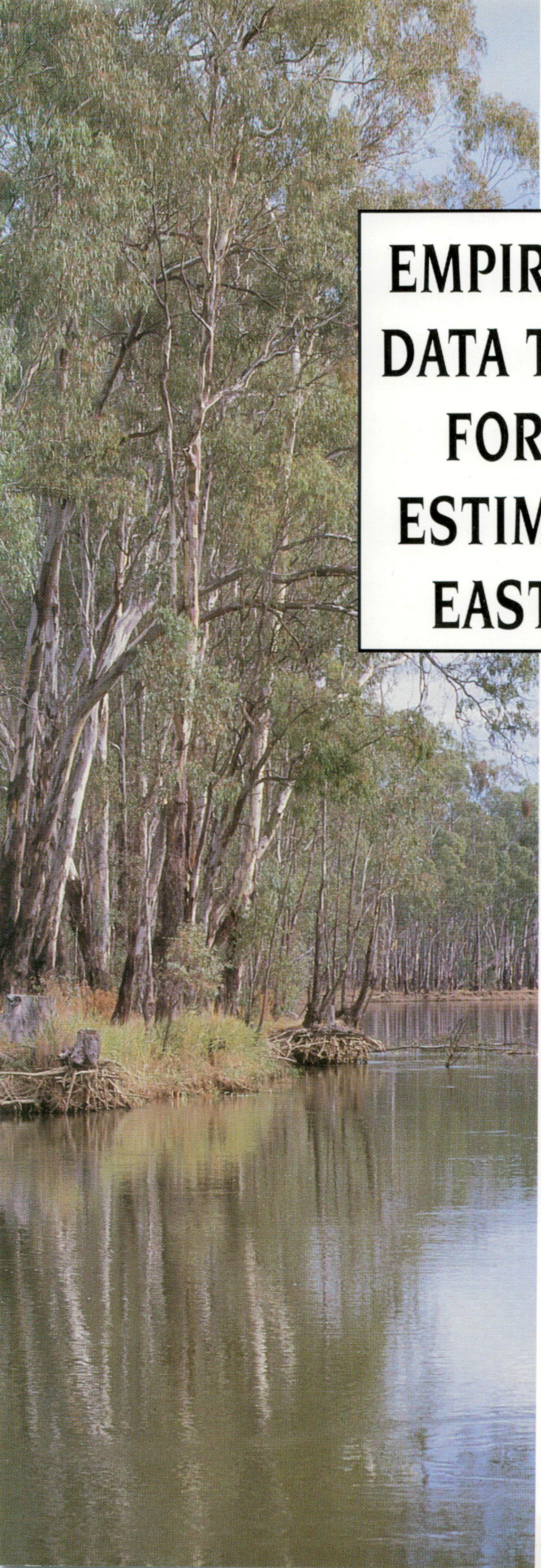

EMPIRICAL ANALYSIS OF DATA TO DERIVE LOSSES FOR DESIGN FLOOD ESTIMATION IN SOUTH-EASTERN AUSTRALIA

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Report 96/5
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COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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Empirical analysis of data to derive losses for design flood estimation in south eastern Australia

Bibliography.
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PREFACE

In common with all of the core projects of the CRC, Project D1 "Improved Loss Modelling for Design Flood Estimation and Flood Forecasting" was identified and developed by industry and research representatives working together. They saw the need, and potential, for research to address the question, "How much rain becomes runoff?".

This report is related to design hydrograph estimation, in which the starting point is a (hypothetical) storm of a given level of severity. It deals with the specific problem of determining the proportion of the applied storm which becomes streamflow (the remainder being 'loss'), such that the design level of severity of the resultant hydrograph is preserved.

The design losses given in this report have been shown (see CRC Report 96/6) to provide a more accurate estimate of design peak flows than has hitherto been possible. In other words, this project has produced some very useful design information for the engineering profession.

I'd like to take this opportunity to acknowledge the efforts of Peter Hill (Project Leader) and his project team for their fine achievements in this work.

Russell Mein
Program Leader

SUMMARY

This report presents some of the significant outcomes from a major research project "Improved Loss Modelling for Design Flood Estimation and Flood Forecasting" undertaken by the CRC for Catchment Hydrology. It details the work undertaken to derive improved design losses from the empirical analysis of data.

A methodology has been outlined in this report for deriving design losses which overcomes the basic incompatibility between design rainfalls and losses used for design flood estimation. Losses have been calculated for rainfall bursts (not complete storms) which have been selected in a manner consistent with that used to select the rainfall bursts used to derive the design rainfall temporal patterns in Australian Rainfall and Runoff, 1987.

Prediction equations have been developed for the losses for use in south-eastern Australia. The baseflow index (the fraction of the total streamflow which is baseflow) was found to be significant in explaining the variability in the calculated losses. The geology-vegetation index defined by Lacey (1996b) is recommended for estimating the baseflow index for ungauged catchments.

When applied in conjunction with unfiltered temporal patterns, the new areal reduction factors (Siriwardena and Weinmann, 1996) and a non-linear runoff-routing model, the losses have shown to produce peak flows that are consistent with the results of flood frequency analysis. However, the verification of design losses is dependent upon the choice of all of the key inputs in the modelling process. Different assumptions about any of the key inputs, such as the filtering of temporal patterns, areal reduction factors or runoff-routing model characteristics, could affect the conclusions.

The new design losses are recommended for design flood estimation for south-eastern Australia on the basis that:

- they are based on a detailed study using methodology that is consistent with the derivation of design rainfalls;
- they incorporate plausible relationships with catchment and climatic characteristics, and rainfall duration;
- they produce satisfactory results when tested on 11 representative catchments in the region.

The losses are recommended for use with unfiltered temporal patterns and the new areal reduction factors for long duration with the interim recommendations for short durations (Siriwardena and Weinmann, 1996).

It is recommended that a similar methodology as detailed in this report be applied to derive design loss values for other parts of Australia.

ACKNOWLEDGMENTS

Valuable guidance and suggestions were provided by the project reference panel which included Tom McMahon, Rory Nathan, Jim Elliott, Leon Soste and Sri Srikanthan.

Hydrometric data was provided by the Bureau of Meteorology, the (former) Rural Water Corporation and ACT Electricity and Water.

Geoff Lacey provided valuable comment on the development and application of the geology-vegetation index for the prediction of baseflow index for ungauged catchments.

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1. INTRODUCTION

This report presents some of the significant outcomes from a major research project "Improved Loss Modelling for Design Flood Estimation and Flood Forecasting" undertaken by the CRC for Catchment Hydrology. It details the work undertaken to derive improved design losses from the empirical analysis of data.

Hundreds of millions of dollars are spent annually in Australia on works which require an estimate of a design flood (Walsh et al., 1991) and, for all rainfall-based estimation methods, the design loss is a key determinant in the estimation of a design flood of a given annual exceedance probability.

The procedure for estimating a design flood hydrograph with specified annual exceedance probability (AEP) for a catchment starts with a design rainfall of the desired AEP. As indicated in Figure 1-1, the probability of the calculated design flood peak will depend upon the choice of the critical storm duration, areal reduction factor, storm temporal pattern, *design losses*, runoff model, model parameters and the baseflow.

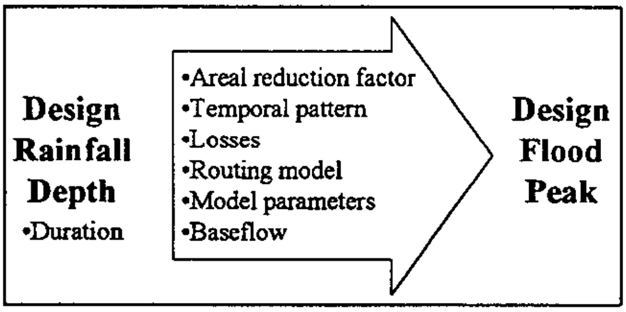

Figure 1-1 Event Based Design Flood Estimation

Each of these components has a distribution of possible values and the probability of the calculated flood peak should theoretically account for the effect of the combined probabilities. In the light of the current lack of information on the true distribution of each of the components and the complexity involved, the recommendation in Australian Rainfall and Runoff (IEAust. 1987; hereafter referred to as AR&R) is to take some 'central' or 'typical' value for each of the key inputs.

Of all of the key inputs in Figure 1-1, there is least guidance available in AR&R on appropriate values for design losses and this constitutes one of the greatest weaknesses in Australian flood design (Pilgrim and Robinson, 1988). Most of the losses that are summarised in AR&R are biased towards wet antecedent conditions (ie losses are too low) and are also incompatible with the design rainfall information (Hill and Mein, 1996). With the exception of Western Australia, there is no relationship between the losses and catchment characteristics.

The report is presented as follows. Chapter 2 reviews the inadequacies in the current design losses. The adopted methodology is outlined in Chapters 3 and 4 and the results of the empirical analysis are given in Chapters 5 to 7. In Chapters 8 and 9 the mean catchment losses are related to catchment characteristics. Chapter 10 summarises the verification of losses undertaken by Hill et al. (1996a).

2. REVIEW OF CURRENT DESIGN LOSSES

In a recent report, Nandakumar et al. (1994) have reviewed infiltration theory and conceptual loss models; Section 2.1 summarise some of the key points pertinent to this study. The currently recommended losses in AR&R are presented in Section 2.2 and some of their limitations are discussed.

2.1 Conceptual Lumped Loss Models

Loss is defined as the precipitation that does not appear as direct runoff, and the loss is attributed to the following processes (refer to Figure 2-1):
- interception by vegetation;
- infiltration into the soil;
- retention on the surface (depression storage);
- loss through the stream bed and banks (transmission).

The loss is assumed to be dependent on the physical characteristics and the climatic environment of the catchment. The loss exhibits both temporal and spatial variability.

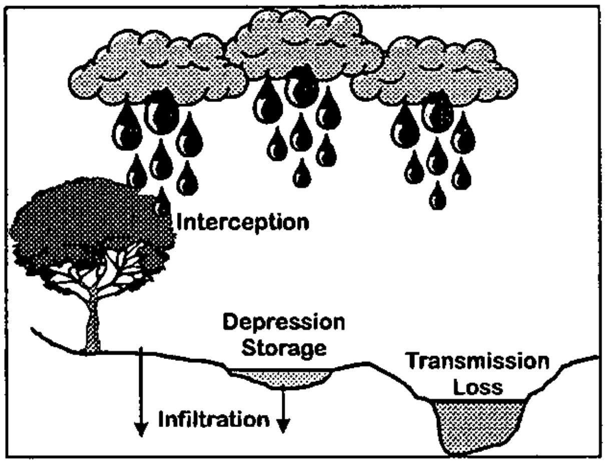

Figure 2-1 Physical Processes which Contribute to Rainfall Loss

In many loss models, the interception, depression storage and transmission losses are not directly accounted for and the loss is simply treated as infiltration into the soil. Empirical equations (such as Horton) and analytical solutions to the complex equations for the water movement in the soil (such as Philip and Green Ampt) have been used to express the reduction of infiltration capacity with time.

Simplified lumped conceptual loss models are widely used because of their simplicity. This is especially true for design losses which are of a probabilistic nature and for which the added complexity of more theoretical models is not warranted.

The most commonly used conceptual loss model in Australia is the initial loss-continuing loss model (refer to Figure 2-2). The initial loss occurs in the beginning of the storm prior to the commencement of surface runoff. The continuing loss is the average rate of loss throughout the remainder of the storm.

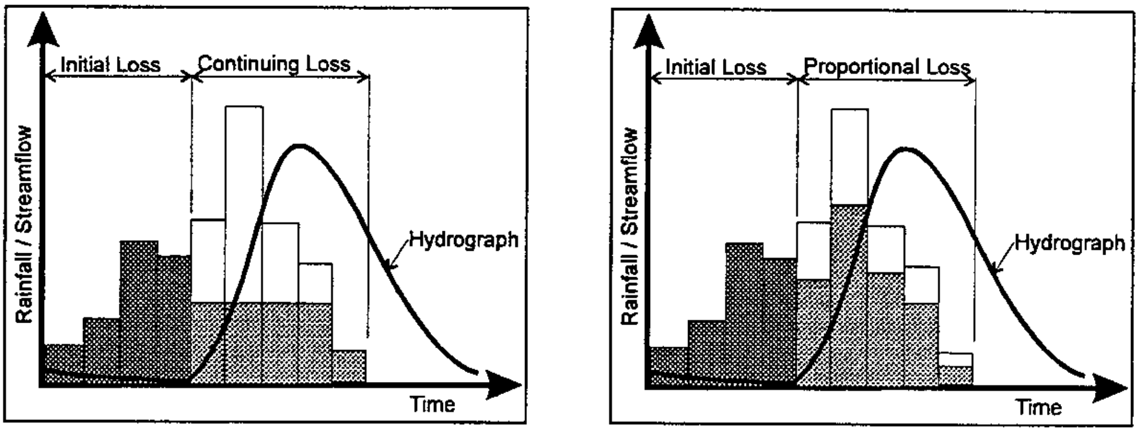

Figure 2-2 Hyetograph showing Initial Loss-Continuing Loss and Initial Loss-Proportional Loss (shaded areas indicate parts of hyetograph not being converted to direct runoff)

The concept of initial loss is a simplification of the many processes contributing to the loss and assumes that surface runoff commences at the same time everywhere in the catchment. The initial loss-continuing loss model is based upon consideration of runoff being generated by infiltration excess. However, in recent years a second runoff generating mechanism, that of saturated overland flow, has been identified. This assumes that runoff is generated from the saturated portions of the catchment, whose area increases with the duration and severity of the storm.

The consideration of this variable contributing area has led to the formulation of the initial loss-proportional loss model (refer to Figure 2-2). The proportional loss is the average proportion of loss after surface runoff has commenced, this can be regarded as 100 percent runoff from the saturated portion of the catchment, zero runoff from the remainder.

Although the initial loss-proportional loss model is a theoretically superior loss model in catchments where runoff is predominantly generated by saturated overland flow, there is virtually no guidance in AR&R as to suitable values of proportional losses for design.

2.2 Currently Recommended Design Losses

As discussed above, the lack of information on design losses is considered to be the greatest limitation in current design flood estimation. The design loss values which are available for the initial loss-continuing loss model, and recommended in AR&R for south-eastern Australia are shown in Table 2-1. There is virtually no information on the initial loss-proportional loss model and the recommended value of initial loss varies over a large range (from 0 to 35 mm).

It is important to note that for a large portion of Victoria (north and west of the Great Dividing Range), the only recommendation for design loss is that it is "probably as for similar areas of NSW".

Table 2-1 Currently Recommended Design Losses (extracted from AR&R)

Location	Median Values of Parameters	References
ACT	Initial loss zero Continuing loss 1.0-3.6 mm/h (depending on ARI)	Knee (1986)
New South Wales		
East of the western slopes	Initial loss 10 to 35 mm, varying with catchment size and mean annual rainfall. Continuing loss 2.5 mm/h	Cordery (1970), Cordery and Webb (1974) and Avery (1986)
Arid Zone, mean annual rainfall ≤ 300 mm	Initial loss 15 mm Continuing loss 4 mm/h	Cordery et al. (1983)
Victoria		
South and east of the Great Dividing Range	Continuing loss 2.5 mm/h	Cordery & Pilgrim (1983)
	Initial loss 25-35 mm	MMBW
	Initial loss 15-20 mm	Rural Water Commission
North and west of the Great Dividing Range	Probably as for similar areas of NSW	Information provided verbally at seminar in Melbourne, August 1985

Many studies (such as Hill and Mein, 1996; and Walsh et al., 1991) have found that the use of the design losses with the design rainfalls recommended in AR&R result in the overestimation of design peak flows, when compared with a frequency analysis of recorded peak flows. This indicates that, for many catchments, the design losses recommended in AR&R are too low.

From a consideration of the processes outlined in Section 2.1, it would be expected that loss values would depend on catchment characteristics such as vegetation, climate and soil. However, the many attempts to link losses to catchment characteristics have been largely unsuccessful, due to in part to the spatial variability of rainfall and catchment characteristics and to the inadequacy of current soil classification to reflect infiltration properties (Cordery and Pilgrim, 1983), and Table 2-1 does not give any catchment characteristics. For this reason, it has proven difficult to use the results of the studies referred to in Table 2-1 to estimate the design losses for any particular catchment.

In addition to the problem of the scarcity of information on design losses, AR&R identifies two inadequacies in the current loss values, most of which were derived from analyses of large flood events (for example those used to calibrate runoff routing models). These are:

- The selection of high runoff events for loss derivation is biased towards wet antecedent conditions (ie. losses tend to be too low);
- Storm losses do not account for the nature of design rainfall information in Chapters 2 and 3 of AR&R, which has been derived from bursts within longer duration storms (ie. losses tend to be too high).

It is recognised in AR&R that these two inadequacies should have opposite effects, however it is implicitly assumed by users of the current design loss values that they fully compensate one for the other.

Waugh (1991) examined the effect of the first inadequacy. From a study of five Western Australian catchments, he concludes that the selection of runoff events for the estimation of design loss underestimates the design loss, and can result in over-estimation of the design flood magnitude by up to 20 percent. This is because many sizeable summer storms yielded little or no runoff, due to dry antecedent conditions, and were not included in the analysis.

As to the second inadequacy, Srikanthan and Kennedy (1991) examined the degree to which the rainfall bursts used to generate design temporal patterns were embedded within longer duration storms. They found that, for a given probability of exceedance, rainfall prior to the rainfall bursts decreased with increasing duration. This is because the longer duration bursts tend to represent complete storms.

2.2.1 Excessively Long Critical Durations

The critical duration of design rainfall for a catchment is that duration which gives the largest design peak flow. It depends on catchment characteristics and on the variation of the rainfall magnitude and temporal pattern with duration. Many authors have noted that, when applying the design losses recommended in AR&R to the design rainfalls, the resulting critical duration is excessively long.

It would be reasonable to expect that the critical duration would increase with catchment size, but a number of studies have found the critical duration not to depend on catchment area. For example, in a study of 22 NSW catchments (ranging in areas from 25 to 6,560 km^2), Walsh et al. (1991) found that the critical duration was independent of catchment size; in temporal pattern Zone 1, the 36 and 48 hour durations were consistently critical, and in Zone 2, the 18 and 30 hour durations were consistently critical.

Hill and Mein (1996) also noted excessively long durations, when applying the AR&R methodology to 8 Victorian catchments with catchment areas ranging from 32 to 153 km^2. For all but one catchment in temporal pattern Zone 1, the 36 hour temporal pattern was critical. In addition, the 72 hour temporal pattern was found to be critical for one catchment in Zone 2 which has a catchment area of only 60 km^2.

Hill and Mein (1996) state that the excessively long critical duration are caused by:

- Temporal patterns which include sub-intervals with excessively heavy rainfall, and which are not consistent with the estimated average recurrence interval (ARI) of the complete pattern. This can be alleviated by fully filtering the temporal patterns to ensure that no sub-interval has an ARI which is greater than the ARI of the complete pattern.
- The use of the same design value of initial loss for all durations. In order to be consistent with the derivation of design rainfalls in AR&R, the design initial loss should increase with increasing duration. This is discussed in greater detail in Section 3.1.
- the time increment used in AR&R for the longer duration temporal patterns is too long, and for the smaller catchments, it approaches the response time of the catchment.

3. A NEW METHODOLOGY FOR DERIVING LOSSES FOR RAINFALL BURSTS

This chapter outlines a methodology for estimating losses which are consistent with the design rainfalls contained in AR&R. This involves the estimation of losses for bursts of rainfall which are embedded within longer duration storms. The term 'burst' is used in this report to refer to an intense part of a storm; it should not be confused with the use of the term 'burst' in rainfall-runoff modelling (eg Laurenson and Mein, 1995) where the term is used simply to delineate successive periods of rainfall.

3.1 Design Losses Consistent with Design Rainfalls

3.1.1 Selection of Bursts for Design Temporal Patterns

The inconsistency between design temporal patterns and design losses was outlined in Section 2.2. The intensity-frequency-duration (IFD) estimates of design rainfall and the design temporal patterns in AR&R were derived from intense rainfall bursts, whereas design losses in AR&R have been derived using complete events. To be consistent with the derivation of the design temporal patterns, loss values need to be derived for rainfall bursts (rather than complete storms) selected using the same criteria as adopted in the derivation of the design temporal patterns.

The design temporal patterns in AR&R were derived from the analysis of a database of 83 pluviograph stations (Rowbottom, et al., 1986). For each station, the *n* highest rainfall totals (*n* equal to the number of years of record) were obtained for each of 20 different durations. A burst was defined by Kennedy, et al. (1991) as "*these durations may be part of a storm, may exceed the duration of a storm, or may include more than one storm.*"

The criteria used by Kennedy et al. (1991) to select the bursts were that:

- the rainfall burst had to be one of the *n* highest values for that duration;
- successive falls of a given duration did not overlap in time;
- the burst was rejected if it included significant interpolated data;
- the rain did not have to persist over the entire length of the specified duration. The convention adopted was that the storm burst duration began when the rain began.

The same criteria were applied in this study to select the rainfall bursts to be analysed and the storms within which they occurred.

3.1.2 Losses for Embedded Rainfall Bursts

Having identified the selection criteria for rainfall bursts, it is then necessary to consider the estimation of losses for bursts of rainfall embedded within longer duration storms. The difference between the initial loss for a burst and for a storm is illustrated in Figure 3-1, which depicts a 6 hour burst embedded in a longer duration storm. The initial loss for the *storm* is assumed to be *the depth of rainfall prior to the commencement of surface runoff*. The initial loss for the *burst* however is the portion of the storm initial loss *which occurs within the burst.*

The burst initial loss can range from zero (if the burst occurs after surface runoff has commenced) up to the storm initial loss.

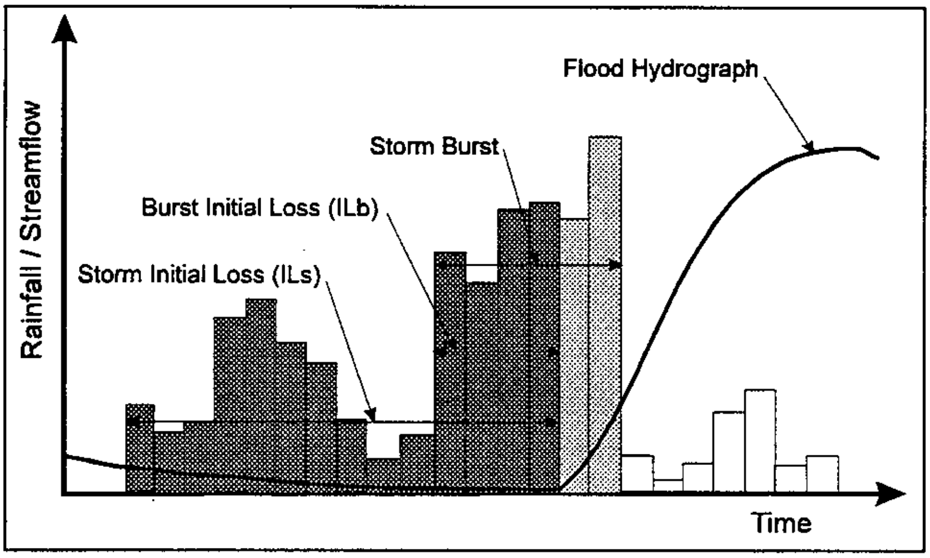

Figure 3-1 Initial Loss for an Embedded Rainfall Burst

It is therefore evident that the burst initial loss not only depends on the antecedent wetness and other catchment characteristics which influence the storm initial loss, but also on the degree to which the burst is embedded within the complete storm. The rainfall before the burst is therefore important in calculating the burst initial loss.

It is expected that the average *burst* initial loss for longer durations will approach the *storm* initial loss, as a greater proportion of the bursts will represent complete storms (Srikanthan and Kennedy, 1991). The average *storm* initial loss should be independent of the duration of the bursts used to select the events.

For both the initial loss-continuing loss and the initial loss-proportional loss models, the continuing and proportional loss is assumed to be invariant with time; therefore, both the continuing loss rate and proportional loss relevant for the burst are the same as that for the complete storm. This implies that the continuing and proportional losses should be derived in the conventional manner; from a consideration of the difference between the volume of rainfall after initial loss has been satisfied and the surface runoff volume.

3.2 Computation of Event Loss Parameters

This section describes the identification of rainfall bursts in a manner which is consistent with that used to derive the design temporal patterns contained in AR&R. Baseflow is separated for the corresponding runoff events to obtain hydrographs of surface runoff and loss parameters calculated for each rainfall burst for both the initial loss-continuing loss (IL/CL) and initial loss-proportional loss (IL/PL) models.

3.2.1 Selection of Bursts

The identification of rainfall bursts was undertaken using the HYRINT program, written by HYDSYS Pty Ltd specifically for this study. This program searches the pluviograph record (in

HYDSYS archive format) with a 'window' of a specified duration and identifies all events which have an intensity greater than a user defined threshold. A minimum separation can be specified to ensure that the events do not overlap. Eight different durations can be searched simultaneously, each with a different threshold and minimum separation.

For this study, the 1 year average recurrence interval (ARI) intensity was estimated for each catchment for durations of 2, 6, 12, 24 and 48 hours using the guidelines contained in AR&R. All bursts which had an average intensity greater than the 1 year ARI intensity were then identified using HYRINT. The minimum separation between bursts was set as zero (ie. the bursts could not overlap but could follow one another with no gap).

The events identified using HYRINT were visually checked for timing errors, and missing or extrapolated data. Firstly, the baseflow was separated from the total streamflow as described below in Section 3.2.2. The separated surface runoff and rainfall were plotted for each event and were carefully checked for any apparent data errors which may affect the derived loss parameters (eg. runoff starting before the rainfall, missing or extrapolated data). All events which had suspected data errors were removed from the analysis.

For the 22 catchments, the identification of all rainfall bursts which had an average intensity (over 1 of the 5 different durations) which exceeded the 1 year ARI intensity and subsequent data checking resulted in a total of 1,059 bursts being analysed.

3.2.2 Baseflow Separation

As only the hydrograph of surface runoff is of interest in the loss calculations, the observed total streamflow hydrographs first had to be separated into surface runoff and baseflow components. In this study, differentiation between flow components was not made according to physical sources of runoff, but rather on the basis of travel times.

The baseflow was separated using the algorithm shown in Equation 3.1 with a filter factor of 0.925, 3 passes and a 60 minute time interval. The use of the filter and the selection of the parameters is discussed in Hill et al. (1996b).

$$f_k = a.f_{k-1} + \frac{1+a}{2}(y_k - y_{k-1}) \qquad (3.1)$$

where: f_k is the filtered quick response at the kth sampling instant
y_k is the total streamflow; and
a is the filter parameter (or factor).

The method has the advantage that it is objective, repeatable and that a large number of years of data can be processed in minutes. The disadvantage is that, like most other methods of baseflow separation, it is not based upon physical processes and the exact separation is not known. There is also little guidance on the selection of appropriate parameters and the separated baseflow is sensitive to the choice of parameters.

The methodology outlined for calculating losses relies on the estimation of storm initial loss from the start of surface runoff. The separation of baseflow and estimation of the surface runoff hydrograph is therefore quite important. No problems were encountered using the digital filter technique to separate baseflow, and for most events the surface runoff dropped to a value close to zero before the start of each event. An example of the total streamflow and separated baseflow is shown in Figure 3-1.

