    88.661  116912.541    572.400  MAR  23   .001
  86    89.703  116922.472    572.600  MAR  23   .001
  87    90.234  116932.403    572.600  MAR  23   .001
  88    90.764  129733.403    611.000  APR   1   .001
  89    91.295  129822.864    611.000  APR   1   .001
  90    91.826  129832.795    611.000  APR   1   .001
  91    92.357  129842.726    611.000  APR   1   .001
  92    92.887  129852.657    611.000  APR   1   .001
  93    93.418  129872.519    611.000  APR   1   .001
  94    94.214  129882.450    611.000  APR   1   .001
  95    95.011  129902.312    611.000  APR   1   .001
  96    95.541  129951.167    611.000  APR   1   .001
  97    96.338  129961.098    611.033  APR   1   .001
  98    97.930  129971.039    611.165  APR   1   .001
  99    99.257  129981.760    611.266  APR   1   .001
 100   100.584  129991.691    611.387  APR   1   .001
 101   101.911  130001.632    611.509  APR   1   .002
 102   102.972  130021.484    611.751  APR   1   .001
 103   103.503  130031.415    611.873  APR   1   .001
 104   104.565  130051.270    612.116  APR   1   .001
 105   106.488  130061.209    612.237  APR   1   .001
 106   108.015  130071.140    612.358  APR   1   .001
 107   109.342  130081.071    612.480  APR   1   .001
 108   110.403  130091.002    612.601  APR   1   .001
 109   110.934  130100.933    612.723  APR   1   .001
 110   111.465  130110.864    612.844  APR   1   .001
 111   113.057  130120.795    612.965  APR   1   .001
 112   113.588  130140.657    613.208  APR   1   .001
 113   114.119  130150.588    613.329  APR   1   .001
 114   114.650  130170.450    613.572  APR   1   .001
 115   115.180  130210.174    614.058  APR   1   .020
 116   115.977  130329.346    615.514  APR   1   .010
 117   116.807  130339.277    615.636  APR   1   .008
 118   117.038  130369.070    616.000  APR   1   .006
 119   117.569  130618.725    618.607  APR   1   .004
 120   121.039  130996.726    619.000  APR   1   .001
 121   124.735  131006.655    619.000  APR   1   .001
 122   125.265  131016.586    619.000  APR   1   .001
 123   125.796  131203.278    619.000  APR   1   .007
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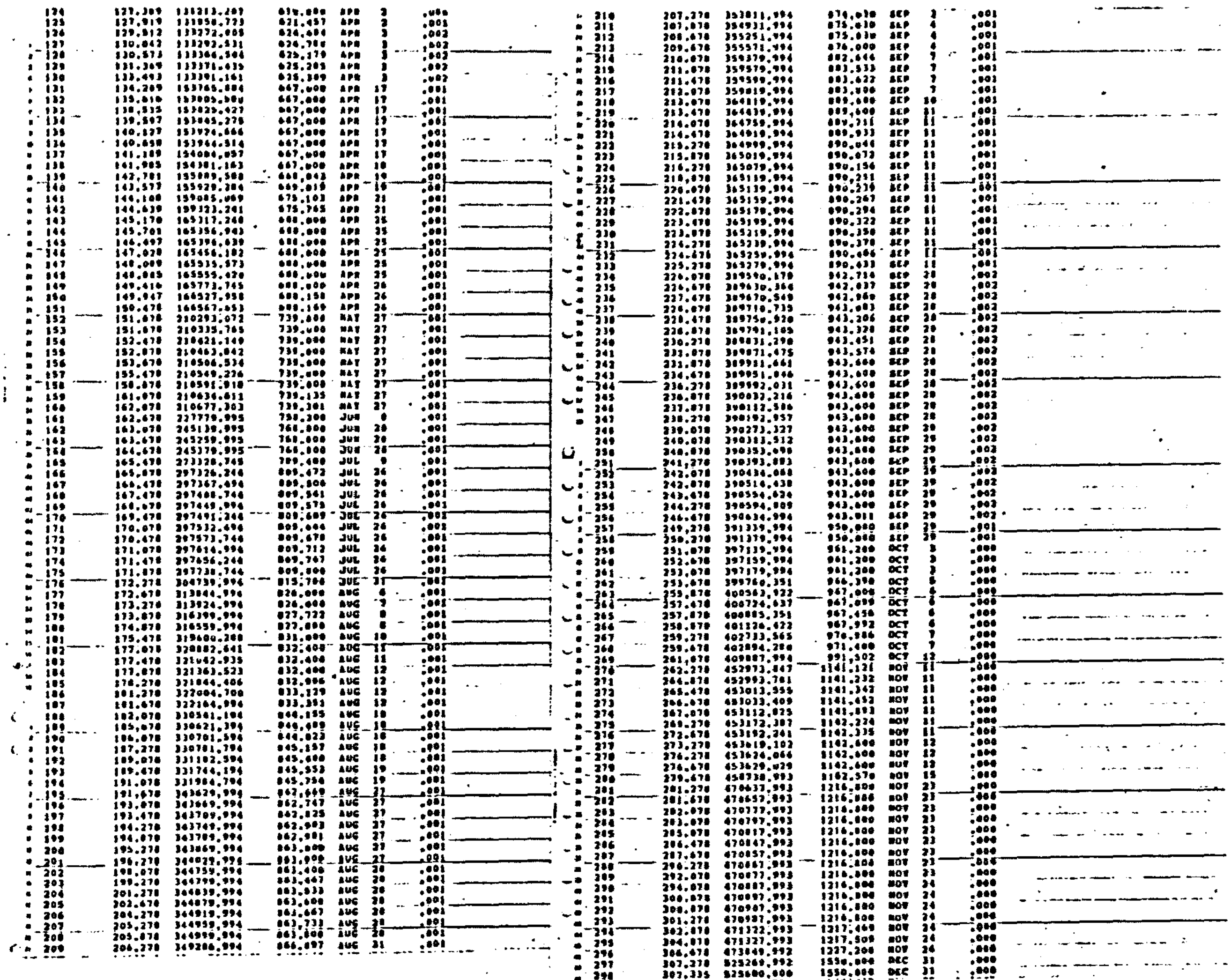
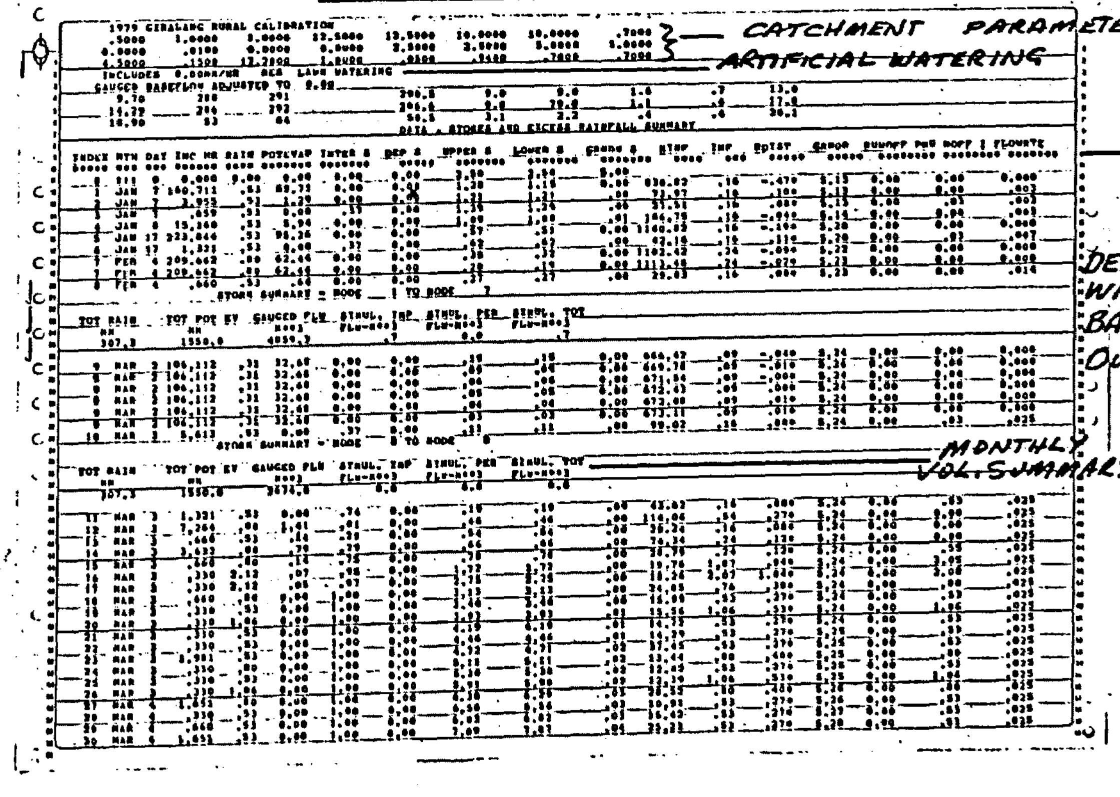


RESULTS


1979 GIRALANG RURAL CALIBRATION
INCLUDES 0.0MM/HR LAWN WATERING
GAUGED BASEFLOW ADJUSTED TO
DATA , STORES AND EXCESS RAINFALL SUMMARY
STORM SUMMARY - NODE 1 TO NODE 7
TOT RAIN
TOT POT EV
GAUGED FLW
STORM SUMMARY - NODE 8 TO NODE 8

CATCHMENT PARAMETER SET

ARTIFICIAL WATERING

DETAILED WATER/ BALANCE OUTPUT

MONTHLY VOL. SUMMARY.

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 31 MAR  4   1.981  .80  0.00  1.00  0.00   7.40   7.45    .05   37.13   .00   .410   5.29  0.00   .00   .025
 32 MAR  4    .660  .00  0.00  1.00  0.00   7.06   7.05    .05   13.34   .00   .410   5.30  0.00   .00   .025
 33 MAR  4    .330  .00   .06   .94  0.00   8.24   8.25    .05    8.41   .00   .490   5.30  0.00   .71   .025
 34 MAR  4    .330  .53   .00   .94  0.00   8.49   8.49    .05    7.78   .47   .240   5.31  0.00   .45   .025
 35 MAR  4   2.641  .53   .06   .54  0.00   8.73   8.69    .07   26.02   .41   .240   5.33  0.00  0.00   .025
 36 MAR  4  12.546  .53  2.17  0.00  0.00   8.40   8.30    .13   74.55   .16  -.020   5.46  0.00  0.00   .025
 37 MAR 14 223.219  .53 40.00  0.00  0.00   4.20   3.21   0.00  810.51   .16 -1.610   6.57  0.00  0.00  0.000
 38 MAR 14   1.820  .80   .30   .29  0.00   3.83   3.82    .05   36.62   .24   .620   6.57  0.00  0.00   .029
 39 MAR 14   2.151  .53   .01   .01  0.00   3.90   3.89    .08   41.87   .16   .080   6.58  0.00  0.00   .029
 40 MAR 14    .662  .53   .20   .18  0.00   3.98   3.97    .08   21.48   .16   .090   6.58  0.00  0.00   .029
 41 MAR 14   1.986  .53   .06  0.00  0.00   4.03   4.02    .02   39.39   .16   .070   6.58  0.00  0.00   .029
 42 MAR 14    .165  .53   .07   .32  0.00   4.10   4.10    .02   50.10   .16   .000   6.59  0.00  0.00   .029
 43 MAR 14    .496 1.59   .22   .85  0.00   4.56   4.56    .02   17.07   .91   .460   6.59  0.00  1.34   .029
 44 MAR 14    .165 3.72   .07   .95  0.00   6.14   6.14    .07    7.50  3.57  1.700   6.59  0.00  3.60   .029
 45 MAR 14    .165 3.72   .07   .95  0.00   8.17   8.17    .07    7.40  3.60  1.030   6.59  0.00  3.64   .029
 46 MAR 14    .165 2.39   .07   .95  0.00   9.14   9.14    .07    5.40  2.25  1.170   6.59  0.00  2.12   .029
 47 MAR 14    .331 1.33   .14   .90  0.00   9.98   9.97    .03    6.05  1.30   .640   6.59  0.00  1.18   .029
 48 MAR 14    .165 1.33   .07   .95  1.00  10.59  10.50    .03    3.35  1.23   .620   6.60  0.00  1.25   .029
 49 MAR 14    .165 1.33   .07   .95  1.00  11.22  11.22    .03    2.64  1.20   .600   6.60  0.00  1.25   .029
 50 MAR 14    .165  .53   .07   .95  1.00  11.46  11.46    .03    1.94   .40   .240   6.60  0.00   .40   .029
 51 MAR 14   9.763  .80  1.00  0.00  1.00  11.60  11.65    .14   38.04   .78   .310   6.73  0.00  0.00   .029
 52 MAR 15   1.986 1.33  0.00   .93  0.00  11.76  11.71    .13    9.13   .40   .310   6.74  0.00   .93   .029
 53 MAR 15    .165 1.33  0.00  1.00  0.00  12.37  12.36    .14    1.33  1.26   .650   6.77  0.00  1.33   .029
 54 MAR 15    .165 1.86  0.00  1.00  1.00  12.50  12.50    .40     .64   .64   .320   6.80   .21  1.56   .029
 55 MAR 15    .165 2.30  0.00  1.00  1.00  12.50  12.50    .97     .55   .55   .280   6.86  1.03  2.39   .029
 56 MAR 15    .165 1.06  0.00  1.00  1.00  12.50  12.50   1.42     .54   .54   .270   6.95   .52  1.06   .025
 57 MAR 15    .165  .53  0.00  1.00  1.00  12.50  12.50   1.83     .53   .53   .270   7.07  0.00   .53   .029
 58 MAR 15    .165  .53  0.00  1.00  1.00  12.50  12.50   2.22     .53   .51   .260   7.22   .00   .53   .029
 59 MAR 15    .331  .53  0.00  1.00   .77  12.50  12.50   3.11    1.05   .77   .380   7.47  0.00   .53   .029
 60 MAR 15    .165  .00  0.00  1.00  1.00  12.50  12.50   3.05     .52   .52   .260   7.67   .00   .00   .029
 61 MAR 15    .165 2.39  0.00  1.00  1.00  12.50  12.50   3.35     .52   .52   .260   7.88  3.07  2.39   .029
 62 MAR 15    .165 2.92  0.00  1.00  1.00  12.50  12.50   3.63     .52   .52   .260   8.12  2.40  2.92   .029
 63 MAR 15    .165 4.25  0.00  1.00  1.00  12.50  12.50   3.89     .51   .51   .260   8.37  3.73  4.25   .029
 64 MAR 15    .165 1.59  0.00  1.00  1.00  12.50  12.50   4.14     .51   .51   .260   8.64  1.08  1.59   .029
 65 MAR 15    .165 1.06  0.00  1.00  1.00  12.50  12.50   4.37     .51   .51   .260   8.92   .55  1.06   .098
 66 MAR 15    .165  .00  0.00  1.00  1.00  12.50  12.50   4.58     .51   .51   .260   9.22   .70   .00   .151
 67 MAR 15    .331  .00  0.00  1.00   .00  12.50  12.50   5.01    1.02   .00   .450   9.69  0.00   .00   .094
 68 MAR 15    .331  .53  0.00  1.00   .71  12.50  12.50   5.23    1.02   .71   .360  10.10  0.00   .53   .063
 69 MAR 15   7.281 1.06   .50   .55   .09  12.50  12.50   3.45   22.18   .09   .440  12.65  0.00   .40   .001
 70 MAR 15   1.324  .53   .13   .87  1.00  12.50  12.47   3.05    4.01  0.00  0.000  13.29   .05   .40   .001
 71 MAR 15   8.605  .53   .40   .66   .68  12.50  12.50   3.18   25.96   .72   .340  14.03  0.00   .05   .001
 72 MAR 15    .331  .00  0.00  1.00   .57  12.50  12.50   3.44    1.00   .57   .290  15.15  0.00   .00   .001
 73 MAR 15    .331 1.33  0.00  1.00   .95  12.50  12.50   3.16    1.00   .95   .470  15.45  0.00  1.33   .001
 74 MAR 15    .331 1.33  0.00  1.00  1.00  12.50  12.50   3.74    1.00  1.00   .500  15.80   .78  1.33   .001
 75 MAR 16  10.923  .53   .06   .40   .77  12.50  12.50   3.20   33.83   .77   .380  18.07  0.00  0.00   .001
 76 MAR 16   3.641  .53   .05   .17   .92  12.50  12.41   1.78   10.93  0.00  0.000  18.70  0.00  0.00   .001
 77 MAR 17  26.608 1.86  3.73  0.00  0.00  12.49  11.81    .54   86.32   .18   .040  20.54   .14  0.00  0.000
 78 MAR 17    .993  .53   .17   .26  0.00  12.23  12.20    .40    2.90   .16   .420  20.62  0.00  0.00   .001
 79 MAR 18  32.505  .40  4.96  0.00  0.00  11.01  10.53    .36   78.43   .24  -.400  21.30  0.00  0.00   .001
 80 MAR 18    .331 1.33   .17   .81  0.00  10.97  10.96    .26    3.30   .40   .440  21.37  0.00   .66   .001
 81 MAR 21  63.720  .53  9.67  0.00  0.00   8.35   7.41   0.00  223.36   .36  -.340  22.43  0.00  0.00  0.000
 82 MAR 21  43.200 1.06  7.55  0.00  0.00   5.77   5.10    .01  206.15   .32  -.310  22.76  0.00  0.00  0.000
 83 MAR 21   1.490  .80  0.00   .56  0.00   5.67   5.66    .01   27.58   .24   .250  22.76  0.00   .10   .001
 84 MAR 23    .166 2.92  0.00  1.00  0.00   6.90   6.90    .02    8.34  2.40  1.240  22.76  0.00  2.97   .001
 85 MAR 23    .166 1.06  0.00  1.00  0.00   7.43   7.43    .02    6.06  1.06   .510  22.76  0.00  1.04   .001
 86 MAR 23    .166  .53  0.00  1.00  0.00   7.70   7.69    .02    6.24   .53   .270  22.76  0.00   .53   .001
 87 APR  1 213.351  .53 38.60  0.00  0.00   3.93   3.06   0.00  825.30   .53 -1.465  23.65  0.00  0.00  0.000
 88 APR  1   1.490  .53  0.00   .37  0.00   3.50   3.57    .00   33.59   .16   .310  23.65  0.00   .03   .001
                    STORM SUMMARY - NODE   18 TO NODE   88

 TOT RAIN     TOT POT ET  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
   MM            MM          M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1556.8      17996.7       737.4     14417.6     15155.0

 89 APR  1    .166  .53  0.00   .74  0.00   3.60   3.65    .01   10.62   .16   .080  23.65  0.00   .53   .001
 90 APR  1    .166  .53  0.00  1.00  0.00   3.79   3.79    .01   10.53   .27   .140  23.65  0.00   .53   .001
 91 APR  1    .166  .53  0.00  1.00  0.00   4.05   4.05    .01   10.37   .53   .270  23.65  0.00   .53   .001
 92 APR  1    .331  .53  0.00  1.00  0.00   4.32   4.32    .01   14.53   .53   .270  23.65  0.00   .53   .001
 93 APR  1    .166  .00  0.00  1.00  0.00   4.72   4.72    .01    9.77   .00   .400  23.65  0.00   .00   .001
 94 APR  1    .331  .00  0.00  1.00  0.00   5.11   5.11    .01   13.47   .00   .400  23.65  0.00   .83   .001
 95 APR  1    .828  .53  0.00  1.00  0.00   5.38   5.37    .01   21.19   .53   .270  23.66  0.00   .77   .001
 96 APR  1    .166  .80   .12   .98  0.00   5.77   5.77    .01    8.57   .80   .400  23.66  0.00  1.47   .001
 97 APR  1    .166 1.59   .12   .91  0.00   6.56   6.56    .01    8.12  1.58   .790  23.66  0.00  1.71   .001
 98 APR  1    .166 1.33   .12   .92  0.00   7.18   7.18    .02    7.23  1.34   .670  23.66  0.00  1.31   .001
 99 APR  1    .166 1.33   .12   .92  0.00   7.80   7.80    .02    6.83  1.34   .670  23.66  0.00  1.31   .001
100 APR  1    .166 1.33   .12   .91  0.00   8.42   8.42    .02    5.92  1.31   .670  23.66  0.00   .83   .001
101 APR  1    .331 1.06   .24   .83  0.00   8.91   8.90    .02    7.53   .98   .490  23.66  0.00   .41   .001
102 APR  1    .166  .53   .12   .91  0.00   9.09   9.09    .02    4.57   .36   .180  23.66  0.00   .83   .001
103 APR  1    .331 1.06   .24   .83  0.00   9.67   9.67    .03    6.48   .98   .490  23.67  0.00  2.00   .001
104 APR  1    .166 2.12   .12   .92  0.00  10.55  10.54    .03    3.91  1.75   .900  23.67  0.00  1.21   .001
105 APR  1    .166 1.33   .12   .92  0.00  11.17  11.16    .03    3.75  1.24   .620  23.67  0.00  1.21   .001
106 APR  1    .166 1.33   .12   .91  0.00  11.79  11.78    .03    3.00  1.24   .670  23.67  0.00   .84   .001
107 APR  1    .166 1.06   .12   .92  0.00  12.27  12.27    .03    3.30   .98   .490  23.67  0.00   .41   .001
108 APR  1    .166  .53   .12   .91  0.00  12.49  12.49    .03     .78   .45   .210  23.68  0.00   .41   .001
109 APR  1    .166  .53   .12   .92   .21  12.50  12.50    .21     .56   .23   .120  23.69  0.00  1.67   .001
110 APR  1    .166 1.59   .12   .92  1.00  12.50  12.50    .60     .49   .49   .250  23.74   .21   .28   .001
111 APR  1    .331  .53   .24   .83   .73  12.50  12.50   1.30     .56   .73   .360  23.86  0.00   .41   .001
112 APR  1    .166  .53   .12   .92   .50  12.50  12.50   1.67     .49   .49   .250  23.96  0.00   .28   .001
113 APR  1    .331  .53   .24   .83   .52  12.50  12.50   2.00     .99   .82   .240  24.15  0.00   .04   .038
114 APR  1    .662  .53   .49   .46   .46  12.50  12.50   2.14    1.97   .44   .220  24.45  0.00  0.00   .018
115 APR  1   1.986  .80  1.46  0.00   .43  12.50  12.50   2.04    5.91   .44   .220  24.97  0.00  0.00   .008
116 APR  1    .166  .53   .12   .30   .59  12.50  12.50   1.92     .49  0.00  0.000  25.17  0.00   .07   .006
117 APR  1    .497  .53   .36   .44   .75  12.50  12.49   1.73    1.40   .60   .060  25.32  0.00  0.00   .004
118 APR  1    .828  .53   .61   .38   .90  12.50  12.47   1.52    2.48   .01   .010  25.86  0.00   .18   .001
119 APR  1   9.600 3.45  3.19  0.00  0.00  12.50  12.50   1.54   28.84  1.62   .710  26.09  1.00  1.72   .001
120 APR  1    .166 3.72  0.00  1.00  1.00  12.50  12.50   1.91     .49   .49   .250  27.01  1.72   .33   .001
121 APR  1    .166  .53  0.00  1.00  1.00  12.50  12.50   2.25     .49   .60   .350  27.18   .04   .53   .007
122 APR  2   3.145  .53  0.00  1.00   .77  12.50  12.50   2.22    8.34   .77   .380  27.96  0.00  1.50   .006
123 APR  2    .166 1.50  0.00  1.00  1.00  12.50  12.50   3.55     .80   .48   .350  28.12   .07  0.00   .001
124 APR  2  10.759  .53  1.66  0.00   .84  12.50  12.50   1.67   31.85   .73   .370  29.73  0.00  0.00   .002
125 APR  3  33.568 1.50  8.23  0.00  0.00  12.40  11.85    .62   76.66  1.33   .340  31.30  0.00  0.00   .002
126 APR  3    .329  .53   .10   .30  0.00  12.27  12.26    .50    1.00   .16   .300  31.43  0.00  0.00   .002
127 APR  3   1.333  .53   .35   .40  0.00  12.31  12.31    .51    4.39   .16   .080  31.53  0.00   .07   .002
128 APR  3    .882  .00   .03   .94   .06  12.41  12.41    .40     .37   .17   .180  31.55  0.00   .77   .002
129 APR  3    .329 2.12   .16   .83   .08  12.50  12.50   1.33    1.13  1.13   .570  31.66  0.00  2.83   .002
130 APR 17 169.789  .40 20.85  0.00  0.00   6.53   5.06   0.00  809.75  1.32 -2.230  34.47  0.00  0.00  0.000
130 APR 17 169.789  .40 20.85  0.00  0.00   2.78   2.35   0.00  731.11   .13  -.174  34.84  0.00  0.00  0.004
131 APR 17    .663 1.33  0.00   .93  0.00   2.76   2.76    .00   24.01   .40   .410  34.90  0.00   .93   .001
132 APR 17    .331 2.92  0.00  1.00  0.00   4.19   4.18    .00   16.60  2.85  1.430  34.96  0.00  3.32   .001
133 APR 17    .331 1.06  0.00  1.00  0.00   4.73   4.72    .00   14.31  1.06   .530  34.90  0.00  1.04   .001
134 APR 17   1.323  .53  0.00  1.00  0.00   4.98   4.97    .01   28.89   .53   .270  34.90  0.00   .53   .001
135 APR 17    .331  .53  0.00  1.00  0.00   5.34   5.34    .01   13.04   .53   .270  34.90  0.00   .53   .001
136 APR 17    .992  .53  0.00  1.00  0.00   5.51   5.50    .02   31.11   .53   .270  34.91  0.00   .53   .001
137 APR 18   4.205  .80  0.00  1.00  0.00   5.90   5.85    .04   67.35   .00   .400  34.93  0.00   .00   .001
138 APR 18  25.110  .80  3.83  0.00  0.00   6.15   5.91    .37  166.93   .00   .370  35.13  0.00  0.00  0.000
139 APR 18    .662  .80   .18   .43  0.00   6.14   6.13    .04   10.42   .24   .230  35.14  0.00   .12   .001
140 APR 21  82.546  .53  8.00  0.00  0.00   3.49   3.20   0.00  284.89   .16  -.616  35.49  0.00  0.00  0.000
141 APR 21   3.970  .53   .64  0.00  0.00   4.38   4.36    .02   56.31   .16   .200  35.50  0.00  0.00   .001
142 APR 25  99.906  .53 13.24  0.00  0.00   3.29   2.60   0.00  323.06   .16  -.014  35.70  0.00  0.00  0.000
143 APR 25    .662  .53  0.00   .37  0.00   2.27   2.27    .00   35.13   .16   .100  35.71  0.00   .03   .001
144 APR 25    .662  .80  0.00   .93  0.00   2.39   2.39    .00   35.17   .24   .171  35.71  0.00   .00   .001
145 APR 25    .992  .53  0.00  1.00  0.00   2.62   2.61    .00   31.84   .46   .230  35.71  0.00   .33   .001
146 APR 25   1.323 1.06  0.00  1.00  0.00   3.15   3.14    .01   35.63  1.06   .510  35.71  0.00  1.06   .001
147 APR 25    .331  .10  0.00  1.00  0.00   3.44   3.34    .01   15.33   .40   .400  35.71  0.00   .40   .001
148 APR 26   3.815  .53  0.00  1.00  0.00   3.81   3.74    .02   18.48   .11   .270  35.71  0.00   .31   .001
149 APR 26  12.870  .53   .18   .09  0.00   4.04   4.00    .04  323.29   .43   .270  35.76  0.00   .37   .001
150 APR 26    .662  .53   .05   .09  0.00   4.34   4.24    .03   31.10   .42   .240  35.76  0.00   .62   .001
151 MAY 27 131.459  .10  1.47  0.00  0.00   3.17   1.95   0.00  614.47   .09  -.020  36.01  0.00  0.00  0.000
151 MAY 27 131.459  .16  1.47  0.00  0.00   1.45    .96   0.00  615.13   .03  -.355  36.09  0.00  0.00  0.000
151 MAY 27 131.459  .10  1.47  0.00  0.00    .50    .40   0.00  713.10   .03  -.170  36.11  0.00  0.00  0.000
151 MAY 27 131.459  .16  1.47  0.00  0.00    .38    .24   0.00  724.30   .03  -.044  36.11  0.00  0.00  0.000
151 MAY 27 131.459  .10  1.47  0.00  0.00    .13    .13   0.00  737.12   .03  -.040  36.12  0.00  0.00  0.000
151 MAY 27 131.459  .16  1.47  0.00  0.00    .07    .07   0.00  740.00   .03  -.310  36.13  0.00  0.00  0.000
152 MAY 27    .712  .60  0.00   .42  0.00    .16    .16    .00   31.39   .10   .090  36.13  0.00   .10   .001
                    STORM SUMMARY - NODE   89 TO NODE  152

 TOT RAIN     TOT POT ET  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
   MM            MM          M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1556.8       1047.2       473.4      3812.8      4286.2