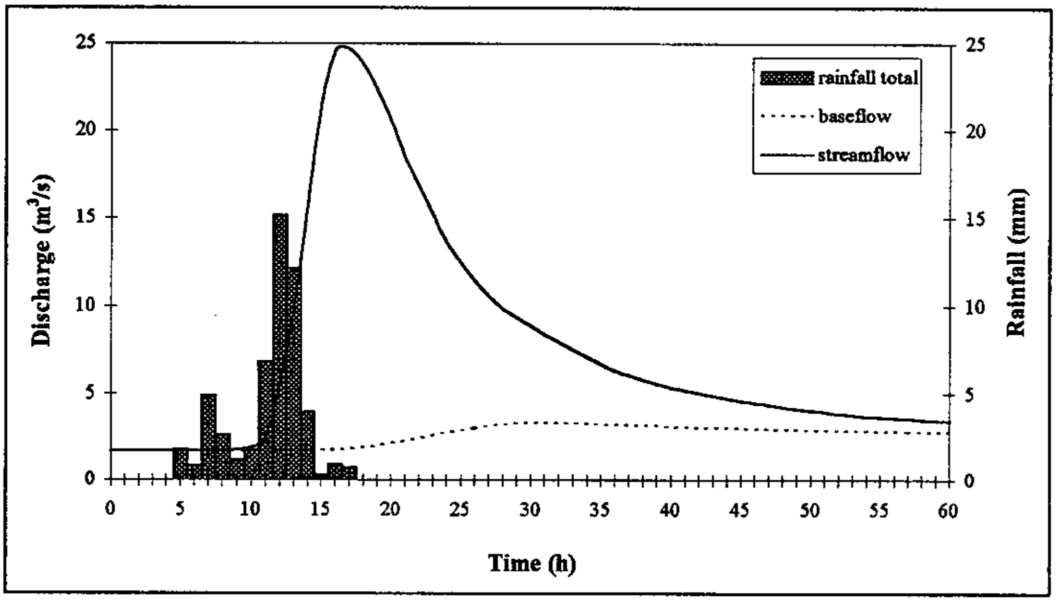

Figure 3-1 Separation of Baseflow for Boggy Creek (27 September 1983)

3.2.3 Calculation of Loss Parameters

The catchment average rainfall was estimated using the daily rainfall stations in close proximity to the catchment. The daily rainfall stations used and their thiessen weights are shown in Appendix A. The temporal pattern of the catchment average rainfall was considered to be the same as that for the point rainfall.

The data files for average catchment rainfall were prepared using the CONVERT program. This program calculates the average catchment rainfall given the total event rainfall for each of the daily rainfall stations. The source code of CONVERT is given in a complementary working document (Hill et al., 1996b).

The loss parameters shown in Table 3-1 and illustrated in Figure 3-2 were computed using the programs BURST (for point rainfall) and AVBURST (for average catchment rainfall). A description of these programs and the details of the required screen and file inputs are given in Hill et al. (1996b).

The storm initial loss is estimated to be the rainfall which occurs prior to the commencement of surface runoff. In this study, a threshold value of surface runoff was specified; it was considered that surface runoff had commenced when the surface runoff threshold was exceeded. The choice of threshold is discussed in Appendix E.

As discussed in Section 3.1, the initial loss for the *burst* is the portion of the storm initial loss which occurs within the burst. The burst initial loss therefore depends on both the storm initial loss and the location of the burst within the complete storm. The burst initial loss can range from zero to the storm initial loss.

Table 3-1 Parameters Calculated by BURST Program

Parameter	Units	Description
P_s	mm	total rainfall depth in the storm
P_b	mm	rainfall depth within the burst
P_a	mm	rainfall depth antecedent to the burst
P_b/P_s	-	ratio of burst rainfall to total storm rainfall
roc	-	volumetric runoff coefficient (volume of runoff divided by the volume of storm rainfall)
IL_s	mm	initial loss for the storm
IL_b	mm	initial loss for the burst
IL_a	mm	initial loss which occurs outside of the burst
CL	mm/h	continuing loss
PL	-	proportional loss
Q_p	mm/h	peak instantaneous surface runoff
ARI	years	average recurrence interval of the rainfall burst

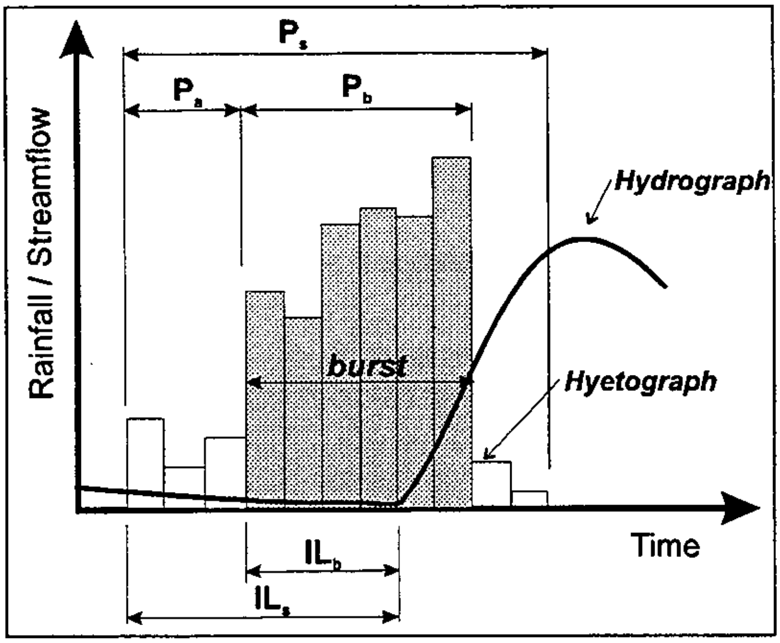

Figure 3-2 Calculated Storm and Loss Parameters

The continuing loss (CL) is assumed to occur at a constant rate after the commencement of surface runoff. The continuing loss was computed in the conventional manner; ie the volume of rainfall after initial loss minus the volume of surface runoff, divided by the duration of the storm. A lower limit of 0 mm/h and an upper limit of 20 mm/h were imposed for the continuing loss, and events with continuing losses outside of this range were excluded from the analysis.

The proportional loss (PL) is assumed to be constant after the commencement of surface runoff. The proportional loss was computed, in the conventional manner, as one minus the ratio of the volume of surface runoff to the volume of rainfall (after initial loss).

4. CATCHMENT SELECTION

Hill (1994) summarises the data availability for 67 Victorian catchments with concurrent pluviograph and streamflow data. From these, 18 Victorian catchments and an additional 4 catchments from the ACT were selected using the following criteria:

- availability of concurrent pluviograph and streamflow data which was generally free of errors;
- small to medium sized rural catchments (catchment areas less than approximately 150 km²);
- unregulated streamflow.

The final criterion was that the set of catchments had to be representative of the range of rural catchments across Victoria and the ACT.

The selected catchments are shown in Table 4-1. They represent the range of catchments across both Victoria and the ACT with mean annual rainfalls ranging from 520 to 1880 mm.

The locations of the selected catchments are shown in Figure 4-3. It is evident from this figure that the catchments cover most of Victoria and the ACT with the exception of:

- the north-west of Victoria (because of the scarcity of unregulated rivers in this region); and
- the alpine region (because of the scarcity of pluviograph stations and the difficulty in accounting for snowmelt).

Table 4-1 Summary of Selected Catchments

Catchment	Code	Area (km²)	Gauging Station	Pluviograph Station	Rainfall (mm)
Tidbinbilla Ck @ Mountain Creek	TI	25	410739	570964*	1120
Chapple Ck @ Chapple Vale	CH	28	235212	090087	1520
Goodman Ck above Lerderderg Tunnel	GO	32	231219	087075	800
Campaspe River @ Ashbourne	CA	33	406208	087153	960
Tarwin River East Branch @ Mirboo	TA	43	227228	085227	1140
Ginninderra Ck u/s Barton Highway	GI	48	410751	570904	640
Snobs Ck @ Snobs Ck Hatchery	SN	51	405257	088023	1660
Myers Ck @ Myers Flat	MY	55	407258	081003	520
Jerrabomberra Ck @ Four Mile Creek	JE	55	410743	570973	610
Ford River @ Glenaire	FO	56	235229	090087	1520
Glenelg River @ Big Cord	GL	57	238231	089019	680
Warrambine Ck @ Warrambine	WA	57	233223	089094	660
Spring Ck @ Fawcett	SP	60	405261	088153	720
La Trobe River @ Near Noojee	LA	62	226222	086323	1480
Orroral River @ Crossing	OR	90	410736	570966	750
Aire River @ Wyelangta	AI	90	235219	090087	1880
Moonee Ck @ Lima	MO	91	404208	082107	1060
Cobbannah Ck @ Bairnsdale	CO	106	224209	085250	840
Boggy Ck @ Angleside	BO	108	403226	083031	1080
Wanalta Ck @ Wanalta	WN	108	405229	081115	540
Tarwin R East Branch @ Dumbalk Nth	TE	127	227226	085227	1140
Lerderderg River @ Sardine Ck	LE	153	231213	087017	1080

* Note: Two pluviographs were used for the Tidbinbilla Creek Catchment; 570964 operated up to December 1985 and 570945 was used after this date.

A map of each catchment showing the location of hydrometric stations is given in Appendix A.

A further 6 catchments were initially selected but later discarded because of problems with the data. The details of the discarded catchments and the reasons for their omission are given in Appendix A.

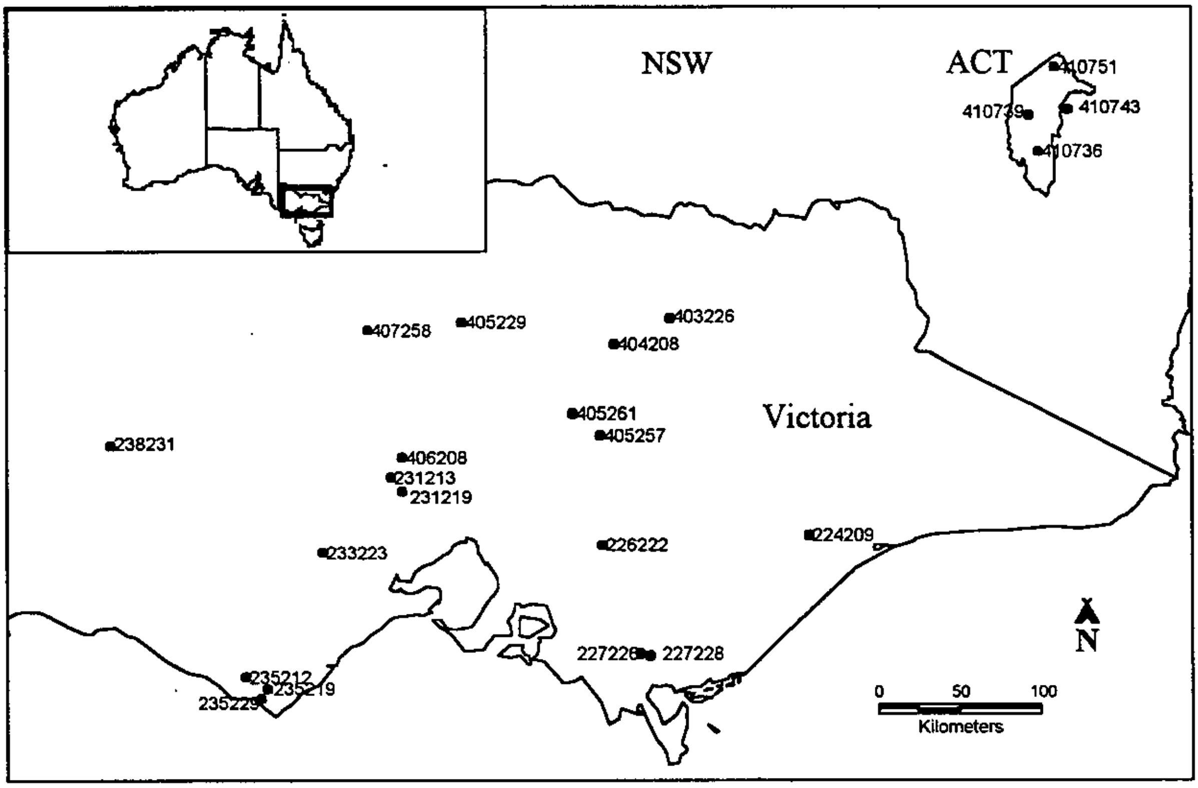

Figure 4-3 Locations of Selected Catchments

5. COMPUTED MEAN LOSS PARAMETERS

Loss parameters were calculated for the 1,059 bursts identified in Section 3.2.1 using the methodology outlined in Section 3.2.3. The loss parameters for each burst are given in Hill et al. (1996b). This chapter details the mean loss parameters for each catchment and then examines the seasonal variation of the loss parameters.

5.1 Mean Catchment Losses

The loss parameters depend on the antecedent conditions and therefore there is a large variation between loss parameters calculated for different events on the same catchment. For each catchment, the loss estimates are a sample from the distribution of loss values. In the light of the current lack of information on the true distribution of losses and the complexity involved, the current approach is to take some 'central' or 'typical' value for a design loss value. AR&R recommends the use of the median value, although it is stated that it is not possible to rigorously prove that the use of median values will lead to a flood estimate of similar probability to that of the design rainfall (AR&R, p6).

The approach adopted in this study is to use the mean as the measure of the central value rather than the median. This is because it is unclear as to what the correct measure of the central value should be and most descriptive statistics are based about the mean.

Because bursts of rainfall were used to identify the events, some storms were selected more than once; ie. a storm may contain more than one burst of a given duration or may include bursts of different durations. For the analysis of storm bursts in Chapter 6 these events are analysed separately (total of 1,059 bursts), however in the determination of mean storm losses in this chapter, each storm is only included once in the average (total of 408 storms).

For events where no surface runoff was produced, or the surface runoff did not exceed the adopted threshold of 0.01 mm/h (refer to Appendix E), the initial loss was estimated as the total rainfall and no continuing or proportional loss was calculated. For this reason, less values were used to calculate the mean continuing and proportional losses than were available for calculating the mean storm initial losses. A total of 408 storms were used in the calculation of mean initial loss and 260 storms in the calculation of mean continuing and proportional loss.

The mean proportional loss was not calculated directly as the mean of the proportional losses for each storm on a particular catchment. This is because the proportional loss is not an absolute measure of loss but a ratio of the loss to the rainfall after the storm initial loss has been satisfied. The mean proportional loss was therefore calculated as the mean loss volume divided by the mean storm rainfall after initial loss had been satisfied. For this reason, no confidence limits for the mean proportional loss were calculated. The geometric mean was also calculated and was found not to differ significantly from the calculated mean.

The mean values of storm initial loss, continuing and proportional losses are shown in Figure 5-1, Figure 5-2 and Figure 5-3 respectively. The 90 percent confidence limits about the mean are indicated for the storm initial loss and the continuing loss. The mean values are tabulated in Appendix B.

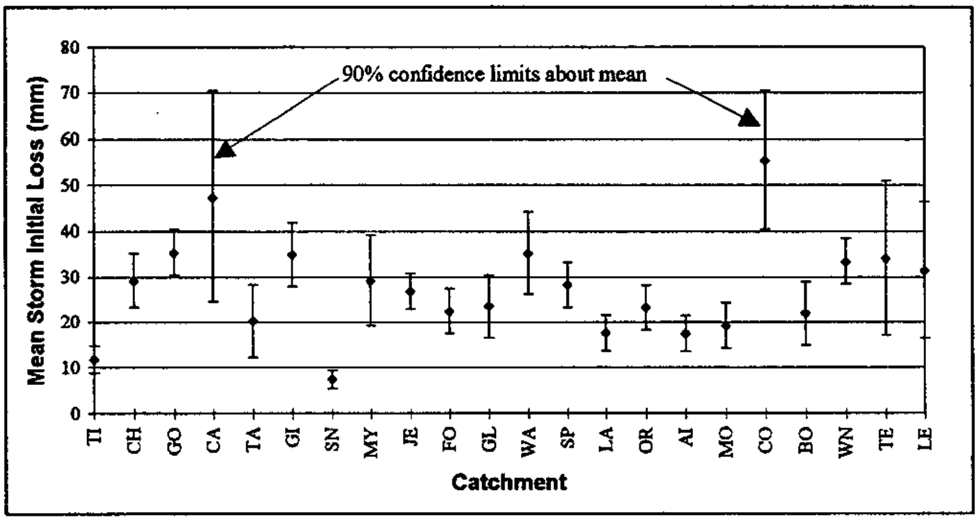

Figure 5-1 Mean Storm Initial Loss by Catchment

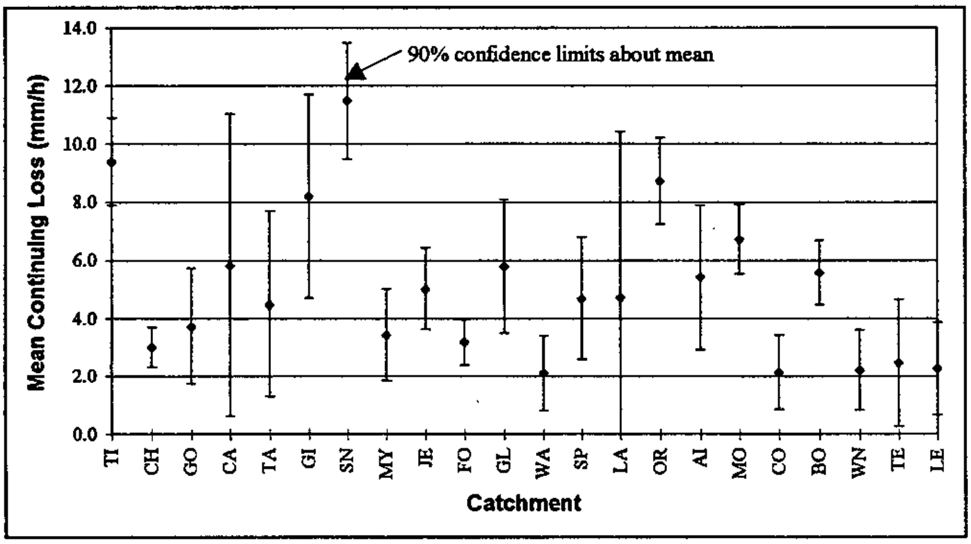

Figure 5-2 Mean Continuing Loss by Catchment

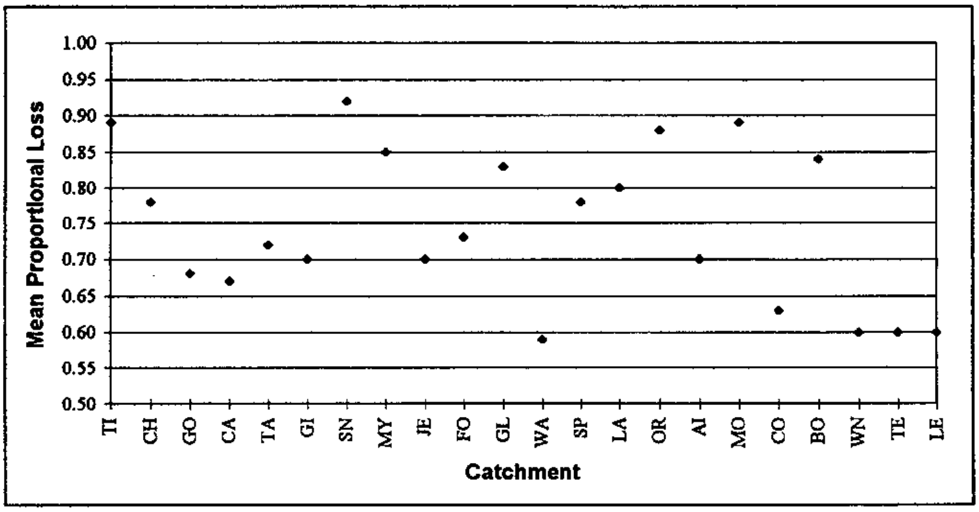

Figure 5-3 Mean Proportional Loss by Catchment

5.1.1 Use of Point Rainfall versus Catchment Average Rainfall

The results presented in Section 5.1 (and Appendix B) were calculated using catchment *average* rainfall. Some preliminary work was initially undertaken using *point* (ie. pluviograph) rainfall and the resultant mean loss parameters compared.

Statistical t-tests were carried out to compare the mean values of IL_s, CL and PL computed with point and average catchment rainfalls. The t-test results indicated that, even for the smaller catchments, the mean values of loss parameters calculated using catchment average rainfall were significantly different from those computed with point rainfall. The catchment average rainfall was used in all subsequent analyses, to avoid dependence on the choice of a single raingauge.

5.2 Seasonal Variation of Storm Losses

In the previous sections, mean losses were derived for each catchment, without consideration as to how those losses vary throughout the year. Because initial loss, and possibly the continuing and proportional losses, are related to antecedent moisture, it is expected that there would be a seasonal variation in the derived losses.

The number of events for individual catchments was not sufficient to study the seasonal variation of derived losses for individual catchments, so the data were standardised by dividing by the mean loss for the catchment and then pooled. This assumes that the study catchments form a homogeneous region with respect to the seasonal effects on losses. The mean standardised loss was then calculated for each month.

A sinusoidal variation of losses was apparent, and equations of the form of Equation 5.1 were fitted to the mean standardised storm initial, continuing and proportional losses. The relationship has a period of 12 months, an amplitude of α and a phase shift of β.

$$\text{standardised loss} = 1.0 + \alpha \sin\left[0.167\pi\left(\text{month} + \beta\right)\right] \qquad (5.1)$$

The 2 fitted parameters are summarised in Table 5-1 for each loss parameter; the table shows that a strong seasonal variation exists. For initial and continuing losses, the mean monthly loss varies by up to ±30 percent of the mean value over the entire year. Although the seasonal variation for the proportional loss is not as pronounced, the month of the year still accounts for a variation of the monthly mean from the yearly average of over 10 percent. This means that seasonal effects can explain a considerable proportion of the total scatter in the storm losses.

Table 5-1 Parameters for Seasonal Variation of Losses

Loss	α	β	r^2	SE
Storm Initial Loss	0.381	0.413	0.80	0.14
Continuing Loss	0.303	1.55	0.75	0.13
Proportional Loss	0.115	0.682	0.72	0.06

The seasonal variation of mean losses is shown in Figure 5-4, Figure 5-5 and Figure 5-6.

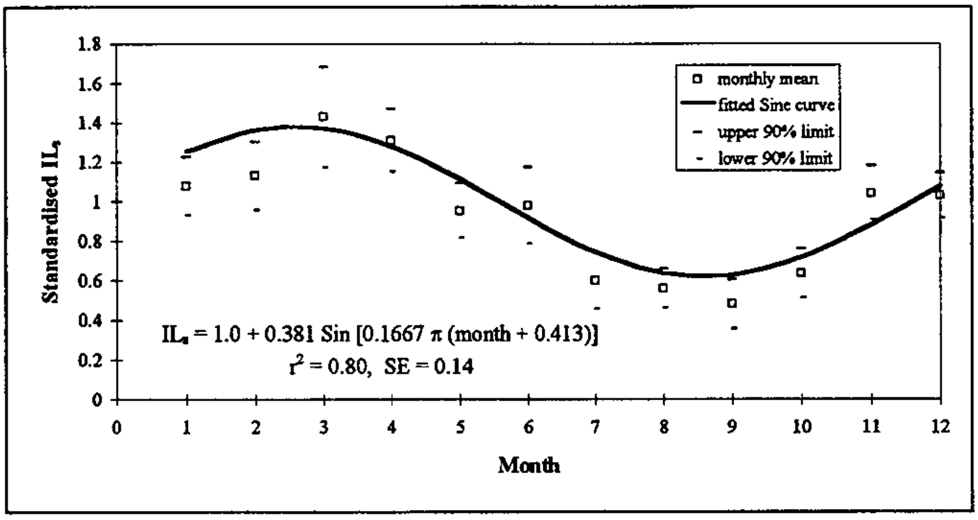

Figure 5-4 Monthly Variation of Storm Initial Loss (pooled data)

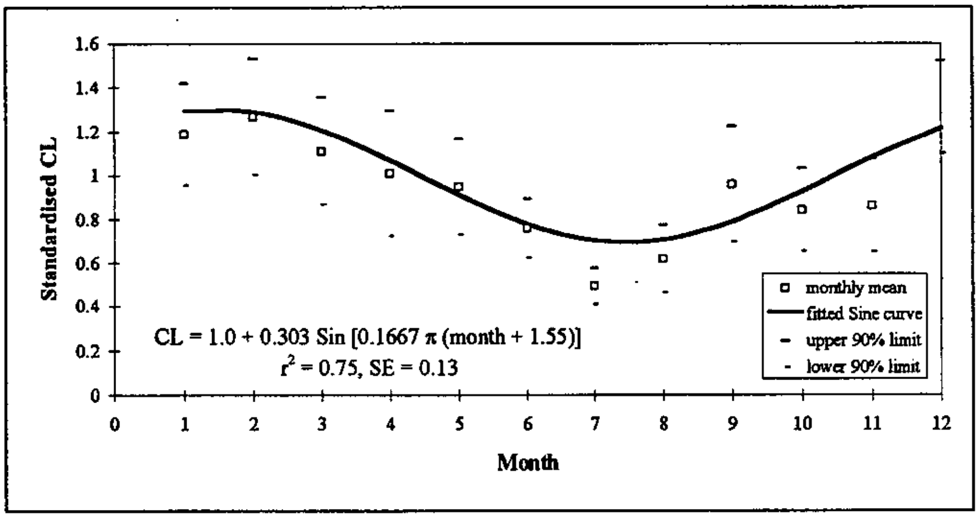

Figure 5-5 Monthly Variation of Continuing Loss (pooled data)

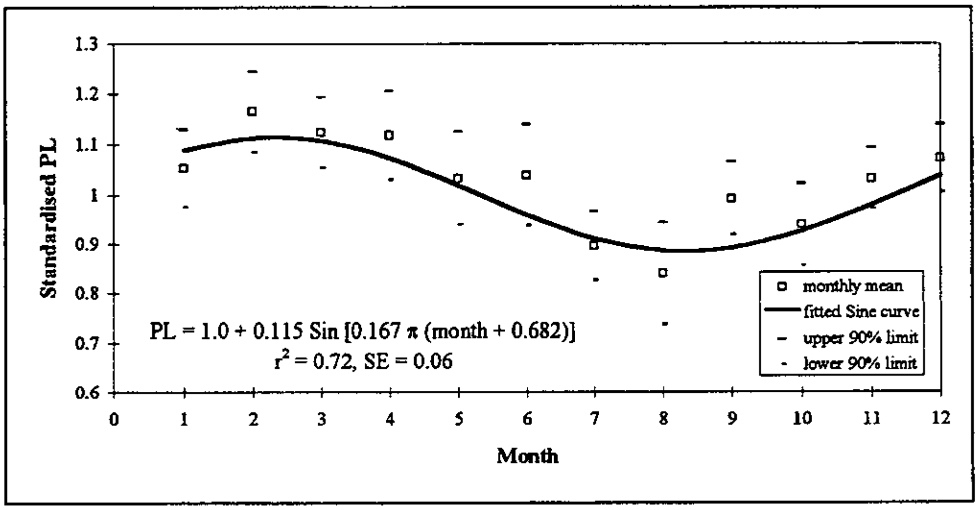

Figure 5-6 Monthly Variation of Proportional Loss (pooled data)

6. RELATIONSHIP BETWEEN BURST AND STORM INITIAL LOSSES

In the preceding chapter, average loss parameters were calculated for 408 storms on 22 catchments. However, as shown in Figure 3-1, the *storm* initial loss does not account for the embedded nature of the rainfall bursts. The initial loss for a ***burst*** depends upon the initial loss for the storm and also on the location of the burst within the storm. In this chapter the ***burst*** initial loss (IL_b) is related to the *storm* initial loss (IL_s).

6.1 Comparison of Rainfall Bursts with Complete Storms

The distribution of the ratio of the rainfall in the burst P_b to the rainfall in the complete storm P_s is shown in Figure 6-1 for all 1,059 bursts identified in Section 3.2.1.