153 MAY 27   1.423  .18  0.00   .98  0.00    .38    .38    .04   45.20   .34   .130  36.13  0.00   .00   .001
154 MAY 27    .712  .40  0.00  1.00  0.00    .67    .67    .00   30.06   .38   .190  36.13  0.00   .40   .001
155 MAY 27    .713  .06  0.00  1.00  0.00    .87    .87    .04   30.61   .86   .464  36.13  0.00   .00   .001
156 MAY 27    .713 1.30  0.00  1.00  0.00   1.77   1.77    .00   29.47  1.50   .900  36.12  0.00  1.00   .001
157 MAY 27    .713 2.60  0.00  1.00  0.00   3.07   3.07    .00   27.36  2.60  1.304  36.12  0.00  3.40   .001
158 MAY 27    .712 3.00   .13   .91  0.00   4.57   4.56    .03   34.30  3.00  1.500  36.13  0.00  2.07   .001
159 MAY 27    .712 1.80   .17   .88  0.00   5.02   5.01    .01   26.77   .91   .450  36.13   .04   .83   .001
160 JUN  8 142.522  .30  9.45  0.00  0.00   3.36   2.24   0.00  672.30   .18  -.070  36.46  0.00  0.00  0.000
160 JUN  8 142.522  .30  9.45  0.00  0.00   1.19   1.09   0.00  754.30   .09  -.300  36.56  0.00  0.00  0.000
161 JUN 20 144.687  .20  5.30  0.00  0.00    .57    .54   0.00  848.90   .06  -.190  36.60  0.00  0.00  0.000
                    STORM SUMMARY - NODE  153 TO NODE  160

 TOT RAIN     TOT POT ET  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
   MM            MM          M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1556.8        277.0       113.1         0.0       113.1

161 JUN 20 144.667  .20  5.30  0.00  0.00    .39    .37   0.00  826.78   .46  -.007  36.61  0.00  0.00  0.000
162 JUN 20   2.000  .60  0.00   .42  0.00    .37    .37    .00   54.11   .18   .100  36.61  0.00   .10   .001
163 JUN 20   2.000 1.80  0.00  1.00  0.00    .38    .38    .00   53.78   .42   .314  36.61  0.00  1.00   .001
164 JUL  9 232.906  .40 10.30  0.00  0.00    .35    .33   0.00 1199.06   .40  -.040  36.64  0.00  0.00  0.000
164 JUL  9 232.906  .40 10.30  0.00  0.00    .18    .17   0.00 1208.07   .12  -.040  36.65  0.00  0.00  0.000
165 JUL 26 199.979  .20 10.04  0.00  0.00    .10    .09   0.00 1079.64   .06  -.030  36.65  0.00  0.00  0.000
                    STORM SUMMARY - NODE  161 TO NODE  164

 TOT RAIN     TOT POT ET  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
   MM            MM          M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1556.0        416.0        13.3         0.0        13.3

165 JUL 26 199.979  .20 10.04  0.00  0.00    .06    .08   0.00 1033.83   .46  -.010  36.65  0.00  0.00  0.000
166 JUL 26    .600  .60   .03   .40  0.00    .18    .15    .00   30.01   .10   .000  36.65  0.00   .07   .001
167 JUL 26    .600 1.00   .03   .98  0.00    .34    .34    .00   30.61   .40   .200  36.65  0.00   .87   .001
168 JUL 26    .600 1.30   .03   .98  0.00    .93    .93    .00   30.15  1.10   .500  36.65  0.00  1.17   .001
169 JUL 26    .600  .10   .03   .98  0.00   1.32   1.32    .00   24.10   .70   .340  36.66  0.00   .77   .001
170 JUL 26    .600  .60   .03   .98  0.00   1.61   1.61    .00   27.00   .58   .300  36.66  0.00   .87   .001
171 JUL 26    .600  .40   .03   .98  0.00   1.79   1.79    .00   27.35   .30   .160  36.65  0.00   .31   .001
172 JUL 26    .600  .40   .03   .98  0.00   1.98   2.08    .00   24.79   .41   .200  36.66  0.00   .17   .001
173 JUL 26    .600  .40   .03   .98  0.00   2.27   2.27    .00   30.13   .38   .190  36.66  0.00   .16   .001
174 JUL 26   1.378  .40   .05   .94  0.00   2.44   2.48    .01   37.54   .38   .190  36.66  0.00   .15   .001
175 JUL 31 116.660  .40  9.90  0.00  0.00   1.31   1.31   0.00  640.00   .36  -.420  36.76  0.00  0.00  0.000
176 AUG  4 131.338  .40 10.30  0.00  0.00    .04    .00   0.00  835.11   .13  -.310  36.81  0.00  0.00  0.000
                    STORM SUMMARY - NODE  165 TO NODE  175

 TOT RAIN     TOT POT ET  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
   MM            MM          M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1550.0        231.6        87.9         0.0        87.9
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177 AUG  7   1.333  .40   0.00   .02  0.00   .71   .71   .00  42.14   .10   .110 36.81 0.00   .10  .001
178 AUG  8  41.350  .40   1.72  0.00  0.00   .62   .61   .00 333.67   .10   .026 36.82 0.00  0.00 0.000
179 AUG  8   2.667 1.00    .08   .05  0.00   .76   .76   .00  62.03   .10   .160 36.82 0.00   .42  .001
180 AUG 10  30.672  .40   1.20  0.00  0.00   .80   .49  0.00 311.51   .23  -.071 36.83 0.00  0.00 0.000
181 AUG 11  21.333 1.00   1.40   .02  0.00   .80   .79   .00 210.13   .40   .310 36.84 0.00  0.00  .001
182 AUG 11   2.672  .40   0.00   .30  0.00   .91   .93   .00  61.27   .12   .049 36.84 0.00   .10  .001
183 AUG 12   5.343  .40   0.00   .30  0.00   .91   .91   .00  90.94   .12   .080 36.84 0.00   .40  .001
184 AUG 12   8.015  .40    .01   .31  0.00   .97   .97   .00 115.20   .12   .059 36.84 0.00  0.00  .001
185 AUG 12   2.672 3.00    .22   .04  0.00  2.27  2.32   .01  40.46  2.81  1.260 36.84 0.00  2.47  .001
186 AUG 12   2.672  .40    .22   .04  0.00  2.31  2.34   .01  51.10   .24   .129 36.85 0.00   .10  .001
187 AUG 18 139.603  .40  10.00  0.00  0.00  1.22  1.11  0.00 749.32   .24  -.420 36.96 0.00  0.00 0.000
188 AUG 18   1.337 3.60    .33   .77  0.00  2.44  2.46   .00  40.24  2.40  1.339 36.96 0.00  2.77  .001
189 AUG 18   1.337  .40    .33   .77  0.00  2.55  2.56   .00  36.32   .17   .080 36.97 0.00   .07  .001
190 AUG 18   1.337 1.20    .33   .77  0.00  3.03  3.02   .01  30.06   .97   .489 36.97 0.00   .87  .001
191 AUG 18   6.347 1.80    .24   .93  0.00  3.81  3.79   .02  76.96  1.67   .790 36.98 0.00  1.56  .001
192 AUG 19  10.693  .40    .15   .89  0.00  3.91  3.86   .04 111.81   .21   .138 37.01 0.00   .25  .001
193 AUG 19   4.010 1.60    .20   .86  0.00  4.61  4.61   .04  59.87  1.40   .770 37.03 0.00  1.40  .001
194 AUG 27 194.007  .40  10.92  0.00  0.00  2.30  2.00  0.00 892.01   .46  -.059 37.45 0.00  0.00 0.000
195 AUG 27    .667 1.40    .08   .93  0.00  2.40  2.40   .00  25.02   .42   .400 37.45 0.00   .02  .001
196 AUG 27    .667  .40    .08   .93  0.00  2.56  2.56   .00  26.30   .13   .162 37.46 0.00   .12  .001
197 AUG 27    .667  .80    .08   .95  0.00  2.93  2.93   .00  26.41   .75   .376 37.46 0.00   .72  .001
198 AUG 27    .667  .40    .08   .93  0.00  3.20  3.20   .01  21.76   .35   .272 37.46 0.00   .32  .001
199 AUG 27   1.333  .40    .02   .99  0.00  3.30  3.37   .01  31.09   .35   .170 37.46 0.00   .30  .001
200 AUG 27   2.667 1.00   0.00  1.00  0.00  3.87  3.86   .02  49.47   .99   .509 37.46 0.00  1.00  .001
201 AUG 28  12.167 1.80    .40   .72  0.00  4.76  4.69   .04 120.11  1.80   .919 37.51 0.00  1.40  .001
202 AUG 28    .667 1.70    .07   .95  0.00  5.10  5.10   .05  18.60   .92   .590 37.52 0.00  1.13  .001
203 AUG 28    .667 2.00    .07   .95  0.00  6.14  6.15   .06  18.64  1.95   .980 37.52 0.00  1.83  .001
204 AUG 28    .667 1.40    .07   .93  0.00  6.83  6.83   .06  14.42  1.35   .679 37.53 0.00  1.33  .001
205 AUG 28    .667 1.80    .07   .95  0.00  7.61  7.60   .04  14.80  1.55   .780 37.53 0.00  1.53  .001
206 AUG 28    .667 1.00    .07   .93  0.00  8.08  8.07   .07  13.17   .72   .399 37.54 0.00   .93  .001
207 AUG 28    .667  .60    .07   .95  0.00  8.35  8.34   .05  12.05   .55   .280 37.55 0.00   .53  .001
208 AUG 31  71.480  .40   2.10  0.00  0.00  7.74  7.05  0.00 310.07   .35  -.059 38.40 0.00  0.00 0.000
209 SEP  3  75.417 1.00   7.13  0.00  0.00  6.50  6.05  0.00 334.46   .30  -.260 39.03 0.00  0.00 0.000
                       STORM SUMMARY - NODE  176 TO NODE  209

 TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
    MM           MM         M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1850.0      1187.5      261.4         0.0       261.4

210 SEP  4  18.667  .60   1.00  0.00  0.00  3.10  3.05   .05 139.01   .10   .310 39.11 0.00  0.00  .001
211 SEP  4   5.333  .80    .10  0.00  0.00  5.23  5.19   .05  43.03   .24   .180 39.14 0.00  0.00  .001
212 SEP  6   5.333 1.00    .17   .90  0.00  5.36  5.32   .06  62.65   .30   .170 39.17 0.00   .33  .001
213 SEP  7  63.467  .40   6.64  0.00  0.00  3.51  3.27  0.00 347.05   .12  -.680 39.47 0.00  0.00 0.000
214 SEP  7   3.333 1.00    .09   .80  0.00  3.54  3.53   .01  55.60   .30   .270 39.47 0.00  0.00  .001
215 SEP  7    .333  .40    .09   .30  0.00  3.59  3.59   .01  15.42   .12   .070 39.48 0.00  0.00  .001
216 SEP  7   3.667  .60    .10   .57  0.00  3.66  3.67   .02  90.45   .18   .090 39.48 0.00   .14  .001
217 SEP 10  71.467 3.00   8.10  0.00  0.00  2.44  2.20  0.00 421.08   .59  -.310 39.66 0.00  0.00 0.000
218 SEP 11   8.333  .40   0.00   .30  0.00  2.47  2.41   .01  80.67   .12   .140 39.66 0.00  0.00  .001
219 SEP 11   5.333  .60    .11   .62  0.00  2.51  2.49   .01  66.74   .18   .180 39.67 0.00   .16  .001
220 SEP 11   2.667  .80    .22   .75  0.00  2.56  2.55   .01  33.43   .12   .070 39.67 0.00   .17  .001
221 SEP 11   1.333  .80    .11   .92  0.00  3.03  3.03   .02  35.97   .55   .280 39.68 0.00   .65  .001
222 SEP 11    .333  .60    .03   .98  0.00  3.00  3.04   .02  16.56   .52   .260 39.68 0.00   .57  .001
223 SEP 11   1.000  .40    .08   .94  0.00  3.20  3.20   .02  25.21   .36   .180 39.68 0.00   .32  .001
224 SEP 11    .667 2.60    .04   .96  0.00  4.35  4.34   .02  22.97  2.34  1.270 39.68 0.00  2.34  .001
225 SEP 11    .333 1.70    .03   .98  0.00  5.13  5.13   .03  13.70  1.16   .580 39.68 0.00  1.37  .001
226 SEP 11    .333 1.40    .03   .98  0.00  5.82  5.81   .02  12.86  1.38   .690 39.69 0.00  1.37  .001
227 SEP 11    .333 1.60    .03   .98  0.00  6.51  6.50   .03  11.75  1.38   .690 39.69 0.00  1.37  .001
228 SEP 11    .333  .60    .03   .98  0.00  6.79  6.79   .02  10.64   .58   .290 39.69 0.00   .57  .001
229 SEP 11    .333  .40    .03   .98  0.00  6.98  6.98   .02  10.10   .38   .190 39.69 0.00   .37  .001
230 SEP 11    .333  .40    .03   .98  0.00  7.17  7.17   .02   9.07   .38   .190 39.69 0.00   .37  .001
231 SEP 11    .333  .40    .03   .98  0.00  7.36  7.34   .03   8.57   .38   .190 39.70 0.00   .37  .001
232 SEP 11    .333  .60    .03   .98  0.00  7.65  7.64   .03   7.77   .58   .290 39.70 0.00   .57  .001
233 SEP 20 202.585  .40  26.14  0.00  0.00  1.88  1.67  0.00 774.20   .38 -1.670 40.54 0.00  0.00 0.000
233 SEP 20 202.585  .40  26.14  0.00  0.00  1.68  1.64  0.00 943.65   .12  -.470 40.70 0.00  0.00 0.000
234 SEP 20    .670  .60    .12   .33  0.00  1.65  1.65   .00  26.69   .18   .210 40.70 0.00  0.00  .002
235 SEP 20    .670  .80    .12   .81  0.00  1.77  1.77   .00  34.76   .24   .120 40.78 0.00   .65  .002
236 SEP 20    .670  .60    .12   .91  0.00  1.97  1.97   .00  26.48   .41   .200 40.78 0.00   .45  .002
237 SEP 20    .670  .40    .12   .91  0.00  2.13  2.13   .00  26.07   .31   .160 40.78 0.00   .28  .002
238 SEP 20    .670  .40    .12   .91  0.00  2.28  2.26   .00  25.66   .31   .166 40.78 0.00   .28  .002
239 SEP 20    .670 1.40    .12   .91  0.00  2.94  2.94   .01  25.31  1.31   .660 40.78 0.00  1.28  .002
240 SEP 20    .670  .80    .12   .91  0.00  3.34  3.28   .01  23.61   .73   .360 40.78 0.00   .68  .002
241 SEP 20    .670  .80    .03   .98  0.00  3.65  3.65   .01  23.00   .71   .360 40.78 0.00   .77  .002
242 SEP 20    .670 2.80   0.00  1.00  0.00  5.04  5.04   .01  22.18  2.78  1.390 40.78 0.00  2.80  .002
243 SEP 20    .670 1.60   0.00  1.00  0.00  5.86  5.83   .01  19.41  1.60   .800 40.79 0.00  1.60  .002
244 SEP 20    .670  .60   0.00  1.00  0.00  6.14  6.13   .02  17.19   .66   .300 40.79 0.00   .66  .002
245 SEP 20   1.339 1.00   0.00  1.00  0.00  6.63  6.63   .03  24.52  1.00   .500 40.80 0.00  1.00  .002
246 SEP 20   1.340  .40   0.00  1.00  0.00  6.83  6.81   .03  22.91   .40   .210 40.80 0.00   .40  .002
247 SEP 29   1.339  .80   0.00  1.00  0.00  7.22  7.20   .04  22.29   .80   .410 40.81 0.00   .80  .002
248 SEP 29    .670 1.00   0.00  1.00  0.00  7.71  7.70   .04  14.06  1.00   .510 40.82 0.00  1.00  .002
249 SEP 29    .670  .80   0.00  1.00  0.00  8.11  8.10   .05  12.92   .80   .400 40.82 0.00   .80  .002
250 SEP 29    .670  .40   0.00  1.00  0.00  8.30  8.29   .05  12.01   .40   .200 40.83 0.00   .40  .002
251 SEP 29    .670  .80   0.00  1.00  0.00  8.70  8.69   .05  11.57   .80   .400 40.84 0.00   .80  .002
252 SEP 29   1.339  .80   0.00  1.00  0.00  9.09  9.07   .06  16.25   .80   .410 40.85 0.00   .80  .002
253 SEP 29    .670  .60   0.00  1.00  0.00  9.31  9.37   .06   9.71   .60   .310 40.86 0.00   .60  .002
254 SEP 29    .670  .80   0.00  1.00  0.00  9.78  9.78   .07   9.10   .80   .410 40.87 0.00   .80  .002
255 SEP 29    .670 2.20    .31   .78  0.00 10.87 10.86   .07   8.20  2.20  1.110 40.88 0.00  1.99  .002
256 SEP 29  11.750 2.00   4.09  0.00  0.00 10.82 10.20   .14  50.48  2.28   .550 41.03 0.00  0.00  .001
257 SEP 29    .667 1.00   2.99   .78  0.00 10.86 10.34   .14   6.48   .30   .270 41.05 0.00   .30  .001
258 OCT  3  86.000  .80  11.20  0.00  0.00  7.38  6.33  0.00 318.23   .54 -1.110 42.25 0.00  0.00 0.000
259 OCT  3    .333 1.60   0.00  1.00  0.00  7.15  7.15   .04   9.21   .60   .430 42.25 0.00  1.10 0.000
                       STORM SUMMARY - NODE  209 TO NODE  258

 TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
    MM           MM         M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1850.0      8121.9      344.3         0.0       344.3

260 OCT  3    .333  .40   0.00  1.00  0.00  7.35  7.35   .01   9.60   .40   .200 42.25 0.00   .44 0.000
261 OCT  5  43.006  .60   3.19  0.00  0.00  6.31  6.04   .01 271.87   .60  -.220 42.64 0.00  0.00 0.000
262 OCT  6  13.393 2.20    .41   .87  0.00  6.74  6.60   .07 102.76  1.20   .080 42.73 0.00  1.09 0.000
263 OCT  6   2.679 1.60    .30   .91  0.00  7.26  7.21   .07  34.25  1.17   .650 42.74 0.00  1.50 0.000
264 OCT  6   2.670  .40    .36   .75  0.00  7.41  7.37   .08  31.89   .33   .180 42.77 0.00   .04 0.000
265 OCT  6   4.018 1.00    .54   .62  0.00  7.77  7.71   .09  60.41   .75   .390 42.80 0.00   .44 0.000
266 OCT  7  26.786  .40   3.99  0.00  0.00  7.20  6.91   .09 147.09   .12  -.150 43.11 0.00  0.00 0.000
267 OCT  7   2.679  .40    .41  0.00  0.00  7.13  7.08   .09  33.17   .12   .210 43.14 0.00  0.00 0.000
268 OCT 12 116.562 1.40  30.10  0.00  0.00  5.63  3.31  0.00 381.46   .42 -1.330 43.60 0.00  0.00 0.000
269 NOV 11 119.683  .20  24.94  0.00  0.00  1.72  1.57  0.00 624.42   .06  -.580 43.83 0.00  0.00 0.000
                       STORM SUMMARY - NODE  259 TO NODE  268

 TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
    MM           MM         M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1850.0         0.0       39.2         0.0        39.2

269 NOV 11 119.683  .20  24.94  0.00  0.00   .81   .79  0.00 604.10   .06  -.200 43.88 0.00  0.00 0.000
269 NOV 11 119.683  .20  24.94  0.00  0.00   .42   .40  0.00 711.35   .06  -.190 43.90 0.00  0.00 0.000
269 NOV 11 119.683  .20  24.94  0.00  0.00   .31   .31  0.00 734.11   .06  -.070 43.91 0.00  0.00 0.000
269 NOV 11 119.683  .20  24.94  0.00  0.00   .13   .11  0.00 730.25   .06  -.030 43.91 0.00  0.00 0.000
269 NOV 11 119.683  .20  24.94  0.00  0.00   .07   .07  0.00 731.25   .06  -.010 43.91 0.00  0.00 0.000
270 NOV 11    .331 2.60    .11   .92  0.00   .07   .07   .00  28.93  1.40   .800 43.91 0.00  1.99 0.000
271 NOV 11    .331  .60    .11   .92  0.00  1.13  1.13   .00  19.64   .52   .260 43.91 0.00   .49 0.000
272 NOV 11    .331 1.30    .11   .92  0.00  1.69  1.69   .00  19.23  1.12   .560 43.91 0.00  1.09 0.000
273 NOV 11   1.324  .40    .44   .69  0.00  1.85  1.85   .00  18.61   .32   .160 43.91 0.00   .08 0.000
274 NOV 11    .993 2.30    .33   .77  0.00  2.80  2.79   .00  32.54  1.09   .550 43.91 0.00  1.03 0.000
275 NOV 11    .331 1.40    .11   .92  0.00  4.18  4.30   .01  16.58  3.17  1.590 43.92 0.00  3.20 0.000
276 NOV 12   3.116  .80    .26   .81  0.00  4.64  4.60   .03  81.54   .52   .260 43.93 0.00   .31 0.000
277 NOV 12    .083 3.00   0.00  1.00  0.00  4.62  4.63   .03   4.55  2.81  1.430 43.94 0.00  3.00 0.000
278 NOV 12    .083  .40   0.00  1.00  0.00  4.77  4.27   .03   5.64   .40   .200 43.94 0.00   .40 0.000
279 NOV 18  95.166 3.00  10.97  0.00  0.00  3.87  3.45  0.00 416.44  3.00  -.400 44.32 0.00  0.00 0.000
280 NOV 23 171.313 1.60  31.21  0.00  0.00  1.87  1.50  0.00 930.43   .40  -.350 44.60 0.00  0.00 0.000
281 NOV 23    .333  .40   0.00   .30  0.00  1.70  1.70   .00  10.10   .12   .200 44.60 0.00  0.00 0.000
282 NOV 23   2.000  .40   0.00   .56  0.00  1.85  1.85   .00  48.16   .12   .060 44.60 0.00   .30 0.000
283 NOV 23    .333 1.00   0.00  1.00  0.00  2.13  2.13   .04  30.13   .34   .204 44.60 0.00  3.00 0.000
284 NOV 23    .333 2.00   0.00  1.00  0.00  2.13  2.13   .00  17.68  2.00  1.000 44.60 0.00  2.90 0.000
285 NOV 23    .500 1.40   0.00  1.00  0.00  3.03  3.03   .01  19.96  1.40   .700 44.60 0.00  1.40 0.000
286 NOV 23    .167 1.30   0.00  1.00  0.00  4.43  4.43   .01  10.36  1.70   .600 44.60 0.00  1.30 0.000
287 NOV 23    .167 2.60   0.00  1.00  0.00  5.73  5.73   .01   9.68  3.60  1.300 44.60 0.00  2.60 0.000
288 NOV 23    .167 1.00   0.00  1.00  0.00  6.43  6.43   .01   8.30  1.00   .800 44.60 0.00  1.90 0.000
289 NOV 24    .167 3.00   0.00  1.00  0.00  7.43  7.43   .01   7.10  3.00  1.000 44.60 0.00  2.00 0.000
290 NOV 24    .167  .00   0.00  1.00  0.00 10.01 10.07   .01   4.94  4.00  2.000 44.60 0.00   .99 0.000
291 NOV 24    .167  .40   0.00  1.00  0.00 11.02 11.02   .01   2.63   .00   .400 44.60 0.00   .00 0.000
292 NOV 24   1.333  .40   0.00  1.00  0.00 11.22 11.19   .04   3.71   .40   .200 44.61 0.00   .40 0.000
293 NOV 24   5.383 1.60    .67   .83  0.00 12.01 11.87   .11  35.00  1.60   .810 44.67 0.00   .93 0.000
294 NOV 24    .083 3.00    .04   .97   .01 12.20 12.34   .11    .99   .44   .390 44.67 0.00  1.94 0.000
295 NOV 26  62.033 1.00   9.69  0.00  0.00 10.70  9.87   .03 331.34  2.46   .110 45.50 0.00  0.00 0.000
296 DEC 31 142.833  .10  83.00  0.00  0.00  9.11  4.32  0.00 485.29   .02 -1.820 46.50 0.00  0.00 0.000
                       STORM SUMMARY - NODE  269 TO NODE  296

 TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
    MM           MM         M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1850.0         0.0      389.3         0.0       389.3

296 DEC 31 142.833  .10  83.00  0.00  0.00  3.37  3.00  0.00 670.50   .03  -.700 46.77 0.00  0.00 0.000
296 DEC 31 142.833  .10  83.00  0.00  0.00  1.05   .97  0.00 765.17   .03  -.350 46.96 0.00  0.00 0.000
296 DEC 31 142.833  .10  83.00  0.00  0.00   .51   .48  0.00 805.67   .03  -.170 46.88 0.00  0.00 0.000
296 DEC 31 142.833  .10  83.00  0.00  0.00   .35   .34  0.00 873.95   .03  -.090 46.79 0.00  0.00 0.000
296 DEC 31 142.833  .10  83.00  0.00  0.00   .13   .13  0.00 832.50   .03  -.040 46.94 0.00  0.00 0.000
297 DEC 31   8.500  .06   0.00   .04  0.00   .13   .13   .00  97.35   .03   .019 46.94 0.00  0.00 0.000
                       OUTPUT SUMMARY - FULL RUN

 TOT RAIN    TOT POT EV  GAUGED FLW  SIMUL. IMP  SIMUL. PER  SIMUL. TOT
    MM           MM         M**3     FLW-M**3    FLW-M**3    FLW-M**3
   307.3       1850.0     30189.8     3443.7     16229.6     19673.3

             MAXIMUM STORAGE DEPTH SUMMARY

           INT STOR/CAP    DEP STOR/CAP    UPPER STOR/CAP    LOWER STOR/CAP
DEPTH(MM)      1.00            1.00            12.50             12.50
INDEX          10              84              84                84
DAY            2               18              18                18
MONTH          MAR             MAR             MAR               MAR

             MAX WINTER STORAGE DEPTH SUMMARY

           INT STOR/CAP    DEP STOR/CAP    UPPER STOR/CAP    LOWER STOR/CAP
DEPTH(MM)      1.00            0.00            10.87             10.86
INDEX          154             0               255               255
DAY            27              0               20                20
MONTH          MAY             111             SEP               SEP

             MAX SUMMER STORAGE DEPTH SUMMARY

           INT STOR/CAP    DEP STOR/CAP    UPPER STOR/CAP    LOWER STOR/CAP
DEPTH(MM)      1.00            1.00            12.50             12.50
INDEX          10              84              84                84
DAY            2               18              18                18
```

END OF DETAILED OUTPUT.

TOTAL VOLUME SUMMARY

ANNUAL MAX. STORES SUMMARY FOR ANNUAL RUN.