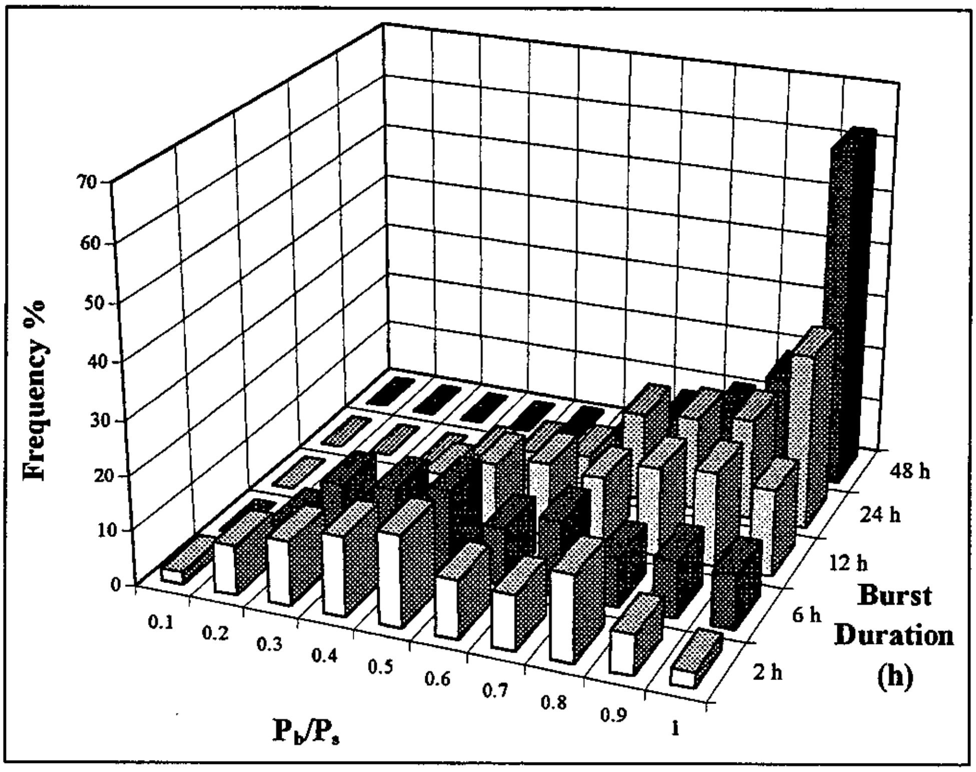

Figure 6-1 Distribution of the Ratio of Burst Rainfall to Storm Rainfall

It is clear from Figure 6-1 that, as the duration of the bursts increases, more bursts represent complete storms. For a duration of 48 hours for example, more than 60 percent of the bursts exceeded 90 percent of the total storm rainfall. It would therefore be expected that the initial loss for the burst should increase with increasing burst duration and approach the storm initial loss.

It is also interesting to examine the storm rainfall prior to the burst. Table 6-1 shows the mean and median rainfall prior to the burst and the mean and median ratio of the burst rainfall to the storm rainfall depth for each duration of rainfall burst.

From Table 6-1, it is clear that the average rainfall antecedent to the burst decreases with increasing burst duration. The increasing ratio of P_b/P_s is consistent with Figure 6-1.

Table 6-1 Mean Ratio of Burst and Storm Rainfall, and Depth of Antecedent Rainfall

Duration (h)	P_b/P_s mean	P_b/P_s median	P_a (mm) mean	P_a (mm) median
2	0.50	0.47	20	7
6	0.56	0.54	22	13
12	0.68	0.70	18	9
24	0.79	0.82	12	3
48	0.90	0.94	5	1

6.2 Distribution of IL_b/IL_s

The approach adopted in this study to calculate the initial loss for the burst is to firstly calculate the mean initial loss for the complete storm (see Chapter 5) and then determine the initial loss for the burst as a fraction of the initial loss for the storm. This presumes that there is a well defined relationship between the initial losses for bursts and storms.

The distribution of the ratio of the burst initial loss to the storm initial loss is shown in Figure 6-2. This figure clearly shows that for the short durations, many of the bursts are embedded within longer duration storms (burst initial losses which are close to 0). For the longer durations, the greatest proportion of bursts represent complete storms (burst initial losses which are close to the storm initial loss), although there is still a significant proportion with burst initial losses close to zero.

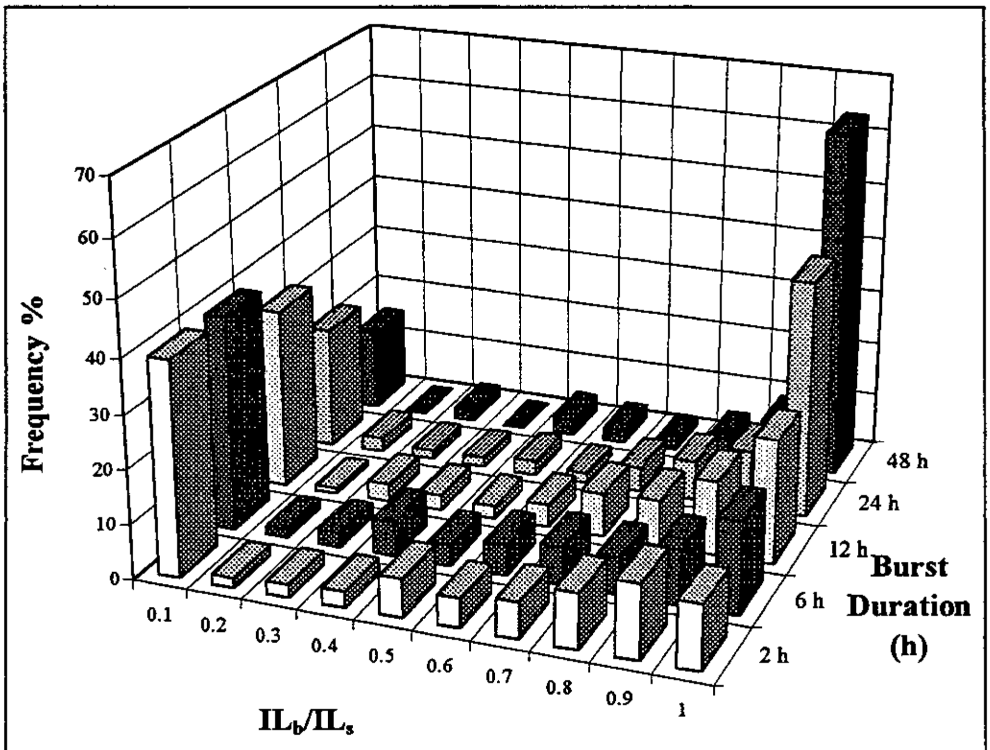

Figure 6-2 Distribution of the Ratio of Burst Initial Loss to Storm Initial Loss

For the two shortest durations considered (2 and 6 hours), nearly 40 percent of the bursts were embedded in longer duration storms in such a way that virtually all of the loss occurred before the start of the burst (IL_b less than 10 percent of IL_s). More than 60 percent of the 48 hour bursts, represent complete storms (IL_b greater than 90 percent of IL_s).

It is evident from Figure 6-2 that the ratio of IL_b to IL_s for a given duration is extremely variable with modes at the upper and lower end of the scale. Thus, no single measure of centrality (mean, median, etc) can adequately represent the distribution of values.

6.3 Generalisation of IL_b/IL_s

Examination of the mean ratios of the IL_b to IL_s showed a weak trend with mean annual rainfall (wetter catchments having generally lower values of IL_b/IL_s). This would be expected, as wetter catchments have a greater likelihood of bursts being embedded in longer duration storms, and hence a lower IL_b.

In order to derive a value of IL_b for design, an equation was fitted to the mean values of IL_b/IL_s from each duration and catchment (22 catchments and 5 durations for each catchment). The number of mean values was reduced because for some durations and catchments, there were very few events. The selection criteria were that the number of values used to derive the mean IL_b/IL_s had to be greater than 2, and the standard error about the mean divided by the mean less than 0.3.

Equation 6.1 was developed using 75 values of IL_b/IL_s and the results are plotted in Figure 3-1. While the relatively low values of r^2 indicate considerable scatter about the fitted line, even after allowing for the effect of mean annual rainfall, the relationship should provide a satisfactory basis for probability-based design. Nevertheless, it should be remembered that there is a significant chance of IL_b/IL_s being close to zero, even for longer duration bursts.

$$IL_b = IL_s\left\{1-\frac{1}{1+142\frac{\sqrt{(duration)}}{MAR}}\right\} \qquad N=75,\ r^2=0.43,\ SE=0.18 \qquad (6.1)$$

6.4 Seasonal Variation of Burst Initial Loss

A strong seasonal variation in *storm* loss parameters was shown in the preceding section. In this section the *burst* initial losses are examined to see whether they also have a seasonal variation.

6.4.1 Occurrence Of Bursts

The temporal occurrence of the storm bursts used in the analysis is shown in Table 6-2, and shows that the longer duration rainfall bursts are fairly evenly distributed throughout the year. It is also apparent that the short duration rainfall bursts are more likely to occur in summer and early autumn, as the short duration bursts are likely to be caused by thunderstorms.

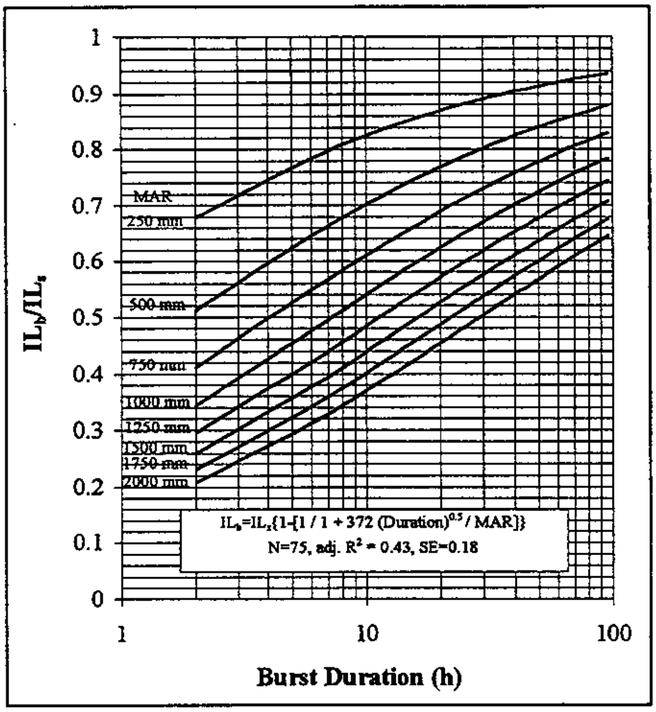

Figure 6-3 Variation of IL_b/IL_s with Burst Duration and Mean Annual Rainfall

Table 6-2 Monthly Distribution of Rainfall Bursts

Month	Number of bursts for Duration (h)					
	2	6	12	24	48	*Total*
Jan.	38	32	28	23	17	*138*
Feb.	34	23	14	12	12	*95*
Mar.	29	33	27	30	24	*143*
Apr.	18	23	25	29	25	*120*
May	5 *	20	20	17	17	*74*
Jun.	1 *	12	13	15	18	*58*
Jul.	-	6 *	10	14	12	*36*
Aug.	1 *	11	10	11	10	*42*
Sept.	6 *	15	15	15	13	*58*
Oct.	9 *	17	14	20	15	*66*
Nov.	12	20	16	17	12	*77*
Dec.	27	31	27	22	17	*124*
Total	*180*	*243*	*219*	*225*	*192*	*1059*

* not used for the fitting of curves (N < 10)

6.4.2 Seasonal Variation of IL_b

An examination of the seasonal distribution of IL_b values showed a distinct seasonal variation. The IL_b values were standardised by dividing by the mean value for each duration and catchment and mean values calculated for each month. Again, an equation of the form of Equation 5.1 was fitted to the mean monthly values (only months with greater than 10 values were used in the analysis). The parameters are shown in Table 6-3. No equation could be fitted for the 2 hour duration bursts because there were 6 months of the year for which no mean value was calculated (less than 10 values in each month).

Table 6-3 Parameters for Seasonal Variation of Burst Initial Losses

Duration (h)	α	β	adj. r^2	SE
2	-	-	-	-
6	0.566	0.825	0.74	0.25
12	0.444	1.058	0.75	0.19
24	0.478	0.925	0.76	0.21
48	0.540	0.465	0.84	0.18

The seasonal variation of the burst initial losses for the 48 hour bursts are shown in Figure 6-4. The seasonal variations of the burst initial losses for the remaining durations is shown in Appendix C. They confirm the trend for the seasonal variation of burst initial losses to be even more pronounced than that of the storm initial losses.

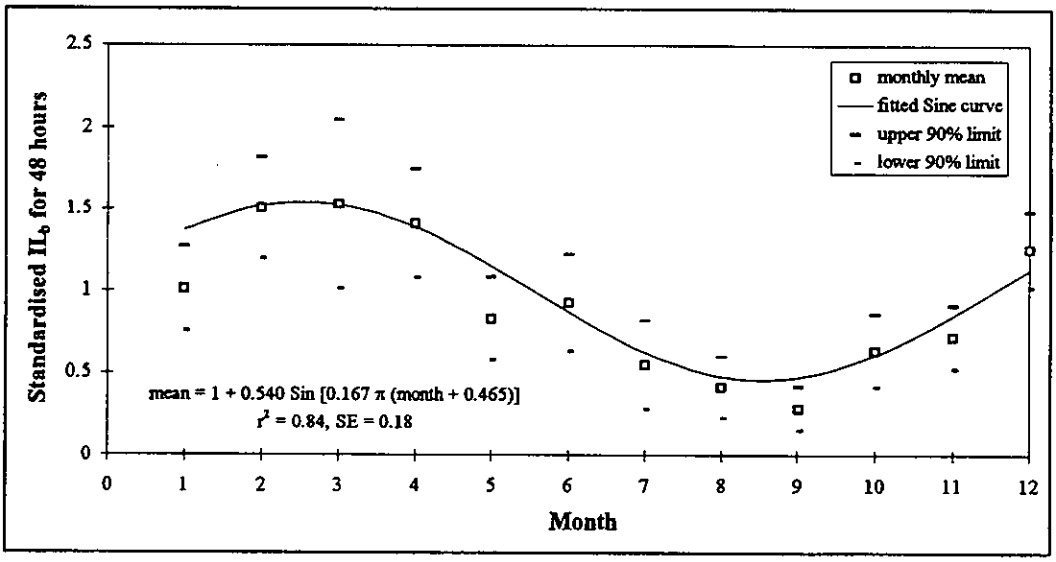

Figure 6-4 Monthly Variation of Standardised *IL_b* for 48 hours duration

6.4.3 *Seasonal Variation of* IL_b/IL_s

Given the marked seasonal variation of storm losses found in Sections 5.2 and 6.4, the ratio of IL_b to IL_s was examined to see if there was any consistent seasonal variation.

An equation of the form of Equation 6.2 was fitted to the mean IL_b/IL_s for each month; the fitted parameters and the goodness of fit are shown in Table 6-4.

$$\frac{IL_b}{IL_s} = \delta + \alpha \sin[0.167\pi(\text{month} + \beta)] \qquad (6.2)$$

Table 6-4 Parameters for Seasonal Variation of IL_b/IL_s

Duration (h)	δ	α	β	adj. r^2	SE
2	-	-	-	-	-
6	0.375	0.134	0.961	0.54	0.10
12	0.483	0.085	2.254	0.45	0.08
24	0.617	0.076	2.582	0.25	0.10
48	0.742	0.122	1.767	0.77	0.05

No relationship could be developed for the 2 hour duration because of the lack of bursts during winter and spring (Table 6-2). As expected, the value of δ increases with increasing burst duration. The seasonal variation of IL_b/IL_s is not as pronounced as that found for the loss parameters in Section 5.2 and 6.4.

The seasonal variation of IL_b/IL_s for a 48 hour duration (giving the strongest relationship) is shown in Figure 6-5, and Appendix C shows the plots for the other 3 durations.

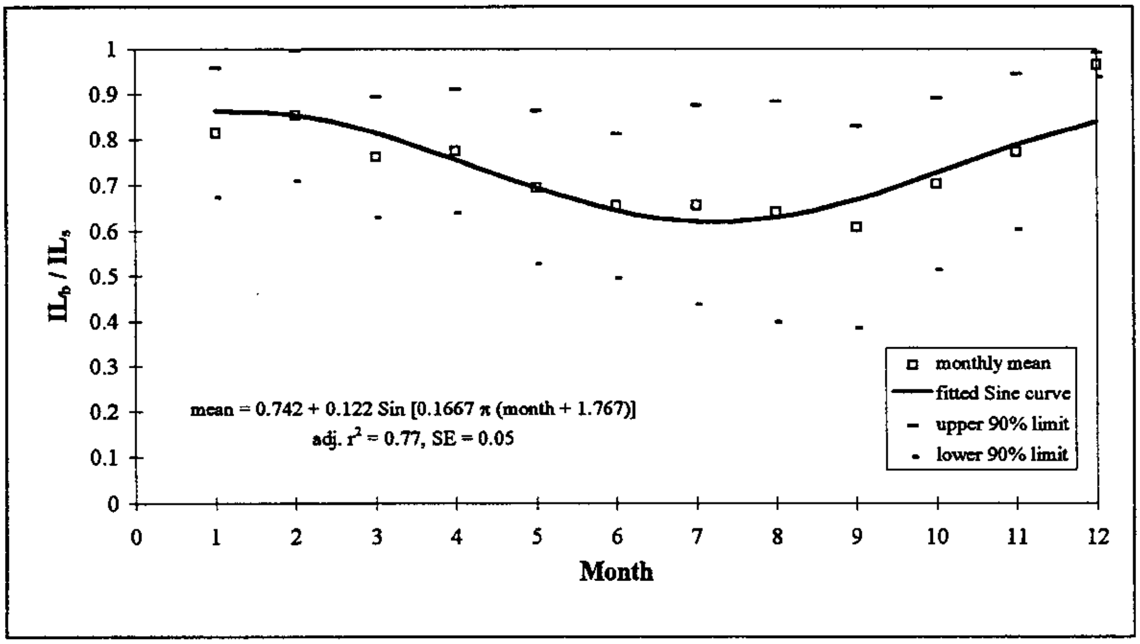

Figure 6-5 Monthly Variation of IL_b/IL_s for 48 hour duration Bursts

7. VARIATION OF LOSSES WITH STORM SEVERITY

The analysis in the preceding chapters used pooled data irrespective of the severity of the storm. This chapter will examine if a relationship exists between the average recurrence interval (ARI) of the rainfall burst and the losses.

7.1 Distribution of Burst Average Recurrence Intervals

The analysis of the variation of losses with ARI is hindered by the lack of observed bursts with large ARIs. This, coupled with the high variability in observed losses, makes it very difficult to identify any possible variation of losses with ARI.

The distribution of ARIs for the 1,059 rainfall bursts identified as having an ARI of greater than 1 year is shown in Figure 7-1. Over half (56 percent) of the bursts have ARIs of less than 2 years; only 4 percent of bursts had ARIs of greater than 20 years.

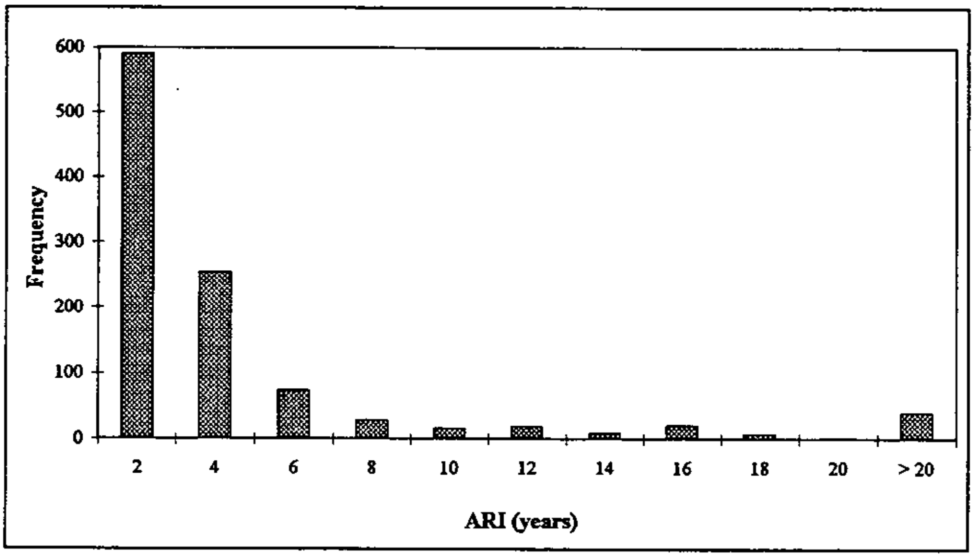

Figure 7-1 Distribution of Burst ARIs

7.2 Relationship between Storm Losses and Severity

Since the number of events for individual catchments was insufficient to study the variation of losses with ARI, the data were standardised by dividing by the mean loss for the catchment and then pooled.

The derived loss parameters for each of the 1,059 bursts are plotted against ARI in Figure 7-2, Figure 7-3 and Figure 7-4. From these figures, it is difficult to determine any trend of losses with ARI because of the very large scatter and the lack of events with large ARIs.

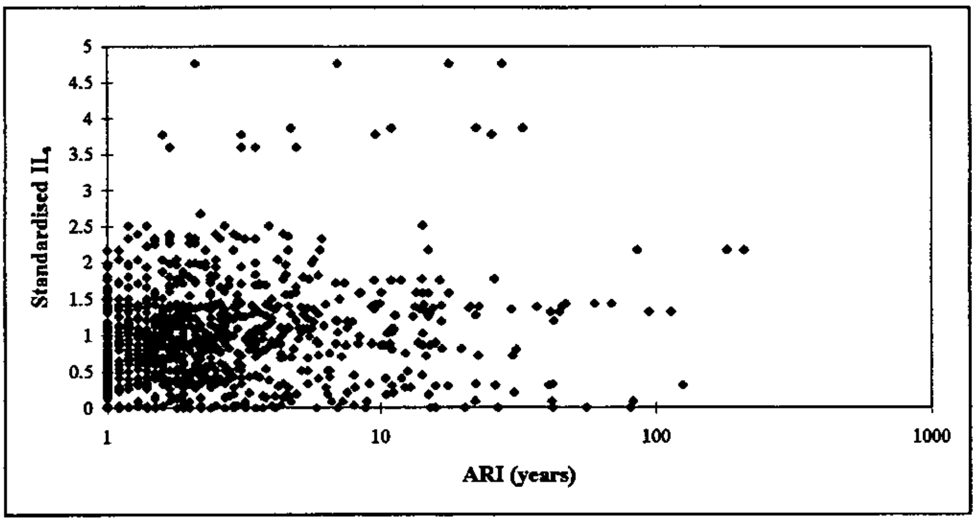

Figure 7-2 Variation of Storm Initial Loss with ARI (all catchments)

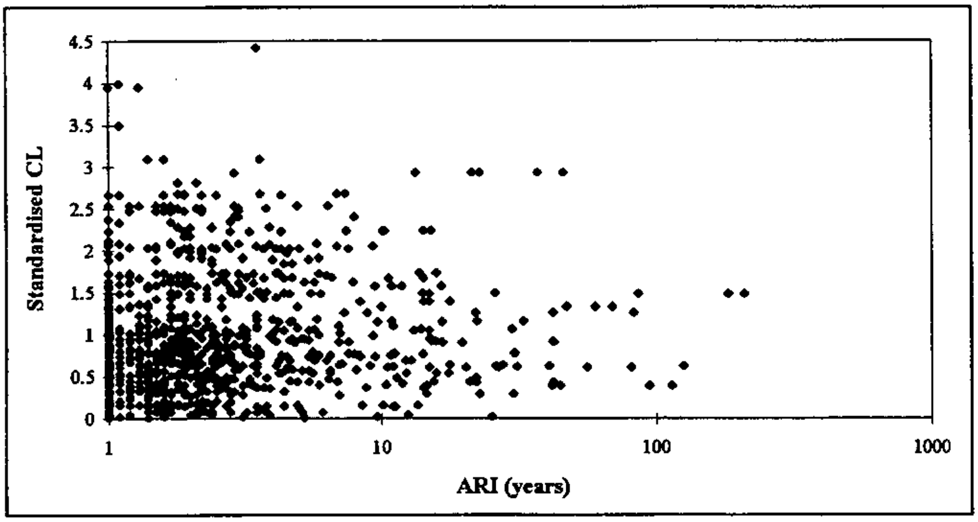

Figure 7-3 Variation of Continuing Loss with ARI (all catchments)

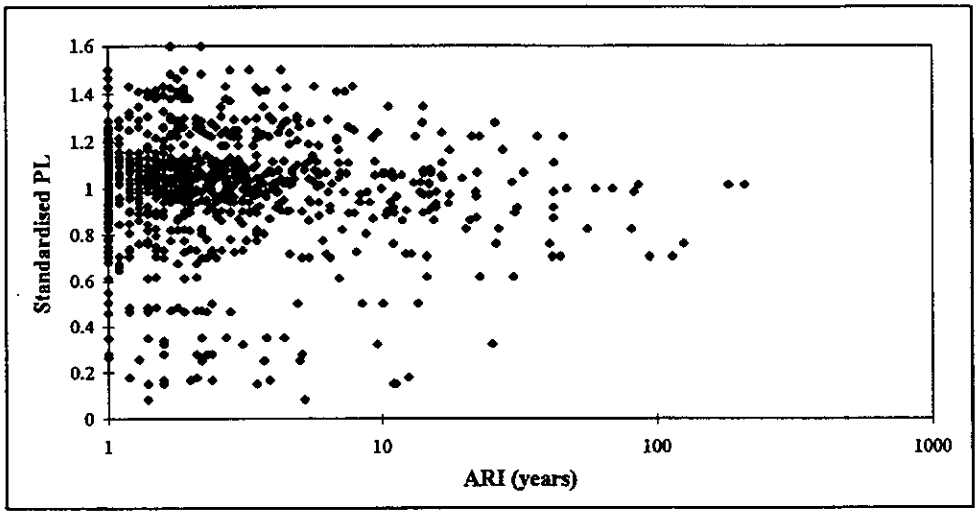

Figure 7-4 Variation of Proportional Loss with ARI (all catchments)

In order to overcome these difficulties, the data were grouped into three ranges according to their ARI; 1 to 2 years, 2 to 20 years and greater than 20 years. The mean, standard deviation and number of values in each group are shown in Table 7-1.

Table 7-1 Mean Losses for Different Classes of ARI

	Standardised IL_s			Standardised CL			Standardised PL		
ARI Range	mean	std. dev.	N	mean	std. dev.	N	mean	std. dev.	N
1-2	0.933	0.559	590	0.949	0.696	517	1.012	0.241	517
2-20	1.071	0.749	429	1.061	0.713	407	0.990	0.257	407
>20	1.228	1.171	40	1.027	0.758	40	0.923	0.200	40

The t-test was used to determine if the means listed in Table 7-1 are significantly different; the results are shown in Table 7-2. At the 5% significance level, the means of the '2 to 20 year ARI' and the 'greater than 20 year' means were not significantly different. For both the storm initial loss and the continuing loss, the mean of the '1 to 2 year ARI' events was significantly lower than the '2 to 20 year ARI' events.

Table 7-2 Significance Test for Mean of Different Classes of ARI

	P-value from t-test		
Ranges of ARI	IL_s/av. IL_s	CL/av. CL	PL/av. PL
1-2, 2-20	0.001*	0.005*	0.183
2-20, >20	0.358	0.894	0.113

* significant at 5% level

The results of the t-test indicate that both storm initial loss and continuing loss for ARIs of less than 2 years are approximately 5 to 6 percent lower than the losses for ARIs of greater than 2 years. This small reduction of loss for low ARIs is not considered to be of any practical significance, and does not indicate any general trend for losses to increase with ARI.

The distribution of values within each class of ARI is shown in Appendix D.

7.3 Relationship between Burst Losses and Severity

Table 7-3 shows the mean IL_b/IL_s for 3 different classes of ARI. The t-test was used to indicate whether the means are significantly different. Although the mean IL_b/IL_s appears to decrease with ARI, the difference is not significant at the 5 percent level.

In Appendix D the ratio of IL_b to IL_s is plotted against the ARI of the rainfall burst for burst durations of 2, 6, 12, 24 and 48 hours. These plots indicate the large variability of IL_b/IL_s and the consequent difficulty in determining any trend with ARI.