```
MONTH        MAR             MAR              MAR              MAR

     ANNUAL SUMMARY PERCENTAGE TIME UPPER SOIL STORAGE   LEVELS
PARTITION INCREMENT    TOTAL HRS    SUM >= PREV. INCS   PROB OF EXCEEDANCE %
  0.000 -   .500        3221.79         8760.00            100.00
   .500 -  1.000        1047.96         5538.21             63.22
  1.000 -  1.500         844.61         4490.65             51.26
  1.500 -  2.000         529.00         3646.04             41.62
  2.000 -  2.500         648.37         3117.04             35.58
  2.500 -  3.000         327.96         2468.67             28.18
  3.000 -  3.500           8.70         2140.71             24.44
  3.500 -  4.000         719.09         2132.01             24.34
  4.000 -  4.500         297.16         1412.92             16.13
  4.500 -  5.000          28.97         1115.76             12.74
  5.000 -  5.500         257.11         1086.80             12.41
  5.500 -  6.000          83.63          834.68              9.53
  6.000 -  6.500          72.13          751.05              8.57
  6.500 -  7.000         109.02          708.92              8.09
  7.000 -  7.500         137.46          619.91              6.94
  7.500 -  8.000          78.30          382.45              4.37
  8.000 -  8.500          79.63          304.15              3.47
  8.500 -  9.000           3.66          224.22              2.56
  9.000 -  9.500           2.36          220.58              2.52
  9.500 - 10.000           1.33          218.20              2.49
 10.000 - 10.500           4.00          216.91              2.48
 10.500 - 11.000          55.95          216.91              2.48
 11.000 - 11.500          24.58          160.96              1.84
 11.500 - 12.000          11.91          136.46              1.56
 12.000 - 12.500         124.54          124.54              1.42

  297  DEC 31   8.500   .06   0.00   .06   0.00   .13   .13   0.00   .02   .01  46.987  0.00  0.00  0.00

                 ANNUAL MAXIMUM  30.0 MIN  BURST STATISTICS
  MAX RAINFALL = IMPERV RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30  12.993  369             28.000  0.00   0.00   3.6035      3.23
 DAY -5  12.993  280             10.170  0.00   0.00   3.0054      3.45
 DAY -1  12.993  280              9.340  0.00   0.00   3.0054      3.45
 HRS-12    .993  280              9.250  0.00   0.00   3.0054      3.45
 HRS -1  11.993  284              6.200  1.00   0.00   3.1333      3.13
 MIN-30  12.493  285              6.400  1.00   0.00   3.1310      3.13
 NOV 23          287      0.00    0.000  1.00   0.00   6.7289      6.73   0.00   0.00
 NOV 23          288      9.00    1.670  1.00   0.00   6.6282      6.63   0.00   1.47
 NOV 24          289     19.00    3.620  1.00   0.00   7.6274      7.63   0.00   3.00
 NOV 24          290     29.00    9.670  1.00   0.00  10.6264     10.62   0.00   6.00
 NOV 24          291     30.00    9.700  1.00   0.00  11.0247     11.02   0.00    .08
                                                                          0.00   9.79    .10

                 ANNUAL MAXIMUM  60.0 MIN  BURST STATISTICS
  MAX RAINFALL = IMPERV RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30  16.993  269             23.030  0.00   0.00   3.6035      3.23
 DAY -5  16.993  280              6.380  0.00   0.00   3.0054      3.45
 DAY -1  16.993  280              5.490  0.00   0.00   3.0054      3.45
 HRS-12   4.993  280              8.390  0.00   0.00   3.0054      3.45
 HRS -1  15.993  283              1.970   .56   0.00   1.8521      1.85
 MIN-30  16.493  285              1.470  1.00   0.00   3.1310      3.13
 NOV 23          285      0.00    0.000  1.00   0.00   3.0105      3.01   0.00   0.00
 NOV 23          286      9.00    1.080  1.00   0.00   4.4294      4.43   0.00   1.00
 NOV 23          287     19.00    3.600  1.00   0.00   5.7299      5.73   0.00   2.60
 NOV 23          288     29.00    5.400  1.00   0.00   6.6283      6.63   0.00   1.80
 NOV 24          289     39.00    7.400  1.00   0.00   7.6274      7.63   0.00   2.00
 NOV 24          290     49.00   13.400  1.00   0.00  10.6264     10.62   0.00   6.00
 NOV 24          291     59.00   14.200  1.00   0.00  11.0247     11.02   0.00    .80
 NOV 24          292     60.00   14.290  1.00   0.00  11.2229     11.19   0.00    .00
                                                                          0.00  14.29    .14

                 ANNUAL MAXIMUM 120.0 MIN  BURST STATISTICS
  MAX RAINFALL = IMPERV RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30  20.120    9             44.610  0.00   0.00    .2712       .27
 DAY -5  20.120   37             22.120  0.00   0.00   8.4784      8.38
 DAY -1  20.120   37             21.090  0.00   0.00   8.4784      8.38
 HRS-12   8.120   50              3.600   .05   0.00  11.3238     11.32
 HRS -1  19.120   52              1.510  0.00   0.00  11.6765     11.45
 MIN-30  19.620   52              1.170  0.00   0.00  11.6765     11.45
 MAR 15           53      0.00    0.000   .93   0.00  11.7619     11.71   0.00   0.00
 MAR 15           53      3.07     .610  1.00   0.00  12.3663     12.36   0.00    .41
 MAR 15           54     13.00    2.270  1.00   1.00  12.5000     12.50    .21   1.86
 MAR 15           55     22.93    4.660  1.00   1.00  12.5000     12.50   1.83   2.39
 MAR 15           56     32.86    5.730  1.00   1.00  12.5000     12.50    .52   1.06
 MAR 15           57     42.70    6.250  1.00   1.00  12.5000     12.50   0.00    .53
 MAR 15           58     52.72    6.780  1.00   1.00  12.5000     12.50    .00    .53
 MAR 15           59     72.58    7.310  1.00    .77  12.5000     12.50   0.00    .53
 MAR 15           60     82.80    8.110  1.00   1.00  12.5000     12.50    .06    .00
 MAR 15           61     92.43   10.900  1.00   1.00  12.5000     12.50   1.67   2.30
 MAR 15           62    102.36   13.420  1.00   1.00  12.5000     12.50   3.40   3.93
 MAR 15           63    112.29   17.660  1.00   1.00  12.5000     12.50   3.73   4.25
 MAR 15           64    120.00   18.900  1.00   1.00  12.5000     12.50    .84   1.24
                                                                         11.46  18.90  11.83
       7.90       61        64                  60.2        8.3       8.1        1.6        .0       8.3
       9.35       60        66                  38.8        3.6       3.0         .0        .1       3.3
      11.90       64        65                  51.3        3.0       2.1         .1        .1       6.1

                 ANNUAL MAXIMUM  30.0 MIN  BURST STATISTICS
  MAX PERVIOUS RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30   8.266    9             54.310  0.00   0.00    .4082       .41
 DAY -5   8.266   37             31.800  0.00   0.00   8.4613      8.47
 DAY -1   8.266   37             31.500  0.00   0.00   8.6613      8.47
 HRS-12  20.266   51             12.620   .05   0.00  11.5354     11.53
 HRS -1   7.266   56              4.900  1.00   1.00  12.5000     12.50
 MIN-30   7.766   59              3.470  1.00    .74  12.5000     12.50
 MAR 15           60      0.00    0.000  1.00    .01  12.5000     12.50   0.00   0.00
 MAR 15           61      0.38    1.560  1.00   1.00  12.5000     12.50   1.32   1.99
 MAR 15           62     10.22    4.490  1.00   1.00  12.5000     12.50   2.31   2.92
 MAR 15           63     20.15    8.730  1.00   1.00  12.5000     12.50   3.64   4.25
 MAR 15           64     30.00    9.440  1.00   1.00  12.5000     12.50    .19    .30
                                                                          7.46   9.46   7.48

                 ANNUAL MAXIMUM  60.0 MIN  BURST STATISTICS
  MAX PERVIOUS RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30   3.266    9             53.060  0.00   0.00    .4082       .41
 DAY -5   3.266   37             29.350  0.00   0.00   8.4613      8.47
 DAY -1   3.266   37             26.330  0.00   0.00   8.4613      8.47
 HRS-12  15.266   51             10.300   .95   0.00  11.5354     11.53
 HRS -1   2.266   56              3.690  1.00   1.00  12.5000     12.50
 MIN-30   3.266   59               .990  1.00    .06  12.5000     12.50
 MAR 15           59      0.00    0.000  1.00    .64  12.5000     12.50   0.00   0.00
 MAR 15           60      3.36     .810  1.00    .91  12.5000     12.50   0.00    .27
 MAR 15           61     13.20    2.400  1.00   1.00  12.5000     12.50   1.58   2.39
 MAR 15           62     23.22    5.320  1.00   1.00  12.5000     12.50   2.31   2.92
 MAR 15           63     33.15    8.870  1.00   1.00  12.5000     12.50   3.64   4.38
 MAR 15           64     43.08   11.160  1.00   1.00  12.5000     12.50    .99   1.59
 MAR 15           65     53.00   12.330  1.00   1.00  12.5000     12.50    .67   1.06
 MAR 15           66     60.00   12.830  1.00   1.00  12.5000     12.50    .14    .58
                                                                          9.18  13.06   9.18

                 ANNUAL MAXIMUM 120.0 MIN  BURST STATISTICS
  MAX PERVIOUS RUNOFF = IMP FRACT =    .01
 DATE    CLOCK   DATA  ACCUM    ACCUM   %                  SIMULATED DATA
  OR      TIME   INDEX  TIME     RAIN   %     IS      DS      US        LS     PERV  IMPERV
 TIME    (HRS)          (MIN)    (MM)   %    (MM)    (MM)    (MM)      (MM)   RNOFF RNOFF
 DAY-30   6.120    9             45.400  0.00   0.00    .4082       .41
 DAY -5   6.120   37             22.090  0.00   0.00   8.4613      8.47
 DAY -1   6.120   37             22.060  0.00   0.00   8.6613      8.47
 HRS-12  18.120   51              3.010   .95   0.00  11.5354     11.53
 HRS -1   5.120   52              2.170  0.00   0.00  11.7801     11.52
 MIN-30   5.620   53              1.030  0.00   0.00  11.7801     11.52
 MAR 15           53      0.00    0.000  1.00    .01  12.4338     12.43   0.00   0.00
 MAR 15           54      3.00     .080  1.00   1.00  12.5000     12.50    .02    .06
 MAR 15           55     12.93    2.450  1.00   1.00  12.5000     12.50   1.66   2.30
 MAR 15           56     22.86    3.510  1.00   1.00  12.5000     12.50    .37   1.06
 MAR 15           57     32.79    4.050  1.00    .56  12.5000     12.50   0.00    .53
 MAR 15           58     42.72    4.580  1.00    .74  12.5000     12.50   0.00    .53
 MAR 15           59     62.65    5.110  1.00    .64  12.5000     12.50   0.00    .53
 MAR 15           60     72.50    5.900  1.00    .01  12.5000     12.50   0.00    .80
 MAR 15           61     82.43    8.390  1.00   1.00  12.5000     12.50   1.58   2.30
 MAR 15           62     92.36   11.210  1.00   1.00  12.5000     12.50   2.31   2.92
 MAR 15           63    102.29   16.460  1.00   1.00  12.5000     12.50   3.64   4.35
 MAR 15           64    112.22   17.050  1.00   1.00  12.5000     12.50    .99   1.59
 MAR 15           66    120.00   17.996  1.00   1.00  12.5000     12.50    .37    .63
                                                                         10.94  18.30  11.02
       7.48       61        64                  60.2        8.3       8.1        1.3        .0       8.3
       9.10       60        66                  39.9        2.4       2.9         .0        .1       3.3
      11.02       64        65                  51.3        3.0       2.1         .0        .1       6.1
```

ANNUAL SUMMARY
% TIME OF DEFINED
LEVELS OF MOISTURE
IN UPPER STORE

ANNUAL MAX
IMPERV. RUNOFF-
RAINFALL STATISTICS
FOR 30, 60, 120 MIN
BURSTS. INCLUDES
ANTICEDENT
RAINFALL AND
SIMULATED MOIST.
SUMMARIES.

TOT. PER R.
TOT IMP R.
TOT WTD R.

AS ABOVE
EXCEPT
MAX
PERVIOUS
RUNOFF

```
                 ANNUAL MAXIMUM  30.0 MIN  BURST STATISTICS
 MAX WEIGHTED RUNOFF - IMP FRACT =    .01
DATE    CLOCK    DATA  ACCUM     ACCUM  0                SIMULATED DATA
 OR      TIME    INDEX  TIME      RAIN  0     IS     DS      US       LS     PERV  IMPERV
TIME    (HRS)          (MIN)      (MM)  0   (MM)   (MM)    (MM)     (MM)    RNOFF RNOFF
DAY-30   8.266    9               54.310  0.00   0.00    .4082      .41
DAY -5   8.266   37               31.800  0.00   0.00   0.6613     0.47
DAY -1   8.266   37               31.500  0.00   0.00   0.6613     0.47
HRS-12  20.266   51               12.670   .95   0.00  11.5354    11.53
HRS -1   7.266   56                4.909  1.00   1.00  12.5000    12.50
MIN-30   7.766   59                2.810  1.00    .74  12.5000    12.50
MAR 15           60       0.00     0.000  1.00    .01  12.5000    12.50   0.00  0.00
MAR 15           61       9.29     3.330  1.00   1.00  12.5000    12.50   1.32  1.99
MAR 15           62      18.22     4.250  1.00   1.00  12.5000    12.50   2.31  2.92
MAR 15           63      28.15     8.500  1.00   1.00  12.5000    12.50   3.64  4.25
MAR 15           64      30.00     9.270  1.00   1.00  12.5000    12.50    .19   .30
                                                                          7.46  9.46   7.48

                 ANNUAL MAXIMUM  60.0 MIN  BURST STATISTICS
 MAX WEIGHTED RUNOFF - IMP FRACT =    .01
DATE    CLOCK    DATA  ACCUM     ACCUM  0                SIMULATED DATA
 OR      TIME    INDEX  TIME      RAIN  0     IS     DS      US       LS     PERV  IMPERV
TIME    (HRS)          (MIN)      (MM)  0   (MM)   (MM)    (MM)     (MM)    RNOFF RNOFF
DAY-30   3.266    9               53.060  0.00   0.00    .4082      .41
DAY -5   3.266   37               29.550  0.00   0.00   0.6613     0.47
DAY -1   3.266   37               29.330  0.00   0.00   0.6613     0.47
HRS-12  15.266   51               10.380   .95   0.00  11.5354    11.53
HRS -1   2.266   55                3.690  1.00   1.00  12.5000    12.50
MIN-30   2.766   58                 .850  1.00    .86  12.5000    12.50
MAR 15           59       0.00     0.000  1.00    .64  12.5000    12.50   0.00  0.00
MAR 15           60       3.36      .000  1.00    .01  12.5000    12.50   0.00   .27
MAR 15           61      13.29     7.390  1.00   1.00  12.5000    12.50   1.58  2.39
MAR 15           62      23.22     8.310  1.00   1.00  12.5000    12.50   2.31  2.92
MAR 15           63      33.15     9.560  1.00   1.00  12.5000    12.50   3.64  4.25
MAR 15           64      43.08    11.150  1.00   1.00  12.5000    12.50    .99  1.59
MAR 15           65      53.00    13.210  1.00   1.00  12.5000    12.50    .47  1.06
MAR 15           66      60.00    13.940  1.00   1.00  12.5000    12.50    .16   .56
                                                                          9.15 13.04   9.19

                 ANNUAL MAXIMUM 120.0 MIN  BURST STATISTICS
 MAX WEIGHTED RUNOFF - IMP FRACT =    .01
DATE    CLOCK    DATA  ACCUM     ACCUM  0                SIMULATED DATA
 OR      TIME    INDEX  TIME      RAIN  0     IS     DS      US       LS     PERV  IMPERV
TIME    (HRS)          (MIN)      (MM)  0   (MM)   (MM)    (MM)     (MM)    RNOFF RNOFF
DAY-30   6.120    9               45.400  0.00   0.00    .4082      .41
DAY -5   6.120   37               22.890  0.00   0.00   0.6613     0.47
DAY -1   6.120   37               22.660  0.00   0.00   0.6613     0.47
HRS-12  18.120   51                3.810   .95   0.00  11.5354    11.53
HRS -1   5.120   52                2.170  0.00   0.00  11.7501    11.52
MIN-30   5.620   52                1.034  0.00   0.00  11.7501    11.52
MAR 15           53       0.00     0.000  1.00    .01  12.4339    12.43   0.00  0.00
MAR 15           54       3.08      .039  1.00   1.00  12.5000    12.50    .02   .56
MAR 15           55      13.93     2.410  1.00   1.00  12.5000    12.50   1.66  2.39
MAR 15           56      22.86     3.470  1.00   1.00  12.5000    12.50    .37  1.06
MAR 15           57      32.79     4.010  1.00    .86  12.5000    12.50   0.00   .53
MAR 15           58      42.72     4.540  1.00    .76  12.5000    12.50   0.00   .53
MAR 15           59      62.58     5.070  1.00    .64  12.5000    12.50   0.00   .53
MAR 15           60      72.58     5.860  1.00    .81  12.5000    12.50   0.00   .80
MAR 15           61      82.43     8.250  1.00   1.00  12.5000    12.50   1.58  2.39
MAR 15           62      92.36    11.170  1.00   1.00  12.5000    12.50   2.31  2.92
MAR 15           63     102.29    15.620  1.00   1.00  12.5000    12.50   3.64  4.25
MAR 15           64     112.22    17.010  1.00   1.00  12.5000    12.50    .99  1.59
MAR 15           65     120.00    17.830  1.00   1.00  12.5000    12.50    .37   .83
                                                                         10.94 18.38  11.01

0371  LPO 0920  TYPEWB FILE PERIPHERAL CHARGE   84.20        $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

SAME AS ABOVE
EXCEPT
MAX WEIGHTED
RUNOFF
75% PERV. D.GRASS
25% IMPERV.

The following briefly summarises the main components of the ARBM output:

- At the end of each time increment, the duration of the increment, the incremental rainfall and pan evaporation are given together with the water depth in each of the stores including interception, depression, upper, lower and groundwater. Additionally, runoff depths are given for the groundwater and the pervious and impervious surface components. Where gauged peak flow data are available, they are input and subséquently shown as output to allow volume checks between simulated and gauged data.

- At the end of the detailed output described above, which is optional, a summary output is provided detailing a number of run statistics abstracted from the full run results. These include; an Accumulated Gauged and Simulated Runoff table in cubic metres to compare overall simulation; a Maximum Storage Depth summary - Winter and Summer; a table detailing the percentage time of moisture levels in the upper store being at certain levels; and a series of Maximum Event Burst statistics for up to four defined durations. The details of these last tables are given in the sample output shown earlier in the Chapter. In brief, for each event duration, data is summarised up to one month before each event with accumulated rainfall and resident moisture store values being given 30 days, 5 days, 1 day, 12 hours, 1 hour and 30 minutes prior to the start of the abstracted maximum event under consideration. Three scans are carried out for each selected duration to find, in the total period, the maximum pervious, impervious and weighted runoff depths.

4.2.2.1 Urban Land Domains. For a model to predict total urban runoff behaviour it needs to be capable of discerning between different land types. These have been classified here as urban land domains.

In Canberra these can be broadly split into the following groups:

(1) Residential lawns (incorporating areas of imported topsoil with sown grasses irregularly watered from domestic sources).

(2) Dry grass areas (generally associated with public open spaces adjacent to residential allotments. Usually natural topsoils and native grasses with little or no artificial watering).

(3) Irrigated playing fields (incorporating areas of imported sandy topsoils with sown grasses irrigated on a regular basis from domestic sources).

(4) Native and planted forest areas (urban fringe areas including parks and undeveloped areas such as Black Mountain nature reserve).

Soil moisture measurements were taken during 1979 and 1980 on the Canberra urban catchments described in Chapter 3. The effects of lawn watering on residential allotments on a catchment wide basis was found to be marginal. Combined, types (1) and (2) generally make up to 75% of the pervious area in any particular urban catchment and as such greater emphasis has been placed on these rather than types (3) and (4) in this thesis. Domains (3) and (4) have however been considered as in some areas they can be significant and it was necessary to assess, in particular, the effects of heavy watering of playing fields on runoff production.

The ARBM was subsequently used to simulate excess rainfall using Canberra pluviograph data recorded between 1933 and 1970 for domain types (1), (2), (3) and (4). The output from this analysis was used to assess the long term trigger mechanisms for runoff generation from these domains.

As indicated, the reference parameter set was taken from values suggested by Black & Aitken and closely resembled their published set for the Yarralumla Creek Urban Catchment in South Canberra. As described above using this set little, if any, pervious runoff was predicted.

Gauged rainfall/runoff data was obtained for the Gungahlin rural catchment for the years 1977, 1978 and 1979.

From that record it was very apparent that significant runoff was generated in each of the three years, none of which was abnormal.

Based on these records it was evident that there would be contributing runoff from similar pervious areas in the adjoining Giralang urban catchment.

From examination of the soil characteristics and grass cover within the Gungahlin catchment it was concluded that they closely resembled the typical dry grass and poor residential lawn areas within the Giralang urban catchment.

Based on this premise it was possible using the three years of record available on Gungahlin to calibrate the ARBM for that catchment. The resulting parameter set which has been designated 'Dry Grass' is shown in Table 4-3.

As can be seen, it differs significantly from the reference set (Table 4-2) and reflects the greatly reduced infiltration potential required to match simulated and gauged runoff data. The reference set in fact predicted no runoff at all over the same three years.

TABLE 4-3

DRY GRASS PARAMETER SET

Parameter	Description	Value	Unit
CAPIMP	Impervious store capacity	.5	mm
ISC	Interception store capacity	1.0	mm
DSC	Depression store capacity	1.0	mm
USC	Upper soil store capacity	12.5	mm
LSC	Lower soil store capacity	12.5	mm
UH	(Maxrate of water uptake from roots	10.0	mm/day
LH	(for upper and lower soil stores	10.0	mm/day
ER	Proportion of transpiration from US	.7	-
FIMP	Proportion of catchment that is impervious	.25	-
GN	Variable rate groundwater recession factor	1.0	-
KG	Constant rate groundwater recession factor	.94	-
SO	Sorptivity	4.5	$mm/min^{1/2}$
A	Function of soil conductivity	.15	mm/min
AO	(Redistribution	17.28	-
A1	(parameters	1.0	-
LDF	Lower soil drainage factor	.05	-
ECOR	Ratio of Potential Evaporation to A class pan	.7	-
IAR	Proportion of rainfall intercepted by vegetation	.7	-

4.2.2.2 ARBM Model Results. Figure 4-6 shows scatter diagrams for respective simulated and recorded flows on a monthly, yearly and significant storm basis for the Gungahlin catchment using the 'Dry Grass' parameter set based on data for 1977,78,79.

An objective function based on the Σsquare of the difference between the estimated and observed runoff, similar to that adopted by Black & Aitken (1977), was used to calibrate the remaining sensitive parameters LSC, A1, LDF, DSC, ISC after the direct adoption of average measured values for SO, A or Ko, to achieve a minimum value.

Calibration was carried out in an ordered fashion firstly obtaining the best fit for monthly totals then individual significant storm events and then, finally checking annual totals.

As can be seen from the diagrams shown on Figure 4-6, the scatter was still significant after considerable parameter adjustment. It is believed that finer matching would require structural changes to the program and/or variable parameters in place of the present constant values to better reflect seasonal effects.

The adopted parameter set for dry grass was used to simulate moisture changes during the period July 1979 through December 1979 as shown on Figure 4-7. Because of the scatter between individual dry grass station moisture levels above and below the simulated values, it was not possible to quantify if the fit was as close as could be expected. It was decided to leave the parameter set as it was and to test the overall tolerance of the estimate by testing its effect on model output in respect to changes in runoff volumes and runoff peaks. This is described later in Chapter 4.

Additionally during the observed period 1979 through 1981, there was considerable apparent interflow from the relatively small Gungahlin catchment occurring some hours after the cessation of rainfalls that could not be adequately modelled using the ARBM.

Another problem would appear to be in the accuracy of the gauged runoff itself particularly at low flows. The gauging weir and instrumentation was not specifically designed to measure small flows below .01 m^3/s but rather to measure significant storm runoff. It was the accumulation of the low flows that made up the majority of the runoff and consequently calibration based on monthly or annual accumulated flows was not necessarily the most appropriate and convincing method.

Based on appropriate parameter changes related to measurable catchment characteristics such as So and Ko, parameter sets were developed to represent residential lawns, irrigated playing fields and natural forested areas (Black Mountain).

As it was not possible to obtain individual gauged runoff data from these individual areas, use was made of the soil moisture gauging program described in Chapter 3 to help calibration in particular the natural forested area.

Residential lawns and irrigated playing field parameter sets were derived in a relative sense by varying SO and Ko parameters in line with measured values.

LSC, for irrigated playing fields and residential lawns, was arbitrarily adjusted to reflect the increased drainage capacity of the prepared topsoils. A1 was adjusted in line with the algorithms given by Black & Aitken, 1977.

Additionally, artificial watering in line with water use policy for irrigated playing fields and a nominal watering for residential lawns was input as defined in Table 4-4.

A summary of these results is shown on Figure 4-7.

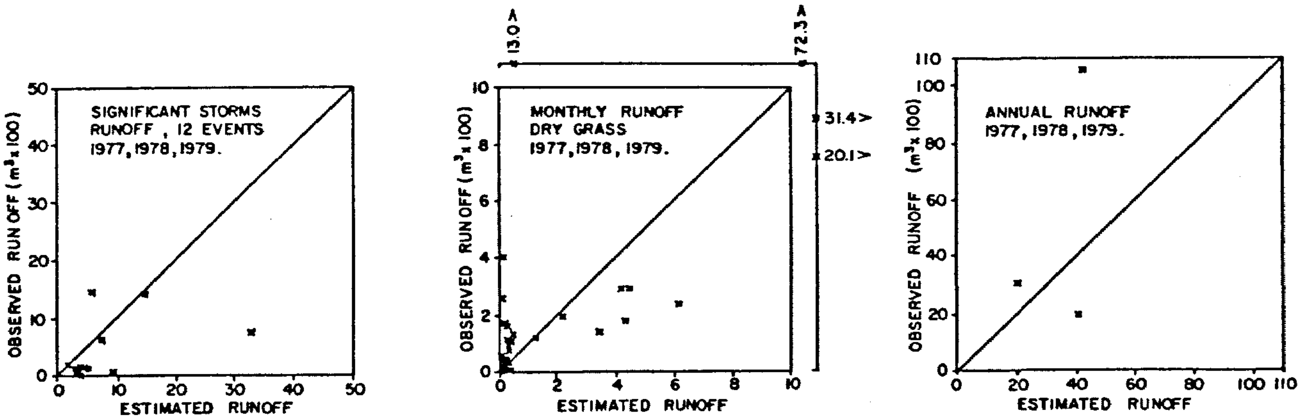
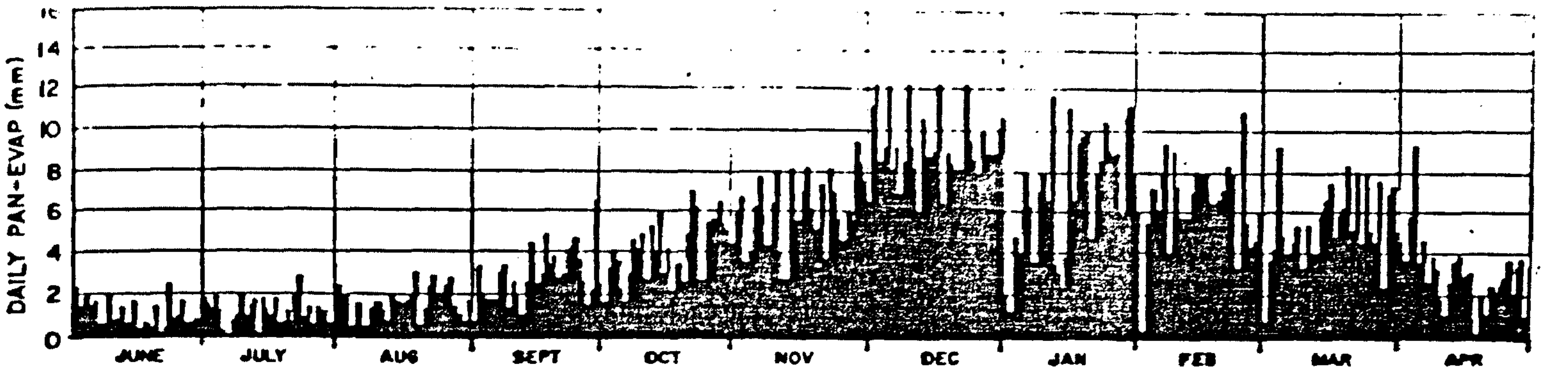
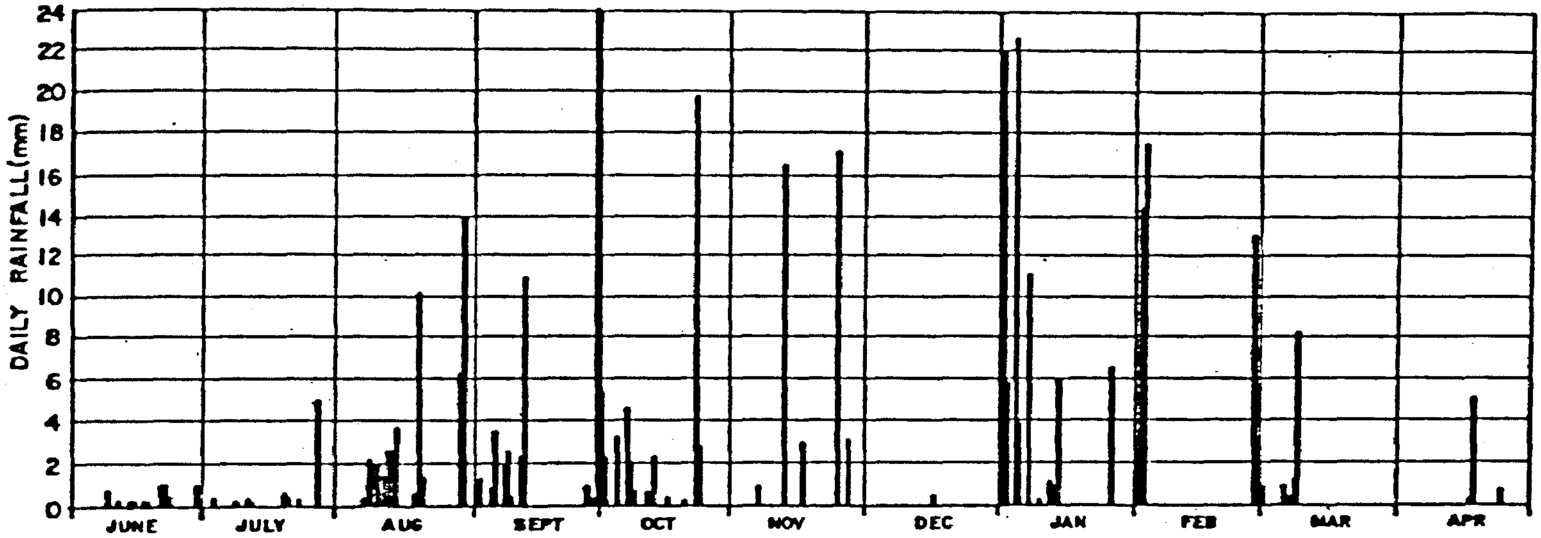


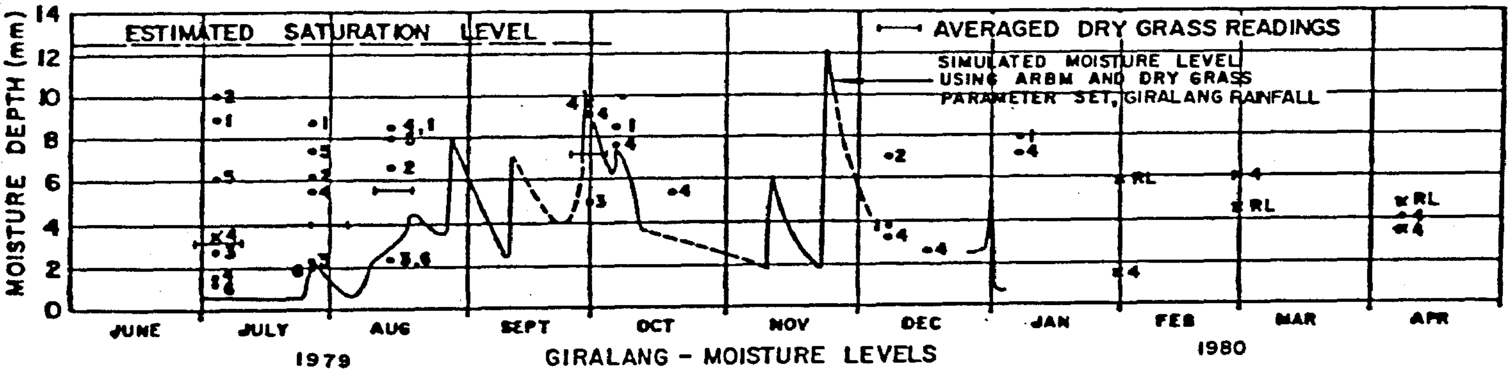
FIGURE 4-6 Gungahlin Scatter Diagrams



PAN - EVAPORATION



DAILY RAINFALL-CITY GAUGE

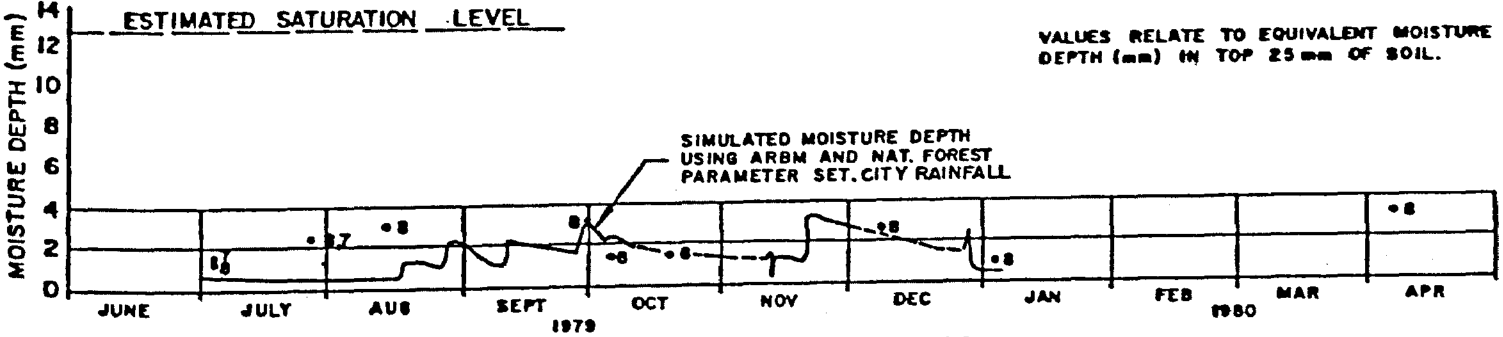


GIRALANG - MOISTURE LEVELS

- ·1 STATION ADJACENT TO CREEK
- ·2 IRRIGATED PLAYING FIELD
- ·3,4,5,6 DRY GRASS
- ·7,8 NATURAL FOREST

- x OVEN DRYED SAMPLES
- • NUCLEAR SAMPLES BASED ON DENSITY
- RL RES. LAWN RANDOM SAMPLE
- 2. STATION No.