Table 7-3 Mean IL_b/IL_s for Different Classes of ARI

		IL_b/IL_s for ARI range			P-value from t-test	
		1-2	2-20	>20	1-2, 2-20	2-20, >20
2 h	mean	0.441	0.376	0.785	0.289	-
	std. dev.	0.376	0.393	-		
	N	110	61	1		
6 h	mean	0.445	0.392	0.214	0.314	0.473
	std. dev.	0.400	0.376	0.429		
	N	148	81	4		
12 h	mean	0.558	0.471	0.282	0.125	0.218
	std. dev.	0.401	0.402	0.354		
	N	108	98	7		
24 h	mean	0.662	0.639	0.526	0.679	0.348
	std. dev.	0.406	0.389	0.411		
	N	113	93	14		
48 h	mean	0.793	0.734	0.727	0.280	0.954
	std. dev.	0.341	0.378	0.359		
	N	99	80	9		

7.4 Analysis of Antecedent Rainfall

In light of the high variability in losses and the lack of sufficient events with large ARIs, it is not possible to make any conclusion from the empirical analysis of concurrent rainfall and streamflow data as to how design losses vary with rainfall burst ARI.

A more promising approach to determine the relationship between losses and ARI is by analysing rainfall antecedent to bursts for a range of rainfall ARIs. There is a well documented relationship between the antecedent rainfall and the initial loss, and this approach should give a qualitative estimate of how initial loss varies with rainfall burst ARI. However, it would not reveal if and how both the continuing and proportional losses vary with the ARI of the burst.

8. CATCHMENT CHARACTERISTICS AFFECTING LOSS

It is desirable that the mean losses derived in Chapter 5 be related to easily measurable catchment characteristics so that they can be applied to catchments outside of those used in this present study. This chapter discusses some catchment characteristics which are thought to affect losses (Chapter 9 then details the development of the prediction equations).

8.1 Previous Studies

As outlined in Section 2.1 and Figure 2-1, losses are generally attributed to the processes of interception, infiltration, depression storage and transmission loss. From a consideration of these processes, it would be reasonable to assume that derived losses should be highly correlated with physical catchment characteristics such as soil and vegetation. However, this link between losses and physical catchment characteristics has been very elusive, and many authors (such as Cordery and Pilgrim, 1983; and Walsh et al., 1991) have concluded that there is no relationship between mean losses and physical characteristics at catchment scale.

The failure, to date, to relate losses to catchment characteristics is possibly due to the following reasons:

- The loss for a given event is highly dependent on the antecedent conditions (Cordery, 1970) and therefore the mean loss for a catchment will be affected by the sample of events used. This is especially important given the strong seasonal variation of losses noted in Sections 5.2 and 6.4.

- Both the continuing and proportional loss are calculated from the difference between the volume of rainfall (after initial loss) and the observed runoff volume. This means that the calculated loss values reflect any errors in both the rainfall and streamflow data. The high spatial variability of rainfall, and the usually limited coverage of raingauges mean that there is considerable uncertainty associated with the estimate of catchment average rainfall and hence the values of continuing and proportional losses.

- The spatial variation of catchment characteristics. The soil hydraulic properties can vary by several orders of magnitude over a seemingly homogeneous area. This makes it very difficult to estimate representative parameters for a catchment.

- Very little information is available on the hydraulic properties of soils. The current classification of soils in Australia is based upon texture, and little work has been done on the classification of soils according to their hydraulic properties (refer to Section 8.3).

8.2 Catchment and Climate Characteristics

The storm initial loss depends upon both antecedent conditions and physical catchment characteristics. It is expected that both continuing and proportional losses would also be related to physical catchment characteristics, but would be less dependent upon the climatic characteristics which influence antecedent conditions.

In this study both physical characteristics (such as soil, vegetation, slope and baseflow) and climatic characteristics affecting antecedent conditions (such as rainfall and evapotranspiration) will be considered.

8.2.1 Slope

It would be expected that, the steeper the catchment, the lower should be infiltration and depression storage, and hence the loss. There are many different measures of catchment slope. The measure adopted in this study was taken from HydroTechnology (1994) and is the mainstream slope between the 10 and 85 percentile of mainstream length from the catchment outlet; ie. the slope of the (approximately) central 75 percent of the mainstream length.

8.2.2 Baseflow

Previous studies, such as Mein and O'Loughlin (1991), Mein et al. (1995) and Siriwardena and Mein (1996), have related the loss to the pre-storm baseflow. The baseflow index (BFI) is used as the measure of baseflow and is defined as the volume of baseflow divided by the total streamflow volume (Nathan and Weinmann, 1993).

The baseflow was separated using a recursive digital filter as outlined in Section 3.2.2. Initially the baseflow was separated using the same parameters (filter factor of 0.925, 3 passes and one hour time increment) as were used in Section 3.2.2 for the hydrograph separation. This led to overestimating the BFI when compared with sources such as HydroTechnology (1994). A filter factor of 0.925, 1 pass and a 24 hour time increment was therefore adopted for separating the baseflow for calculation of the BFI.

It should be noted that baseflow is not a direct characteristic of the catchment but rather is a product of many different physical catchment characteristics. The use of baseflow is limited to catchments with streamflow data, or alternatively prediction equations for the baseflow parameters based on other catchment characteristics would need to be developed (Section 9.6).

8.2.3 Vegetation

The extent and nature of the vegetative cover should also affect the loss. Vegetation tends to increase loss in 4 different ways:

- interception loss is increased;
- protection of the soil surface from the impact of heavy rain which reduces the chance of surface sealing;
- the formation of macropores is associated with the forest environment;
- depletion of the soil moisture.

For this study, the percentage of the catchment covered by different densities of forest was obtained from a topographic map and used as an indicator of the vegetation. The *type* of native vegetation should also provide a useful indicator of the availability of moisture and the type of soil (Lacey, 1996a).

8.2.4 Rainfall

The relationship between antecedent rainfall and the initial loss for a particular event has been well documented by authors such as Cordery (1970) and Mein et al. (1995). It is therefore expected that the mean initial losses could be related to measures of rainfall (annual average, and variation throughout the year). The depth of rainfall could be represented by the mean annual rainfall or any of the design rainfall intensities obtained from AR&R.

Two other measures of rainfall variability were also considered:

- the mean number of raindays per year; and
- the ratio of the maximum mean monthly rainfall to the minimum mean monthly rainfall.

The mean annual rainfall of a region is also a key determinant of the vegetation and may therefore act as an indicator of the native vegetation.

8.2.5 Evaporation

After rainfall, evaporation is the second most important component in the water cycle. The average evapotranspiration will determine the rate at which moisture is depleted from the soil and this should affect the average storm initial loss. In the past, the potential evapotranspiration (PET) has often been approximated from pan evaporation data because of the scarcity of climate data required to calculate PET directly. However, the problems with the use of pan data are well documented (eg. Watts and Hancock, 1985; Chiew and McMahon, 1992) and HydroTechnology (1995) derived maps of mean monthly PET and actual evapotranspiration (AET) for Victoria using the complementary procedure developed by Morton (1983). This enables PET and AET to be estimated for any location within Victoria without the need to use pan data, and PET estimated using this method was used in this study.

8.3 Soils

As previously mentioned, the assumed important role of infiltration in determining loss would indicate that the soil type should be an important factor in explaining the variability in observed losses. Many authors (such as Cordery and Pilgrim, 1983) have however been unable to find a link between the soil type and the loss. One of the main reasons for this failure is the present classification of soils.

8.3.1 Textural Classification of Soils

Very few parts of Australia have detailed soil surveys and those that have been done are often at too large a scale. By far the most readily accessible classification of Australian soils is found in the 'Atlas of Australian Soils' and the related explanatory notes, as described in Northcote (1971). The classification is based upon soil texture and is mainly relevant to agriculture. It provides little information on the hydraulic conductivity of the various soil classes. There are 725 profile classes in the atlas; the primary subdivision of soils is shown in Figure 8-1.

For this study, the predominant soil in each of the catchments was classified according to texture (listed in Appendix F).

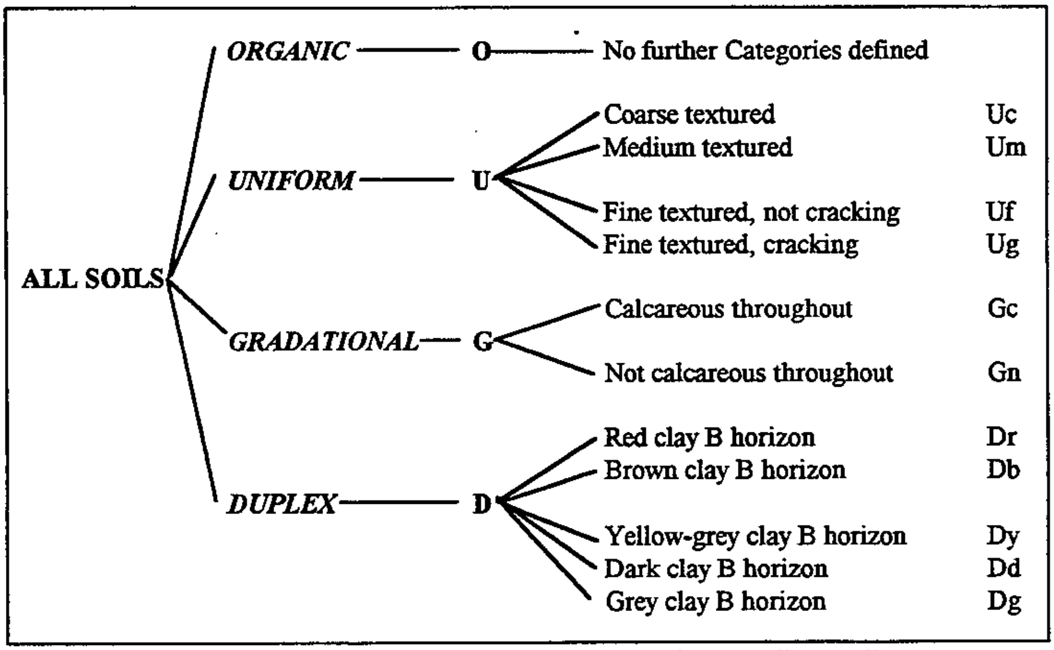

Figure 8-1 Primary Classification of Soils used in Atlas of Australian Soils (Northcote, 1971)

8.3.2 SCS Soil Classification

The United States Soil Conservation Service (SCS) has classified soils in the United States of America into four hydrologic groups (A, B, C, D) according to their infiltration rate (Table 8-1). A curve number is estimated from the hydrologic soil group, the treatment of the soil (effect of cultivated agricultural lands) and the hydrologic condition (the effect of vegetation density), to add more definition to the groupings.

Such a comprehensive hydrologic classification of Australian soils has not been undertaken to date. Eastgate et al. (1979) classified Queensland soils based upon their minimum infiltration and assigned a SCS hydrologic soil group. For Victoria, Milne (1976) assigned the soils in 11 catchments (7 of which are used in this present study) to a SCS hydrologic soil group.

Rajendran et al. (1982) used the SCS soil groups assigned by Milne (1976) and concluded that the textural classification can be linked to the SCS hydrologic soil groupings. This finding has not been followed up because of the difficulties in classifying soils into the four SCS soil groups.

8.3.3 Estimates of Saturated Hydraulic Conductivity

The hydraulic conductivity K is a measure of the ability of the soil to transmit water and should therefore be a strong indicator of loss. The "effective" hydraulic conductivity is usually approximated as a fraction of the saturated hydraulic conductivity K_s.

Table 8-1 SCS Hydrologic Soil Groups (after Rawls et al., 1993)

Group	Description	Texture	Transmission Rate (cm/h)
A	Low runoff potential and high infiltration rates even when thoroughly wetted and consist chiefly of deep, well to excessively drained sands or gravels.	sand, loamy sand, sandy loam	> 0.76
B	moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.	silt loam, loam	0.38 - 0.76
C	low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture.	sandy clay loam	0.13 - 0.38
D	High runoff potential, having very low infiltration rates when thoroughly wetted and consist mainly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over a nearly impervious material.	clay loam, silty clay loam, sandy clay, silty clay, clay	< 0.13

Many different authors have listed typical values of K_s for different textural classes; Table 8-2 gives some examples. These values overestimate the loss because they do not consider the effects of surface sealing and soil layering (Rajendran et al., 1982). The large variation in the listed typical values of K_s, and the difficulty in classifying the soils in a catchment in to one of the soils textures listed in Table 8-2, makes it extremely difficult to assign a typical value of K_s for a given catchment.

Table 8-2 Estimates of Saturated Hydraulic Conductivity

	Estimates of Saturated Hydraulic Conductivity (cm/min)				
Soil Texture	Li et al. (1976)	Brakensiek (1979)	Brakensiek et al. (1981)	McCuen et al., (1981)	Rawls et al., (1993)
Sand	1.056	0.38	0.504	0.410	0.393
Loamy Sand	0.938	0.64	1.318	1.316	0.100
Sandy Loam	0.208	0.10	0.315	0.299	0.036
Silty Loam	0.0432	0.0085	0.027	0.027	0.011
Loam	0.0417	0.019	0.109	0.100	0.022
Sandy Clay Loam	0.0378	0.026	0.082	0.079	0.0050
Silty Clay Loam	0.0102	0.020	0.019	0.018	0.0033
Clay Loam	0.0147	0.0054	0.064	0.061	0.0033
Sandy Clay	0.0130	0.0050	-	0.021	0.0020
Silty Clay	0.0062	0.0065	0.039	0.030	0.0017
Clay	0.0077	0.0078	0.020	0.018	0.0010

Many studies have found little relationship between the textural classification of soils used in the Atlas of Australian Soils (refer to Section 8.3.1) and hydraulic properties. Talsma and Hallam (1980) report that different samples of soil from one such classification had measured mean hydraulic conductivities which differed by more than an order of magnitude. This problem can only be overcome when the field criteria used for classifying soils have a logical physical connection with hydraulic properties (McKenzie and Jacquier, 1996).

McKenzie and Hook (1992) attempted to relate the soil classifications used in the Atlas of Australian Soils to an index of saturated hydraulic conductivity. They defined 4 crude classes of saturated hydraulic conductivity (Table 8-3), and assigned each of the 725 soils used in the Atlas of Australian Soils to one of the classes.

Table 8-3 Four Crude Classes of Saturated Hydraulic Conductivity
(after McKenzie and Hook, 1992)

Class	Saturated Hydraulic Conductivity	Nominal Rate
1	< 0.02 cm/h	Very slow
2	0.02 - 0.2 cm/h	slow
3	0.2 - 2.1 cm/h	moderate
4	> 2.1 cm/h	fast

Using the classification of McKenzie and Hook (1992), the soils in each of the 22 study catchments were assigned into a class of K_s, and mean losses are plotted against this class in Appendix F (using a weighted average value where several soil classes occur in a catchment). No relationship between the derived losses and the index of K_s was apparent.

McKenzie and Jacquier (1996) have measured functional morphology and K_s from 99 horizons from 36 sites in south eastern Australia. They found that useful predictors of K_s were possible using the readily measurable quantities: field texture, grade of structure, areal porosity, bulk density, dispersion index and horizon type. They conclude that a coarse level prediction of K_s is possible in routine soils surveys. It is hoped that this work will lead to better hydraulic descriptions of soils.

9. REGIONALISATION OF DERIVED LOSS VALUES

Based upon the discussion in the preceding chapter, physical catchment characteristics were examined in an attempt to explain the variation in the mean losses calculated in Chapter 5.

9.1 Exclusion of Data

Prior to the development of the prediction equations, the mean losses calculated for catchments with very few events or very large variability were excluded. The mean loss for the catchment was excluded from the analysis if the width of the 90 confidence interval was greater than twice the mean. This resulted in 2 catchments (Cobbannah Creek and La Trobe River) being excluded from the continuing loss calculations.

Because no confidence limits were calculated for the proportional loss (refer to Section 5.1), no such criteria could be adopted. The mean proportional loss for the Campaspe River was excluded because it was based on only 3 values.

9.2 Seasonally Adjusted Losses

In order to determine the effect of physical catchment characteristics on the loss, the effect of antecedent rainfall should first be removed. Antecedent rainfall was not extracted for each event, and only the general effect of antecedent rainfall, as expressed by the seasonal sinusoidal variation of losses noted in Section 5.2, had to be used to calculate seasonally adjusted losses. The parameters of the fitted curve are given in Table 5-1.

The loss for each event was divided by the ratio of the monthly mean to the yearly mean. This meant that, for events in late summer which have generally higher losses due to dry antecedent conditions, the losses were adjusted downwards; for events in late winter, which have generally wetter antecedent conditions, the losses were adjusted upwards. The mean adjusted losses were then used to develop the prediction equations.

The mean seasonally adjusted losses for each catchment are shown in Appendix G. The ratio of loss to adjusted loss reflects the seasonal distribution of storm events in the sample. It could not be related to any meteorological characteristics and there did not appear to be any spatial pattern. The mean of the adjusted losses were used in the derivation of regional equations.

9.3 Selected Catchment Characteristics

The selected catchment characteristics are shown in Table 9-1, and were used in the development of prediction equations. The characteristics for each catchment and the correlation between the individual characteristics are shown in Appendix G.

Table 9-1 Parameters Considered in Regression

Parameter	Description	Source
Area	Catchment area (km^2)	(former) RWC HYDSYS database
Slope	Mainstream slope between the 10 and 85 percentile of mainstream from the catchment outlet	Calculated from 100,000 topographic map
BFI	Baseflow index - the ratio of the volume of baseflow divided by the total streamflow volume	Calculated from streamflow data using a recursive digital filter
%forested	Percentage of catchment covered by forest (pine + dense + medium + scattered)	Measured from 100,000 topographic map
%dense+pine	Percentage of catchment covered by dense and pine forest	Measured from 100,000 topographic map
Infilt_1	Infiltration Index 1 (%forested x Ks_index)	
Infilt_2	Infiltration Index 2 (%forested x Ks_index/slope)	
MAR	Mean annual rainfall (mm)	Calculated from daily rainfall stations with greater than 20 years of record.
${}^{1}I_{2}, {}^{1}I_{48}$	1 year ARI design intensities for 2 and 48 hours	AR&R Vol. 2
${}^{50}I_{2}, {}^{50}I_{72}$	50 year ARI design intensities for 2 and 72 hours	AR&R Vol. 2
${}^{1}I_{48}/{}^{1}I_{2}$	Ratio of 1 year ARI 48 hour and 2 hour intensity	AR&R Vol. 2
${}^{50}I_{72}/{}^{50}I_{2}$	Ratio of 50 year ARI 72 hour and 2 hour intensity	AR&R Vol. 2
PET	Mean annual potential evapotranspiration (mm)	Victoria - HydroTechnology (1995) ACT - estimated from pan evaporation.
MAR-PET	Difference between mean annual rainfall and mean annual potential evapotranspiration (mm)	as above
Wet-days	Mean number of wet days per year	calculated from daily rainfall records.
RAINVar	Ratio of the maximum mean monthly rainfall to the minimum mean monthly rainfall	calculated from daily rainfall records
Ks_index	Index of saturated hydraulic conductivity estimated from soil texture (1-4)	McKenzie and Hook (1992) and Atlas of Australian Soils

In an attempt to find parameters which were strongly related to the mean losses, a number of different parameters which affect infiltration were combined. The first infiltration index was calculated by multiplying the percentage forested by the index of hydraulic conductivity. A second infiltration index was obtained by dividing the first infiltration index by the slope. The infiltration indices do not have any physical interpretation, but were created to see if parameters which influence infiltration were important in explaining the variation in mean losses.

The correlation between the mean seasonally adjusted losses and each of the catchment characteristics is shown in Table 9-2. This shows that the adjusted losses are most highly correlated with the baseflow index (BFI). The adjusted storm initial loss is negatively correlated with BFI which is consistent with wetter catchments generally having higher BFI and lower storm initial loss. The continuing and proportional loss are positively correlated with BFI which reflects the recharge of baseflow.

Table 9-2 Correlation between Mean Adjusted Losses and Catchment Characteristics

	$adj.IL_s$	$adj.CL$	$adj.PL$
Dense+Pine	-0.13	0.37	0.56
AREA	0.22	-0.29	-0.24
BFI	**-0.69**	**0.60**	**0.70**
${}^{1}I_2$	-0.31	0.57	0.36
${}^{1}I_{48}$	-0.31	0.12	0.15
${}^{50}I_2$	-0.08	0.51	0.24
${}^{50}I_{72}$	-0.10	-0.03	0.05
Forest	-0.08	0.21	0.54
Infilt_1	-0.25	0.13	0.25
Infilt_2	0.15	-0.31	-0.07
MAR	-0.48	0.19	0.27
MAR_PET	-0.35	0.00	0.25
MRIndex	-0.36	0.38	0.42
Slope	-0.38	0.39	0.36
PET	-0.09	0.38	-0.10
${}^{1}I_{48}/{}^{1}I_2$	-0.22	-0.10	0.03
${}^{50}I_{72}/{}^{50}I_2$	-0.10	-0.25	-0.03
Ks_index	-0.27	0.01	0.06
Wet_days	-0.06	-0.28	0.06

9.4 Development of Prediction Equations for Adjusted Losses

Given the relatively small number of values, and the large variability in losses, great care was taken in the development of the prediction equations to ensure that the selected independent parameters (and the sign of the coefficients) were consistent with the understanding of the physical process contributing to loss. It is also important that the equations produce reasonable results when extrapolated beyond the range of values used in this study. Because of the small sample, the prediction equations were limited to 1 or 2 independent parameters.

9.4.1 Storm Initial Loss

During the development of the prediction equations for storm initial loss, Cobbannah Creek and Campaspe River were consistently found to be statistical outliers. The mean seasonally adjusted storm initial losses for these two catchments were the largest of the 22 catchments analysed and no catchment characteristics could adequately predict the storm initial loss for these two catchments. It was therefore decided to remove them from the development of the prediction equations.

From a consideration of the independent parameters, the coefficient of determination and the standard error, Equation 9.1 was adopted. In Figure 9-1 the predicted seasonally adjusted storm initial losses are plotted against the mean calculated seasonally adjusted storm initial losses.

$$adj.IL_s = -25.8BFI + 33.8 \qquad r^2=0.55 \qquad SE=5.1 \qquad (9.1)$$

where: *BFI* is the baseflow index

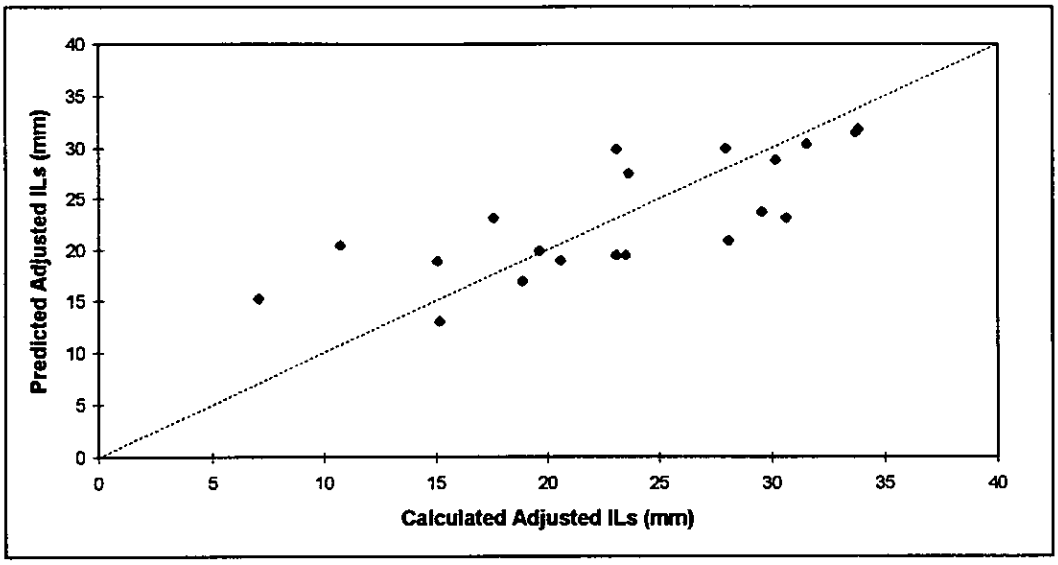

Figure 9-1 Predicted versus Calculated Seasonally Adjusted Storm Initial Loss

9.4.2 Continuing Loss

Prior to the development of the prediction equations, the mean adjusted continuing losses for the Campaspe and La Trobe Rivers were removed because of their very wide confidence limits. Equation 9.2 was developed and in Figure 9-2 the predicted seasonally adjusted continuing loss is plotted against the mean calculated seasonally adjusted continuing loss.

$$adj.CL = 7.97BFI + 0.00659PET - 6.00 \qquad r^2=0.60 \qquad SE=1.5 \qquad (9.2)$$

where: *BFI* is the baseflow index

PET is the mean annual potential evapotranspiration (mm)

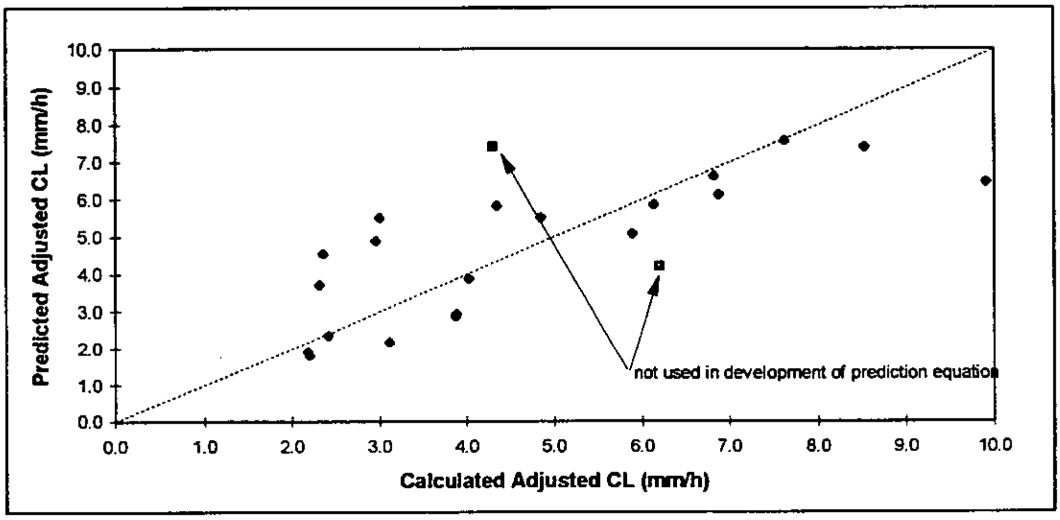

Figure 9-2 Predicted versus Calculated Seasonally Adjusted Continuing Loss

9.4.3 Proportional Loss

Prior to the development of the prediction equations, the mean adjusted proportional loss for the Campaspe River was removed because it was only based upon 3 values. During the development of the prediction equations the mean adjusted proportional loss for the

Lerderderg River was consistently found to be a statistical outlier and it was therefore also removed from the analysis.

Equation 9.3 was developed and in Figure 9-3 the predicted seasonally adjusted proportional loss is plotted against the calculated seasonally adjusted proportional loss.

$$adj.PL = 0.621BFI - 0.000175MAR + 0.662 \qquad r^2{=}0.71 \qquad SE{=}0.063 \qquad (9.3)$$

where: *BFI* is the baseflow index
MAR is the mean annual rainfall (mm)

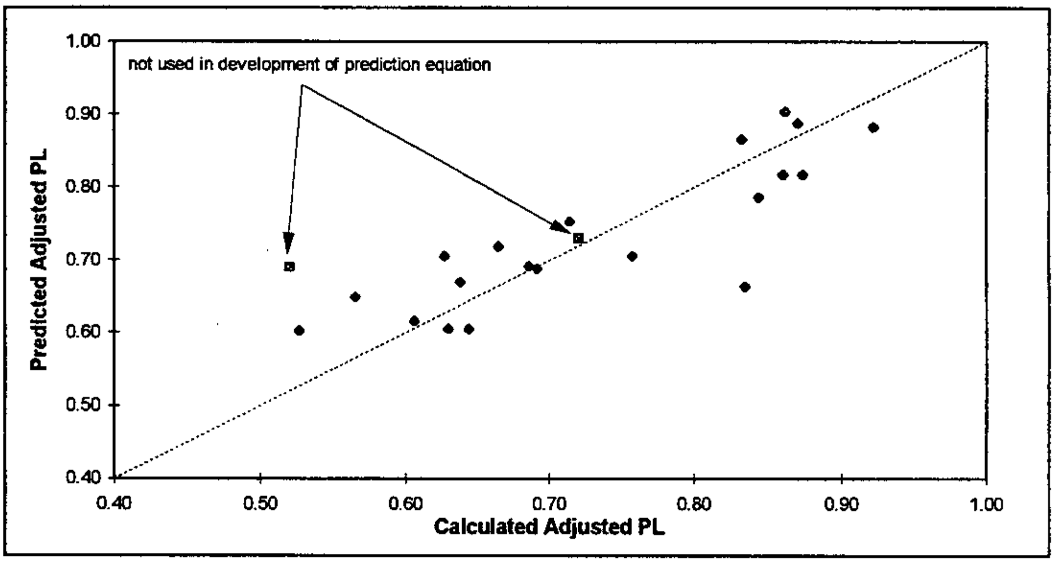

Figure 9-3 Predicted versus Calculated Seasonally Adjusted Proportional Loss

9.5 Application of the Prediction Equations

This study has shown that the storm initial loss and continuing loss vary significantly depending on the season in which the event occurs. The regional prediction equations have been derived using losses which have been adjusted to account for this seasonal variation. If the distribution of events is considered to be uniform throughout the year, the given loss values can be used without correction. However, if the uneven distribution of events found in the sample is considered to be typical, then the storm initial loss should be increased by 8 percent and the continuing loss should be increased by 5 percent.

The range of values used in the development of the prediction equations is shown in Table 9-3. Care should be taken when using the prediction equations for catchments with characteristics outside of the indicated range.

Table 9-3 Range of Values used in the Development of the Prediction Equations

Characteristic	Minimum	Maximum
BFI	0.08	0.81
PET (mm)	1000	1610
MAR (mm)	520	1880

As discussed in Section 9.4, during the development of the prediction equations, not all catchments were considered (some were excluded as outliers) and this implies that the prediction equations may not be applicable for all catchments. At this stage, there is no clear indication of any physical characteristics which may point to catchments for which the developed prediction equations do not apply.

9.6 Prediction of Baseflow Index for Ungauged Catchments

The Baseflow Index (BFI) has proven to be a useful indicator of catchment loss and has been used in all 3 prediction equations. It is however only directly available for gauged catchments.

Lacey (1996a,b) examined the scaling of baseflow; and in particular the prediction of BFI for ungauged catchments. Lacey (1996a) tested the hypothesis that, "A measure of the overall state of soil in a catchment is provided by the natural vegetation communities together with the underlying geology". It was assumed that changes in land use had not changed the hydraulic properties of the soils.

Lacey (1996a) estimated the native vegetation from the Land Conservation Council Victoria reports for different regions for Victoria. Where the native vegetation had been extensively cleared, the original coverage was estimated from nearby undisturbed areas. Lacey (1996b) then classified the native vegetation of the catchments using the following ecological vegetation classes:

- sub-alpine vegetation;
- montane vegetation;
- moist forests;
- dry forests.

Lacey (1996b) combined the ecological vegetation class with the underlying geology to form geology-vegetation classes and the mean BFI was calculated for each class. The geology-vegetation class was found to be useful in explaining approximately 85 percent of the variation in BFI. The geology-vegetation classes and mean BFI for each class are reproduced in Appendix G.

This work allows the prediction of BFI for ungauged catchments based upon the native vegetation, which is available from reports such as the Land Conservation Council Victoria Reports or from an inspection of the catchment, and the underlying geology which is readily available from 1:250,000 geological maps.

10. DESIGN FLOODS ESTIMATED USING NEW LOSSES

The testing of the new losses for design flood estimation is documented in Hill et al. (1996a). for the 11 catchments shown in Table 10-1; the smallest 8 of the catchments were also used to derive the losses.

Table 10-1 Catchments used to Verify Losses

Catchment	Area (km^2)	Gauging Station	Years of inst. peak flows	Rainfall (mm)
Goodman Ck above Lerderderg Tunnel	32	231219	25	800
Ford River @ Glenaire	56	235229	17	1520
Orroral River @ Crossing	90	410736	28	750
Aire River @ Wyelangta	90	235219	28	1880
Moonee Ck @ Lima	91	404208	33	1060
Wanalta Ck @ Wanalta	108	405229	35	540
Tarwin R East Branch @ Dumbalk Nth	127	227226	25	1140
Lerderderg River @ Sardine Ck	153	231213	36	1080
Moe River @ Darnum	214	226209	28	1050
Avon River @ Beazley's Bridge	259	415224	31	565
Seven Cks @ Euroa Township	332	405237	32	925

For each catchment, a flood frequency analysis was undertaken on the recorded peak flows. A RORB model was then calibrated for the catchment using the recorded pluviograph and streamflow data. Hill et al. (1996a) gives details of both the flood frequency analysis and the calibration of the RORB models.

Equations 9.1, 9.2 and 9.3 were used to calculate losses for the 11 catchments and Equation 6.1 was used to calculate the variation of initial loss with duration. The losses were applied to the design rainfalls in AR&R in conjunction with the new areal reduction factors (ARFs) for Victoria derived by Siriwardena and Weinmann (1996). The rainfall excesses were routed through the catchment using the calibrated RORB models, and the baseflow was then added to the peak surface runoff. The resulting design peak flow was compared to that obtained from the flood frequency analysis.

The application of the new IL/CL values with the new ARFs and unfiltered AR&R temporal patterns removed the consistent overestimation observed using the design values from AR&R. For an AEP of 1 in 10, 9 of the 11 catchments had peak flows that were within 25 percent of those from the flood frequency analysis. For an AEP of 1 in 50, 8 of the catchments had a difference in flows of less than 28 percent.

The application of the new IL/PL values with the new ARFs and unfiltered AR&R temporal patterns produced peak flows which were consistently lower than those obtained from the flood frequency analysis. The runoff coefficient (RC=1-PL) was increased until the bias was removed; by 50 percent for an AEP of 1 in 10 and by 80 percent for an AEP of 1 in 50. This is a significant limitation to the use of the IL/PL model for design.

11. CONCLUSION

11.1 Summary

11.1.1 Limitations of Existing Losses

Australian Rainfall and Runoff, 1987 (AR&R) identifies two inadequacies in the current loss values, most of which were derived from analyses of large flood events (for example those used to calibrate runoff routing models). These are:

i. The selection of high runoff events for loss derivation is biased towards wet antecedent conditions (ie. losses tend to be too low);

ii. Storm losses do not account for the nature of design rainfalls, which have been derived from bursts within longer duration storms (ie. losses tend to be too high).

These two sources of error do not compensate each other. Studies by Walsh et al. (1991), Hill and Mein (1996) and Hill et al. (1996a) have shown that the use of the design rainfall and loss information contained in AR&R results in overestimation of the design peak flow for a specified AEP.

A methodology has been outlined in this report for deriving design losses which overcome the basic incompatibility between design rainfalls and losses used for design flood estimation. Losses have been calculated for rainfall bursts (not complete storms) which have been selected in a manner consistent with that used to select the rainfall bursts used to derive the design rainfall temporal patterns in AR&R.

11.1.2 Calculation of Losses from the Empirical Analysis of Data

Losses were calculated for all bursts of rainfall which have an average recurrence interval of greater than 1 year, for 18 Victorian catchments and 4 catchments from the ACT. A total of 1,059 rainfall bursts were analysed from a total of 408 unique storms. Losses were calculated for both the initial loss-continuing loss and initial loss-proportional loss models.

A strong seasonal variation in the calculated losses was observed. Because the number of events for individual catchments was not sufficient to study the seasonal variation of losses, the losses were standardised by dividing by the mean for the catchment. The month of the year explained up to 80 percent of the variation in the standardised losses.

The initial loss for the embedded rainfall burst was also calculated This depends upon the storm initial loss and the location of the burst within the complete storm. The burst initial loss was highly variable and was therefore expressed as a proportion of the storm initial loss.

A prediction equation was developed which calculates the burst initial loss as a function of the storm initial loss, the burst duration and the mean annual rainfall. The initial loss for the burst increases with duration because, for the shorter durations, many of the bursts are embedded within longer duration storms, and for the longer durations, many of the bursts represent complete storms.

A preliminary examination was undertaken to ascertain if there was any trend of the losses with average recurrence interval. In light of the high variability in losses and the lack of extreme events recorded, it was not possible to draw any conclusions as to how losses vary with rainfall severity.

11.1.3 Regionalisation

A number of climatic and physical catchment characteristics were examined to develop prediction equations for the derived losses. Previous studies have been largely unsuccessful in relating losses at catchment scale to physical characteristics, because of the dominance of antecedent conditions, the uncertainty in the estimate of average catchment rainfall, the spatial variation of catchment characteristics and the lack of information on the hydraulic properties of soils.

Prediction equations have been developed for the losses for use in south-eastern Australia. The baseflow index (the fraction of the total streamflow which is baseflow) was found to be significant in explaining the variability in the calculated losses. The geology-vegetation index defined by Lacey (1996b) is recommended for estimating the baseflow index for ungauged catchments (Appendix G).

11.1.4 Testing of New Losses for Design Flood Estimation

Design peak flows were estimated for 11 catchments. The predicted losses were applied to the design rainfalls in AR&R in conjunction with the new areal reduction factors for Victoria calculated by Siriwardena and Weinmann (1996). The rainfall excess was routed through the catchment using calibrated RORB models and the calculated design peak flows compared with those from a flood frequency analysis.

The application of the new IL/CL values with the new ARFs and unfiltered AR&R temporal patterns removed the consistent overestimation observed using the design values from AR&R. For an AEP of 1 in 10, 9 of the 11 catchments had peak flows that were within 25 percent of those from the flood frequency analysis. For an AEP of 1 in 50, 8 of the catchments had a difference in flows of less than 28 percent.

The application of the new IL/PL values with the new ARFs and unfiltered temporal patterns produced peak flows which were consistently lower than those obtained from the flood frequency analysis. The runoff coefficient (RC=1-PL) was increased until the bias was removed; by 50 percent for an AEP of 1 in 10 and by 80 percent for an AEP of 1 in 50. This is a significant limitation to the use of the IL/PL model for design.

The verification of design losses is dependent upon the choice of all of the key inputs in the modelling process. Different assumptions about any of the key inputs, such as the filtering of temporal patterns, ARFs or runoff-routing model characteristics, could affect the conclusions.

11.2 Recommended Design Losses

The new design losses are recommended for design flood estimation for south-eastern Australia on the basis that:

- they are based on a detailed study using methodology that is consistent with the derivation of design rainfalls;
- they incorporate plausible relationships with catchment and climatic characteristics, and rainfall duration;
- they produce satisfactory results when tested on 11 representative catchments in the region.

The losses are recommended for use with unfiltered temporal patterns and the new ARFs for long duration with the interim recommendations for short durations (Siriwardena and Weinmann, 1996).

Storm Initial Loss

The storm initial loss should be estimated using Equation 11.1.

$$IL_s = -25.8BFI + 33.8 \qquad r^2=0.55 \qquad SE=5.1 \qquad (11.1)$$

where: *BFI* is the baseflow index

Burst Initial Loss

The burst initial loss should be calculated for each duration using Equation 11.2.

$$IL_b = IL_s\left\{1 - \frac{1}{1 + 142\dfrac{\sqrt{(duration)}}{MAR}}\right\} \qquad (11.2)$$

where: IL_s is the storm initial loss estimated using Equation 11.1
MAR is the mean annual rainfall (mm)
duration is the design duration (hours)

Continuing Loss

The continuing loss should then be calculated using Equations 11.3.

$$CL = 7.97BFI + 0.00659PET - 6.00 \qquad r^2=0.60 \qquad SE=1.5 \qquad (11.3)$$

where: *BFI* is the baseflow index;
PET is the mean annual potential evapotranspiration (mm);

Runoff Coefficient

If the IL/RC model is to be used for design, the runoff coefficient should be estimated using Equation 11.4.

$$RC = -0.621BFI + 0.000175MAR + 0.338 \qquad r^2=0.71 \qquad SE=0.063 \qquad (11.4)$$

$$\text{AEP of 1 in 10} \quad RC_{10} = 1.5 \times RC$$

$$\text{AEP of 1in 50} \quad RC_{50} = 1.8 \times RC$$

where: BFI is the baseflow index;
MAR is the mean annual rainfall (mm).

The runoff coefficient needs to be increased by 50 percent for an AEP of 1 in 10 and by 80 percent for an AEP of 1 in 50. The runoff coefficient should be increased by a corresponding amount for other AEPs.

Adjustment for Season

This study has shown that the storm initial loss and continuing loss vary significantly depending on the season in which the event occurs. The regional prediction equations have been derived using losses which have been adjusted to account for this seasonal variation. If the distribution of events is considered to be uniform throughout the year, the given loss values can be used without correction. However, if the uneven distribution of events found in the sample is considered to be typical, then the storm initial loss should be increased by 8 percent and the continuing loss should be increased by 5 percent.

11.3 Future Work

Design losses should be derived for other regions of Australia using the methodology outlined in this report. Further testing and verification will also be required.

There still remains a difference of up to 60 percent between the rainfall based estimate and that from a flood frequency analysis for an AEP of 1 in 50. Further work is required to investigate the reason for this discrepancy.

The use of the IL/RC values derived in this study, resulted in the underestimation of design flows. The use of the IL/RC model for design requires further work.

This study does not address the issue of losses for extreme events such as the PMP. The empirical analysis of data is limited by the high variability in losses and the lack of extreme events which have concurrent streamflow and rainfall records. The most promising approach is to examine the rainfall antecedent to extreme bursts of rainfall (such as the GSAM database).

A recursive digital filter was used in this study to separate the baseflow from the total streamflow hydrograph. More work is required on suitable parameters of the filter for separating flood hydrographs.

This study derived losses which were consistent with the design rainfalls contained in AR&R. It is however unlikely that separate analyses of the component factors which are used in the design flood estimation procedure will produce estimates that match those from a frequency analysis of recorded peak flows. A holistic approach is expected to produce the next significant improvement in design flood estimation procedures.

12. REFERENCES

Avery, D. (1986) *Master of Engineering Science Project Report*. School of Civil Engineering, The University of New South Wales.

Brakensiek, D.L., (1979) Comments on Empirical Equations for some Soil Hydraulic Properties by R.B. Clapp and G.M. Hornberber, *Water Resources Research*, Vol. 15, pp 989-992.

Brakensiek, D.L., Engleman, R.L., Rawls, W.J., (1981) Variation within Texture Classes of Soil Water Parameters. *Transactions of the American Society of Agricultural Engineers*, Vol. 24, pp 335-338.

Chiew, F.H.S., McMahon, T.A., (1992) An Australian Comparison of Penman's Potential Evapotranspiration Estimates and Class A Evaporation Pan Data, *Australian Journal of Soil Research*, Vol. 30, pp 101-112.

Cordery, I., (1970) Antecedent Wetness for Design Flood Estimation, *Civil Engineering Transaction*, Institution of Engineers, Australia, 1970, Vol. CE12 No. 2, pp 181-184.

Cordery, I., Webb, S.N. (1974) Flood Estimation in Eastern New South Wales - A Design Method. *Civil Engineering Transactions*, Institution of Engineers Australia, Vol. CE16 pp 87-93.

Cordery, I., Pilgrim, D.H., (1983) On the Lack of Dependence of Losses from Flood Runoff on Soil and Cover Characteristics, *IAHS Pub.* No. 140, pp 187-195.

Cordery, I., Pilgrim, D.H., Doran, D.G., (1983) Some Hydrological Characteristics of Arid Western New South Wales. *Hydrology and Resources Symposium*. I.E.Aust. Nat. Conf. Pub. No. 83/13, pp 287-292.

Eastgate, W.I., Swartz, G.L.. Briggs, H.S., (1979) *Estimation of Runoff Rates for Small Queensland Catchments*, Department of Primary Industries, Queensland Technical Bulletin No. 15.

Hill, P.I., (1994) *Catalogue of Hydrologic Data for Selected Victorian Catchments* Cooperative Research Centre for Catchment Hydrology Working Document No. 94/1

Hill, P.I., Mein, R.G., (1996) Incompatibilities between Storm Temporal Patterns and Losses for Design Flood Estimation, *Hydrology and Water Resources Symposium, Hobart*, I.E.Aust. Nat. Conf. Pub. No. 96/05 pp. 445-451.

Hill, P.I., Mein, R.G., Weinmann, P.E., (1996a) *Testing of Improved Inputs for Design Flood Estimation in South-Eastern Australia*. CRC for Catchment Hydrology Report 96/6.

Hill, P.I., Maheepala, U., Mein, R.G., (1996b) *Empirical Analysis of Data to Derive Losses: Methodology, Programs and Results*. CRC for Catchment Hydrology Working Document 96/5.

HydroTechnology (1994) *Catchment Characteristics for Selected Victorian Catchments*, Department of Conservation and Natural Resources - Victoria.

HydroTechnology (1995) *Derivation of Mean Monthly Evaporation Estimates for Victoria*, Department of Conservation and Natural Resources - Victoria.

HYDSYS, (1994) *HYDSYS User Manual Release 5*, HYDSYS Pty Ltd.

Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff*, Vol. 1&2. (Ed: Pilgrim, D.H.) Institution of Engineers, Australia.

Kennedy, M.R., Turner, L.H. Canterford, R.P. Pearce, H.J., (1991) Temporal Distributions within Rainfall Bursts, *HRS Report* No. 1, Hydrometeorological Advisory Service, Melbourne.

Knee, R., (1986) *Derived Loss Parameters in the ACT.* First Report. Hydrology and Water Resources Unit, Department of Territories, H.W.R. No 86/15, September.

Lacey, G.C., (1996a) *The Scaling of Baseflow.* CRC for Catchment Hydrology. Working Document 96/1.

Lacey, G.C., (1996b) *A Dimensionless Approach to Relate Baseflow and Catchment Characteristics.* CRC for Catchment Hydrology Report. In press.

Land Conservation Council Victoria, (1976) *Report on Corangamite Study Area,* Melbourne.

Land Conservation Council Victoria, (1977) *Report on Alpine Study Area,* Melbourne.

Land Conservation Council Victoria, (1978) *Report on the North Central Study Area,* Melbourne.

Land Conservation Council Victoria, (1978) *Report on the South-Western Area, District 2,* Melbourne.

Land Conservation Council Victoria, (1980) *Report on South Gippsland Study Area,* District 2, Melbourne.

Land Conservation Council Victoria, (1982) *Report on Gippsland Lakes Hinterland Area,* Melbourne.

Land Conservation Council Victoria, (1985) *Report on Melbourne Area District 1 Review,* Melbourne.

Laurenson, E.M., Mein, R.G., (1995) RORB - version 4 Runoff Routing Program incorporating RORB Windows Interface. Monash University, Department of Civil Engineering.

Li, E.A., Shanholtz, V.O., Carson, E.W., (1976) *Estimating Saturated Hydraulic Conductivity and Capillary Potential at the Wetting Front,* Department of Agricultural Engineering, Va. Polytech. Inst. and State Univ., Blacksburg, Report.

McCuen, R.H., Rawls, W.J., Brakensiek, D.L., (1981) Statistical Analysis of the Brooks-Corey and the Green-Ampt Parameters across Soil Textures, *Water Resources Research,* Vol. 17, pp 1005-1013.

McKenzie, N., Hook, J., (1992) *Interpretations of the Atlas of Australian Soils,* Consulting Report to the Environmental Resources Information Network (ERIN), CSIRO Division of Soils, Canberra, Unpublished Report.

McKenzie, N., Jacquier, D., (1996) *Improving the Field Estimation of Hydraulic Properties in Soil Survey, I - Saturated Hydraulic Conductivity,* CSIRO Division of Soils, Divisional Report. (In press).

Mein, R.G., O'Loughlin, E.M., (1991) A New Approach to Flood Forecasting, *Hydrology and Water Resources Symposium, Perth.* I.E.Aust. Nat. Conf. Pub. No. 91/12, pp. 219-224.

Mein, R.G., Nandakumar, N., Siriwardena, L., (1995) *Estimation of Initial Loss from Soil Moisture Indices (Pilot Study)* CRC for Catchment Hydrology Working Document 95/1.

Milne, F.J., (1976) *A Descriptive Catalogue of the Australian Representative Basins, 1975*, Australian Water Resources Council, Department of Natural Resources, AGPS, Canberra.

Morton, F.I., (1983) Operational Estimates of Areal Evapotranspiration and their Significance to the Science and Practice of Hydrology, *Journal of Hydrology*, Vol. 66 pp 1-76.

Nandakumar, N., Mein, R.G., Siriwardena, L., (1994) *Loss Modelling for Flood Estimation - A Review*. CRC for Catchment Hydrology Report 94/4.

Nathan, R.J., Weinmann, P.E., (1993) *Low Flow Atlas for Victorian Streams*, Drought Management Plan for Victoria's Water Resources, Long Term Planning Guidelines Background Report - L3, Department of Conservation and Natural Resources - Victoria.

Northcote, K.H., (1971) *A Factural Key for the Recognition of Australian Soils*, Rellim Technical Publications, South Australia.

Pilgrim, D.H., Robinson, D.K., (1988) Flood Estimation in Australia - Progress to the Present, Possibilities for the Future, *Civil Engineering Transactions*, CE30, pp. 187-206.

Rawls, W.J., Ahuja, L.R., Brakensiek, D.L., Shirmohammadi, A., (1993) Infiltration and Soil Water Movement, In: *Handbook of Hydrology*, (ed) D.R. Maidment, McGraw-Hill, Inc.

Rajendran, R., Mein, R.G., Laurenson, E.M., (1982) *A Spatial Model for the Prediction of Losses on Small Rural Catchments*, Department of Civil Engineering, Monash University, Australian Water Resources Council Technical Paper No. 75, AGPS, Canberra.

Rowbottom, I.A., Pilgrim, D.H., Kennedy, M.R., Cordery, I. (1986) Suitability of ARR Rainfall Temporal Patterns for Design Flood Estimation, *Hydrology and Water Resources Symposium, Brisbane*. I.E.Aust. Nat. Conf. Pub. No 86/13 pp. 328-333.

Siriwardena, L., Mein, R.G., (1996) Development and Testing of a Variable Proportional Loss Model *Hydrology and Water Resources Symposium, Hobart*, , I.E.Aust. Nat. Conf. Pub. No. 96/05 pp. 709-710.

Siriwardena, L., Weinmann, P.E., (1996) *Development and Testing of Methodology to Derive Areal Reduction Factors for Long Duration Rainfalls*. CRC for Catchment Hydrology Report. In press.

Srikanthan, R., Kennedy, M.R., (1991) Rainfall Antecedent to Storm Bursts from which Temporal Patterns were Derived for "Australian Rainfall and Runoff", *International Hydrology and Water Resources Symposium, Perth*, I.E.Aust. Nat. Conf. Pub. No. 91/19, pp. 280-282.

Talsma, T., Hallam, P.M., (1980) Hydraulic Conductivity Measurement of Forest Catchments. *Australian Journal of Soil Research*, Vol. 30, pp 139-148.

Walsh, M.A., Pilgrim, D.H., Cordery, I., (1991) Initial Losses for Design Flood Estimation in New South Wales. *International Hydrology and Water Resources Symposium, Perth*, I.E.Aust. Nat. Conf. Pub. No. 91/19, pp. 283-288.

Watts, P.J., Hancock, N.H., (1985) Evaporation and Potential Evaporation - A Practical Approach for Agricultural Engineers, *Mechanical Engineering Transactions*, Institution of Engineers, Australia, Vol. ME10 No. 4, pp 231-240.

Waugh, A.S. (1991) Design Losses in Flood Estimation, *International Hydrology and Water Resources Symposium, Perth*. I.E.Aust. Nat. Conf. Pub. No. 91/19, pp. 629-630.