VALUES RELATE TO EQUIVALENT MOISTURE DEPTH (mm) IN TOP 25 mm OF SOIL.



BLACK MOUNTAIN - MOISTURE LEVELS

FIGURE 4-7 Long Term (US) Soil Moisture Simulation

Table 4-4 shows the parameter sets developed for the four land domains studied plus the reference set for comparison. It may be noted that the reference set in fact most closely resembles the final set assigned to natural forest rather than the averaged dry grass/residential lawns that are present in the Yarralumla Creek catchment.

TABLE 4-4 Adopted Domain Based Parameter Sets

Parameter	Ref Set	Dry Grass	Resid* Lawns	Irrig.** Playing Field	Natural Forest
CAPIMP	0.5	0.5	0.5	0.5	0.5
ISC	1.0	1.0	1.0	1.0	1.0
DSC	5.0	1.0	1.0	1.0	1.0
USC	12.5	12.5	12.5	12.5	12.5
LSC	200.0	12.5	25.0	25.0	100.0
UH	10.0	10.0	10.0	10.0	10.0
LH	10.0	10.0	10.0	10.0	10.0
ER	0.7	0.7	0.7	0.7	0.7
FIMP	-	-	-	-	-
GN	1.0	1.0	1.0	1.0	1.0
KG	0.94	0.94	0.94	0.94	0.94
SO	7.0	4.5	10.0	10.0	10.0
A	0.5	0.15	0.3	0.42	0.15
AO	57.0	17.28	17.28	17.28	17.28
A1	0.063	1.0	0.5	0.5	0.125
LDF	0.05	0.05	0.05	0.05	0.05
ECOR	0.7	0.70	0.7	0.7	0.70
IAR	0.7	0.7	0.7	0.7	0.7

* Additionally, .05 mm/hr domestic lawn watering was applied over the summer months.

** Similarly, .23 mm/hr domestic irrigation water was applied over the summer months plus .115 mm/hr over the winter period.

As it was the aim of the long term continuous modelling exercise to find a pattern to express, in particular, pre-storm burst antecedence, several sets of statistics were derived and included in the output. As model runs were carried out on an annual basis, purely for data size and computer storage reasons, the summarised statistical data was also expressed in annual terms where appropriate.

Table 4-5 summarises for 'Dry Grass' abstracted output data relating to 30, 60 and 120 min burst events between 1933 and 1970 excluding 1962-1965 inclusive, when data was unavailable due to instrument malfunction. The ARBM model was run in annual data segments with each end of year store status transferred as input to the following year. As stated above the parameter set chosen was the dry grass one shown in Table 4-4 and the rainfall was taken from the Yarralumla Station. Table 4-5 therefore represents a semi-continuous simulated run over 33 years using Yarralumla rainfall and evaporation transposed over the pertinent section of the Giralang catchment.

TABLE 4-5 Annual Maximum Rainfall (Yarralumla) and Annual Maximum Simulated Pervious* Excess Statistics

YEAR	30 MIN BURST		60 MIN BURST		120 MIN BURST	
	Date Rain	Date Excess*	Date Rain	Date Excess*	Date Rain	Date Excess*
1933	Nov 18	Sep 1	Nov 18	Sep 1	Nov 18	Sep 1
	9.74	2.83	18.05	4.69	19.92	7.09
1934	Jan 29	Oct 25	Oct 25	Oct 25	Mar 17	Oct 25
	17.62	10.23	22.78	19.10	26.37	20.13
1935	Nov 13	Dec 3	Nov 13	Dec 3	Jan 12	Apr 14
	17.16	6.80	17.65	6.90	20.36	9.57
1936	Dec 2	Aug 3	Jan 4	Aug 3	Aug 3	Aug 3
	6.90	1.21	8.23	2.43	10.57	4.86
1937	Dec 27	Oct 16	Oct 16	Oct 16	Oct 16	Oct 16
	10.37	8.43	13.08	10.03	16.95	10.21
1938	Feb 22	Feb 22	Feb 22	Feb 22	Feb 22	Feb 22
	16.83	8.49	25.08	9.20	29.93	9.20
1939	Jan 20	Jan 20	Jan 20	Jan 20	Jan 20	Jan 20
	19.46	14.42	22.84	15.51	25.11	15.51
1940	Apr 12	Apr 12	Apr 12	Apr 12	Apr 7	Apr 12
	17.26	15.71	23.18	19.97	31.32	24.06
1941	Jan 16	Jan 3	Jan 1	Jan 3	Jan 16	Jan 3
	7.56	3.32	10.26	5.49	15.84	7.98
1942	Mar 9	Mar 9	Mar 9	Jun 19	Mar 9	Jun 19
	18.13	3.31	27.00	4.44	30.22	5.33
1943	Dec 18	Dec 18	Dec 18	Dec 18	Dec 18	Apr 13
	18.72	6.94	18.86	7.63	20.90	9.15
1944	Jan 1	Jul 4	Jan 1	Jul 4	Nov 24	Jul 4
	15.71	3.53	15.69	3.53	18.76	3.53
1945	Feb 19	Apr 9	Feb 19	Apr 9	Feb 19	Apr 9
	21.95	7.75	27.47	13.07	32.38	20.88
1946	Apr 22	Nov 19	Apr 22	Jan 18	Apr 22	Jan 18
	8.65	4.82	12.18	5.45	17.45	7.97
1947	Dec 15	Dec 15	Dec 15	Dec 15	Dec 15	Dec 15
	24.59	22.97	38.92	35.37	41.35	35.37
1948	Jan 27	May 3	Jan 27	May 3	Feb 15	May 3
	21.66	10.42	27.00	18.42	31.28	22.59
1949	Nov 21	Nov 21	Nov 21	Nov 21	Nov 21	Nov 21
	7.54	5.81	13.82	10.05	20.03	10.82
1950	Mar 22	Mar 22	Nov 9	Mar 22	Nov 9	Nov 9
	13.33	10.38	17.15	12.29	30.08	23.04
1951	Feb 23	Feb 23	Oct 3	Aug 3	Oct 3	Aug 3
	11.74	3.97	13.91	4.28	18.56	6.26
1952	Dec 28	Mar 20	Dec 28	Mar 20	Mar 21	Mar 21
	13.53	7.58	16.84	10.46	21.04	13.28
1953	Apr 13	May 4	Apr 13	May 5	May 5	May 5
	9.47	3.13	12.12	5.69	15.64	8.66

TABLE 4-5 (Continued)

YEAR	30 MIN BURST		60 MIN BURST		120 MIN BURST	
	Date Rain	Date Excess*	Date Rain	Date Excess*	Date Rain	Date Excess*
1954	Jan 19 30.23	Jan 19 14.81	Jan 19 32.48	Jan 19 14.81	Jan 19 33.02	Jan 19 14.81
1955	Oct 21 36.50	Oct 21 25.63	Oct 21 49.47	Oct 21 34.91	Oct 21 67.31	Oct 21 45.37
1956	Feb 14 14.82	Mar 12 6.26	Feb 14 16.30	Mar 12 11.20	Mar 12 24.09	Mar 12 18.08
1957	Jan 22 16.99	Jul 10 3.20	Jan 22 19.02	Jul 10 3.23	Jan 22 19.05	Jul 10 3.44
1958	Mar 8 20.99	Apr 16 14.38	Mar 8 30.69	Apr 16 16.53	Apr 16 38.04	Apr 16 19.59
1959	Feb 11 18.44	Mar 2 14.04	Feb 11 26.93	Mar 2 14.29	Feb 11 29.63	Oct 20 15.21
1960	Dec 15 13.98	Nov 18 3.10	Dec 15 17.22	Dec 2 5.10	Dec 15 22.60	Dec 2 5.26
1961	Nov 19 12.61	Nov 19 10.05	Nov 19 18.63	Nov 19 13.93	Mar 1 25.67	Mar 1 19.73
Missing Record 1962-1965						
1966	Feb 16 17.84	Feb 16 7.47	Feb 16 27.51	Feb 16 8.83	Feb 16 28.98	Feb 16 8.83
1967	Jan 29 4.59	Jan 26 0.20	Jan 29 7.13	Jan 26 0.40	Jan 29 10.49	Jan 26 0.81
1968	Mar 24 21.11	Dec 25 7.03	Mar 24 23.67	Dec 25 8.46	Mar 24 23.87	Dec 25 8.99
1969	Apr 5 12.77	Apr 15 10.74	Apr 15 20.64	Apr 15 16.99	Apr 15 28.99	Apr 15 22.48
1970	Nov 7 22.70	Nov 7 5.80	Nov 7 28.58	Nov 11 8.11	Nov 7 32.18	Nov 11 9.11

All results in mm.
* Pervious excess rainfall results based on dry grass parameter set.

Figure 4-8 shows in graphical form the relationship between pre-burst rainfall as found over the period of record.

As can be seen the correlation between previous 30 day, 5 day and even 1 day rainfalls and following storm bursts and runoff magnitudes is very low. It would appear that the use of such indexes as previously proposed would not bare out in these instances. This is thought to be due to the shortness of the events being investigated.

Table 4-6 shows predicted annual upper soil storage values for the dry grass parameter set, as well as the reference one.

Annual maximum upper storage moisture levels (US) were extracted for both the summer and winter periods to test seasonal sensitivity. Table 4-6 shows a general tendency for lower summer values than winter although the differences are not great. This was generally in agreement with observed data. Rainfall intensity parameters followed the opposite trend with higher summer than winter values. See Pierrehumbert (1974).

As can be also seen from Table 4-6 upper store saturation using the reference set was the exception rather than the rule. This was due mainly to the infiltration capacity attributed by the reference parameter set. Table 4-3 lists the parameter set derived from three years of simulation on the Gungahlin rural catchment. Based on this latter parameter set catchment saturation levels were observed in the simulated run on much more frequent occasions, certainly more frequent than annually.

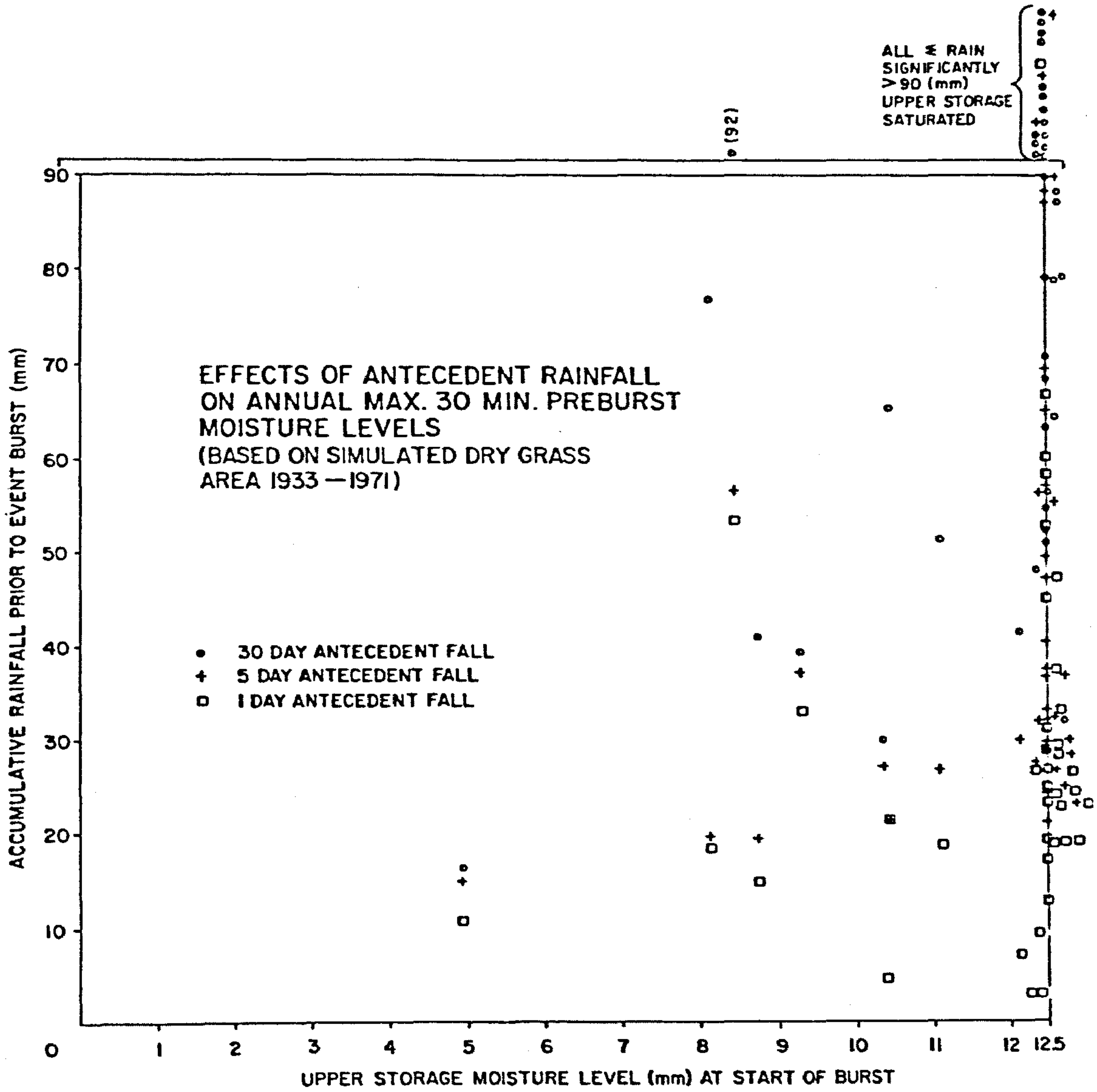


FIGURE 4-8 Antecedent Rainfall - Pre Burst Moisture Scatter Diagram for Simulated Max. Annual Pervious Runoff Events.

TABLE 4-6

Maximum Annual Upper Soil Storage Levels 1933-1969

	REF SET		DRY GRASS		FORESTED AREA	
Year	Summer	Winter	Summer	Winter	Summer	Winter
1933	4.35	7.30	12.49999	12.49999	5.05	10.02
1944	5.83	10.52	12.49999	12.49999	9.96	12.49999
1935	6.47	7.40	12.49999	12.49999	7.87	10.29
1936	5.38	7.20	12.49999	12.49999	7.85	9.75
1937	3.08	6.22	12.49999	12.49999	7.76	8.06
1938	4.88	5.05	12.49999	12.49999	6.15	6.31
1939	5.93	6.91	12.49999	12.49999	9.04	7.47
1940	10.11	6.66	12.49999	12.49999	12.49999	7.64
1941	7.08	3.00	12.49991	12.11	12.48	3.66
1942	2.61	7.56	12.49999	12.49999	5.19	9.71
1943	5.39	6.08	12.49999	12.49999		
1944	3.36	3.85	12.49999	12.49999		
1945	7.54	4.61	12.49999	12.49999		
1946	4.67	6.28	12.49999	12.49999		
1947	10.11	6.87	12.49999	12.49999	N	N
1948	11.22	12.37	12.49999	12.49999	O	O
1949	4.33	6.67	12.49999	12.49999	T	T
1950	12.49999*	12.49999	12.49999	12.49999		
1951	3.29	5.97	12.49999	12.49999	R	R
1952	8.53	9.30	12.49999	12.49999	U	U
1953	2.77	8.66	12.49999	12.49999	N	N
1954	4.63	4.57	12.49999	12.49999		
1955	4.75	8.16	12.49999	12.49999		
1956	8.59	12.42	12.49999	12.49999		
1957	3.75	4.12	12.49999	12.49999		
1958	8.35	8.11	12.49999	12.49999		
1959	8.20	12.11	12.49999	12.49999		
1960	6.22	6.52	12.49999	12.49999		
1961	9.22	11.22	12.49999	12.49999		
1966	5.92	5.87	12.49999	12.49999		
1967	3.26	4.30	12.49999	12.49999		
1968	6.08	9.76	12.49999	12.49999		
1969	9.04	9.81	12.49999	12.49999		

* 12.49999 = Effective Saturation

The ARBM modelling algorithms in fact do not allow the upper soil store to become fully saturated. The model operating in discrete time steps and the moisture storage being calculated at the end of the increment means that the last operation is an infiltration and redistribution movement from the upper store to the lower store thus preventing full saturation.

Rather than simply simulating excess runoff over an extended rainfall period and then carrying out a frequency analysis on the output, it was the objective of this thesis to gain from long term simulation an index or indexes suitable for a particular pervious catchment type that could be transposed between similar catchments. Although it was hoped that gauged catchments could be used to help calibrate modelling parameter sets it was also hoped that the normal non-transportability constraints of mixed pervious-impervious urban catchments frequency analyses could be overcome by isolating the separate major pervious and impervious inputs for use on other similar catchments with different area proportions. This would also allow subsequent analyses or designs to be made on an event basis rather than the more tedious and expensive continuous modelling basis.

It was plainly obvious that the traditional antecedent index based on previous rainfall over a defined period and a catchment parameter was unsatisfactory for urban runoff design analyses. Therefore it was proposed to define an antecedent moisture index based on the sequence of historical events to use in a design context.

4.2.2.3 Development of an Antecedent Moisture Index. An improved index would necessarily need to relate to the catchment parameters affecting the soil moisture profile both on a short as well as long term basis and would secondly need to describe in a statistical sense a relationship with the long term historical rainfall/runoff sequence.

Two antecedent Moisture indexes were proposed at this stage. The first was based on annual maximum upper soil store values. An annual series frequency analysis was carried out on this data to define appropriate frequency curves. Figure 4-9 shows the results of this analysis for the reference set plus the dry grass and forested parameter sets.

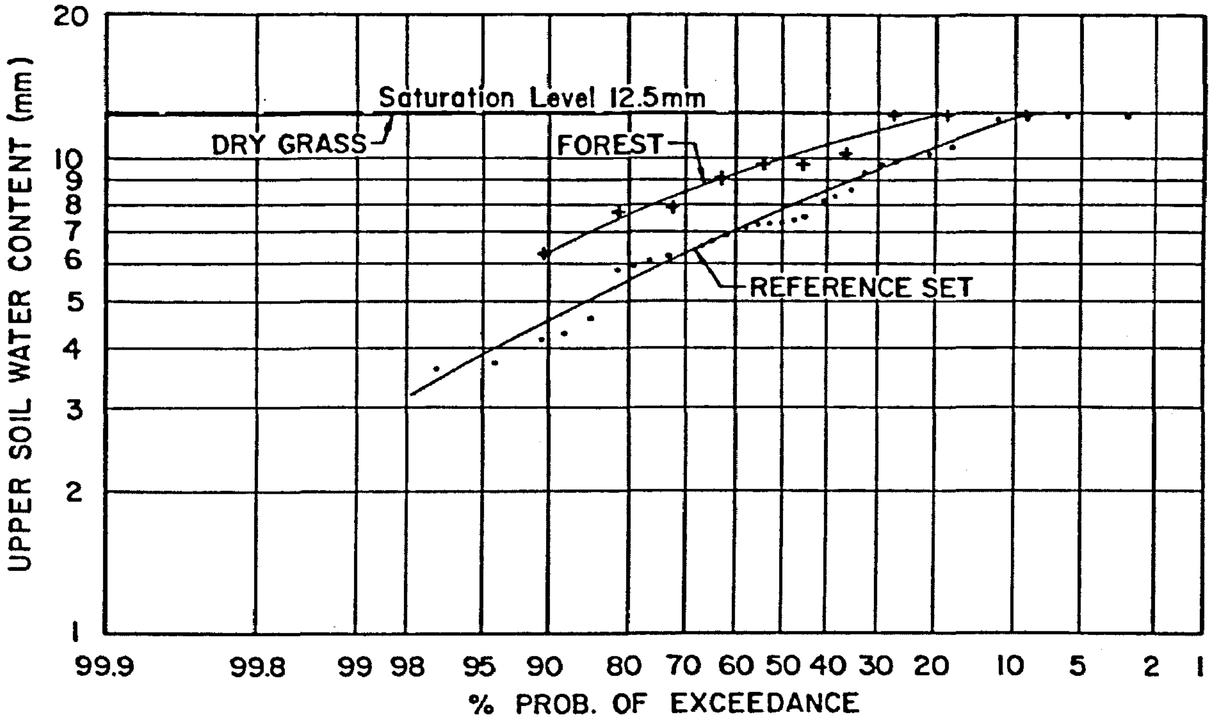
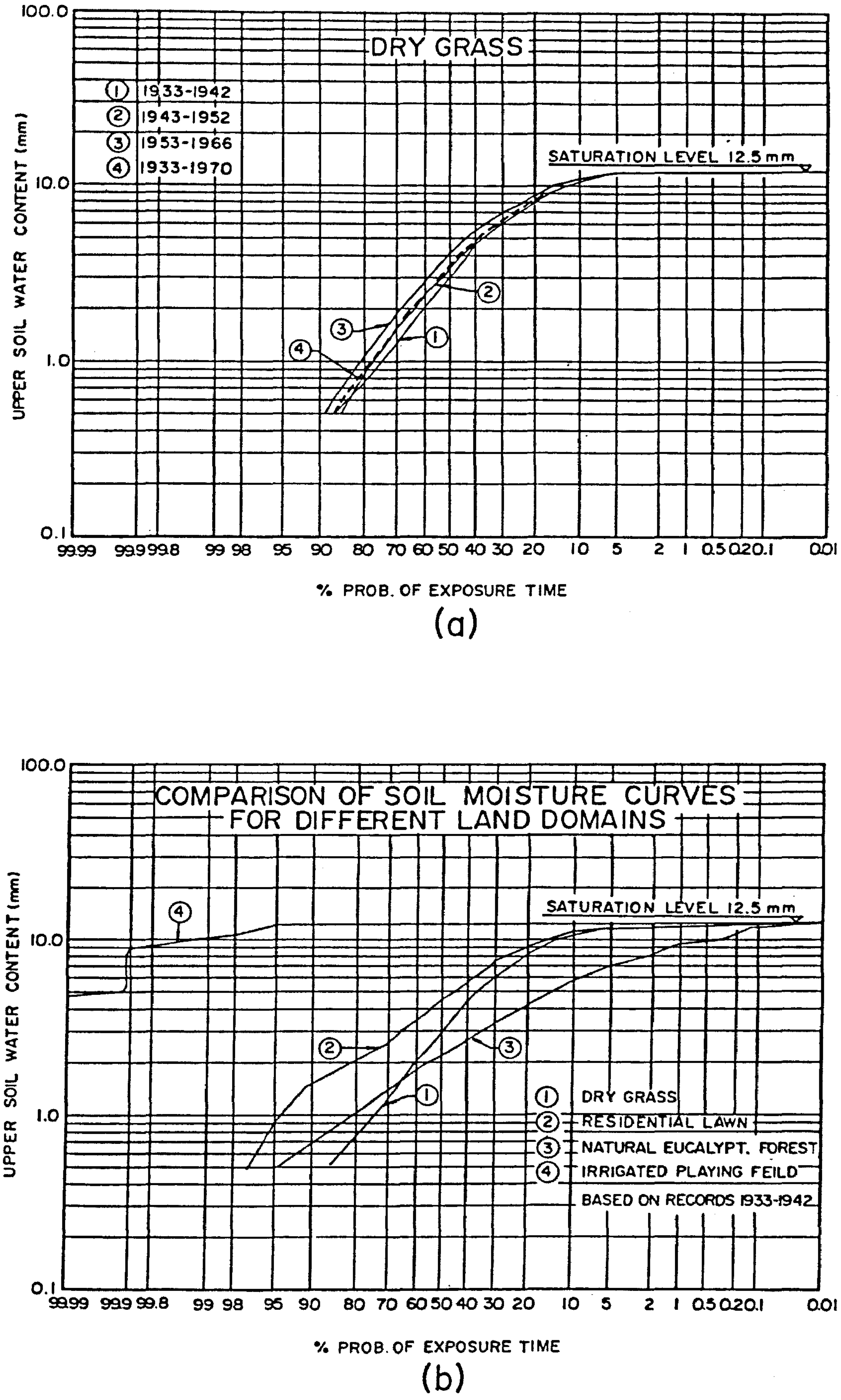


FIGURE 4-9 Probability Curves for Index Type I



(a)

(b)

FIGURE 4-10 Probability Curves for Index Type II

The success of this index depended on the infrequent occurrence of near saturated upper soil storage contents. For bare clay soils or soils with grass cover with poor infiltration capacity this condition could often not be met. As a consequence this type of index was not proceeded with as its application could, being optimistic, only reflect highly pervious areas.

A second index was therefore proposed that would overcome this constraint. This was an index based on the total time of exposure of different magnitudes of upper soil moisture between dry and saturated in the historic/ simulated record. The upper soil moisture capacity was divided into discrete increments and the accumulated exposure time for each increment over the period of record calculated. A frequency analysis was carried out on this data to produce a similar frequency curve as for the first index that would however meet the constraint of sub-annual saturation. The resulting frequency curve for the 'dry grass' set is shown on Figure 4-10a.

The period of record was split into 10 year sequential periods to test the divergence in computed curves using shorter data periods. As can be seen on Figure 4-10a the divergence was only slight indicating that a period of record equal to 10 years was adequate to deduce a stable frequency curve index.

Figure 4-10b shows similar curves computed from 10 years of record 1933-1942 for the four land domains considered.

The sample output from the ARBM shown earlier in this chapter showed a typical curve analysis based on an annual set of results. The longer period curve was deduced by simply accumulating the values in the second column and calculating a total frequency distribution.

The second index defined the probability, at any time, of a certain class interval of moisture being present in the upper soil store based on an extended record period.

The next section of this chapter describes the development of model algorithms to make use of the index described.

4.2.3 Review of Existing Stochastic Deterministic Models.

As catchment wetness in addition to sorptivity, hydraulic conductivity and rainfall rate were found to be the most important parameters in the prediction of runoff supply, it was decided to attempt to collectively use the statistical nature of catchment wetness (expressed in terms of upper soil store moisture content) and rainfall rate with the deterministic infiltration process to develop an event based runoff model.

In this manner it was proposed to present a method whereby after an initial long term water balance analysis was carried out for the region, frequency based estimates would be possible, taking into account the combined effects of antecedent moisture and rainfall for design or analysis.

The basic principle behind this phase of the work was to incorporate joint probability theory to link rainfall and catchment wetness.

It was proposed to apply, if possible, a simplified joint probability technique combined with a deterministic element describing infiltration based on similar methods to those described by Laurenson (1974) for water resources systems and confluence studies.

The effects of catchment wetness on the estimation of excess rainfall for design events have been discussed by others, including Cordery (1970) described earlier, Larson (1965) and Beran (1973). Beran (1973) investigated the uncertainty of preserving the nominal rainfall return period in the design flood. He considered the sensitivity of flood magnitude to variations in return period, storm duration, temporal pattern, infiltration loss rate, base flow and unit hydrograph shape. The sensitivity analysis allowed for an estimate to be made of any quantity of the distribution of flood magnitude based on sampling across all significant rainfall events resulting in runoff and antecedent conditions.

A Catchment Wetness Index (CWI) was computed by Beran using the procedure described by the British Meteorological Office and a five day antecedent precipitation index (API5) using a daily decay constant of 0.5. The formula was:

$$CWI = 125 - SMD + API5 \qquad (4\text{-}1)$$

where SMD = soil moisture deficiency

Beran in a previous study (Beran & Sutcliffe, 1972) observed that wet day rainfall and SMD were statistically independent. He also noted that small changes in the CWI had a marked effect on the resulting flood.

Beran also used joint probability theory to carry out the analytical phase of his study.

Most of the work carried out by Beran as well as Cordery related to rural catchments and did not include the additional complications of urban systems.

Russel et al (1979) presented a similar joint probability approach to the estimation of design flows for an urban drainage study in Surrey, Canada. They presented the following equation to estimate flow peaks:

$$P(Q) = \sum_{i,j,k} P(Q,T_i,V_j,I_k)\ p(T_i)\ p(V_j)\ p(I_k) \qquad (4\text{-}2)$$

where $P(Q,T_i,V_j,I_k)$ = conditional probability of Q being exceeded given that T_i, V_j and I_k occur; and $p(T_i)$, $p(V_j)$, $p(I_k)$ = probabilities of T_i, R_j and I_k occurring. The probabilities were assumed to be independent of one another. T = time of concentration, I = infiltration rate (mm/hr) and V = basin storage constant for an assumed linear reservoir.

In general, Russel et al used a simple rainfall/runoff model (Clarke, 1943) to analyse sixty major storms in the fifteen years of rainfall record. These storms were run through the model using a standard basin time/area curve for each of 120 different combinations of the parameters T, I and V. The resulting peak flows per unit area for each combination were then plotted on Gumbel probability paper (one plotted line for each combination). From there probabilities of exceedance of fifty (50) specified flows were measured. The exceedance probabilities were stored in matrix form with fifty (50) rows - one for each of the specified peak flows and 120 columns - one for each combination of T, I and V.

From the stored data, probabilities of exceedance of the stored flows in any particular drainage basin could be computed if probability distributions of the parameters T, I and V were provided using the above equation.

The method was arranged to accept either probable high and low estimates, or single values of each parameter. It appeared therefore that it was necessary for the designer to supply estimates of T, I, and V, all of which in the form described are somewhat difficult to estimate and even more difficult to physically measure.

The methods proposed by Russel et al showed the necessity to consider the statistical components of the major parameters in the rainfall/runoff process where accurate design estimates were to be made. The method as described, although referring to an urban catchment, considered a watershed as a lumped unit rather than the accumulation of individual land domains proposed in this thesis.

4.2.4 Development of SDRRM Model

This chapter draws on a number of the aspects from the preceding author's work to combine the stochastic components of soil moisture and rainfall intensities (based on local measured and simulated data) with the deterministic infiltration component currently used in the Regional Stormwater Drainage Model, RSWM, to obtain excess rainfall and flood frequency distributions. The methods were to incorporate the different land domains described earlier and be capable of assessing imbedded storm bursts. The model was called a Stochastic/Deterministic Rainfall/Runoff Model (SDRRM).

The model development generally followed the techniques described by Laurenson (1974) involving the use of joint probabilities and the formulation of appropriate transformation matrices to link the probabilities of occurrence of the various input parameters together.

The approach recognised the roles of both the stochastic and deterministic components in the analysis. The deterministic component in this thesis consisted of Philip's infiltration algorithms and the combined moisture storages defined in the ARBM.

In summary the modelling system proposed, shown diagrammatically on Figure 4-11, had as input (Rainfall "R") and output (Excess Rainfall or Peak Runoff "Qo"). The input was transformed to the output by a transformation function representing the deterministic components of the system. In this case the transformation depended also upon the value of an additional input defined here as a "parameter" (Antecedent Moisture "M"). Input, output and the parameter were the stochastic elements of the system and had probability distributions.

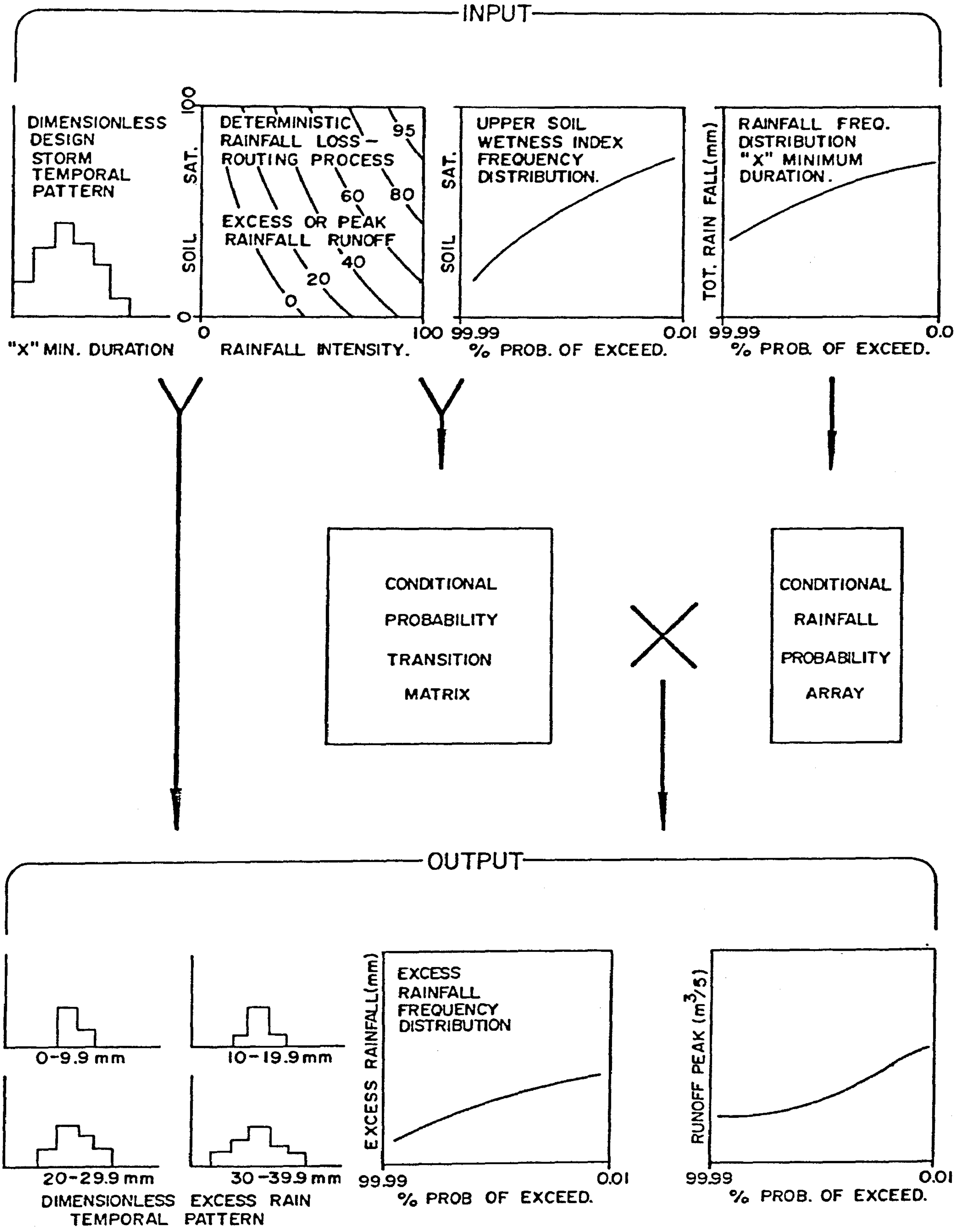

INPUT
DIMENSIONLESS DESIGN STORM TEMPORAL PATTERN
"X" MIN. DURATION
SOIL SAT.
100
0
DETERMINISTIC RAINFALL LOSS – ROUTING PROCESS
95
60
80
EXCESS OR PEAK RAINFALL RUNOFF
40
20
0
0
100
RAINFALL INTENSITY.
SOIL SAT.
UPPER SOIL WETNESS INDEX FREQUENCY DISTRIBUTION.
99.99
0.01
% PROB. OF EXCEED.
TOT. RAIN FALL(mm)
RAINFALL FREQ. DISTRIBUTION "X" MINIMUM DURATION.
99.99
0.0
% PROB. OF EXCEED.
CONDITIONAL PROBABILITY TRANSITION MATRIX
CONDITIONAL RAINFALL PROBABILITY ARRAY
OUTPUT
0-9.9 mm
10-19.9 mm
20-29.9 mm
30-39.9 mm
DIMENSIONLESS EXCESS RAIN TEMPORAL PATTERN
EXCESS RAINFALL(mm)
EXCESS RAINFALL FREQUENCY DISTRIBUTION
99.99
0.01
% PROB OF EXCEED.
RUNOFF PEAK (m³/s)
99.99
0.01
% PROB. OF EXCEED.

FIGURE 4-11 Digrammatic Representation of the SDRRM Model

Using Laurenson's definition, the system here was a concentrative determinate process with one independent parameter.

The probability distribution R and M was determined by frequency analysis based on recorded and/or simulated data described earlier where M equalled the antecedent moisture Index.

The deterministic transformation was derived from a matrix of rainfall vs excess rainfall and peak runoff for a range of antecedent conditions from dry to saturated based on the ARBM infiltration algorithms and the RSWM.

Based on the above matrix, conditional probabilities of the parameter M for a range of (excess rainfall or peak runoff) total rainfall amounts could be deduced.

The objects of the model as proposed were to determine the probability distribution of flood peaks and/or runoff volume (qo_j) from a known probability distribution of rainfall of duration D and a known probability distribution of soil moisture representing catchment antecedent moisture (m_k) and a known deterministic transformation to relate rainfall to excess rainfall or peak runoff.

Model output (Qo) was achieved by the matrix multiplication of an input probability distribution $R = (r_i)$ with a matrix of transition probabilities $A = [a_{ji}]$ defined by the estimation of conditional probabilities for a range of excess rainfalls or runoff peaks and a range of antecedent conditions, ie:

$$Qo = A \times R \qquad (4\text{-}3)$$

or

$$(qo_j)m = [a_{ji}]m \times (r_i)f \qquad (4\text{-}4)$$

where m and f are the dimensions of the vectors representing the probability distributions of output and input respectively.

The matrix A reflects the deterministic component of the system. Based on the work carried out by Beran and Sutcliffe, (1972) it was assumed that antecedent moisture content (M) and the following rainfall distributions were independent events.

As defined, the output Q equaled the multiplication of the input with a matrix of transition probabilities A, the latter being defined as follows:

$$A = a_{ji} = Pr\ (qo = Qo_j/r = R_i) \qquad (4\text{-}5)$$

Any particular value of the antecedent moisture parameter m gave a one to one transformation of r to q. The conditional distribution of q given $r = R_i$ consisted of unity and a set of zeroes, ie, a concentrative process.

There was a conditional distribution of qo not only for each possible value of r but also for each possible value of m. Each possible value of m, say M_k had a certain probability m_k. Therefore the probabilities a_{ji} became:

$$a_{ji} = \sum_k b_{jik} \times m_k \tag{4-6}$$

where b_{jik} is the conditional probability of an output Qo_j given input R_i and a parameter value M_k, ie:

$$b_{jik} = P_r \; (qo = Qo_j/r = R_i, \; m = M_k) \tag{4-7}$$

Figures 4-12(a), (b), (c), (d), (e) and (f) describe the typical process.

Figures 4-3 and 4-10 show typical exceedance probability distributions for rainfall (R) and an antecedent moisture index (M). The rainfall distributions are in respect to the Canberra region and of 18,30,60 and 120 minute durations respectively.

A typical output from the SDRRM is given below for a 30 minute duration event on an urban catchment with 75% dry grass and 25% impervious content in Canberra, together with a program listing and input data stream.

Figure 4-12(a) shows matrices indicating the relationship between rainfall and excess rainfall.

Figure 4-12(b) represents the transition matrix A with individual elements calculated using equation 4-6 and Figure 4-10 by equating r and q to give M_k. m_k was then deduced from Figure 4-10 with $m = M_k$.

Conditional probabilities were then deduced from the above exceedance probabilities to form the a_{ji} elements of the transition matrix.

Figure 4-12(c) shows the transition matrix A together with the rainfall conditional probabilities corresponding to the values of R_i shown. The matrix multiplication of A x R provided the required output Qo, the excess rainfall or peak runoff conditional probability array.

Figure 4-12(d) shows the output of Figure 4-12(c) converted to exceedance probabilities.