Appendix A

CATCHMENT INFORMATION

List of Figures

List of Tables

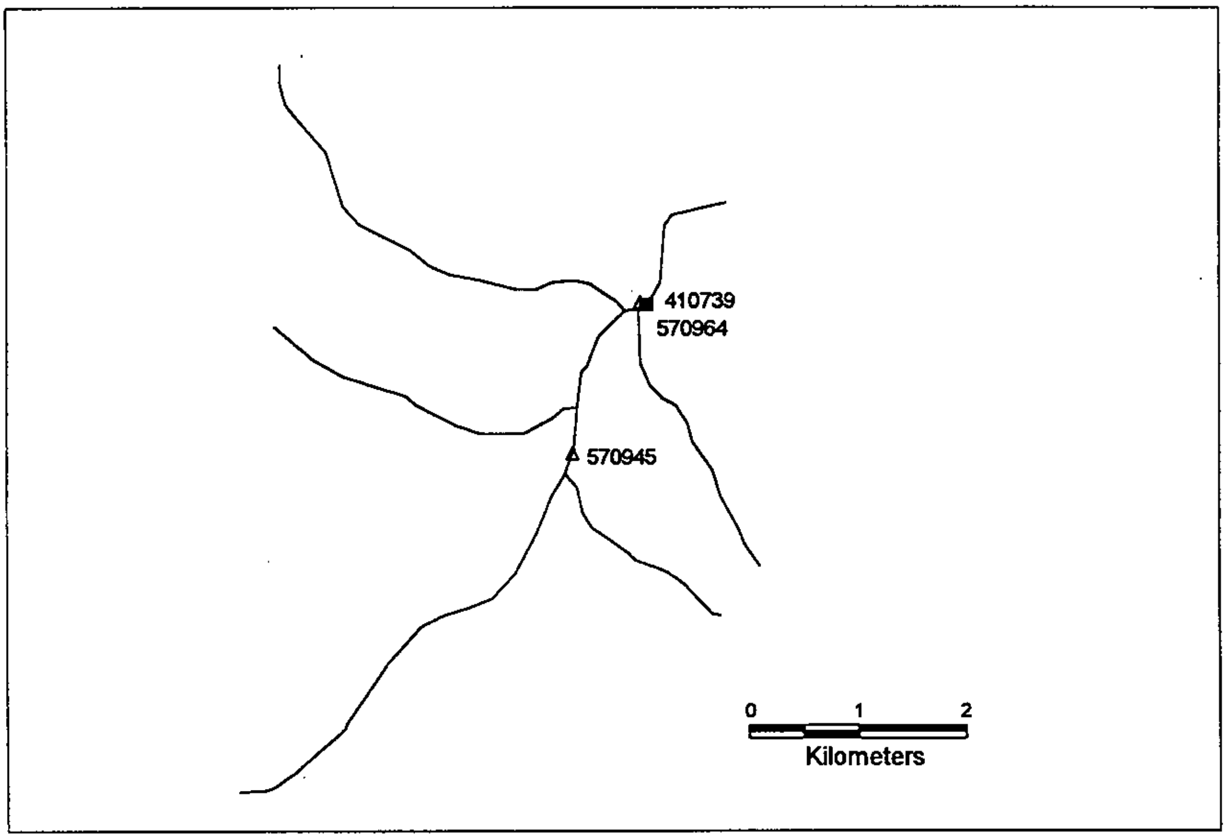

Figure A.1 Tidbinbilla Ck @ Mountain Creek

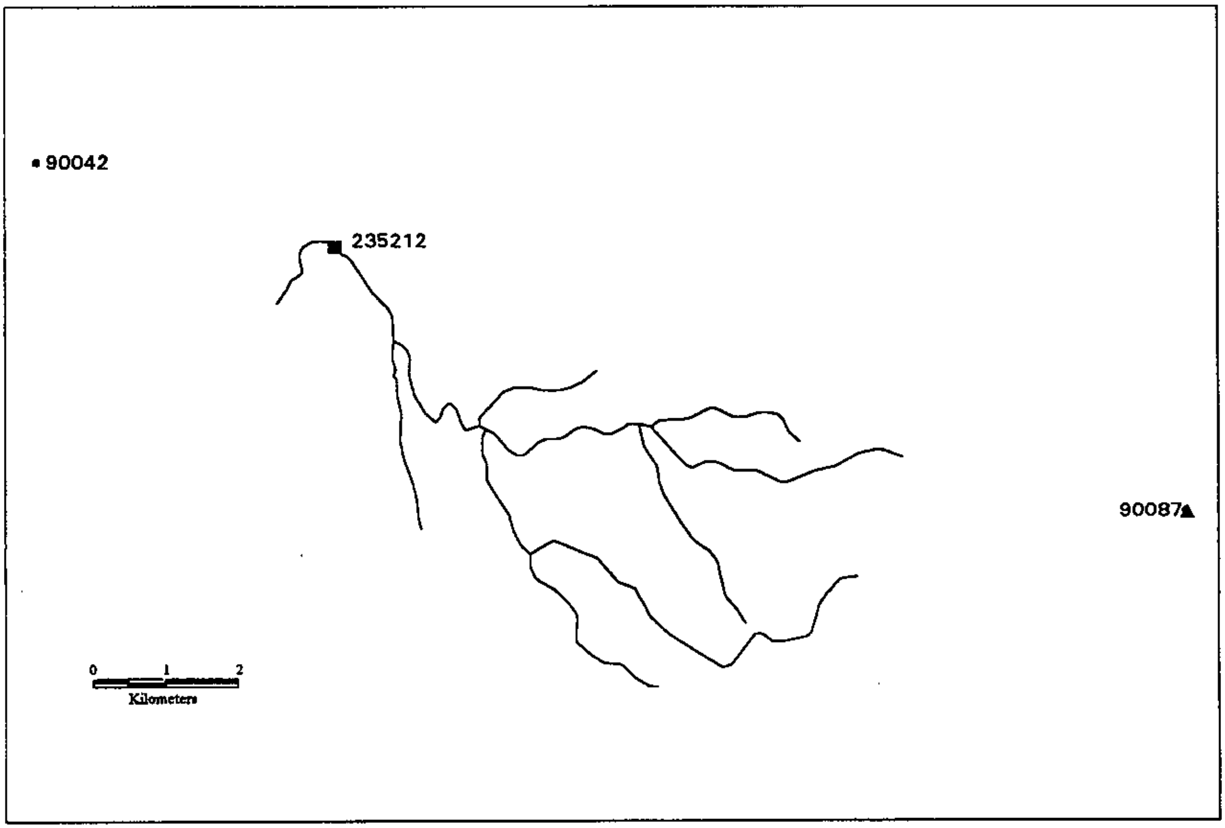

Figure A.2 Chapple Ck @ Chapple Vale

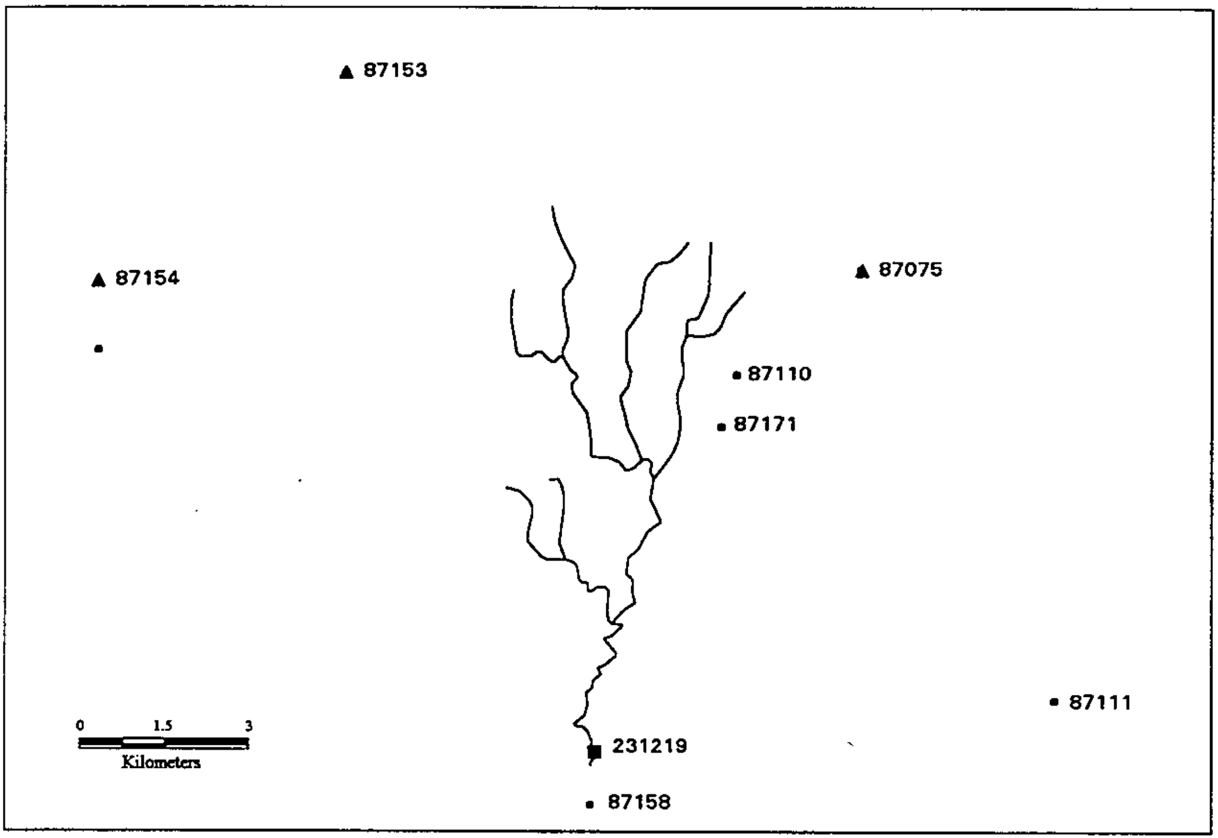

Figure A.3 Goodman Ck above Lerderderg Tunnel

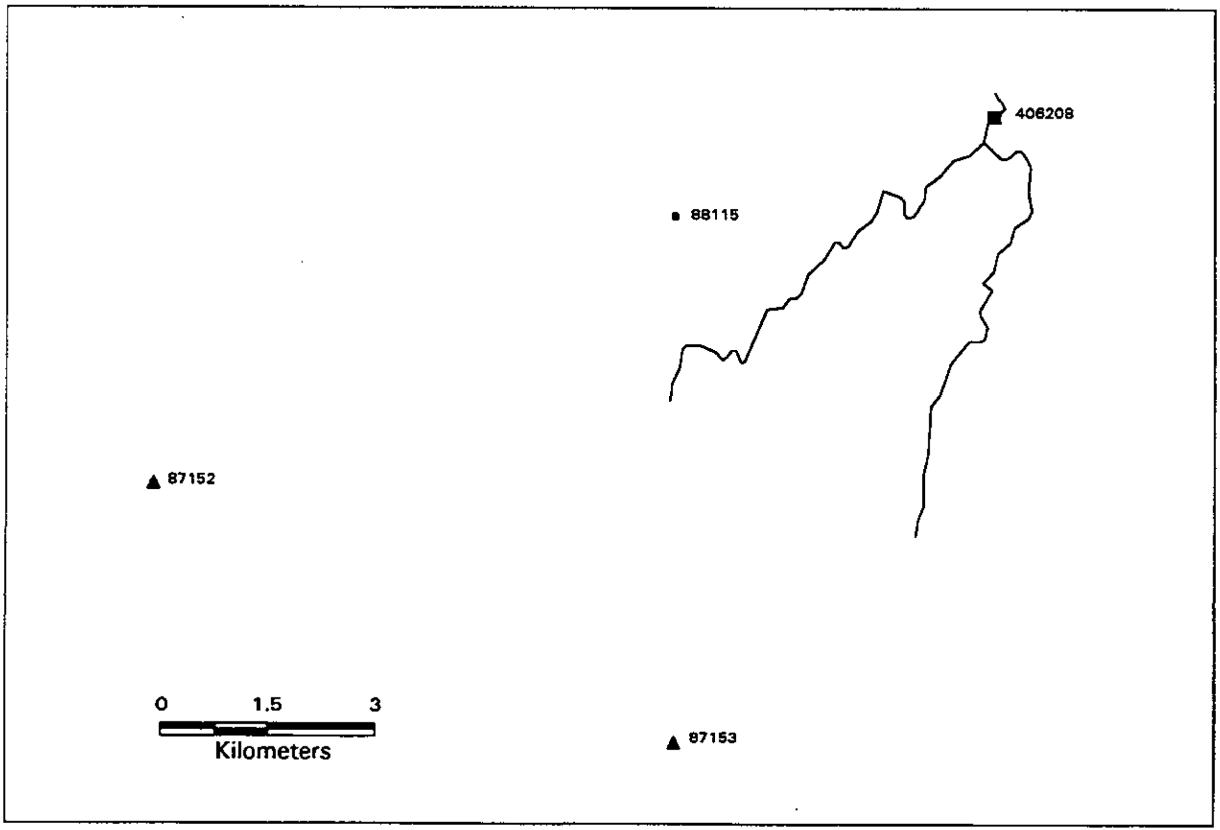

Figure A.4 Campaspe River @ Ashborne

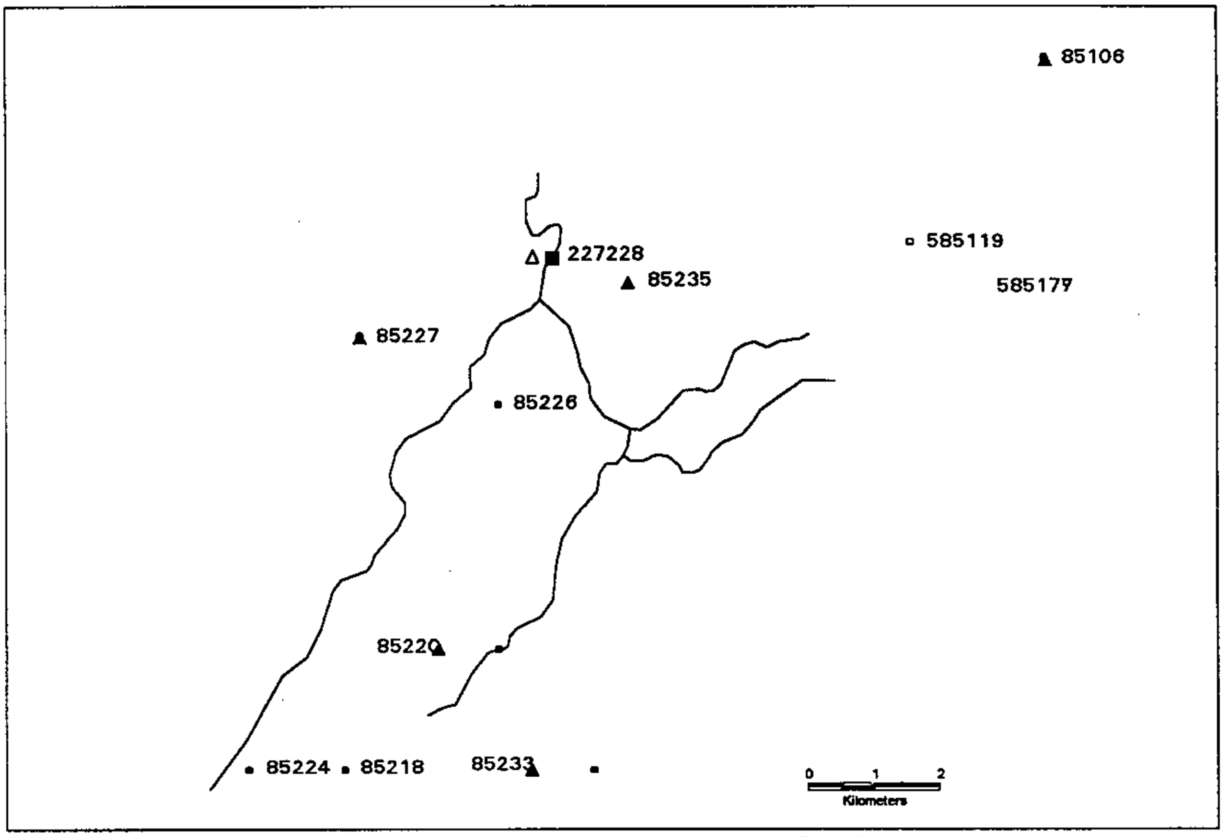

Figure A.5 Tarwin River East Branch @ Mirboo

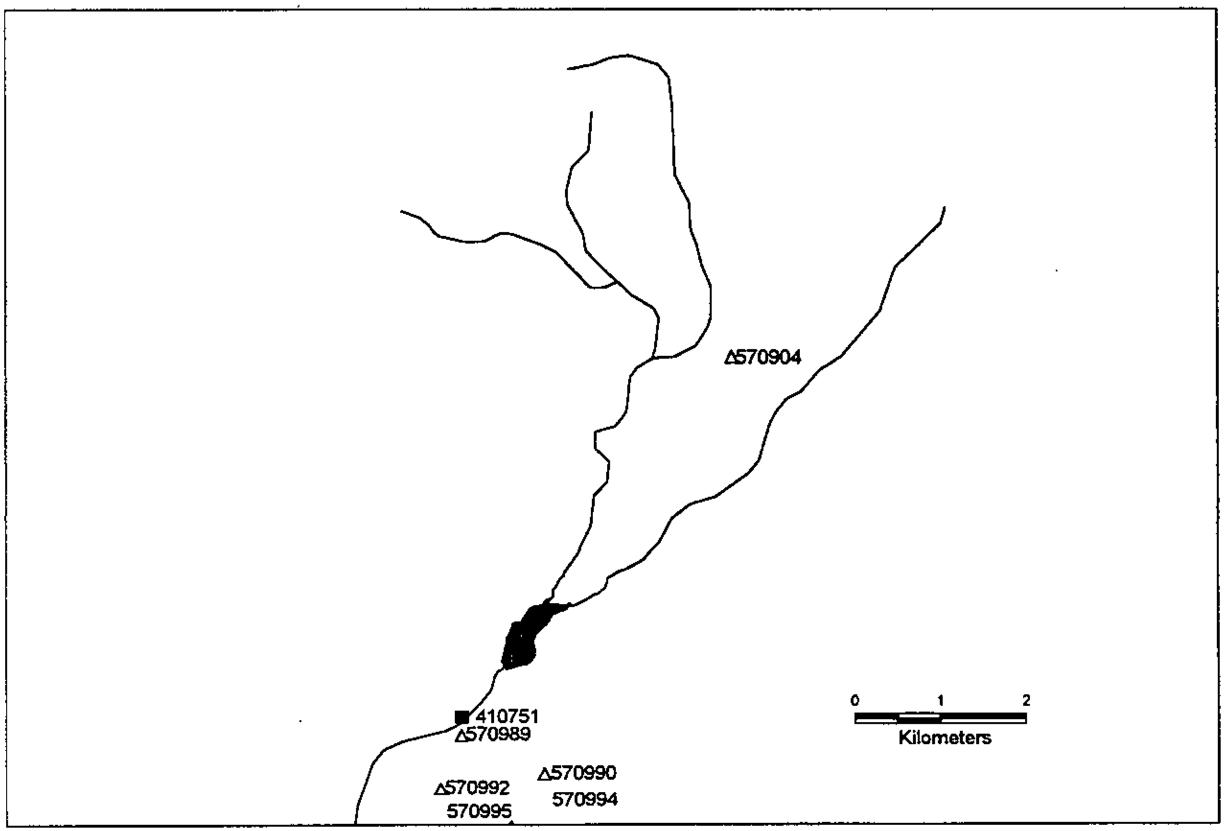

Figure A.6 Ginninderra Ck u/s Barton Highway

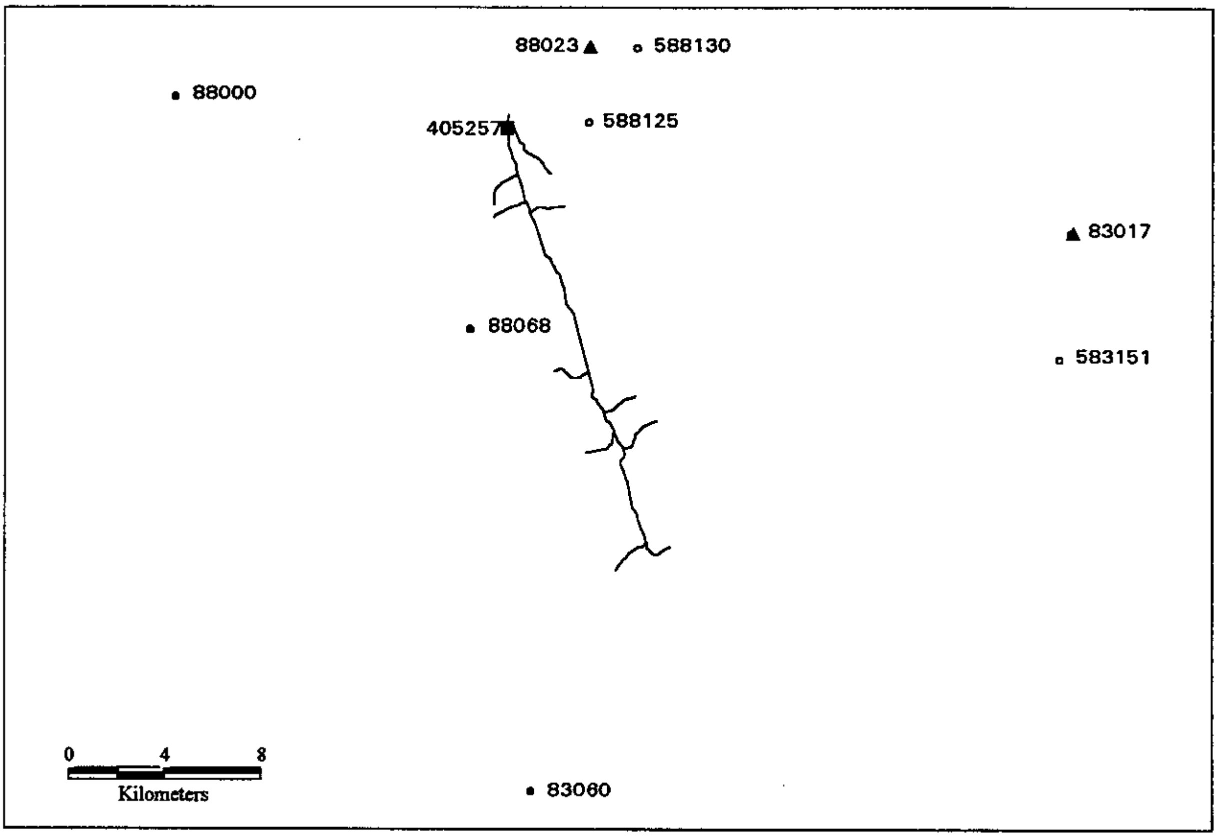

Figure A.7 Snobs Ck @ Snobs Ck Hatchery

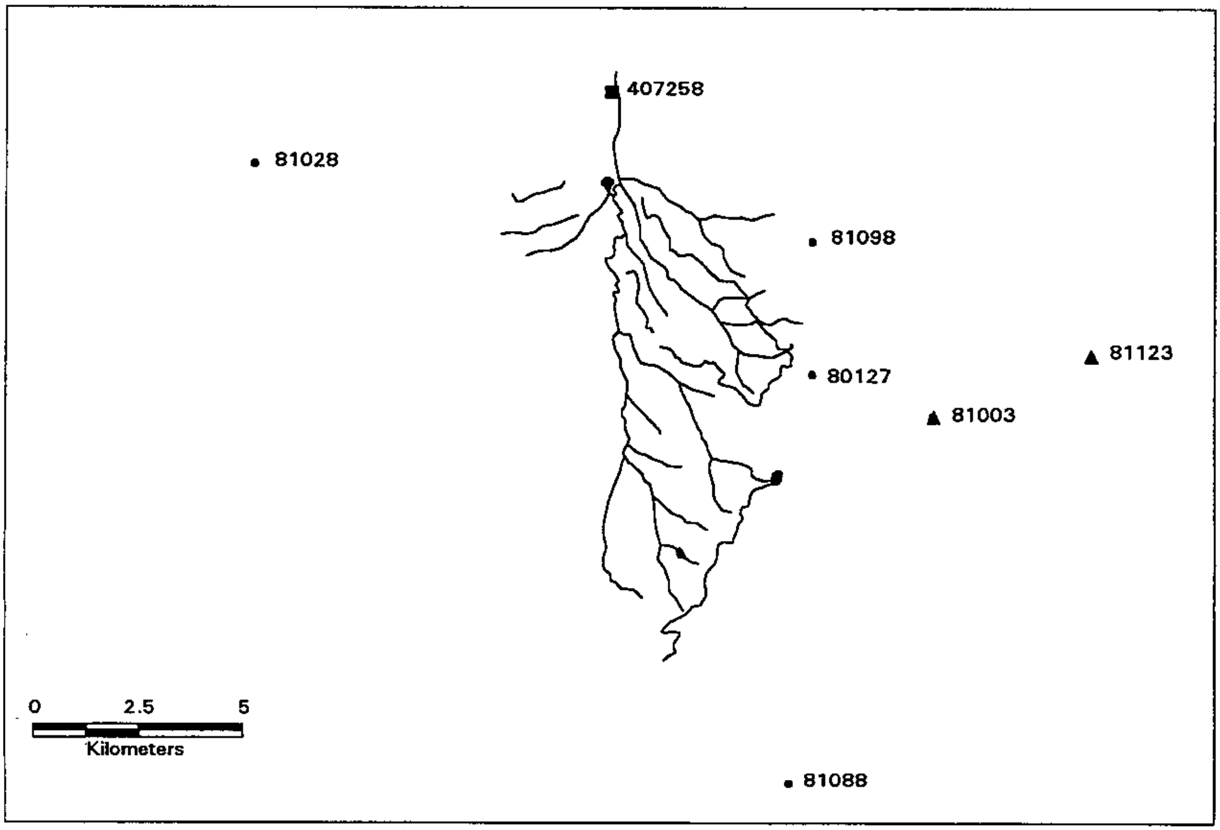

Figure A.8 Myers Ck @ Myers Flat

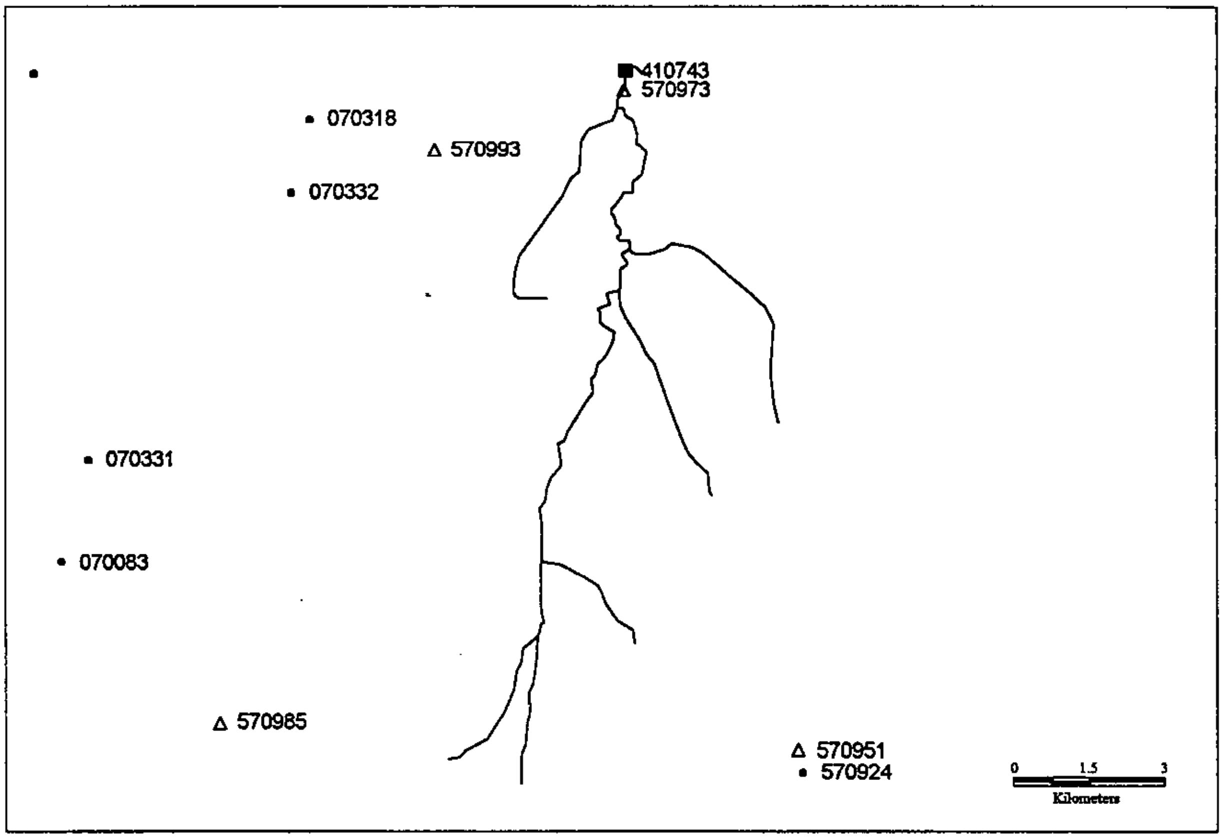

Figure A.9 Jerrabomberra Ck @ Four Mile Creek

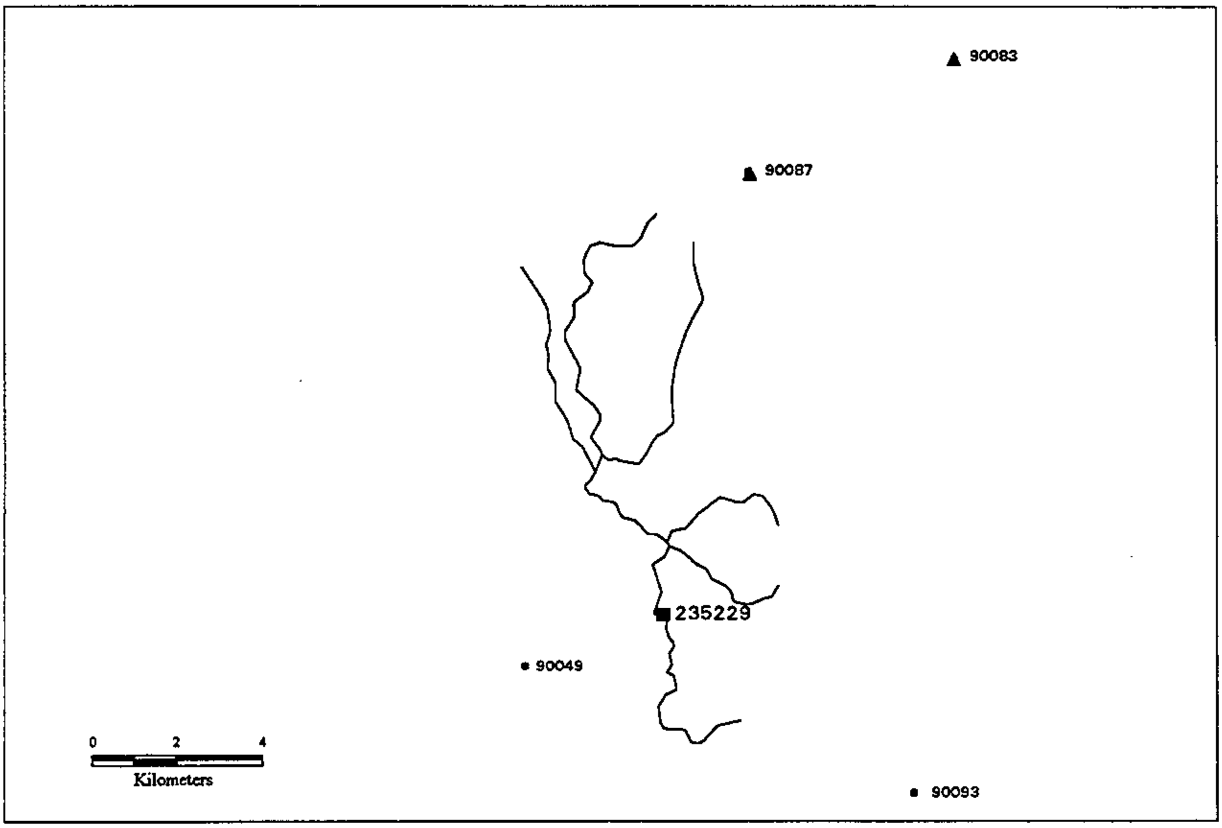

Figure A.10 Ford River @ Glenaire

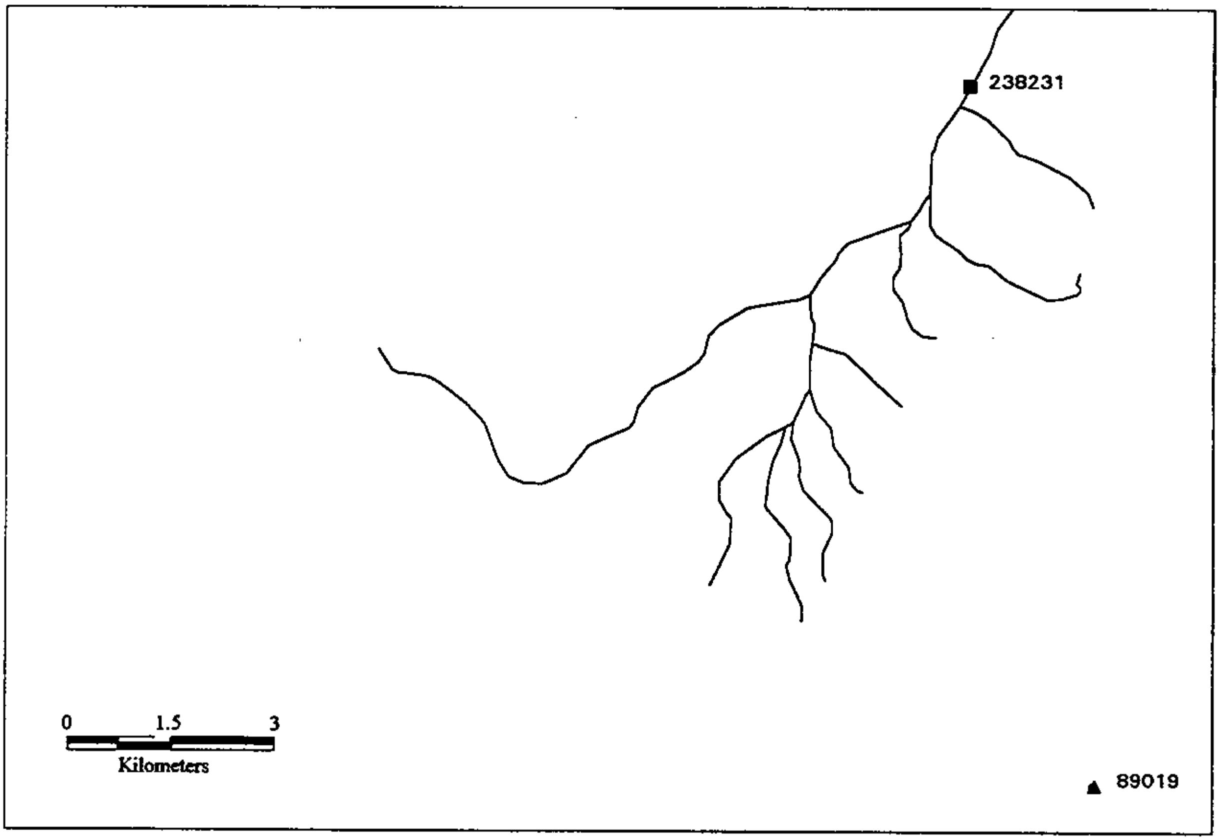

Figure A.11 Glenelg River @ Big Cord

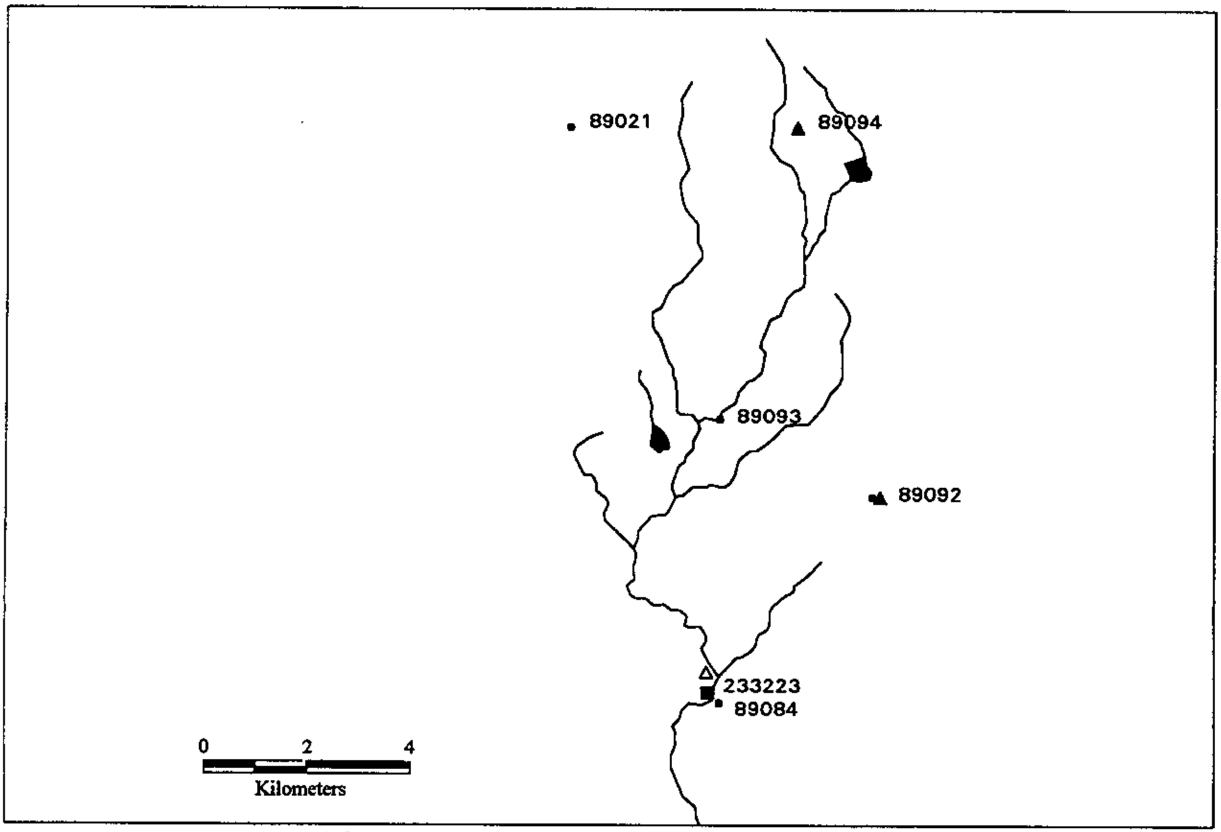

Figure A.12 Warrambine Ck @ Warrambine

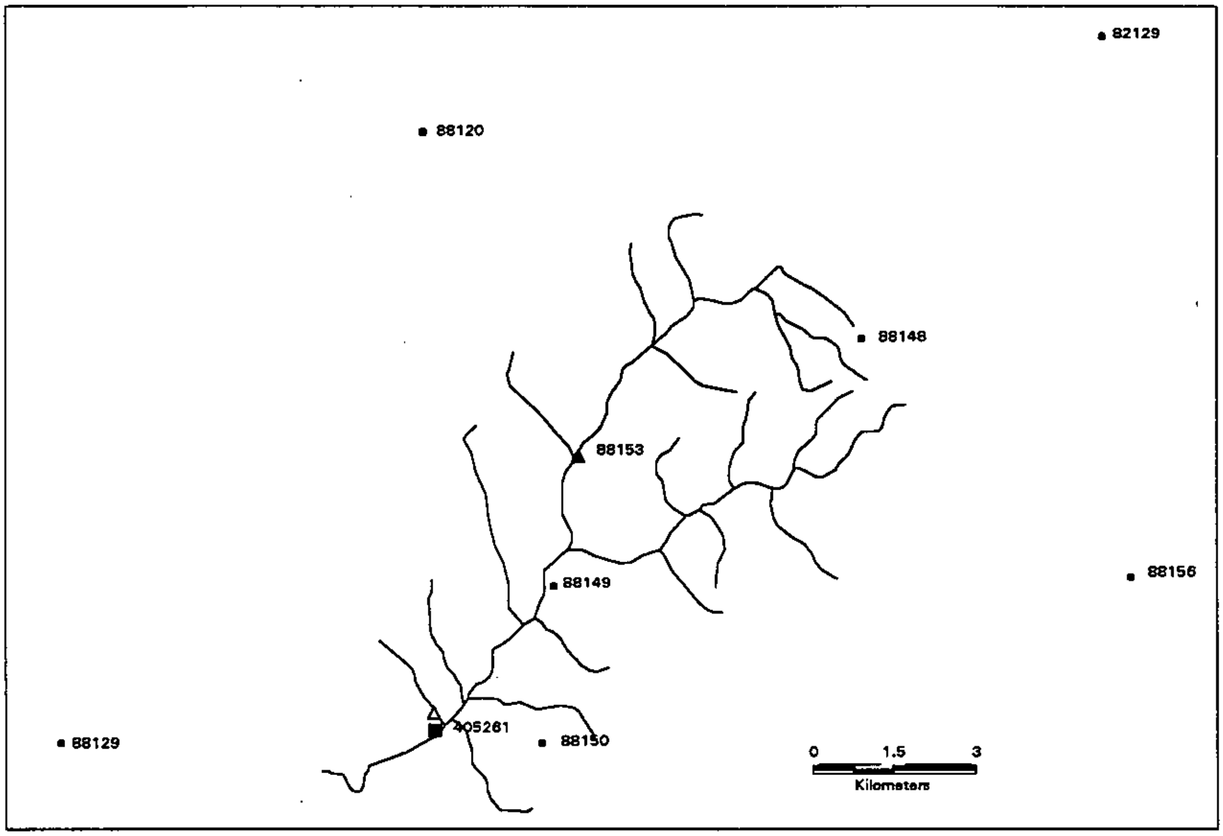

Figure A.13 Spring Ck @ Fawcett

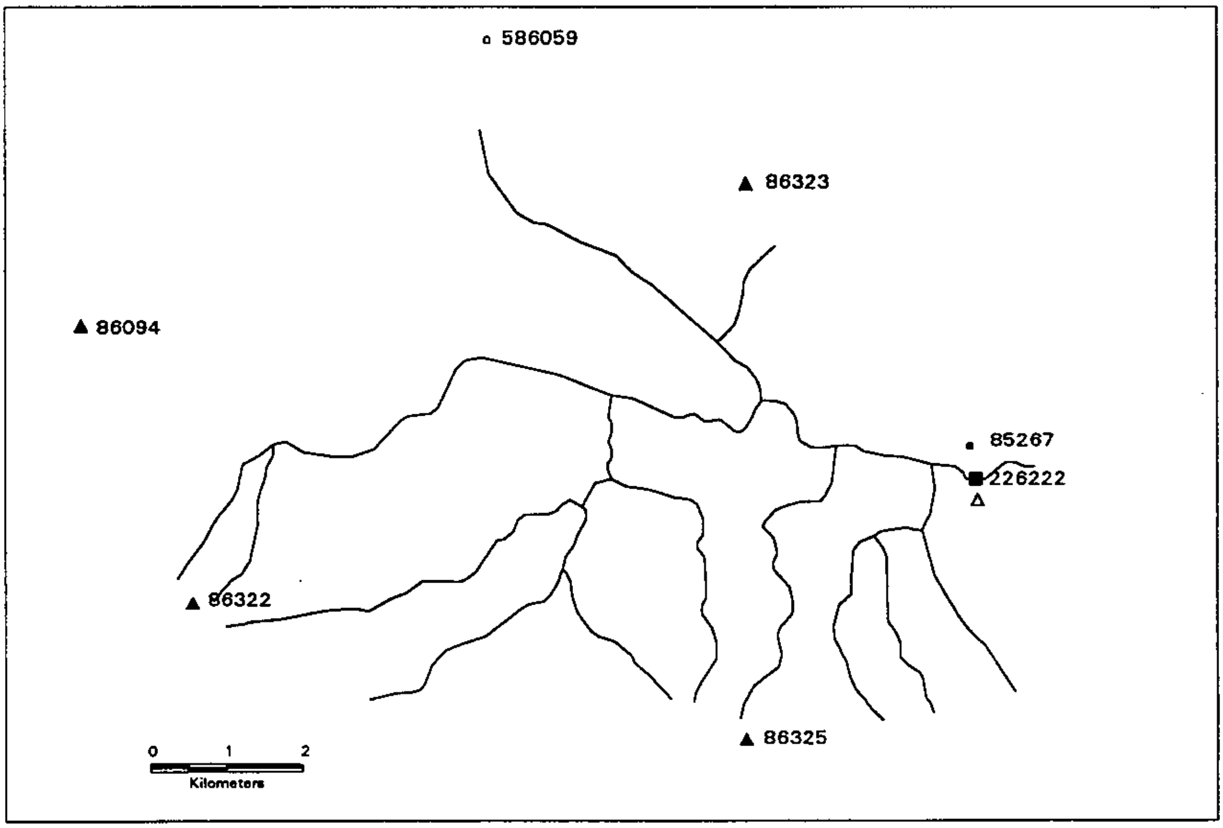

Figure A.14 La Trobe River @ Near Noojee

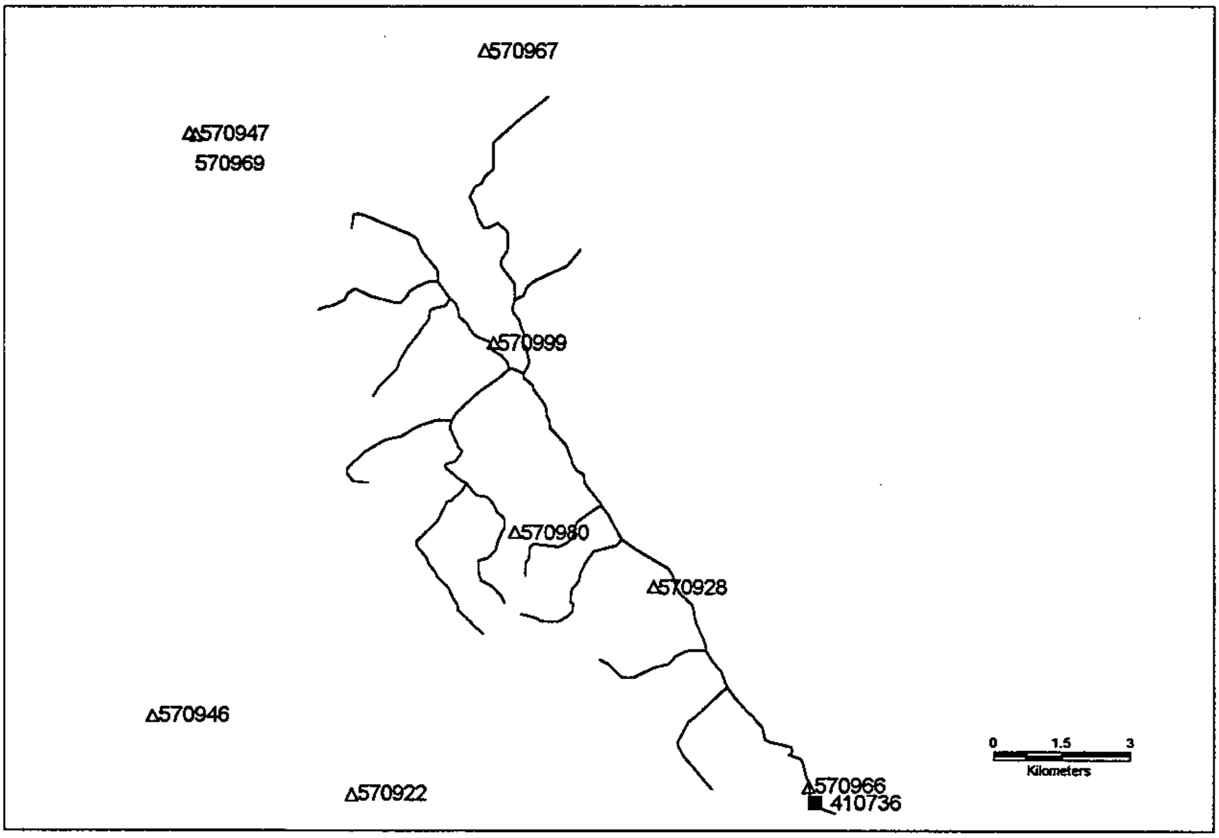

Figure A.15 Orroral River @ Crossing

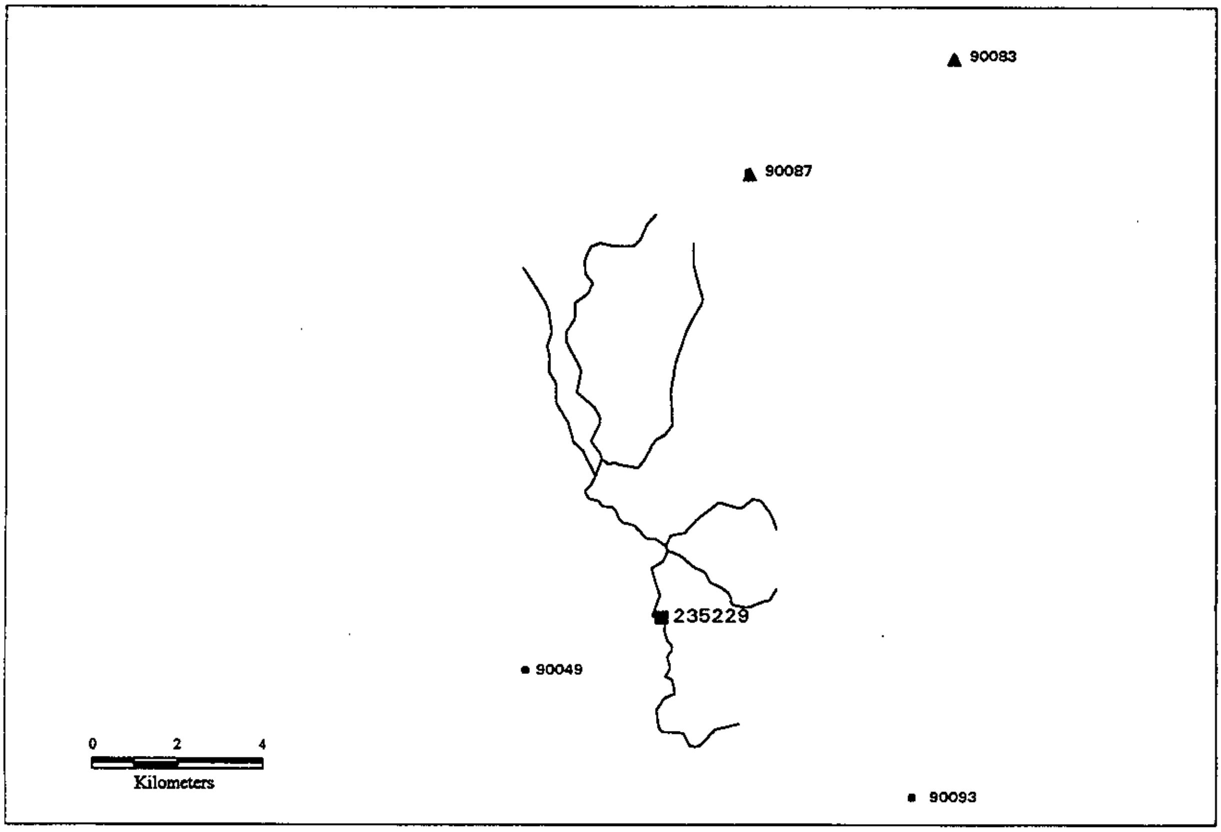

Figure A.16 Aire River @ Wyelangta

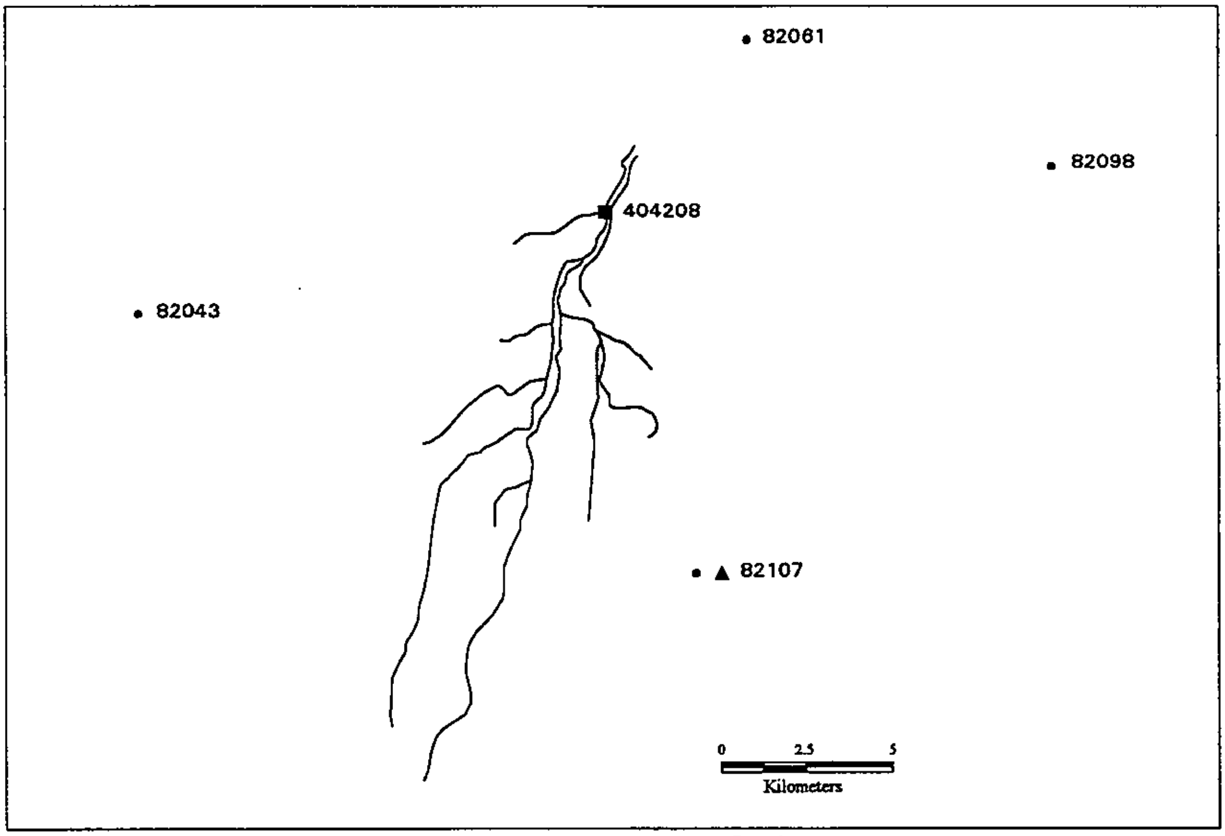

Figure A.17 Moonee Ck @ Lima

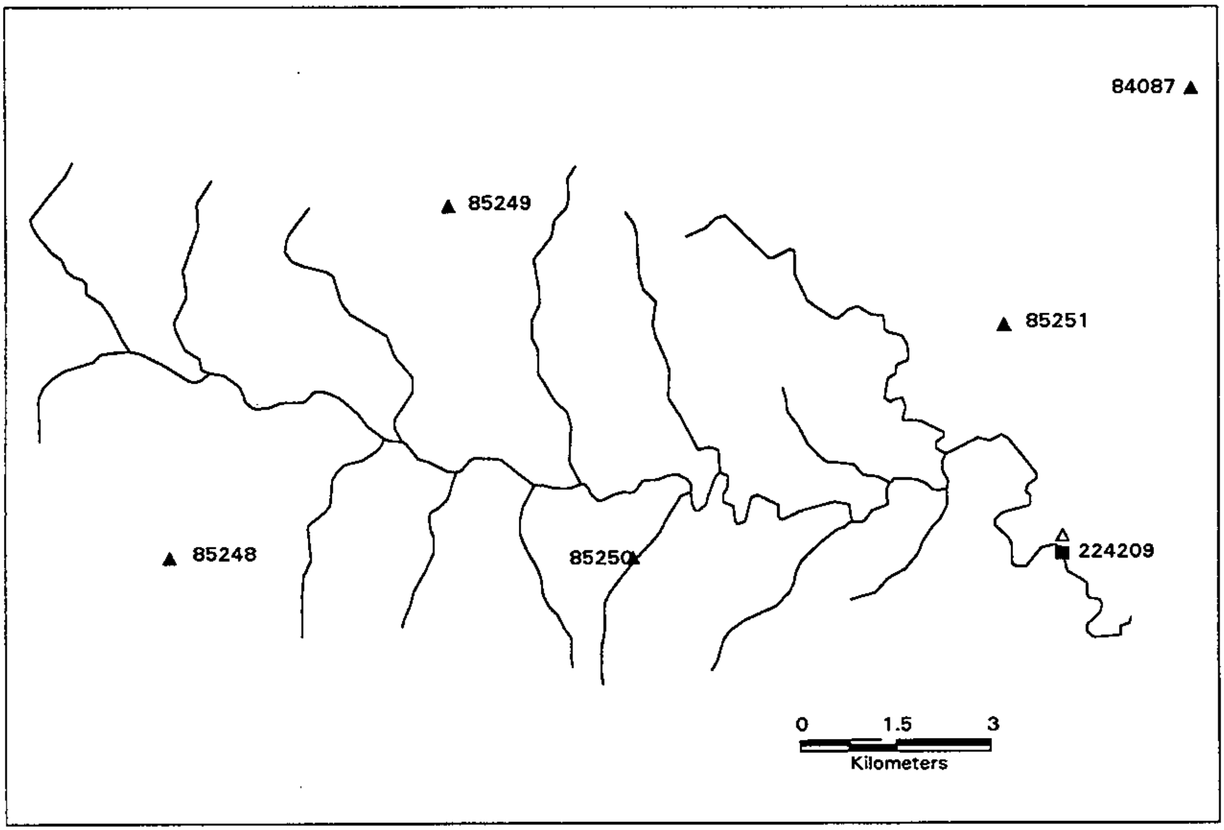

Figure A.18 Cobbannah Ck @ Bairnsdale

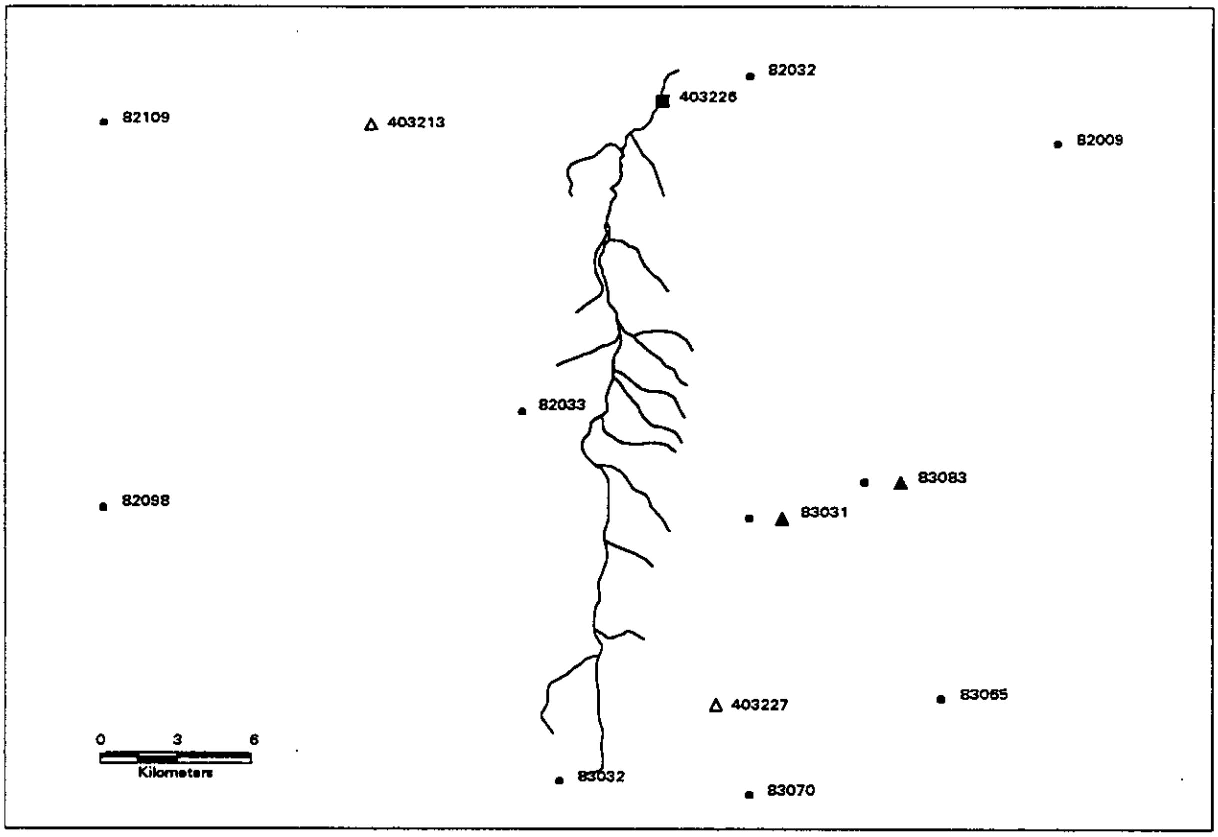

Figure A.19 Boggy Ck @ Angleside

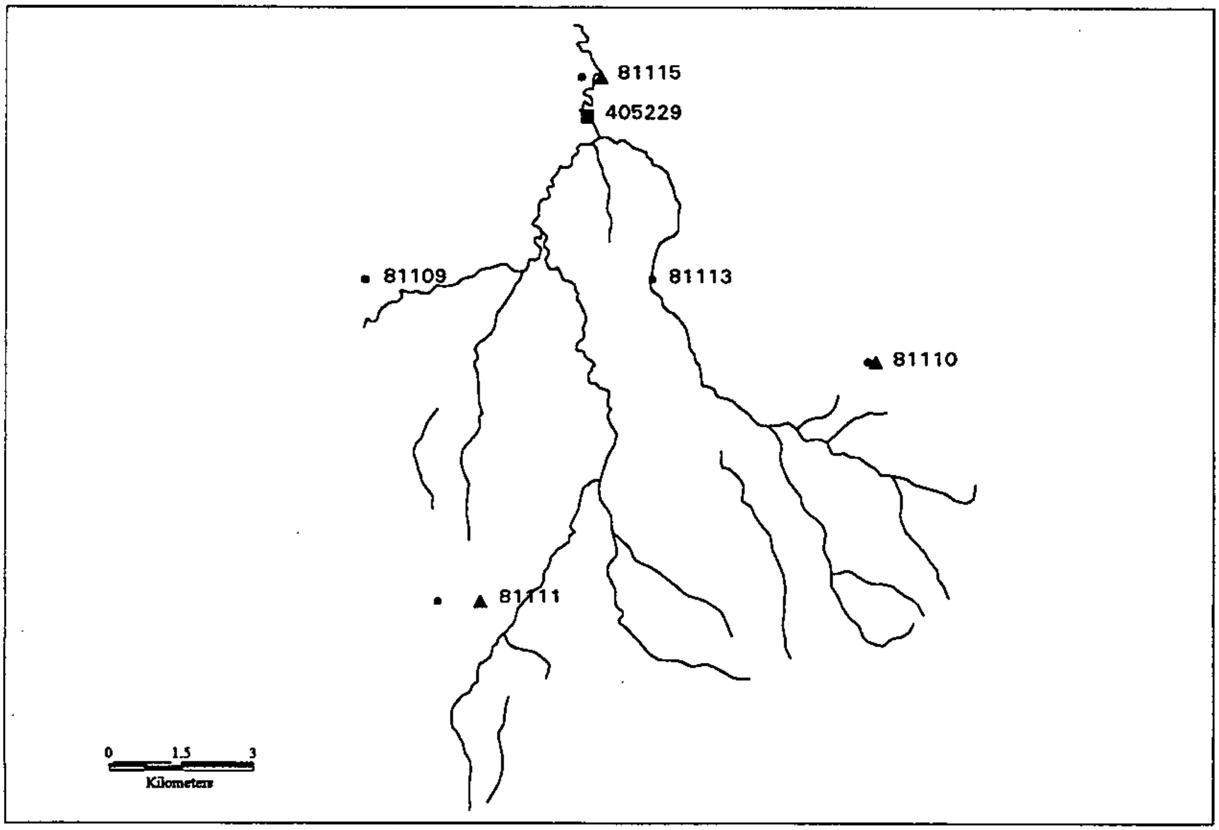

Figure A.20 Wanalta Ck @ Wanalta

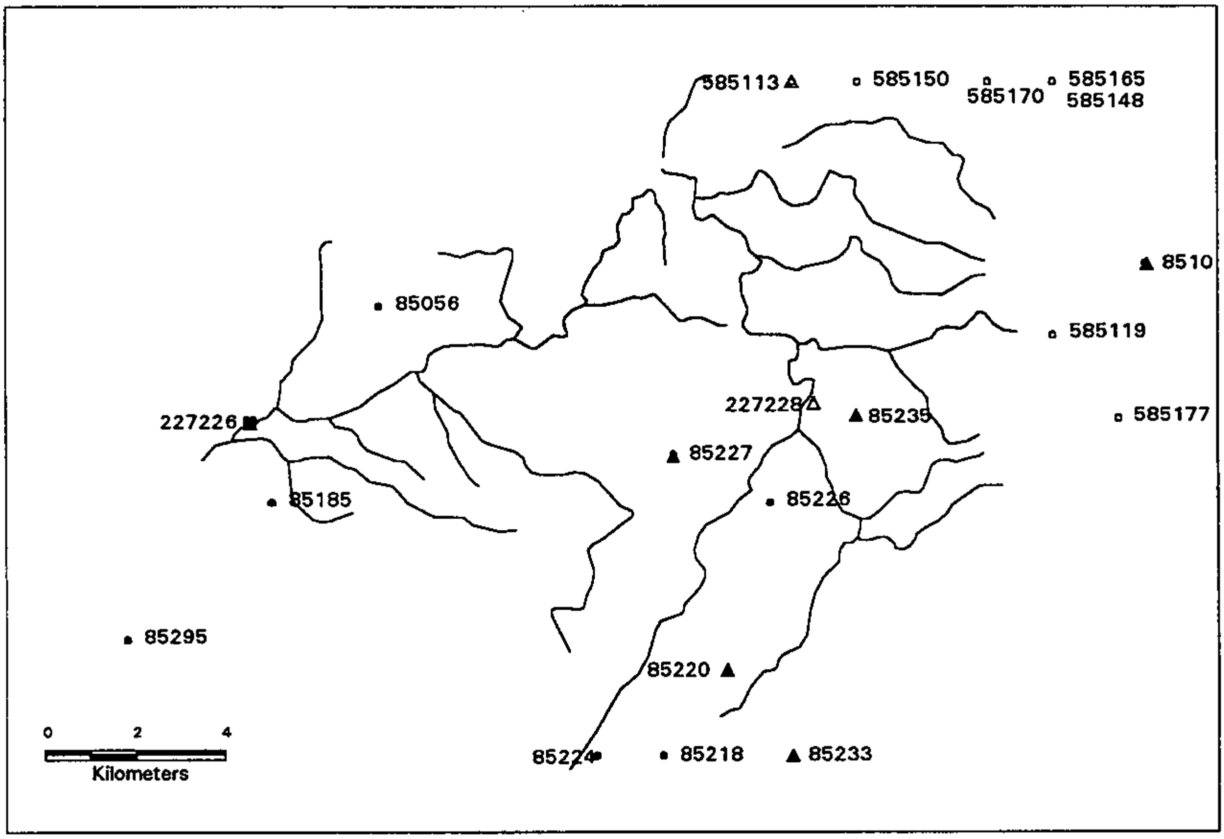

Figure A.21 Tarwin R East Branch @ Dumbalk Nth

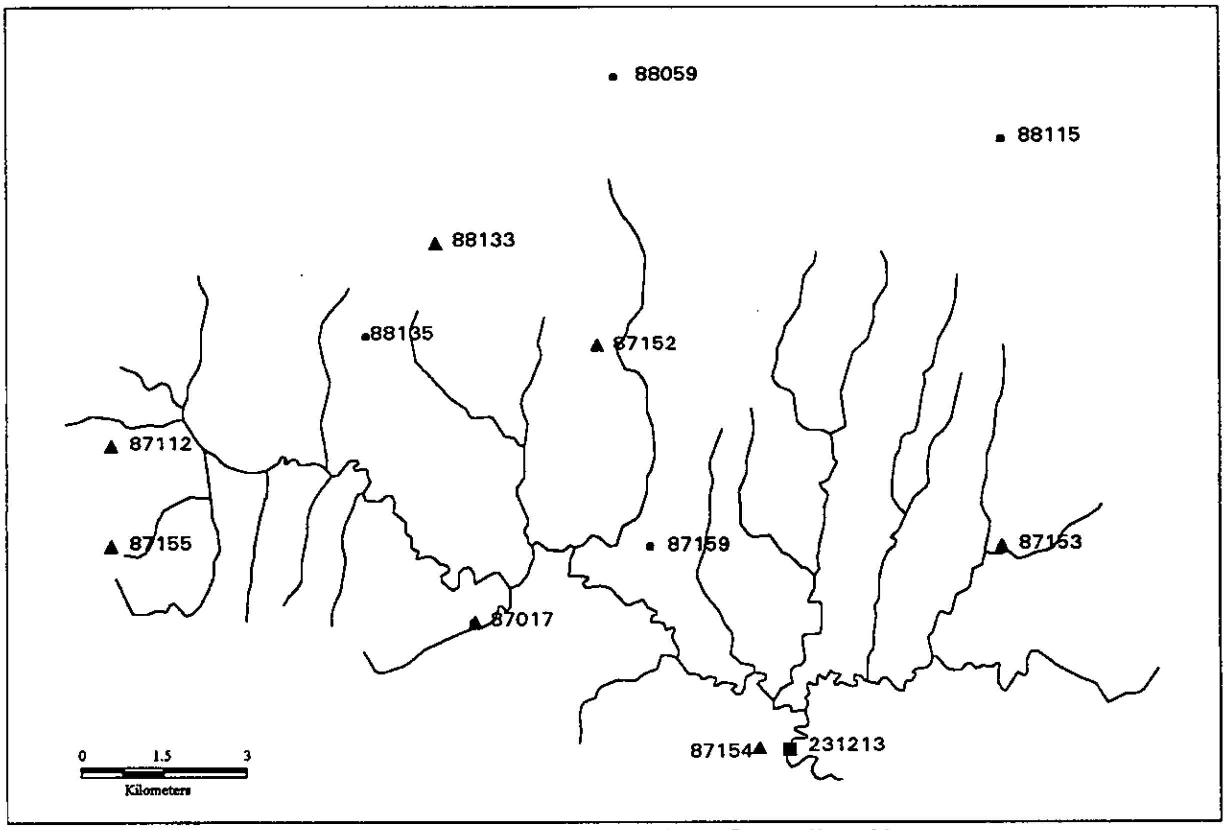

Figure A.22 Lerderderg River @ Sardine Ck

Table A.1 Rejected Catchments

Catchment	Area (km^2)	Gauging Station	Pluviograph Station	Reason for Rejection
Molonglo River @ Cooper Creek	47	410757	570982	Regulated by water supply dam for township of Captain's Flat
Wannon River @ Burrah	137	238225	089019	Lagged streamflow due to heavily vegetated main stream, many timing discrepancies
Wattle Ck @ Navarre	141	415238	079086	Many timing discrepancies
Seven Ck @ Polly McQuinns Weir	153	405234	082042	Flow Regulated by Polly McQuinns Weir, high flows not rated
Burrumbeet Ck @ Lake Burrumbeet	161	236215	089002	Many timing discrepancies, catchment too large
Mt Ida Ck @ Derrinal	174	406226	088029	Many timing discrepancies, catchment too large, few rainfall events

Table A.2 Rainfall Stations used to Calculate Catchment Average Rainfall

Catchment	Rainfall stations used (& thiessen weighting)
TI	570945 (0.86), 570958 (0.02), 570967 (0.12) 570958 (0.01), 570964 (0.74), 570967 (0.25) 570945 (0.98), 570958 (0.02)
CH	090042 (0.36), 099987 (0.64)
GO	087075 (0.56), 087153 (0.12), 087158 (0.32) 087075 (0.88), 087153 (0.12) 087075 (0.68), 087158 (0.32)
CA	087153 (1.0)
TA	085220 (0.28), 085224 (0.14), 085226 (0.29), 085227 (0.04), 085233 (0.03), 085235 (0.23) 085226 (0.59), 085227 (0.07), 085233 (0.34) 085220 (0.42), 085226 (0.51), 085227 (0.04), 085233 (0.03) 085227 (0.47), 085233 (0.53)
GI	570807 (0.14), 570904 (0.81), 570990 (0.05) 570904 (0.83), 570990 (0.17)
SN	088023 (0.16), 088068 (0.84)
MY	080127 (0.52), 081028 (0.03), 081088 (0.04), 081098 (0.41) 080127 (0.52), 081088 (0.04), 081098 (0.44) 081003 (0.11), 081088 (0.11), 081098 (0.78)
JE	570924 (0.32), 570973 (0.43), 570985 (0.08), 570993 (0.17) 570924 (0.41), 570973 (0.59) 570924 (0.34), 570973 (0.59), 570985 (0.07)
FO	090049 (0.39), 090087 (0.59), 090093 (0.02) 090087 (0.85), 090093 (0.15) 090049 (0.98), 090093 (0.02)
GL	089019 (1.0)
WA	089021 (0.04), 089084 (0.14), 089092 (0.07), 089093 (0.44), 089094 (0.31) 089021 (0.04), 089092 (0.12), 089093 (0.53), 089094 (0.31)
SP	088153 (0.33), 088148 (0.28), 088149 (0.25), 088150 (0.14) 088153 (0.33), 088148 (0.28), 088149 (0.39 088153 (0.61), 088149 (0.39) 088153 (0.61), 088149 (0.25), 088150 (0.14)
LA	085267 (0.18), 086094 (0.06), 086322 (0.22), 086323 (0.28), 086325 (0.26) 085267 (0.37), 086094 (0.06), 086322 (0.27), 086323 (0.30) 086094 (0.06), 086322 (0.22), 086323 (0.35), 086325 (0.37) 086094 (0.30), 086323 (0.70)
OR	570928 (0.23), 570966 (0.08), 570967 (0.09), 570980 (0.24), 570999 (0.36) 570966 (0.46), 570967 (0.36), 570969 (0.18) 570966 (0.47), 570967 (0.53 570966 (0.16), 570967 (0.19), 570969 (0.05), 570980 (0.60) 570966 (0.16), 570967 (0.09), 570980 (0.39), 570999 (0.36)
AI	090087 (0.27), 090083 (0.42), 090006 (0.31) 090087 (0.27), 090083 (0.73
MO	082043 (0.16), 082061 (0.05), 082107 (0.79) 082043 (0.77), 082061 (0.23
CO	085248 (0.25), 085249 (0.28), 085250 (0.30), 085251 (0.17) 085249 (0.47), 085250 (0.36), 085251 (0.17) 085248 (0.25), 085249 (0.30), 085250 (0.45) 085248 (0.39), 085250 (0.44), 085251 (0.17)
BO	082032 (0.17), 082033 (0.47), 083031 (0.13), 083032 (0.23)
WN	081110 (0.27), 081111 (0.36), 081109 (0.11), 081113 (0.22), 081115 (0.04) 081110 (0.27), 081111 (0.47), 081113 (0.22), 081115 (0.04) 081111 (0.43), 081109 (0.11), 081113 (0.42), 081115 (0.04) 081111 (0.47), 081113 (0.49), 081115 (0.04)
TE	085056 (0.10), 085106 (0.16), 085218 (0.03), 085220 (0.10), 085226 (0.29), 085227 (0.32) 085106 (0.20), 085227 (0.80)
LE	087017 (0.19), 087152 (0.27), 087153 (0.25), 087154 (0.10), 087155 (0.19) 087017 (0.23), 087152 (0.27), 087153 (0.31), 087155 (0.19) 087017 (0.40), 087152 (0.29), 087153 (0.31) 087017 (0.54), 088059 (0.20), 088135 (0.26)

Appendix B

MEAN CATCHMENT LOSSES

List of Tables

Table B.1 Mean Catchment Storm Initial Loss

Catchment	Code	Area (km²)	N	mean (mm)	median (mm)	SE (mm)	90% limits (mm)
Tidbinbilla Ck @ Mountain Creek	TI	25	31	12	10	1.7	3.00
Chapple Ck @ Chapple Vale	CH	28	23	29	28	3.3	6.00
Goodman Ck above Lerderderg Tunnel	GO	32	19	35	35	2.8	5.00
Campaspe River @ Ashborne	CA	33	7	47	48	11.8	23.00
Tarwin River East Branch @ Mirboo	TA	43	5	20	21	3.8	8.00
Ginninderra Ck u/s Barton Highway	GI	48	20	35	38	4.2	7.00
Snobs Ck @ Snobs Ck Hatchery	SN	51	12	7	8	1.2	2.00
Myers Ck @ Myers Flat	MY	55	9	29	36	5.4	10.00
Jerrabomberra Ck @ Four Mile Creek	JE	55	35	27	25	2.6	4.00
Ford River @ Glenaire	FO	56	23	22	21	2.7	5.00
Glenelg River @ Big Cord	GL	57	17	23	24	4.2	7.00
Warrambine Ck @ Warrabine	WA	57	17	35	26	5.4	9.00