SDRRM - PROGRAM LISTING

```
      PROGRAM ARMA2(INPUT,OUTPUT,TAPE1=OUTPUT,TAPE10=INPUT)
C     PROGRAM ARMA2 COMPUTES EXCESS RUNOFF MATRIX FOR A DEFINED STORM
C     DURATION AND VARIABLES OF UPPER STORAGE (PRE STORM) AND INTENSITY
      REAL IAR,ISC,LSC,LM,LDF,KG,IS,INF,LE,LS,LDR,LEC
      REAL ISI,MEANM(50)
      REAL IDS
      COMMON ASUM(10),Q(1440,2),EXTP(15,2)
      COMMON ACAT,FIMP,BI,BP,UI,UP,SLPI,SLPP,IDUR,INLRN,LENGTH,NORUN
      DIMENSION QMAXT(15,15), DEPTH(15,15),DEPT(200),ICT(10)
      DIMENSION RXI2(15)
      DIMENSION DUR(50),USI(20),XI(20),PUSI(20),PXI(20)
      DIMENSION SS(50)
      DIMENSION TITLE(40),P(1000),RIT(20)
      DIMENSION IPE(15,15),TRE(15,15,15),XRE(500,15)
      DIMENSION RPE(25),RV(25),SV(25),TR(16,16),SR(16)
      DIMENSION TRA(16,16),TRA(16),TRAT(16),TIE(15),TIEP(16)
C                CATCHMENT    CHARACTERISTICS
C     DEPRESSION STORAGE CAPACITY IN (MM)                    DSC
C     INTERCEPTION STORAGE CAPACITY IN (MM)                  ISC
C     UPPER SOIL ZONE STORAGE CAPACITY IN (MM)               USC
C     LOWER SOIL ZONE STORAGE CAPACITY IN (MM)               LSC
C     MAX EVAPOTRANSPIRATION FROM USZ IN (MM/DAY)            UM
C     MAX EVAPOTRANSPIRATION FROM LSZ IN (MM/DAY)            LM
C     PROPORTION OF EVAPOTRANSPIRATION FROM USZ              ER
C     SORPTIVITY OF DRY SOIL IN USZ IN (MM/MIN 1/2)          SO
C     CONTINUING INFILTRATION RATE IN (MM/MIN)               A
C     SOIL MOISTURE REDISTRIBUTION CONSTANTS                 A0
C                                                            A1
C     IMPERVIOUS DEPRESSION STORAGE IN (MM)                  IDS
C     LOWER SOIL ZONE DRAINAGE FACTOR                        LDF
C     GROUNDWATER DEPLETION CONSTANT                         KG
C     PROPORTION OF RAIN INTERCEPTED BY VEGETATION           IAR
C     RATIO OF EVAPORATION FROM PAN TO EST. POT. EVAPOT.     ECOR
C     PROPORTION OF CATCH. AREA THAT IS IMPERVIOUS           FIMP
C     STORAGE CAPACITY OF IMPERVIOUS AREA IN (MM)            CAPIMP
C     GROUNDWATER ROUTING CONSTANT                           GN
      READ(10,1499) NJOBSS
      IAI=0
 1499 FORMAT(I5)
      DO 1001 NJS=1,NJOBSS
      READ(10,1500)TITLE
      WRITE(1,2500)TITLE
 2500 FORMAT(1H1,40A2)
 1500 FORMAT(40A2)
      READ(10,1501)CAPIMP,ISC,DSC,USC,LSC,UM,LM,ER
      WRITE(1,7779)CAPIMP,ISC,DSC,USC,LSC,UM,LM,ER
 7779 FORMAT(1H ,8F10.4)
      READ(10,1501)IDS,FIMP,XIIS,XIDS,US,LS,GS,GN
      WRITE(1,7779)IDS,FIMP,IS,DS,US,LS,GS,GN
      READ(10,1501)SO,A,A0,A1,LDF,KG,ECOR,IAR
      WRITE(1,7779)SO,A,A0,A1,LDF,KG,ECOR,IAR
 1501 FORMAT(8F10.0)
      READ(10,7001)IN01,IN02,ACAT,BI,BP,UI,UP,SLPI,SLPP,NORUN,INLRN
 7001 FORMAT(2I5,7F5.0,2I5)
      WRITE(1,7002)IN01,IN02,ACAT,BI,BP,UI,UP,SLPI,SLPP,NORUN,INLRN
 7002 FORMAT(1H ,2I5,7F8.2,2I5)
      READ(10,7006)(ASUM(I),I=1,10)
 7006 FORMAT(10F5.0)
      WRITE(1,7007)(ASUM(I),I=1,10)
 7007 FORMAT(1H ,10F10.2)
      ISI=IS
      DSI=DS
      DTII=INLRN/60.
      READ(10,8001)LENGTH,IROUT,IDUR,IUS,NS,IPRNT,ISOUT,ITAN
 8001 FORMAT(8I10)
C     LENGTH - STORM DURATION IN MINS
C     IROUT - ROUTING INCREMENT IN MINS
C     IDUR - NO. OF INCREMENTS DESCRIBING TEMPORAL PATTERN
C     IUS - NO. OF UPPER SOIL STORE INCREMENTS TO BE RUN
C     NS - NO. OF INTENSITY INCREMENTS TO BE RUN
C     IPRNT - NO. OF FULL OUTPUT REQUESTS
C     DUR(I) - TEMPORAL PARTITION MAGNITUDE (IN FRACTIONS)
C     USI(I) - INITIAL  UPPER SOIL STORE VALUES
C     XI(I) - RAINFALL INTENSITY (MM/HR)
C     PUSI(I),PXI(I) - FULL OUTPUT POINTER
      READ(10,8002)(DUR(I),I=1,IDUR)
 8002 FORMAT(8F10.0)
      READ(10,8002)(USI(I),I=1,IUS)
      READ(10,8002)(XI(I),I=1,NS)
      IF(IPRNT.EQ.0) GO TO 4001
      READ(10,8003)((PUSI(I),PXI(I)),I=1,IPRNT)
 8003 FORMAT(8F10.0)
 4001 CONTINUE
      READ(10,8040)RANGE
 8040 FORMAT(F10.0)
      READ(10,3333)NPE
 3333 FORMAT(I10)
      IF(NPE.EQ.0) GO TO 1001
      READ(10,3334)(RPE(I),RV(I),SV(I),I=1,NPE)
 3334 FORMAT(3F10.0)
       DO 4500 LLI=1,IUS
       DO 4500 LLJ=1,NS
      DO 666 NN=1,15
      DO 666 MM=1,2
  666 EXTP(NN,MM)=0.0
       US=USI(LLI)
       LS=US*LSC/USC
      IS=XIIS
      DS=XIDS
      S=SO*(1.-US/USC)
      A2=0
      A3=0
      RDC=0.0
      LEC=0.0
      CGR=0.0
      UEC=0.0
      CINF=0.0
      CLDR=0.0
      TS=0.0
      IDS=0.0
C     START SIMULATION OF INTERFACE PROCESS
      IF(IPRNT.EQ.0) GO TO 4073
      DO 4070 IV=1,IPRNT
      IF(PUSI(IV).NE.USI(LLI)) GO TO 4070
      IF(PXI(IV).NE.XI(LLJ)) GO TO 4070
      WRITE(1,6000)
 6000 FORMAT(1H ,45X,"DATA , STORES AND EXCESS RAINFALL SUMMARY"/)
      WRITE(1,5045)USI(LLI),XI(LLJ)
 5045 FORMAT(1H ,"INITIAL SOIL MOISTURE CONTENT = ",F5.2,
     1" RAINFALL INTENSITY = ",F7.2/)
      WRITE(1,6001)
 6001 FORMAT(1H ,"PERIOD DUR EXS  TOT RAIN  POT EVAP  INTER S   DEP S
     1  UPPER S   LOWER S   GROUN S   RINF     INF   EXRAIN P    MOIST
     2  EXRAIN W GWR")
      WRITE(1,6002)IAI,DURA,DJ,DJ,IS,DS,US,LS,GS
 4070 CONTINUE
 4073 CONTINUE
      JJJ=0
      DURA=0.0
      DJ=0.0
      TTS=IS+DS+US+LS+GS
      EXPI=0.0
      EXI=0.0
      EXW=0.0
      DT=IROUT/60.
      DTT=LENGTH/IDUR
      KX=DTT/IROUT
      KX1=1
      KX2=KX
      DO 4005 K=1,IDUR
      DO 4006 L=KX1,KX2
      P(L)=(XI(LLJ)*DUR(K)*LENGTH/60.)/KX
 4006 CONTINUE
      KX1=KX2+1
 4005 KX2=KX2+KX
      NNN=LENGTH/IROUT
      RXI(LLJ)=XI(LLJ)*LENGTH/60.
      DO 100 JJJ=1,NNN
      PP=P(JJJ)
      TT=IROUT/60.
      PEE=0
      TI=TT     *60.
      DURA=TT
      TF=DURA/24.0
      PEJ=PEE     *ECOR
      PEC=PEJ
      EMAX=0.7
      XIP=PP
      PIP=PP
      VPI=0
      PIIP=PP-PIP
      XIT=TT
      IP=PP
 3310 NI=0
 3311 NI=NI+1
      IP=IP/NI
      PP=IP
      TT=TT/NI
      PEJ=PEJ/NI
      DURA=TT
      PEE=PEE/NI
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      PIIP=PIIP/NI
      PEC=PEJ
      TF=TF/NI
      TI=TI/NI
      AOIA=(ISC-IS)
      QDS=DS
      QLS=LS
      IF((PP*IAR)-AOIA)813,813,814
  813 QIS=IS+PP*IAR
      QDS=DS
      QUS=US
      GO TO 6510
  814 QIS=ISC
      QDS=0
      QUS=US+DS+PP-AOIA
 6510 IF(PEJ.EQ.0) GO TO 6500
      IF(PEJ.GT.QIS) GO TO 6501
      QIS=QIS-PEJ
      GO TO 6500
 6501 PET=PEJ-QIS
      QIS=0
      IF(PET.GE.QDS) GO TO 6502
      QDS=QDS-PET
      GO TO 6500
 6502 PET=PET-QDS
      QDS=0.
      FU=QUS*(1.-EXP(-TF*UM/USC))
      FL=QLS*(1.-EXP(-TF*LM/LSC))
      IF(PET.GE.FU) GO TO 6503
      QIN=ER*PET
      GO TO 6504
 6503 QIN=ER*FU
 6504 QUS=QUS-QIN
      IF(PET.LT.FL) GO TO 6517
      LE=(1.-ER)*FL
      GO TO 6518
 6517 LE=(1.-ER)*PET
 6518 QLS=QLS-LE
      GO TO 6505
 6500 LE=0.
      QIN=LE
 6505 ROT=TI*A0*(1+A1)*EXP(A3*LS)
      IF(ROT.GT.20.0) ROT=20.0
      ROD=(QUS-A1*QLS-A2)*(1-EXP(-ROT))/(1.+A1)
      IF(TF.LE.1.5) GO TO 4449
      STORE=(ISC-IS)+(DSC-DS)+(USC-US)+QIN+ROD
      IF(TF.GT.10.0) GO TO 3311
      IF(IP.LT.0.0001) GO TO 4449
      IF(STORE.LT.IP) GO TO 3311
 4449 VPI=VPI+TT
C     SIMULATION OF CATCHMENT WETTING
C
 2020 PIN=PP     *IAR
      IF(PIN.GT.ISC-IS) GO TO 2070
      IS=IS+PIN
      PT=PP     -PIN
      GO TO 2090
 2070 PT=PP-ISC+IS
C
C     MODIFIED PHILLIPS EQUATION
C
      IS=ISC
 2090 INF=S*(SQRT(TS+TI)-SQRT(TS))+.33*A*TI+[illegible]
      INF=INF
      IF(INF.GT.PT+DS) INF=PT+DS
      IF(ROT.LE.0.0) ROT=0.0
      IF(TF.LT.0.5) QIN=0.0
      AX=(USC-US)+ROT+QIN
      IF(INF.LT.AX) GO TO 2160
      INF=AX
 2160 CINF=CINF+INF
      US=US+INF
      DS=DS+PT-INF
      IF(DS.LE.0.) GO TO 2260
      TS=TS+TI
      IF(DS.LE.DSC) GO TO 2280
      RE=DS-DSC
      DS=DSC
      GO TO 2290
 2260 TS=0.
      S=SO*(1.-US/USC)
 2280 RE=0.
C
C     SIMULATION OF CATCHMENT DRYING
C
 2290 IF(PEJ.EQ.0.) GO TO 2560
      IF(PEJ.GT.IS) GO TO 2340
      IS=IS-PEJ
      GO TO 2560
 2340 PET=PEJ-IS
      IS=0.
      IF(PET.GE.DS) GO TO 2390
      DS=DS-PET
      GO TO 2560
 2390 PET=PET-DS
      DS=0.
      FU=US*(1.-EXP(-TF*UM/USC))
      FL=LS*(1.-EXP(-TF*LM/LSC))
      IF(PET.GE.FU) GO TO 2460
      UE=ER*PET
      GO TO 2470
 2460 UE=ER*FU
 2470 UEC=UEC+UE
      US=US-UE
      IF(PET.LT.FL) GO TO 2520
      LE=(1.-ER)*FL
      GO TO 2530
 2520 LE=(1.-ER)*PET
 2530 LEC=LEC+LE
      LS=LS-LE
      GO TO 2570
 2560 LE=0.
      UE=LE
C
C     SIMULATION OF SOIL MOISTURE REDISTRIBUTION
C     RD.GT.0 = FLOW FROM UPPER TO LOWER SOIL ZONE
C     RD.LT.0 = FLOW FROM LOWER TO UPPER SOIL ZONE
C
 2570 RO=TI*A0*(1.+A1)*EXP(A3*LS)
      IF(RO.GT.20.0) RO=20.0
      RD=(US-A1*LS-A2)*(1.-EXP(-RO))/(1.+A1)
      RDC=RDC+RD
      IF(RD.LE.0.0) GO TO 2660
      IF(RD.LE.US) GO TO 2710
      LS=LS+US
      US=0.
      GO TO 2770
 2660 IF(-RD.LE.LS) GO TO 2710
      US=US+LS
      LS=0.
      GO TO 2730
 2710 LS=LS+RD
      US=US-RD
 2730 IF(US.LE.USC) GO TO 2770
      LS=LS+(US-USC)
      US=USC
C
C     SIMULATION OF GROUNDWATER RECHARGE AND RUNOFF
C
 2770 IF(DS.GT.0) GO TO 9770
      TS=0.
      S=SO*(1-US/USC)
 9770 LDR=LS*(1.-EXP(-TF*LDF*SQRT(LS/LSC)))
      IF(LS-LDR.GT.LSC) LDR=LS-LSC
      LS=LS-LDR
      CLDR=CLDR+LDR
      GS=GS+LDR
      GR=0.
      RCOR=SQRT(TF*2.*GN*KG*GS**(GN-1)*TF)-SQRT(TF)
      IF(GS.GT.0) GR=GS/GN*RCOR
      IF(GR.GT.GS) GR=GS
      GS=GS-GR
      CGR=CGR+GR
C
C     END MAIN LOOP OF MODEL
C
      TTS=IS+DS+US+LS+GS
C     IMPERVIOUS AND PERVIOUS RUNOFF
      EXI=0.0
      REU=0.0
      IF(FIMP.EQ.0) GO TO 171
      CAP1=IDS
      CAP=IDS+PP-PIIP
      IF(CAP.GT.CAPIMP) GO TO 131
      IDS=CAP-PEE
      IF(IDS.LT.0.0) IDS=0.0
      EXI=0.0
      EXPI=0.0
      REU=0.0
      GO TO 172
  131 IF((CAP-CAPIMP).LT.PEE) GO TO 331
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      REU=(CAP-CAPIMP)-PEE
      IDB=CAPIMP
      EXI=FIMP*REU
      GO TO 171
  770 REU=0.0
      EXI=0.0
      IDB=CAP-PEE
      IF(IDB.LT.0.0) IDB=0.0
  171 EXPI=RE*(1-FIMP)
  172 CONTINUE
      EXW=EXI+EXPI
      IF(IPART.EQ.0) GO TO 4010
      DO 4015 IV=1,IPART
      IF(PUSX(IV).NE.USX(LLI)) GO TO 4015
      IF(PXI(IV).NE.XI(LLJ)) GO TO 4015
      WRITE(1,4002)JJJ,DURA,PP,PEE,IS,DS,US,LS,CS,IRF,IRF,RE,RO,EXW,
     1CGR
 4002 FORMAT(1H ,I4    ,1X,F8.2,1X,F9.2,1X,F9.2,1X,F9.2,1X,F9.2,1X,F9.2,1
     1X,F10.2,1X,F9.2,F9.2,F7.2,F10.2,F10.2,1X,F4.1,F8.2)
 4015 CONTINUE
 4010 CONTINUE
      ARE(LLI,LLJ)=ARE(LLI,LLJ)+EXW
      TRE(LLI,LLJ,JJJ)=EXW+TRE(LLI,LLJ,JJJ)
      ENTP(JJJ,1)=ENTP(JJJ,1)+RED
      ENTP(JJJ,2)=ENTP(JJJ,2)+RE
      IF((VPZ+.000001).LT.XXY) GO TO 3310
  100 CONTINUE
      IF(IRO1.EQ.1) GO TO 7600
      IF(IRO2.GT.1) GO TO 7601
C        IMPERVIOUS ONLY
      IRN=1
      IKA=1
      CALL LRRN(IRN,LLI,LLJ)
      GO TO 7602
 7601 IF(IRO2.GT.2) GO TO 7603
C     PERVIOUS ONLY
      IRN=2
      IKA=2
      CALL LRRN(IRN,LLI,LLJ)
      GO TO 7602
 7603 IRN=1
C      PERVIOUS + PERVIOUS
      CALL LRRN(IRN,LLI,LLJ)
      IRN=2
      CALL LRRN(IRN,LLI,LLJ)
      IKA=2
      DO 7605 IP=1,NORUN
 7605 Q(IP,2)=Q(IP,1)+Q(IP,2)
C      PERVIOUS + IMPERVIOUS HYDROS STORED IN Q(I,2)
C      CALCULATE PEAK RUNOFF FLOW DEPTH OF RUNOFF
 7602 I=1
      VOL=0.0
  199 DI=Q(I,IKA)+4.0*(Q(I+1,IKA))+Q(I+2,IKA)
      DVOL=DTXX/3.0*DI
      VOL=VOL+DVOL
      I=I+2
      IF(I.GT.(NORUN-2)) GO TO 201
      GO TO 199
  201 IF(I.EQ.NORUN-1) GO TO 202
      GO TO 203
  202 DVOL=DTXX*((Q(NORUN,IKA)+Q(NORUN-1,IKA))/2.0)
      VOL=VOL+DVOL
  203 DEPTH(LLI,LLJ)=VOL*360/ACAT
      QMAX=0.0
      DO 207 I=1,NORUN
  207 IF(Q(I,IKA).GT.QMAX) QMAX=Q(I,IKA)
      QMAXT(LLI,LLJ)=QMAX
 4500 CONTINUE
 7600 DO 7620 KAN=1,IROT
C     FIRST RUN EXCESS RAINFALL PROB. ESTIMATION
C      SECOND RUN IF OPTION ON PEAK RUNOFF PROB. ESTIMATION
      IF(KAN.EQ.1) GO TO 7621
      DO 7622 NR=1,15
      DO 7622 NN=1,15
 7622 ARE(NR,NN)=QMAXT(NR,NN)
 7621 CONTINUE
C      OUTPUT  SUMMARIES
C      OUTPUT OPTIONS - ISOUT = 1 -FULL MATRIX OUTPUT
C                             0  NO OUTPUT
C                      ITSR  = 1  FULL EXCESS RUNOFF TEMPORAL PATTERN TRACE
C                             0  NO OUTPUT
      IF(ISOUT.EQ.0) GO TO 4600
C      MATRIX OUTPUT FOLLOWS
      IF(KAN.EQ.1) GO TO 7889
      WRITE(1,8005)
      WRITE(1,7888)LENGTH
 7888 FORMAT(1H ,43X,"*",I3," MIN. STORM RUNOFF PEAK MATRIX    *")
      WRITE(1,8338)
      GO TO 7625
 7889 WRITE(1,8005)
 8005 FORMAT(1H1,43X,"*******************************************")
      WRITE(1,8006)LENGTH
 8006 FORMAT(1H ,43X,"*",I3," MIN. STORM EXCESS RUNOFF MATRIX *")
      WRITE(1,8338)
 8338 FORMAT(1H ,43X,"*******************************************")
 7625 WRITE(1,8007)
 8007 FORMAT(1H ,10X,"RESULTS BASED ON THE AUSTRALIAN REPRESENTATIVE BAS
     1INS MODEL WITH THE FOLLOWING PARAMETERS AND DATA VARIABLES")
      WRITE(1,8008)ISC,IST,IS,XI
 8008 FORMAT(1H ,10X,"INTERCEPTION STORE CAP. OF ",F5.1," MM   INITIAL I
     1NTERCEPTION STORAGE    ",F5.1," MM   REDISTRIBUTION CONSTS. ",F5.2,
     2" AND ",F5.2)
      WRITE(1,8009)DSC,DST,(DUM(IT),IT=1,IDUR)
 8009 FORMAT(1H ,10X,"DEPRESSION   STORE CAP. OF ",F5.1," MM   INITIAL D
     1EPRESSION  STORAGE     ",F5.1," MM   STORM PATTERN ",8F5.3)
      WRITE(1,8010)USC,SO
 8010 FORMAT(1H ,10X,"UPPER SOIL   STORE CAP. OF ",F5.1," MM   SORPTIVIT
     1Y",21X,F5.1,"      INITIAL LOWER SOIL STORE=INT(US)*LSC/USC"   )
      WRITE(1,8011)LSC,A,FIMP
 8011 FORMAT(1H ,10X,"LOWER SOIL   STORE CAP. OF ",F5.1," MM   HYDRAULIC
     1 CONDUCTIVITY CONST. ",F5.2,8X,"IMPERVIOUS AREA FRACTION = ",F5.2)
      WRITE(1,8012)
 8012 FORMAT(1H ," INITIAL *",30X,"TOTAL RAINFALL (MM)")
      WRITE(1,8013)
 8013 FORMAT(1H ,"UPPER SOIL*",38X,"**********************")
      WRITE(1,8014)(RX(I),I=1,NS)
 8014 FORMAT(1H ,"  STORAGE *",15(F7.2,"*"))
      WRITE(1,8015)
 8015 FORMAT(1H ,131("*"))
      DO 4650 K=1,IUS
      WRITE(1,8016)USX(K),(ARE(K,J),J=1,NS)
 8016 FORMAT(1H ,F10.4,"*",15(F7.2,"*"))
 4650 CONTINUE
      WRITE(1,8015)
C
      IF(KAN.NE.1) GO TO 7626
C
 4600 AA=0
      IF(ITSR.EQ.0) GO TO 5075
      WRITE(1,8337)
 8337 FORMAT(1H ,10X,"EXCESS RUNOFF DIMENSIONLESS TEMPORAL PATTERNS")
      WRITE(1,8777)
 8777 FORMAT(1H ,10X,"**********************************************"//)
      WRITE(1,8339)
 8339 FORMAT(1H ,20X,"TEMPORAL PARTITIONS EXPRESSED IN FRACTIONS")
      DO 4900 I=1,IUS
      DO 4900 J=1,NS
      IF(ARE(I,J).GT.AA) AA=ARE(I,J)
 4900 CONTINUE
      NOFF=AA/RANGE+1.
      KK1=-RANGE
      KK2=0
      DO 4950 IN=1,NOFF
      KK1=KK2
      KK2=KK1+RANGE
      XK1=KK1
      XK2=KK2-.1
      NZ=0
      DO 4961 I=1,IUS
      DO 4961 J=1,NS
      IF(ARE(I,J).EQ.0) GO TO 4961
      IF(ARE(I,J).LT.(KK1)) GO TO 4961
      IF(ARE(I,J).GT.(KK2-.0000001)) GO TO 4961
      NZ=NZ+1
      DO 4962 K=1,NNN
 4962 ZRE(NZ,K)=TRE(I,J,K)/ARE(I,J)
 4961 CONTINUE
      WRITE(1,8967)NZ
 8967 FORMAT(1H ,I10)
      DO 4850 K=1,NNN
      T=0
      S1=0
      DO 4851 J=1,NZ
      T=ZRE(J,K)+T
      S1=S1+ZRE(J,K)*ZRE(J,K)
 4851 CONTINUE
      MEANN(K)=T/NZ
      ADZ=NZ-1
      IF(NZ.LE.1) ADZ=1
      SX(K)=SQRT((S1-NZ*MEANN(K)*MEANN(K))/ADZ)
 4850 CONTINUE
      WRITE(1,8333)XK1,XK2,(MEANN(K),K=1,NNN)
      WRITE(1,8336)(SX(K),K=1,NNN)
 8333 FORMAT(1H ,"RANGE",F5.1," TO",F5.1," MM",3X,8F10.4)
 8336 FORMAT(1H ,"STD DEVS.",11X,8F10.4)
 4950 CONTINUE
 7626 CONTINUE
C      JOINT PROBABILITY ANALYSIS
 5075 CONTINUE
C      DEVELOPMENT OF TRANSITION MATRIX
      RNG=ARE(15,15)/15
      NRNG=RNG+1
      DO 6201 K=1,15
 6201 RXI2(K)=NRNG*K
      IC=16
      DO 5016 I=1,15
      IC=IC-1
      DO 5015 J=1,15
      IP=IC-1
      IF(I.EQ.15) GO TO 5010
      RR(J)=(ARE(J,IC)+ARE(J,IP))/2.0
      GO TO 5015
 5010 RR(J)=ARE(J,IC)/2.0
 5015 CONTINUE
      IN=16
      DO 5020 K=1,16
      IN=IN-1
      IF(K.NE.1) GO TO 5553
      TZP=0.0
      GO TO 5554
 5553 CONTINUE
      IF(K.EQ.16) GO TO 5088
      RZ=RXI2(IN)
      GO TO 5077
 5088 RZ=0.0
 5077 CALL INTRP(RR,USX,15,RZ,TZ,1)
C      TZ = INTERPRETED UPPER SOIL CONTENT MATCHING I & IK
      CALL INTRP(SY,RPE,NPE,TZ,TZP,2)
C      TZP = CORRESPONDING EXCEEDANCE PROBABILITY
 5554 CONTINUE
 5020 TN(K,I)=TZP
C      TN = EXCEEDANCE PROB MATRIX .
 5016 CONTINUE
      WRITE(1,5123)
 5123 FORMAT(1H1,2X)
      WRITE(1,5057)((TN(I,J),J=1,15),I=1,16)
 5057 FORMAT(1H ,15F8.3)
      DO 5022 I=2,16
      K=I-1
      DO 5022 J=1,15
 5022 TNA(K,J)=(TN(I,J)-TN(K,J))/100.0
C      TNA = CONDITIONAL PROB MATRIX (TRANSITION MATRIX)
      WRITE(1,5059)((TNA(I,J),J=1,15),I=1,15)
 5059 FORMAT(1H ,15F8.5)
      IJ=16
      DO 5023 I=1,16
      IJ=IJ-1
      IF(I.NE.1) GO TO 5551
      RAV=0.0
      GO TO 5552
 5551 CONTINUE
      IF(I.EQ.16) GO TO 5049
      RXY=RXI(IJ)
      GO TO 5078
 5049 RXY=0.0
 5078 CALL INTRP(RY,RPE,RPE,RXY,RAV,2)
C      RAV = EXCEEDANCE PROB OF RAINFALL
 5552 CONTINUE
      TRRT(I)=RAV
 5023 CONTINUE
      DO 5024 I=2,16
      K=I-1
 5024 TAR(K)=(TRRT(I)-TRRT(K))/100.0
C      TAR = CONDITIONAL RAINFALL PROBABILITIES
      WRITE(1,5061)TAR
 5061 FORMAT(1H ,F14.6)
      DO 5991 I=1,15
 5991 TIE(I)=0.0
      DO 5027 I=1,15
      DO 5027 J=1,15
 5027 TIE(I)=TNA(I,J)*TAR(J)+TIE(I)
      WRITE(1,5062)TIE
 5062 FORMAT(1H ,F15.7)
C      TIE = CONDITIONAL IE PROBABILITIES
      TR=0
      DO 5028 I=1,15
      TR=TR+TIE(I)
 5028 TIEF(I)=TR*100.
C      TIEF = EXCEEDANCE EXCESS RUNOFF PROBABILITIES
      TL=RXI2(NS)
      DIV=RXI2(NS)/NS
      WRITE(1,5051)
 5051 FORMAT(1H1,10X,"EXCESS  RUNOFF  FREQUENCY  CURVE")
      IF(KAN.EQ.1) GO TO 1212
      WRITE(1,5902)
 5902 FORMAT(1H ,12X,"M**3/S",13X,"RUNOFF PEAK PROB")
      GO TO 1213
 1212 WRITE(1,5892)
 5892 FORMAT(1H ,16X,"MM",13X,"RUNOFF EXC PROB")
 1213 DO 5029 I=2,16
      TL = TL-DIV
      K=I-1
      WRITE(1,5050)TL,TIEF(K)
 5050 FORMAT(1H ,2F20.3)
 5029 CONTINUE
      IF(KAN.EQ.1) GO TO 7620
      WRITE(1,3683)
 3683 FORMAT(///,10X,"RUNOFF DEPTH(MM) SUMMARY")
      RANGE=QMAXT(IUS,NS)/10.0+.0001
      FK1=-RANGE
      FK2=0
      DO 3680 IN=1,10
      FK1=FK2
      FK2=FK1+RANGE
      XK1=FK1
      XK2=FK2-.1
      NZ=0
      DO 3681 I=1,IUS
      DO 3681 J=1,NS
      IF(QMAXT(I,J).EQ.0) GO TO 3681
      IF(QMAXT(I,J).LT.FK1) GO TO 3681
      IF(QMAXT(I,J).GT.(FK2-.000001)) GO TO 3681
      DEPT(NZ)=DEPTH(I,J)
      NZ=NZ+1
      ICT(IN)=NZ
 3681 CONTINUE
      T=0
      S1=0
      DO 3682 J=1,NZ
      T=DEPT(J)+T
      S1=S1+DEPT(J)*DEPT(J)
 3682 CONTINUE
      DMENV=T/NZ
      ADZ=NZ-1
      IF(NZ.LE.1) ADZ=1
      SDVV=SQRT((S1-NZ*DMENV*DMENV)/ADZ)
      WRITE(1,3684)XK1,XK2,DMENV,SDVV
 3684 FORMAT(1H ,"RANGE",F5.1," TO ",F5.1," MEAN DEPTH = ",
     1F20.2,"  STD DEV. = ",F20.2)
 3680 CONTINUE
 7620 CONTINUE
 1001 CONTINUE
99999 STOP
      END
      SUBROUTINE INTRP(SF,OF,NF,HF,OFX,NSC)
      DIMENSION SF(NF),OF(NF)
      IF(NSC.NE.1) GO TO 300
      DO 1212 I=1,NF
      IF(SF(I)-HF)1212,3,2
    3 OFX=OF(I)
      GO TO 100
    2 IF(I.EQ.1) GO TO 400
      OFX=OF(I)-(SF(I)-HF)/(SF(I)-SF(I-1))*(OF(I)-OF(I-1))
      GO TO 100
  400 OFX=OF(1)
      GO TO 100
 1212 CONTINUE
      OFX=OF(I-1)
      GO TO 100
  300 DO 1313 I=1,NF
      IF(SF(I)-HF)8,6,1313
    6 OFX=OF(I)
      GO TO 100
    8 OFX=OF(I)-(HF-SF(I))/(SF(I-1)-SF(I))*(OF(I)-OF(I-1))
      GO TO 100
 1313 CONTINUE
      OFX=OF(I-1)
  100 RETURN
      END
      SUBROUTINE LRRM(IRN,LLI,LLJ)
C     LAURENSON RUNOFF ROUTING MODEL
      REAL KK,KK2,N
      COMMON ASUB(10),Q(1440,2),ERTP(15,2)
      COMMON ACAT,FIMP,BI,BP,UI,UP,SLPI,SLPP,IDUR,INLRN,LENGTH,NORUN
      DIMENSION F(1440,10),FD(1440)
C    EXPAND EXCESS RAINFALL TEMPORAL PATTERN
      NORUN=LENGTH/INLRN
      DT=INLRN/60.
      DTT=LENGTH/IDUR
      KI=DTT/INLRN
      DO 699 J=1,10
      KI1=1
      KI2=KI
      DO 700 K=1,IDUR
      DO 701 L=KI1,KI2
      F(L,J)=ERTP(K,IRN)/KI*ASUB(J)*INLRN/6.0
  701 CONTINUE
      KI1=KI2+1
  700 KI2=KI2+KI
  699 CONTINUE
      IF(IRN.EQ.2) GO TO 801
C     IMPERVIOUS RUN
      A=ACAT*FIMP/100.
      B=BI
      SC=SLPI
      U=UI
      GO TO 802
C     PERVIOUS RUN
  801 A=ACAT*(1-FIMP)/100.
      B=BP
      SC=SLPP
      U=UP
  802 IF(B.GT.0.0) GO TO 803
      B=0.285*A**0.52/((1.0+U)**1.972)/(SC**0.499)
```

```
  803 N=-0.285
      IR=2
C     ROUTING PROCESS BEGINS
      DO 99 J=1,10
      DO 6363 I=1,NORUN
      CORR=FIMP
      IF(IRN.EQ.2) CORR=1.-FIMP
 6363 FD(I)=F(I,J)*CORR
      IF(J.EQ.1) GO TO 26
      DO 27 I=1,NORUN
   27 FD(I)=FD(I)+Q(I,IRN)
   26 CONTINUE
      DO 100 I=1,NORUN
      X1=FD(I-1)
      X2=FD(I)
      IF(I.EQ.1) Q1=0.0001
      IF(I.NE.1) Q1=Q((I-1),IRN)
      IF(Q1.LE.0.0) Q1=0.0001
      KK=B*(Q1**N)
      II=0
      KK2=KK
  101 C1=(0.5*DT)/(KK2+0.5*DT)
      C2=(KK-0.5*DT)/(KK2+0.5*DT)
      Q2=C1*X2+C1*X1+C2*Q1
      IF(Q2.LE.0.0) Q2=0.0001
      KK2=B*(Q2**N)
      II=II+1
      IF(II.GT.IR) GO TO 200
      GO TO 101
  200 Q(I,IRN)=Q2
  100 CONTINUE
   99 CONTINUE
 9999 RETURN
      END
```

INPUT DATA

```
      1
       30 MIN STORM DRY GRASS
50      1.0     1.0     12.5    12.50   10.     10.     .7
0       .25     0.0     0.0     1.05    11.39   0.      1.0
.5      .15     17.20   1.0     .05     .94     .7      .7
   2    3100.   0    02.     01.5  1.5   300   1
  10   10   10   10   10   10   10   10   10   10
        30       6       8      15      15        3       1
        .14     .25     .25     .19     .07
0.      1.      2.      3.      4.      5.      6.      7.
8.      9.      10.     11.     11.5    12.0    12.5
10.     20.     30.     40.     50.     60.     70.     80.
90.     100.    110.    120.    130.    140.    150.
0.      50.     6.      80.     12.8    150.
10.
       23
.0      10000.  12.5
.01     75.     12.4
.05     61.     12.35
.20     50.5    12.3
.5      44.5    12.25
1.0     39.0    12.2
2.0     35.0    12.1
5.      28.5    12.00
10.     25.     10.7
20.     21.     8.00
30.     19.2    6.00
40.     18.     4.50
50.     17.     3.00
60.     16.5    2.00
70.     15.8    1.30
80.     15.3    0.75
90.     14.5    .40
95.     14.     .25
98.     13.8    .13
99.     13.4    .1
99.9    13.     .07
99.99   12.8    .05
100.    0.      0.
EOI
```

CATCHMENT PARAMETER SET

CATCHMENT CHARACTORISTICS
AREA
SLOPE
URBANISATION
ROUTING COEF.

ISOCHRONAL AREAS

RAINFALL/MOISTURE
MATRIX DIMENSIONS

Prob. of Exceed.
data – Rainfall
Moisture

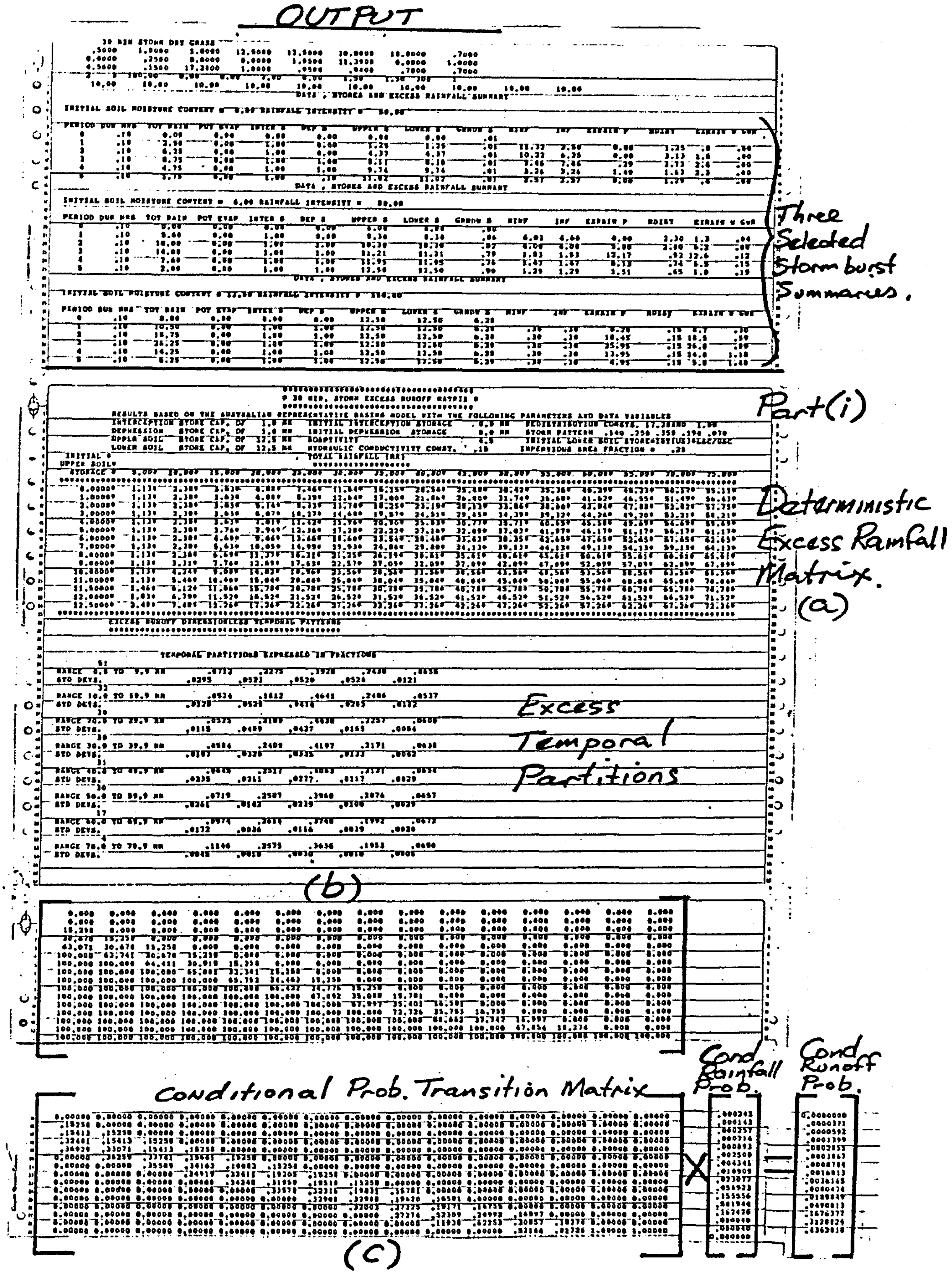
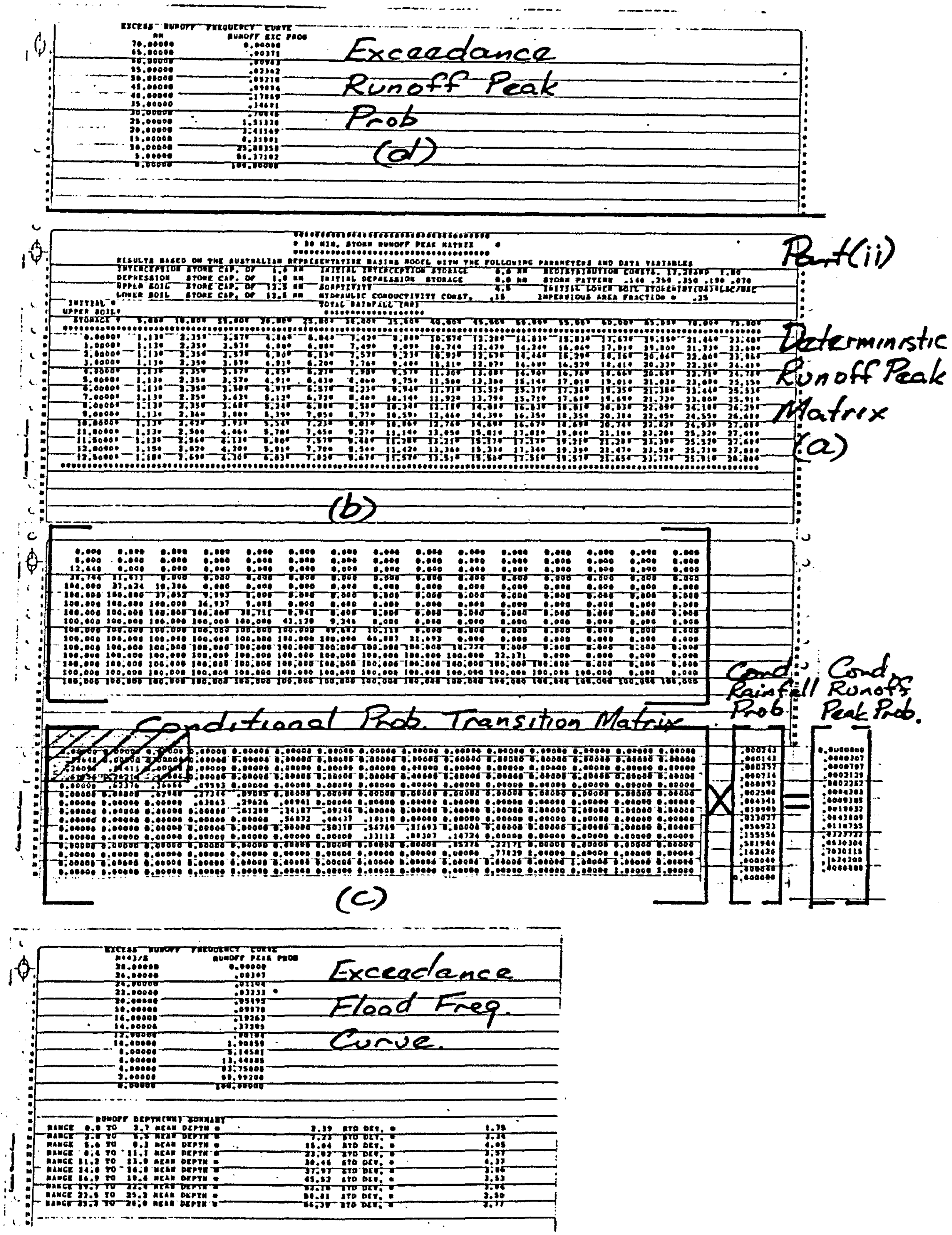

OUTPUT
Three Selected Storm burst Summaries.
Part(i)
Deterministic Excess Rainfall Matrix. (a)
Excess Temporal Partitions
(b)
Conditional Prob. Transition Matrix
Cond Rainfall Prob.
Cond Runoff Prob.
X
=
(c)

FIGURE 4-12 SDRRM Model Output



EXCESS RUNOFF FREQUENCY CURVE

MM RUNOFF EXC PROB

30 MIN. STORM RUNOFF PEAK MATRIX

RESULTS BASED ON THE AUSTRALIAN REPRESENTATIVE BASINS MODEL WITH THE FOLLOWING PARAMETERS AND DATA VARIABLES

INTERCEPTION STORE CAP. OF 1.0 MM INITIAL INTERCEPTION STORAGE 0.0 MM REDISTRIBUTION CONSTS. 17.20AND 1.00

DEPRESSION STORE CAP. OF 1.0 MM INITIAL DEPRESSION STORAGE 0.0 MM STORM PATTERN .140 .250 .350 .190 .070

UPPER SOIL STORE CAP. OF 12.5 MM SORPTIVITY 4.5 INITIAL LOWER SOIL STORE=INT(UA)+LSC/USC

LOWER SOIL STORE CAP. OF 12.5 MM HYDRAULIC CONDUCTIVITY CONST. .15 IMPERVIOUS AREA FRACTION = .25

INITIAL UPPER SOIL STORAGE

TOTAL RAINFALL (MM)

EXCESS RUNOFF FREQUENCY CURVE

M**3/S RUNOFF PEAK PROB

RUNOFF DEPTH(MM) SUMMARY

Exceedance
Runoff Peak
Prob
(d)
Part(ii)
Deterministic
Runoff Peak
Matrix
(a)
(b)
Cond.
Rainfall
Prob.
Cond.
Runoff
Peak Prob.
Conditional Prob. Transition Matrix
(c)
Exceedance
Flood Freq.
Curve.

FIGURE 4-12 (Continued)

The model currently assesses in the first instance excess rainfall in the terms of a frequency distribution together with averaged excess rainfall hyetographs for incremental ranges, then on a second pass computés runoff peaks at the catchment outlet based on a separate pervious/impervious catchment routing using the Laurenson runoff routing module from the RSWM as shown on Figure 4-13 for each of the locations in the matrix.

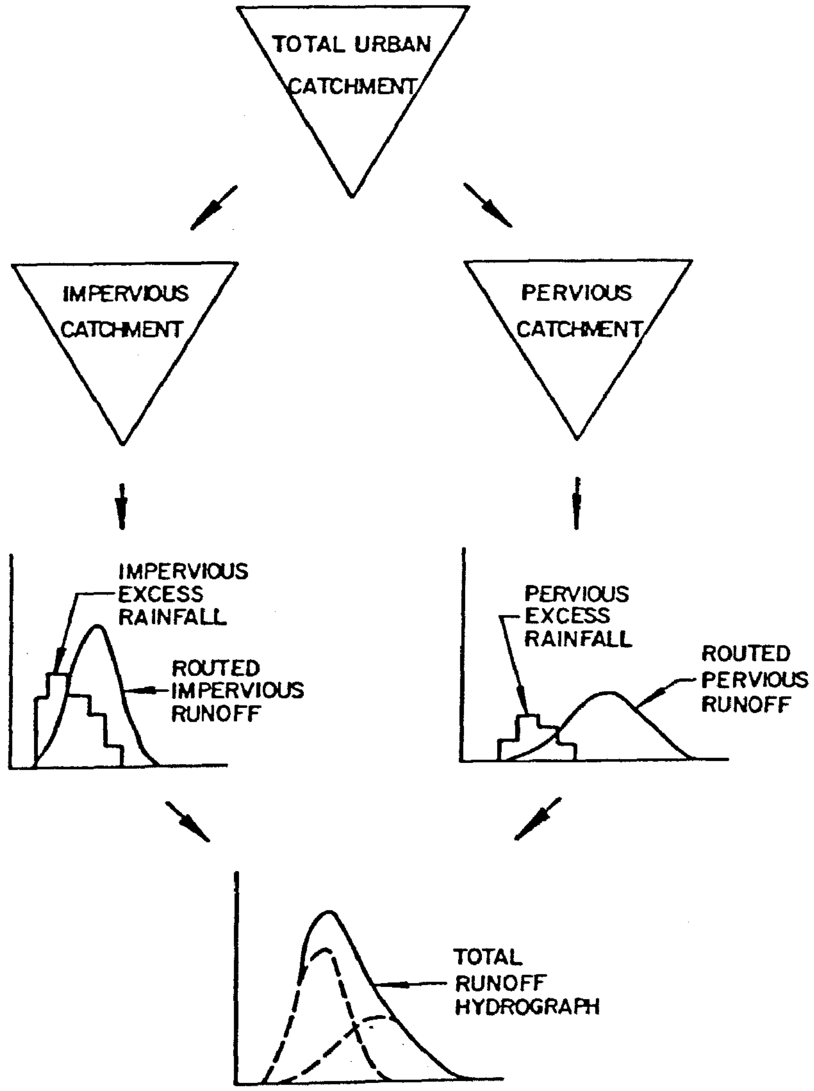

TOTAL URBAN CATCHMENT
IMPERVIOUS CATCHMENT
PERVIOUS CATCHMENT
IMPERVIOUS EXCESS RAINFALL
ROUTED IMPERVIOUS RUNOFF
PERVIOUS EXCESS RAINFALL
ROUTED PERVIOUS RUNOFF
TOTAL RUNOFF HYDROGRAPH

FIGURE 4-13 Flow Diagram of SDRRM Routing Operations

4.2.5 Results from SDRRM.

The combined stochastic/deterministic model described is proposed as a suitable replacement to traditional rainfall loss models being particularly suited to frequency based excess rainfall estimates as well as the estimation of runoff frequency curves for both rural and urban catchments.

Figure 4-11 provides a diagrammatic representation of the proposed model to be used in a design environment. As can be appreciated from the figure, the input consists of four elements, namely a design storm temporal pattern, an antecedent moisture frequency distribution, a rainfall frequency distribution and deterministic matrices relating excess rainfall and hydrographs with total rainfall corresponding to variations in pre-burst antecedent moisture. Output from the model is in two parts (see figure 4-12), firstly an excess rainfall frequency distribution together with a range of excess rain temporal patterns. The range of excess temporal patterns is an extension of the singular rainfall temporal pattern. This comes about by the fact that there are a large number of different variations in temporal patterns able to provide equal magnitudes of total excess rainfall. It has been possible to rank the patterns into ranges of excess rainfall and thereby reduce the total number of possible shapes required in a design estimate.

Excess patterns for a particular range were deduced by averaging all the excess patterns deduced in the transition matrix analysis with totals within the range after reducing the ordinates to dimensionless values.

The proposed procedure differed from conventional loss subtraction methods in so much as after the selection of an appropriate design frequency and event duration one simply abstracted the appropriate excess rainfall volume and corresponding excess rainfall temporal pattern from the model output.

Part(ii) of the output (see figure 4-12) was set out similarly to the first part, however, in this instance it gave a peak runoff frequency distribution rather than an excess rainfall frequency curve.

It must be appreciated that it is not strictly correct to use an individual excess rainfall to compute the same frequency runoff peak by routing as for the excess rainfall curve the peak frequency curve is a statistical distribution and can occur from a number of varying excess rainfall magnitudes and temporal patterns.

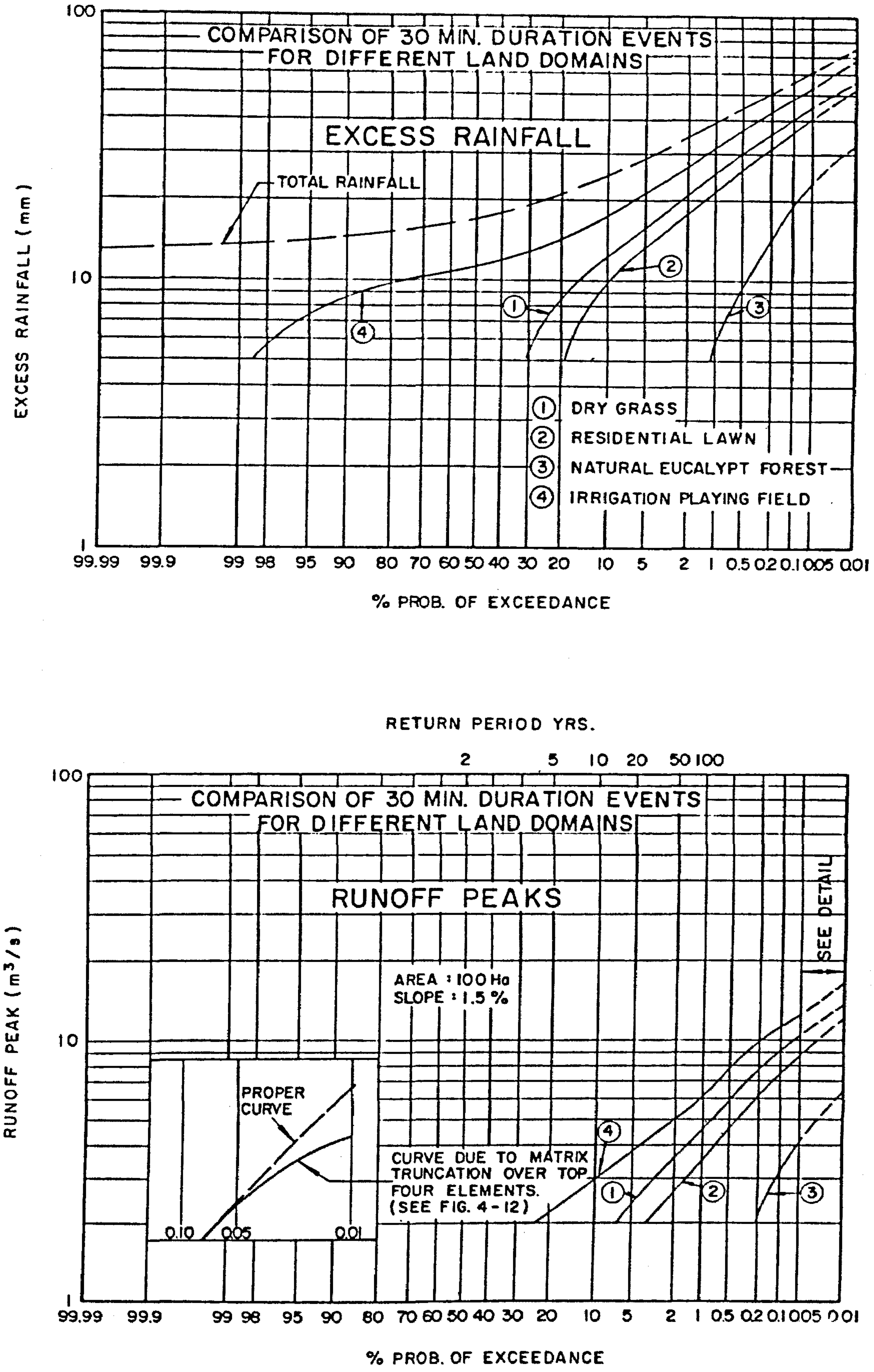


FIGURE 4-14 Simulated Excess Rainfall and Runoff Peaks for Different Land Domains

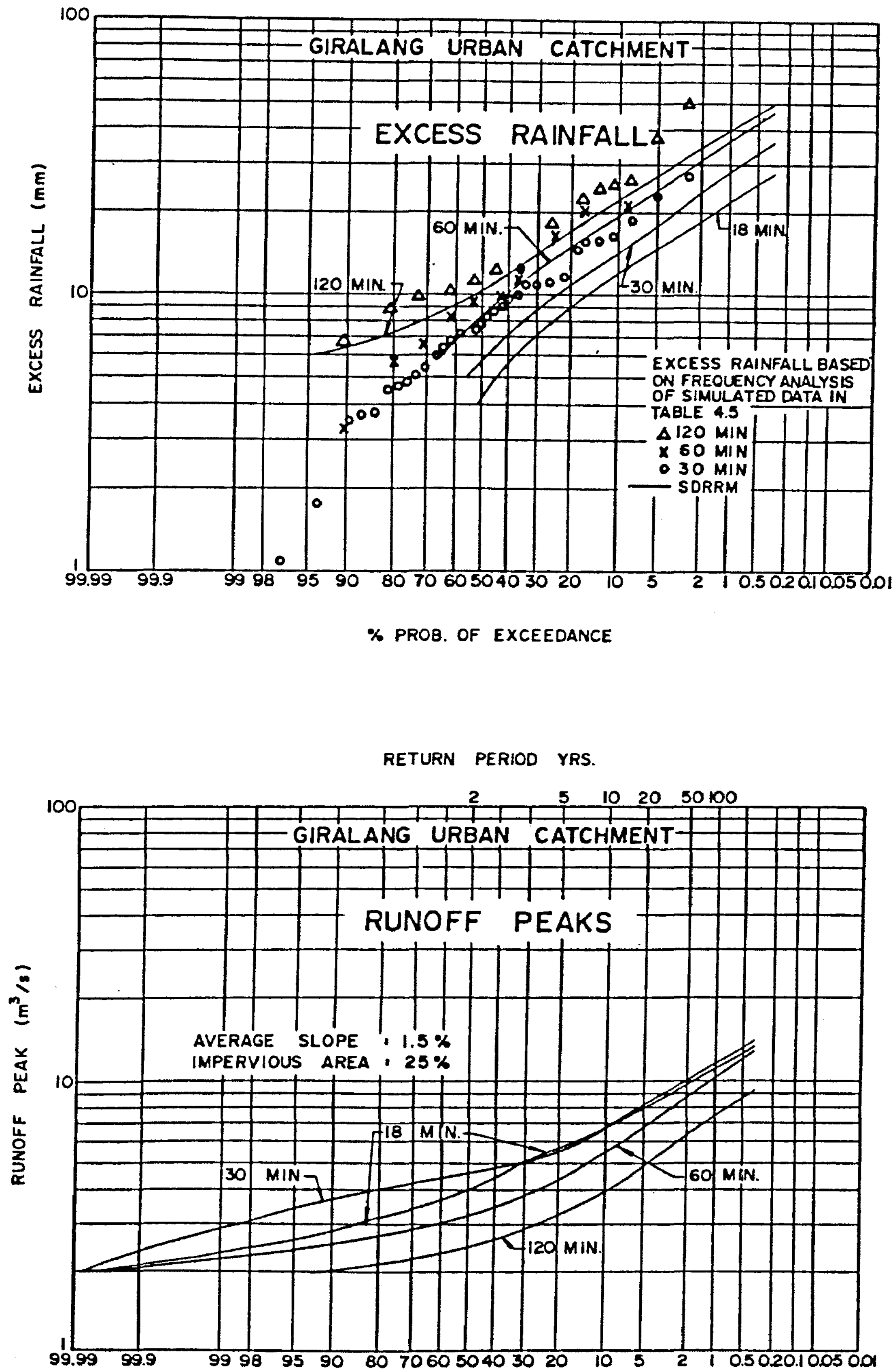


FIGURE 4-15 Simulated Excess Rainfall and Runoff Peaks for Giralang

Figure 4-14 shows the results of the SDRRM model for a typical catchment of 100 hectares and average slope of 1.5% for the four different land domains studied.

The advantages of the SDRRM model, for the determination of excess rainfall, over more conventional initial loss and continuing loss methods was that the indeterminacy of appropriate loss rate was removed from the procedure. Resulting excess rainfall magnitudes and distributions should therefore reflect suitable design events for a required frequency.

Figure 4-15 shows the results for the Giralang urban catchment for events ranging in duration from 18 through 120 minutes. The results were based on the 75% pervious areas being represented by the dry grass parameter set.

Figure 4-15 also shows the results of a frequency analysis based on annual maximum excess rainfalls shown on Table 4-5 to derive excess frequency curves for 30, 60 and 120 minute burst durations.

This was carried out to help test the validity of the alternative SDRRM joint probability model over traditional frequency analysis methods. The resulting annual maximum frequency results tended to be slightly higher than the SDRRM results however with the short period of record some deviation was not unexpected.

The computer output on figure 4-12 shows the computational components of the method including the transition matrices.

The resulting runoff values accruing from the shaded portion of the transition matrix(c) are however subject to errors due to the truncation of matrix elements. The insert on figure 4-14 indicates the type of problem encountered at the high end of the probability scale. To overcome this potential problem however, it is only necessary to select the range of probabilities required with this in mind so as the non- truncated elements are in the area of interest.

4.3 Parameter Assessment for Ungauged and Gauged Urban Catchments.

The main elements necessary to successfully use the SDRRM model are listed as follows:

(a) Catchment Parameters. The complete list of pervious catchment response parameters is shown in Table 4-4. The actual values used depend on the predominant land domain being studied. In contrast to the long term water balance requirements the number of significant parameters for the SDRRM is limited to the parameters affecting catchment response during short term events. These include So, Ko, DSC, USC and LSC.

On ungauged catchments, values for Sorptivity (So) and hydraulic conductivity (Ko) must be selected from appropriate literature such as that published by Talsma (1969) and also listed in Chapter 3, Table 3-1.

On gauged catchments it may be possible to calibrate appropriate So and Ko values by event simulation studies based on measured and estimated runoff volumes and measured rainfall. Additionally, direct assessments of sorptivity and hydraulic conductivity may be made using infiltrometer rings. Chapter 3 addressed the applicability of measuring these parameters, as well as a number of others, in the field.

(b) Rainfall-Intensity-Frequency-Duration Data. This information is usually readily available in most major cities in Australia and appropriately set out in ARR (1977). Similarly, dimensionless temporal patterns for most regions throughout Australia for all normal storm burst durations are published in ARR (1977).

(c) Soil Moisture Antecedence Frequency Data. The derivation of this data has been described in Chapter 4.2. This in brief was based on long term model simulation using the Australian Representative Basins Model (ARBM) and parameters related to particular urban land domains.

On gauged catchments, catchment simulation to optimise parameters can be carried out. This can be supplemented by actual measurement of individual parameters where possible (see Chapter 3).Additionally, it is necessary to have a reasonable period of pluviograph record on which to base the long term water balance analysis. In this thesis approximately 33 years of record was used. A record length of 10 years is thought to be the minimum appropriate for such an anlysis.

On ungauged catchments, model parameters need to be estimated from published literature.

4.4 Runoff Generation from Different Land Domains

In Chapter 4.2, soil moisture frequency distributions for a range of urban land domains were given. These related to pervious areas such as residential lawns, dry grass areas, natural forested areas and irrigated playing fields.

Figure 4-14 showed clearly the differences in both excess rainfall magnitudes and runoff peaks for the different land domains used.

Comparing the Figures 4-10 and 4-14 it was evident that, although the antecedent moisture index curves for dry grass was below that of residential lawns, the resulting excess rainfall and peak runoff curves are reversed with dry grass producing the higher magnitude of runoff. This was due to the higher infiltration characteristics of residential lawns more than compensating for the higher initial moisture index.

Figure 4-10 also showed the antecedent moisture curves for natural forest and dry grass crossing at about the 65% probability of exceedance level. It is not clear why this was so, however as shown on Figure 4-14 even at the higher probable levels the magnitudes at corresponding points for natural forest were significantly less than in dry grass area.

Based on the results shown on Figure 4-14 it was evident that the particular land domain curves have significant effects on the resulting runoff results.

Figure 4-16 shows resulting peak runoff frequency curves based on different parameter sets and input parameters for the Giralang urban catchment. The curves range from irrigated playing fields to natural forest.

Additionally a dry grass - uniform temporal pattern combination was selected to test the significance of the temporal pattern chosen.

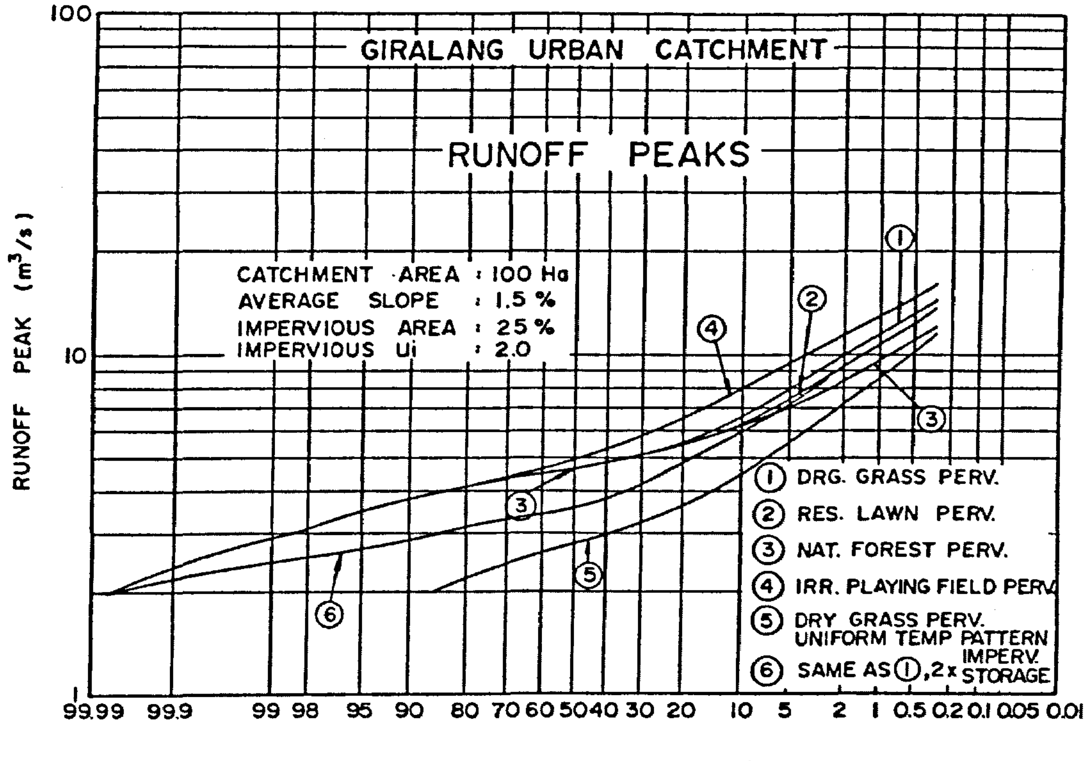


FIGURE 4-16 Sensitivity of Runoff Peaks to Land Domains, Giralang Catchment

4.5 Comparative Analysis Employing the SDRRM and Existing Runoff Estimating Procedures

4.5.1 Introduction

This phase of the thesis reviewed some of the currently applied urban flow frequency analysis techniques for catchment runoff peak and volume estimations and compared them with the methods proposed in this thesis based on the urban Mawson catchment, in the south of Canberra, described in Chapter 3.

The methods reviewed were the rational formula as prescribed in ARR (1977), a locally developed regional frequency method developed in the A.C.T. by Fitzgerald (1975), a frequency analysis of the limited available data for the Mawson catchment, the version of the RSWM described in Chapter 1, the RSWM with proposed stochastic rainfall excess input and finally the SDRRM model direct.

Stochastic and infiltration data necessary for the proposed procedures recommended in this thesis were transposed from the Giralang catchment. No field measurements were carried out on the Mawson catchment. In this way it was proposed to test the transfer of the data from Giralang to other similar constituted catchments within the region and hence the general portability of the proposed model.

4.5.2 Catchment Data

(a) Catchment Features. The Mawson catchment is a fully urbanised catchment as described in Chapter 3 and shown on Figure 3-3. A thin strip of rural land has been left along the southern border of the catchment and this is isolated from the remainder of the catchment by cutoff drains. Catchment slopes range from 1% near its outlet to 15% in the upper reaches.

The existing stormwater collection system consists of underground stormwater pipes which, together with overland flow paths in grass floodways across public land and roadways, provide flood protection to all private property up to and including a once in 100 year storm event.

Entrances to pipes are generally by way of side entry pits plus sag type entry pits at low points in the roadways and depressions.

Pipes sizes range from 150 mm diameter pipes, which collect roof runoff, to multiple 1800 mm diameter pipes at the catchment outlet.

(b) Land Type Breakup. Using the 1:2500 Orthophoto plans plus limited field based assessment, the following list was prepared showing the breakup of the various land types within the catchment:

(1)	Impervious area	115 ha

(2)	Residential lawn	150 ha
(3)	Dry grass area	170 ha
(4)	Irrigated area	10 ha
	TOTAL	445 ha

4.5.3 Rational Formula Method of Analysis

The Rational Formula, following the procedures described in Chapter 12, ARR (1977), was used to evaluate the capacity of the existing pipe system and to determine the flow paths of any overflows resulting from rarer storms.

The estimated flow peaks were determined throughout the catchment for the 1, 2, 5, 10, 20 and 100 year return frequency based on the system existing as at 1979 employing subareas of 5 hectares or less. The adopted tc time for the catchment was 30 minutes.

A frequency curve based on the results of this analysis is shown on Figure 4-17, Curve 1.

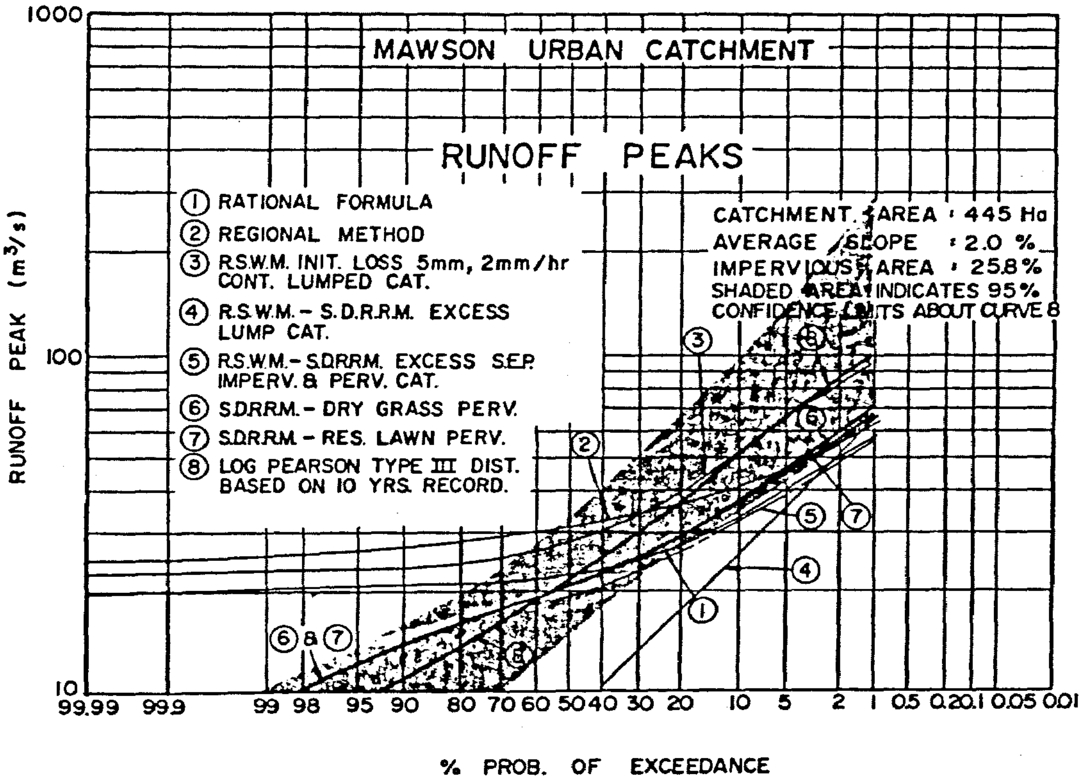


FIGURE 4-17 Comparative Simulations for Mawson

4.5.4 Regional Flood Frequency Technique

A runoff peak frequency curve for Mawson was prepared by Fitzgerald (1980), using his Key Station Regional Method (Fitzgerald, 1975) based on extrapolated frequency analyses of over 30 selected gauged catchments, mainly rural, representing each of the three regional districts defining the A.C.T.

Figure 4-17, Curve 2, shows the frequency curve derived.

4.5.5 Runoff Routing Approach Employing a Design Storm With Initial and Continuing Losses

In this analysis the Mawson catchment was considered in a similar fashion to Fitzgerald's method, as a lumped watershed.

The total catchment area of 415 hectares was split into 10 isochronal areas. The RSWM was employed as described in Chapter 2 with an urbanisation parameter 'U' estimated at 0.80.

Initial and continuing loss rates were set at 8 mm/hr and 5 mm/hr respectively. These were based on generally accepted values widely adopted in the past over the region by both government authorities and private organisations.

Appropriate duration design storms were derived for the region adopting the dimensionless temporal patterns and intensity-frequency-duration curves published in ARR (1977), for a range of storm frequencies between a once in one year and once in 100 year event.

Using the described data the RSWM was applied giving the results summarised as a frequency curve on Figure 4-17, Curve 3.

4.5.6 Runoff Routing Approach Employing a Stochastically Derived Rainfall Excess Lumped Catchment

Using the proposed SDRRM model described earlier in Chapter 4 and the catchment breakdown indicated for Mawson, weighted lumped excess hyetographs were estimated for a range of runoff event frequencies with a duration of 30 minutes.

The excess hyetographs were directly input into the RSWM to produce runoff hydrographs. The resulting frequency curve of runoff peaks is shown on Figure 4-17, Curve 4.

The analysis was based on a lumped runoff volume deduced from the proportions of impervious and pervious areas in the catchment and averaged infiltration and storage delay effects. The objectives of this approach were aimed at establishing the likely error of shortcutting the full SDRRM model by negating the high computer time necessary for the second step of computing the 15 x 15 runoff peak matrix. It did not allow for the separae development of pervious and impervious hydrograph components.

4.5.7 Runoff Routing Approach Employing a Stochastically Derived Rainfall Excess-Separate Pervious-Impervious Considerations

This procedure followed the previous one except the SDRRM model was only used to provide the pervious runoff component. The impervious contribution was derived by appropriate routing via the RSWM of an excess hyetograph made up of the design storm minus an initial depression storage loss of 2 mm.

The results of this method are also shown on Figure 4-17, Curve 5.

4.5.8 Direct Application of the SDRRM

In this case the full SDRRM was applied to the Mawson catchment to obtain directly a flood frequency curve. Two curves 6 and 7 are shown on Figure 4-17 to describe the results based on pervious areas of dry grass and residential lawns respectively. The true value would lie somewhere in between. The rainfall frequency duration data was based on a log-normal distribution of the rainfall data at the Mawson gauge.

4.5.9 Frequency Analysis of Gauged Data

As a final comparison an attempt to validate the SDRRM model and derived moisture data a frequency analysis was carried out on the 11 years of gauged data available for Mawson

Two frequency distributions were selected for this analysis these being the Log-Normal and the Log-Pearson Type III. Table 4-7 shows the annual max. flow peaks for station GS410753 Mawson for the years 1971 through 1981.

TABLE 4-7 Annual Max. Gauged flow Peaks Mawson.

YEAR	DATE	Max Corresp. Hrly Rain(mm) Mawson Stn	Annual Max. Peak (m^3/s)
1971	26 Jan	100.	110*
1972	13 Feb	25.6	24.6
1973	4 Nov	14.9	18.9
1974	21 Mar	42.1	31.3
1975	11 Feb	9.9	14.7
1976	16 Oct	8.5	9.75
1977	14 Jan	28.8	44.8
1978	20 Mar	32.4	57.8
1979	24 Nov	9.3	12.3
1980	4 Jan	16.0	14.5
1981	6 Jan	23.0	43.0

* Estimated peak prior to Gauging Station being established.

As the period of record was relatively short (11 yrs) it was necessary to look carefully at the individual peaks for possible outliers. The 1971 estimated peak of 110 m^3/s resulted from an exceptional event with the time of concentration precipitation being of at least a once in 1000 yr frequency.(Fitzgerald, (1980)).

The period on which the SDRRM model results were based was 1932 - 1970 inclusive. In this period no rainfall event of similar duration exceeded a once in 100 yr frequency.

It was thought prudent therefore to exclude, at this stage, the 1971 annual max. peak from the analysis.

The mean, std. deviation and coefficient of skewness of the logarithms of the Ann. Max. Peaks shown in table 4-7 are 1.3617, .2655 and .1714 respectively. Based on the Chi X^2 test, the Log-Pearson distribution was a more suitable distribution and therefore it was adopted for comparison purposes.

This resulted in a median runoff peak of 22.65 m^3/s. The full plot of the Log-Pearson Type III distribution is plotted as curve 8 on figure 4-17.

4.5.10 Discussion on the Methods and Their Results

The resulting runoff peak frequency curves for Mawson based on the seven methods of computation described are shown on Figure 4-17 .

The variations at any selected frequency are, to say the least, significant with an "order of" difference being apparent between the two extreme curves.

One of the main outcomes was the large disparity between the lumped catchment and separate segment versions of the proposed SDRRM-RSWM model. The results clearly showed the inappropriateness of using total catchment area, weighted rainfall excess and weighted catchment routing effects when considering flow peaks up to say a 10 year return period. The total area of the catchment was in particular a very poor modelling parameter.

A far more appropriate parameter would be an effective contributing area. In events less than say a once in 10 year occurrence this would more closely relate to an effective impervious area.

Curve 5 on figure 4-17 was arrived at by routing the excess pervious hyetograph derived by the SDRRM Model and adding this to an impervious hydrograph separately derived from an appropriately routed excess impervious hyetograph. The result is very close to curve 6 which is based on the full SDRRM analysis. This fact is most encouraging as the amount of computer time required to produce curve 5 is very much less than curve 6, as catchment routing is not required for each element in the deterministic matrix.

Although the logic, as detailed earlier, is not entirely correct further work on this line of analysis is proposed to allow use of the model on smaller computing systems.

It can be seen on Figure 4-17 that the difference between the gauged data (curve 8) and the SDRRM model results (curve 6) is still significant. The SDRRM however is the only method that remains within the 95% confidence band over the complete range shown.

Without a greater length of gauged record it is not possible to make any definitive judgement on the correctness of either of the curves particularly in the less frequent range.

Obviously further testing and refining is necessary and this will be carried out as and when further gauged data becomes available.

4.6 APPLICATION OF PROPOSED PARAMETER ESTIMATING AND MODELLING TECHNIQUES

4.6.1 Major Drainage Analysis and Design

For major drainage analyses and significant design orientated runoff estimates it is recommended that the full SDRRM model be applied.

In this way it is possible to assess the full implications of catchment makeup and the interactions of the various individual components. It is also possible to assess the probability of exceedance of not only runoff peaks but also runoff volumes.

Figure 4-18 shows total storm losses based on the results using the SDRRM. They were derived by subtracting excess rainfalls from total rainfalls of similar probability of exceedance levels.

These may be used to quickly indicate the probable losses to be expected from different land domains within the catchment.

Details are given earlier for the detailed application of the SDRRM. This includes a program listing with sample input and output.

4.6.2 Minor Drainage Design

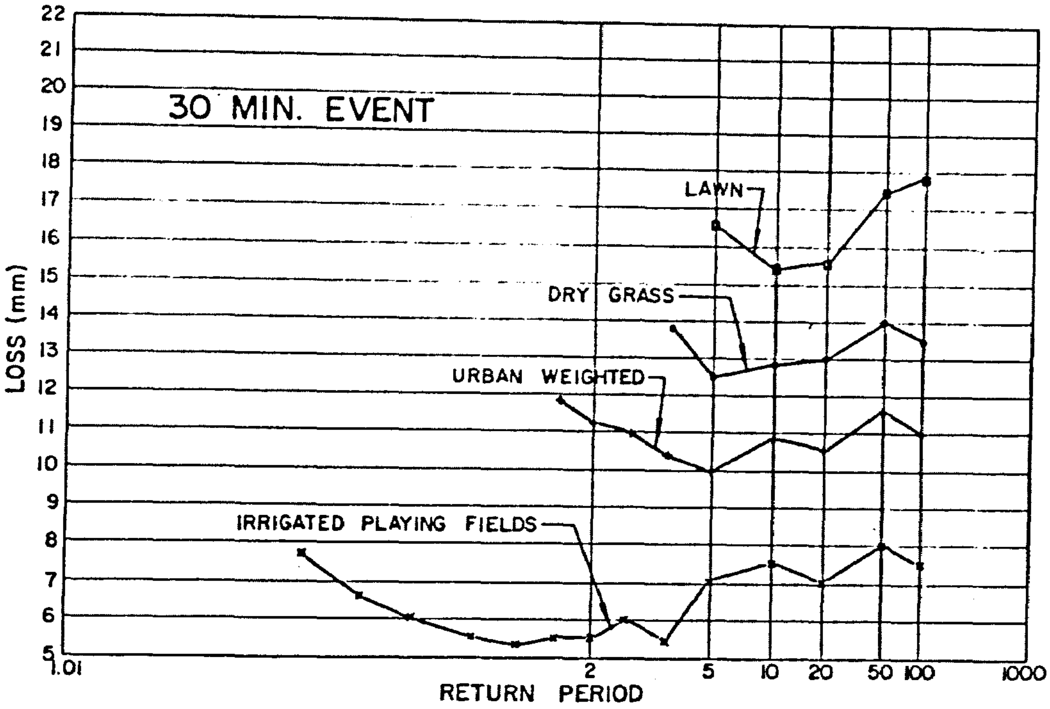
The preceding discussion relates almost solely to the analysis of regional drainage systems requiring the need for full hydrograph generation and/or catchment storage assessment.

In most minor drainage analyses the need for this indepth assessment is not required, rather a simple runoff peak value corresponding to a design frequency is all that is required.

This reasoning has assured that such simple methods as the rational formula will remain with the engineering profession for many years to come.

This phase of the thesis has been aimed at making use of the detailed output results from the developed model described to assess more accurate runoff coefficients for use with the rational formula.

The following describes the proposed methods for achieving this aim.



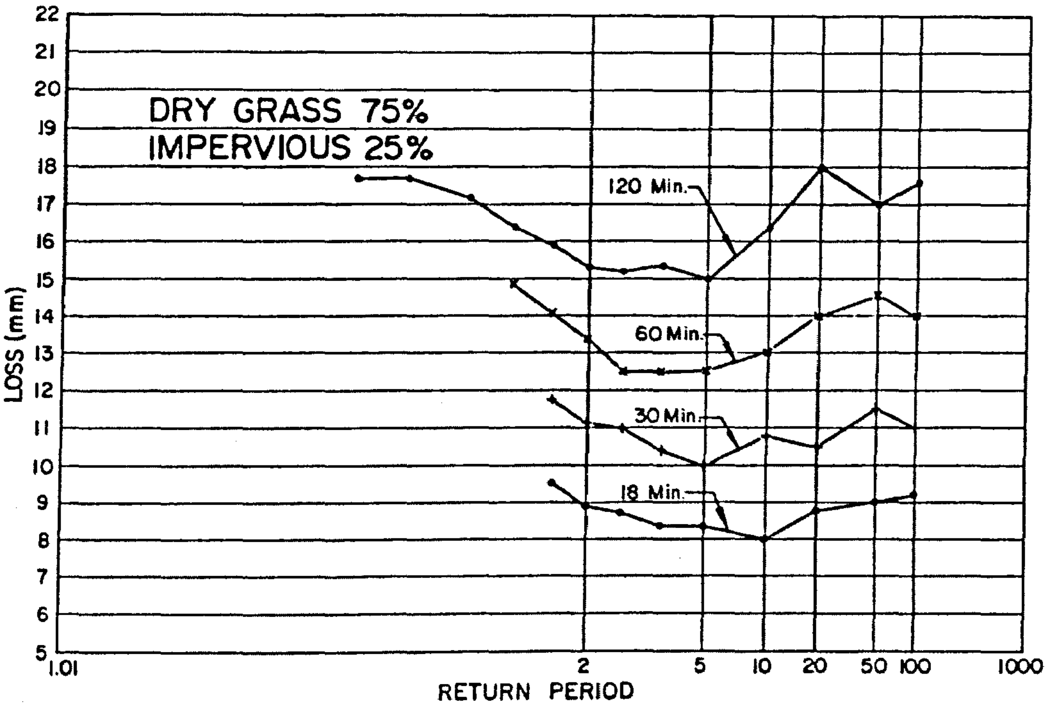


FIGURE 4-18 Simulated Total Storm Losses

Using the approach broadly described in Chapter 2 and the model results generated by SDRRM, rational formula runoff coefficients on a statistical basis have been derived for typical urban catchments in Canberra.

The rational formula expressed in its statistical form was defined as follows:

$$Q(fy) = 1/3.60 \times CIA(Ta,fy) \qquad (4\text{-}8)$$

where:

$Q(fy)$ = peak runoff rate per unit area for a frequency fy

fy = frequency

Ta = rainfall intensity averaging time

I = rainfall intensity in mm/hr for a return period fy and duration Ta

C = Runoff Coefficient

A = catchment area in km^2.

Aitken (1975) presented Eq. 4-8 in the following manner:

$$INPUT = 1/3.60 \times I(T,A) \qquad (4\text{-}9)$$

where:

T = time of concentration

and

$INPUT$ = rainfall input to catchment (m^3/s)

hence

$$C = Q(fy)/INPUT \qquad (4\text{-}10)$$

where:

$Q(fy)$ = peak runoff for frequency fy years in m^3/s.

Based on the Giralang and Mawson catchments in Canberra, described in Chapters 3 and 4, both typical urban watersheds of 94 and 415 hectares respectively and both with a time of concentration of approximately 30 minutes the results of the SDRRM were applied to equation 4-10 to derive rational formula runoff coefficients representative of the total catchment.

Figure 4-19 shows the results of this analysis in graphical form.

Using the same analysis technique runoff coefficients were derived based on a typical 100 hectare catchment with an average slope of 1.5% and T of 30 minutes for the four pervious land domains studied in this thesis. The results from this work are also shown graphically on Figure 4-19.

Within the Canberra region it is recommended that these curves be used in preference to the general curves described in ARR (1977) as they are based on local data and should therefore better reflect the complex inputs that affect their development.

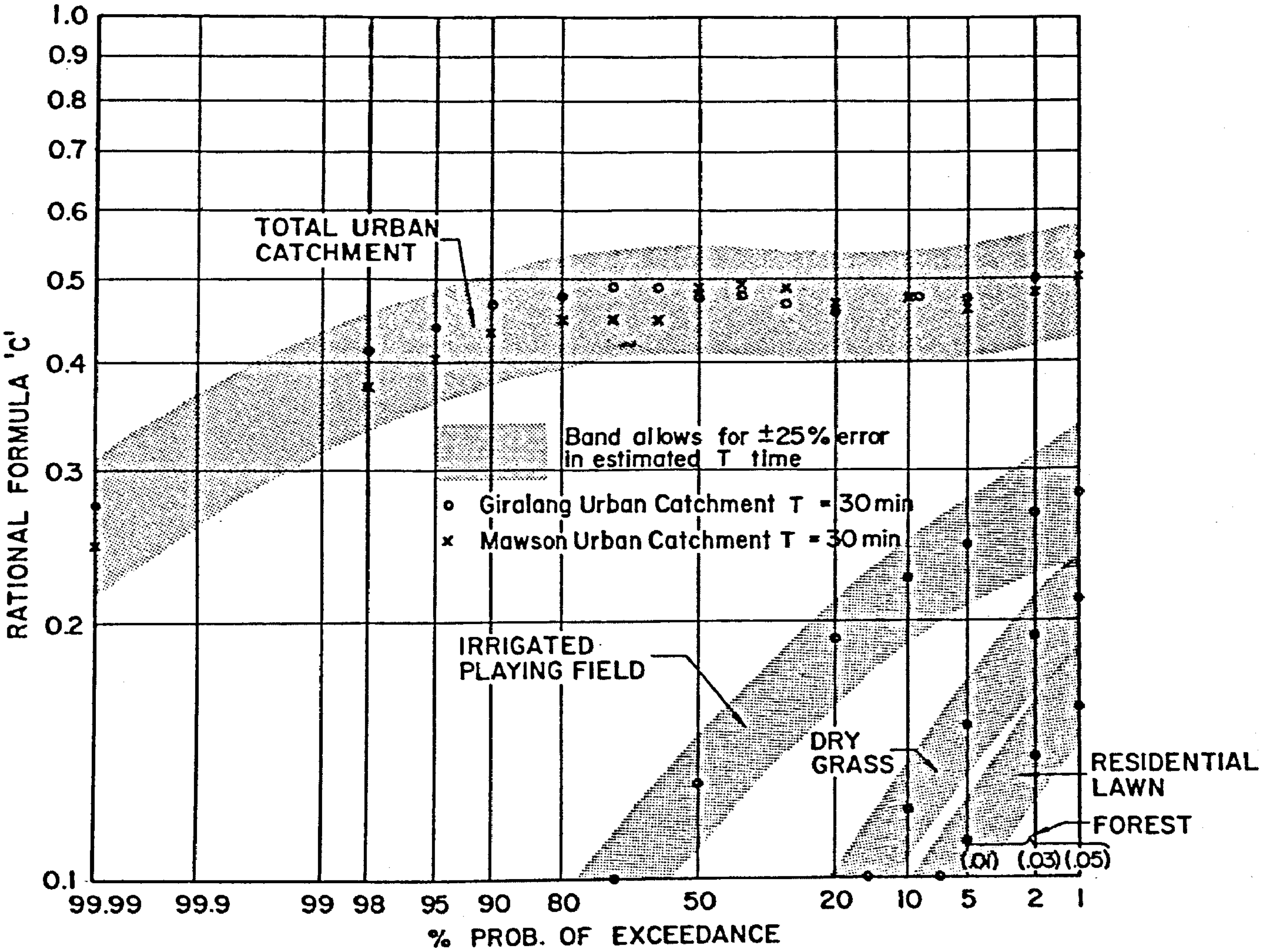


FIGURE 4-19 Simulated Rational Method, Canberra Runoff Coefficients

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Introduction.

The magnitude and frequency of occurrence of hydrologic events is of necessity important to all those whose responsibility it is to design and maintain urban hydraulic structures.

Over recent years the advancement in hydrologic techniques has allowed the designer to capitalise on the basic information that has been collected during a greater part of this century.

In the field of urban stormwater drainage design with its inherent diversities of character the present techniques have, however, fallen short of the data available or able to be measured.

Based on studies carried out by the author over recent years, it had become evident that a large amount of basic information on such things as soil characteristics, catchment breakup and qualitative antecedent moisture indexes etc, have not been included in design analyses except in very vague qualitative ways.

The hydrologic techniques to date, including such methods as the rational formula and even more advanced runoff routing procedures, have, in their present form, failed to cater for this additional input data.

This thesis was based on the premise that there was a need to increase the capability of present modelling techniques and to make use of as much basic data as possible to increase the accuracy of design decisions.

The estimation of flow peaks and volumes in a design context is complicated by the combined stochastic-deterministic nature of the problem.

The two major stochastic elements of the process are rainfall and catchment wetness. The deterministic phase involves the transfer of rainfall to runoff.

In urban drainage analysis to date the effects of catchment wetness on flow estimates has only received nominal attention. Methods have been proposed to include this parameter in current runoff routing techniques.

5.2 Combined Stochastic-Deterministic Urban Drainage Model.

Various land domains have been isolated that broadly describe typical urban catchments in Canberra. These include dry grass areas, residential lawns, irrigated areas, native forest and impervious areas.

Based on long term water balance simulation using Canberra pluviograph records and appropriate catchment parameters, various upper soil moisture indexes were estimated. From these, exceedance probability distributions were derived for each of the above domains to represent pre-burst antecedent moisture indexes.

Excess rainfall and peak runoff exceedance probabilities were then able to be derived by combining the stochastic nature of both rainfall and catchment wetness with a deterministic infiltration process (in this case using methods described by Philip (1957) employing methods similar to those proposed by Laurenson (1974) and described in detail in Chapter 4.

5.3 Summary.

The following points summarise the main results of the research carried out during the course of this thesis. Where deemed necessary recommendations are given for future research where the present work has highlighted inadequacies.

(a) In the calibration of rainfall/runoff models within an urban environment it is not possible to optimise pervious component parameters with catchment outlet gauging only.

It is essential to separate the pervious and impervious contributions by way of subcatchment monitoring or at least using a paired catchment technique as described in Chapter 3.

This is mainly due to the predominant influence of impervious areas, within an urban area, in the development of runoff peaks and volumes. Up to 95% of total annual flow in an average year was made up of the impervious component.

Additionally base flows caused by artificial watering can also make up a significant part of the total annual flow and are usually of the same order or larger than the total pervious flow.

As it is difficult to separate flow contributions not only between impervious and pervious components the additional complexity of artificial watering due to lawn watering and the like make the task of pervious model calibration all that much harder.

In brief the measurement of total runoff is not necessarily a good indicator in the assessment of pervious parameters.

(b) In the short response urban environment there was a need to modify the Australian representative basin model from a purely incremental water balance model to a pseudo continuous model to reflect soil water movements within a particular increment of time.

(c) To simulate peak flows from an urban catchment it was found necessary to model separately the pervious and impervious components of the system due to the non-homogenous nature of the two contributing systems.

(d) It was found that different pervious land domains responded very differently to a similar storm event. Between dry grass and natural forested areas there was a threefold difference in runoff volumes produced at the 100 year frequency level and a fivefold difference in runoff peak.

(e) The effects of lawn watering on runoff production from urban residential lawns was not found to be significant as the increase in potential antecedent moisture was more than offset by the increased infiltration capacity caused by better root development and upper strata structure.

(f) An assessment was made of the implications of possible errors in parameter estimates as well as the sensitivity of point to areal conversion of individual parameters. Figure 4-16 summarises the magnitude of computed peak flow variations based on a range of parameter sets.

It was shown that although the parameter changes were significant the variation in peak flows over the normal frequency range, between the highest and lowest parameter set, was limited to less than 40%.

It was therefore contended that for design estimating purposes, detailed definition of variations in catchment parameters across similar pervious areas was not required or justified.

(g) Based on results of the proposed model, runoff volume frequency distributions appeared to be highly correlated with runoff peak frequency distributions.

This did not however mean that a deterministic routing of say a once in 50 year excess runoff volume would directly give a once in 50 year runoff peak as both were statistical values based on the contributions of a number of combinations of events resulting in similar output magnitudes.

(h) Over the normal frequency range it was shown (see figure 4-18) that total storm losses on a statistical sense were fairly constant although of different magnitudes for each of the land domains studied.

5.4 Conclusions.

In conclusion the methodology put forward in this thesis sought to define, in greater detail, the relative importance of the various factors in an urban or rural catchment, in the production of runoff volumes and peaks.

There is considerable scope for improving the proposed model based on continued reseach into the structure of the water balance model selected and the catchment routing response of the separate land domain inputs, however the present model is believed to be, even at this stage of development, a responsive one able to reflect in far greater detail than other existing procedures, the contributions of the various components of a catchment. A great deal of further testing and development is still required, however this is believed to be justified in line with the continued research necessary to obtain better runoff frequency estimates for engineering design purposes.

One further avenue of development would appear to be in the definition of seasonal soil moisture probability curves ie, Summer and Winter . These combined with similar seasonally defined rainfall probability curves may give further insight into the rainfall/runoff frequency relationship.

There is also scope to improve catchment monitoring techniques to provide more accurate data input to the model. It was the aim of this thesis to assess some of the problems and practical implications and possibilities for future research.

It is contended that there is considerable merit in the further development of techniques to carry out and apply soil moisture monitoring in an urban environment using both nuclear and psychrometer-thermocouple methods.

Further work is recommended to extend the analysis described to other areas in Australia to test variations in parameter response in those locations.

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APPENDIX A

ENGINEERING LOGS

pit no: TP1

sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 1

equipment type and model:
R.L. surface: m
excavation dimensions: m long, m wide
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer kPa 100 200 300 400	structure and additional observations
BH				D UD	0.18			Sandy CLAY; dark brown low plasticity sand fine to coarse	m	MD		Root Zone.
				D UD	0.25 0.46			Clayey Gravelly SAND; Sandy Gravelly CLAY; brown with yellow to grey brown mottling low to medium plasticity sand fine to coarse, gravel to 20mm	M	F		
					0.5							

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3 no resistance ranging to refusal

water
▼ 10 Oct, 73 water level on date shown
▶ water inflow
◀ water outflow

notes – samples and tests
U50 – undisturbed sample 50 mm diameter
D – disturbed sample
N – standard penetration test:figure = result
N* – SPT + sample
Nc – cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D – dry
M – moist
W – wet

consistency/relative density
VS – very soft
S – soft
F – firm
St – stiff
VSt – very stiff
H – hard
Fb – friable
VL – very loose
L – loose
MD – moderately dense
D – dense
VD – very dense

pit no TP2

sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 2

equipment type and model:
R.L. surface: m
excavation dimensions: m long, m wide
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L.	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer 100 200 300 400 kPa	structure and additional observations
				D UD		0.25			Sandy Gravelly CLAY: red brown, low plasticity, sand fine to coarse, gravel to 30mm	D-m	F		Root Zone
				UD UD D		0.85			Sandy CLAY: red brown medium plasticity, sand fine to coarse	m	St		

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3
no resistance ranging to refusal

water
10 Oct, 73 water level on date shown
water inflow
water outflow

notes – samples and tests
U50 – undisturbed sample 50 mm diameter
D – disturbed sample
N – standard penetration test:figure = result
N* – SPT + sample
Nc – cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D – dry
M – moist
W – wet

consistency/relative density
VS – very soft
S – soft
F – firm
St – stiff
VSt – very stiff
H – hard
Fb – friable
VL – very loose
L – loose
MD – moderately dense
D – dense
VD – very dense

pit no. TP3

sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

project: Assessment of Drainage Pattern Girilang Valley
pit location: Station 3

equipment type and model:
excavation dimensions: m long, m wide
R.L. surface: m
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer kPa 100 200 300 400	structure and additional observations
				D UD	0.35			Gravelly Clayey SAND, brown, low plasticity sand fine to coarse, gravel to 40mm	D	L		Root Zone Fresh Shale
				D	0.6			Sandy CLAY, yellow brown low plasticity, sand fine to coarse	D	D		

key

method

N	natural exposure
E	existing excavation
BH	backhoe bucket
B	bulldozer blade
R	ripper

support

T timbering

penetration

1 2 3 no resistance ranging to refusal

water

10 Oct, 73 water level on date shown

water inflow

water outflow

notes — samples and tests

U50	undisturbed sample 50 mm diameter
D	disturbed sample
N	standard penetration test:figure = result
N*	SPT + sample
Nc	cone penetrometer

classification symbols and soil description

based on unified classification system

moisture

D	dry
M	moist
W	wet

consistency/relative density

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	moderately dense
D	dense
VD	very dense

engineering log – excavation

pit no. TP4
sheet 1 of 1

office and job no: Canberra C2031

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 4
pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

equipment type and model:
excavation dimensions: m long, m wide
R.L. surface: m
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	100 200 300 400 kPa hand penetrometer	structure and additional observations
				UD D	0.32			Sandy CLAY. grey, low Plasticity, sand fine to coarse	m	mD		Root Zone
				UD D	0.6			CLAY, yellow brown, medium Plasticity, some fine sand	M	St		

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3 no resistance ranging to refusal

water
▼ 10 Oct, 73 water level on date shown
water inflow
water outflow

notes — samples and tests
U50 — undisturbed sample 50 mm diameter
D — disturbed sample
N — standard penetration test:figure = result
N* — SPT + sample
Nc — cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D — dry
M — moist
W — wet

consistency/relative density
VS — very soft
S — soft
F — firm
St — stiff
VSt — very stiff
H — hard
Fb — friable
VL — very loose
L — loose
MD — moderately dense
D — dense
VD — very dense

pit no TP5.
sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 5

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

equipment type and model:
excavation dimensions: m long, m wide
R.L. surface: m
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L.	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer kPa 100 200 300 400	structure and additional observations
									Sandy CLAY; dark brown low plasticity, sand fine to coarse	m	MD		Root Zone
				UD D UD		0.2			Sandy CLAY; grey brown low plasticity sand fine to coarse, trace of gravel to 5mm		D		
						0.4							

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3 no resistance ranging to refusal

water
10 Oct, 73 water level on date shown
water inflow
water outflow

notes — samples and tests
U50 — undisturbed sample 50 mm diameter
D — disturbed sample
N — standard penetration test:figure = result
N* — SPT + sample
Nc — cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D – dry
M – moist
W – wet

consistency/relative density
VS – very soft
S – soft
F – firm
St – stiff
VSt – very stiff
H – hard
Fb – friable
VL – very loose
L – loose
MD – moderately dense
D – dense
VD – very dense

pit no TP 6
sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

project: Assessment of Drainage Pattern Giralang Valley	pit commenced: 4-7-79
	pit completed: 4-7-79
	supervised by: GC
pit location: Station 6	log checked by: C.L.T.

equipment type and model:	R.L. surface: m
excavation dimensions: m long, m wide	datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer 100 200 300 400 kPa	structure and additional observations
				D D				Clayey Sandy Gravel; grey brown, low plasticity, sand fine to coarse, gravel to 25mm	D	L		Root Zone
				UD	0.28			Sandy CLAY, red brown low plasticity, sand fine to coarse, trace of fine gravel	D	F		
								Rock				

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3 no resistance ranging to refusal

water
▼ 10 Oct, 73 water level on date shown
water inflow
water outflow

notes – samples and tests
U50 – undisturbed sample 50 mm diameter
D – disturbed sample
N – standard penetration test:figure = result
N* – SPT + sample
Nc – cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D – dry
M – moist
W – wet

consistency/relative density
VS – very soft
S – soft
F – firm
St – stiff
VSt – very stiff
H – hard
Fb – friable
VL – very loose
L – loose
MD – moderately dense
D – dense
VD – very dense

pit no. TP7

sheet 1 of 1

engineering log - excavation

office and job no: Canberra C2031

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 7

equipment type and model:
R.L. surface: m
excavation dimensions: m long, m wide
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer kPa 100 200 300 400	structure and additional observations
								Silty Sandy GRAVEL, grey brown, Sand fine to coarse, gravel to 150mm	D	VL		Root Zone
				D	0.15			Silty Sandy Gravel, light brown, sand fine to coarse, gravel to 150mm				Tree Roots

key

method
N natural exposure
E existing excavation
BH backhoe bucket
B bulldozer blade
R ripper

support
T timbering

penetration
1 2 3 no resistance ranging to refusal

water
10 Oct, 73 water level on date shown
water inflow
water outflow

notes — samples and tests
U50 — undisturbed sample 50 mm diameter
D — disturbed sample
N — standard penetration test:figure = result
N* — SPT + sample
Nc — cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
D — dry
M — moist
W — wet

consistency/relative density
VS — very soft
S — soft
F — firm
St — stiff
VSt — very stiff
H — hard
Fb — friable
VL — very loose
L — loose
MD — moderately dense
D — dense
VD — very dense

no. TP 8
sheet 1 of 1

engineering log – excavation

office and job no: Canberra C2031

pit commenced: 4-7-79
pit completed: 4-7-79
supervised by: GC
log checked by: C.L.T.

project: Assessment of Drainage Pattern Giralang Valley
pit location: Station 8

equipment type and model:
excavation dimensions: m long, m wide
R.L. surface: m
datum:

method	penetration 1 2 3	support	water	notes samples, tests, etc.	R.L. depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency, rel. density	hand penetrometer 100 200 300 400 kPa	structure and additional observations
								Silty Sandy GRAVEL; dark brown, sand fine to coarse, gravel to 150mm	D	VL		Root Zone
					0.15			Silty Sandy GRAVEL; ~~dark brown~~ light brown, sand fine to coarse gravel to 150mm				
				D								
					0.38							

key

method
- N natural exposure
- E existing excavation
- BH backhoe bucket
- B bulldozer blade
- R ripper

support
- T timbering

penetration
- 1 2 3 no resistance ranging to refusal

water
- ▼ 10 Oct. 73 water level on date shown
- water inflow
- water outflow

notes – samples and tests
- U50 – undisturbed sample 50 mm diameter
- D – disturbed sample
- N – standard penetration test: figure = result
- N* – SPT + sample
- Nc – cone penetrometer

classification symbols and soil description
based on unified classification system

moisture
- D – dry
- M – moist
- W – wet

consistency/relative density
- VS – very soft
- S – soft
- F – firm
- St – stiff
- VSt – very stiff
- H – hard
- Fb – friable
- VL – very loose
- L – loose
- MD – moderately dense
- D – dense
- VD – very dense