Spring Ck @ Fawcett	SP	60	17	28	27	3.1	5.00
La Trobe River @ Near Noojee	LA	62	7	18	19	2.3	4.00
Orroral River @ Crossing	OR	90	36	23	18	3.1	5.00
Aire River @ Wyelangta	AI	90	17	17	19	2.2	4.00
Moonee Ck @ Lima	MO	91	28	19	19	2.7	5.00
Cobbannah Ck @ Bairnsdale	CO	106	13	55	52	8.7	15.00
Boggy Ck @ Angleside	BO	108	33	22	15	4.0	7.00
Wanalta Ck @ Wanalta	WN	108	24	33	31	2.8	5.00
Tarwin R East Branch @ Dumbalk Nth	TE	127	5	34	41	7.8	17.00
Lerderderg River @ Sardine Ck	LE	153	9	31	25	8.0	15.00

Table B.2 Mean Catchment Continuing Loss

Catchment	Code	Area (km^2)	N	mean (mm/h)	median (mm/h)	SE (mm/h)	90% limits (mm/h)
Tidbinbilla Ck @ Mountain Creek	TI	25	31	9.4	8.8	0.9	1.50
Chapple Ck @ Chapple Vale	CH	28	23	3.0	2.6	0.4	0.70
Goodman Ck above Lerderderg Tunnel	GO	32	13	3.7	2.4	1.1	2.00
Campaspe River @ Ashborne	CA	33	3	5.8	6.2	3.1	5.20
Tarwin River East Branch @ Mirboo	TA	43	5	4.5	3.6	1.5	3.20
Ginninderra Ck u/s Barton Highway	GI	48	14	8.2	6.5	2.0	3.50
Snobs Ck @ Snobs Ck Hatchery	SN	51	12	11.5	11.0	1.1	2.00
Myers Ck @ Myers Flat	MY	55	7	3.4	2.7	0.8	1.60
Jerrabomberra Ck @ Four Mile Creek	JE	55	31	5.0	3.4	0.8	1.40
Ford River @ Glenaire	FO	56	23	3.2	2.6	0.5	0.80
Glenelg River @ Big Cord	GL	57	17	5.8	5.1	1.3	2.30
Warrambine Ck @ Warrabine	WA	57	8	2.1	1.5	0.7	1.30
Spring Ck @ Fawcett	SP	60	12	4.7	4.2	1.2	2.10
La Trobe River @ Near Noojee	LA	62	5	4.7	3.4	2.7	5.70
Orroral River @ Crossing	OR	90	36	8.7	7.1	0.9	1.50
Aire River @ Wyelangta	AI	90	17	5.4	3.0	1.4	2.50
Moonee Ck @ Lima	MO	91	28	6.7	6.5	0.7	1.20
Cobbannah Ck @ Bairnsdale	CO	106	12	2.1	1.7	0.7	1.30
Boggy Ck @ Angleside	BO	108	33	5.6	3.7	0.7	1.10
Wanalta Ck @ Wanalta	WN	108	11	2.2	1.4	0.8	1.40
Tarwin R East Branch @ Dumbalk Nth	TE	127	5	2.5	1.7	1.0	2.20
Lerderderg River @ Sardine Ck	LE	153	7	2.3	1.1	0.8	1.60

Table B.3 Mean Catchment Proportional Loss

Catchment	Code	Area (km²)	N	mean
Tidbinbilla Ck @ Mountain Creek	TI	25	31	0.87
Chapple Ck @ Chapple Vale	CH	28	23	0.75
Goodman Ck above Lerderderg Tunnel	GO	32	13	0.65
Campaspe River @ Ashborne	CA	33	3	0.68
Tarwin River East Branch @ Mirboo	TA	43	5	0.67
Ginninderra Ck u/s Barton Highway	GI	48	14	0.66
Snobs Ck @ Snobs Ck Hatchery	SN	51	12	0.90
Myers Ck @ Myers Flat	MY	55	7	0.80
Jerrabomberra Ck @ Four Mile Creek	JE	55	31	0.59
Ford River @ Glenaire	FO	56	23	0.72
Glenelg River @ Big Cord	GL	57	17	0.87
Warrambine Ck @ Warrabine	WA	57	8	0.53
Spring Ck @ Fawcett	SP	60	12	0.73
La Trobe River @ Near Noojee	LA	62	5	0.88
Orroral River @ Crossing	OR	90	36	0.86
Aire River @ Wyelangta	AI	90	17	0.70
Moonee Ck @ Lima	MO	91	28	0.89
Cobbannah Ck @ Bairnsdale	CO	106	12	0.64
Boggy Ck @ Angleside	BO	108	33	0.81
Wanalta Ck @ Wanalta	WN	108	11	0.57
Tarwin R East Branch @ Dumbalk Nth	TE	127	5	0.62
Lerderderg River @ Sardine Ck	LE	153	7	0.50

Appendix C

SEASONAL VARIATION OF BURST INITIAL LOSS

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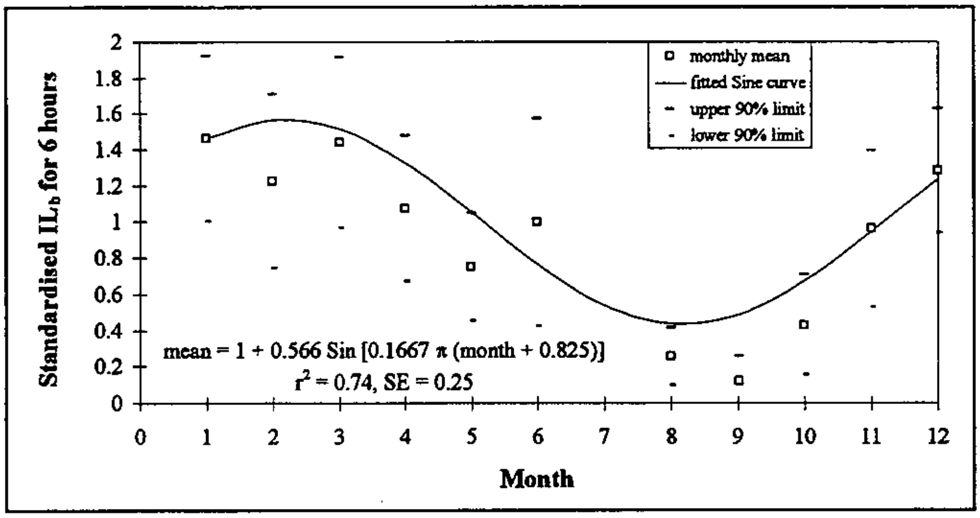

Figure C.1 Monthly Variation of Standardised IL_b for 6 hours

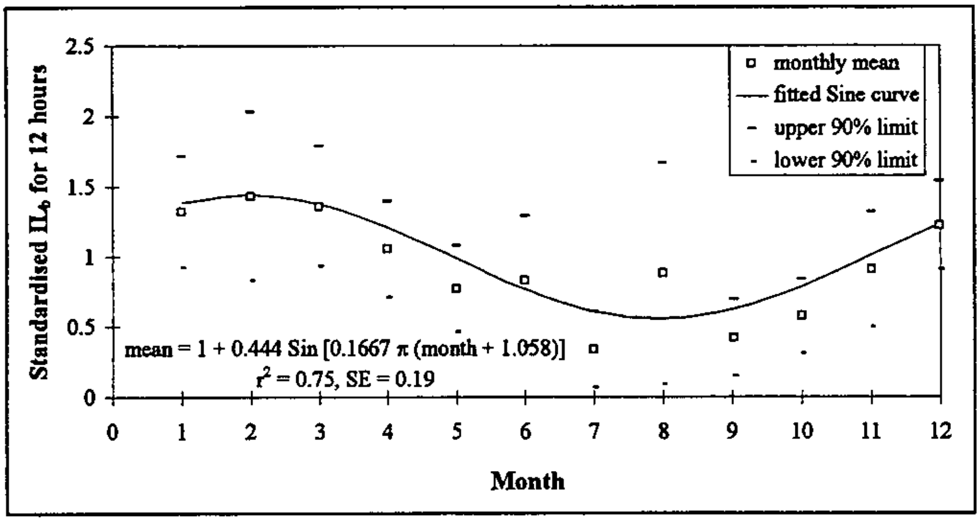

Figure C.2 Monthly Variation of Standardised IL_b for 12 hours

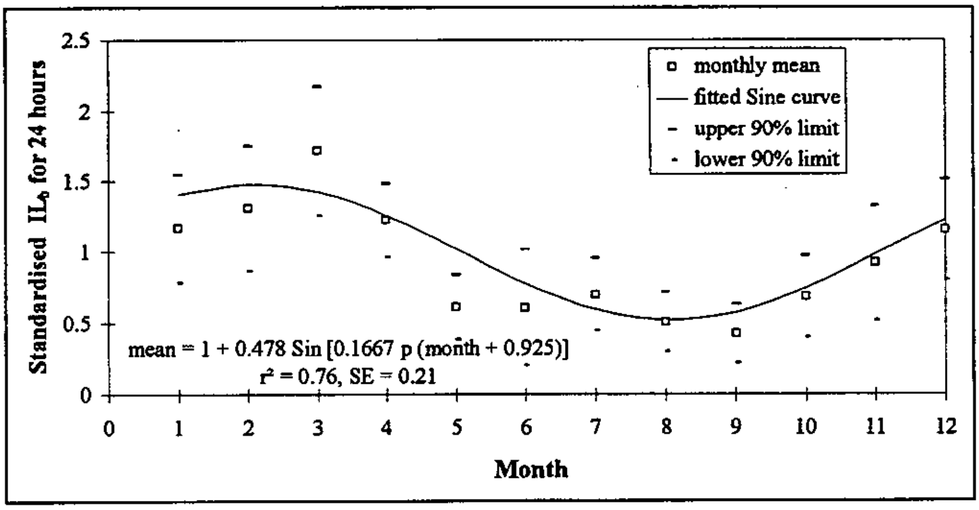

Figure C.3 Monthly Variation of Standardised IL_b for 24 hours

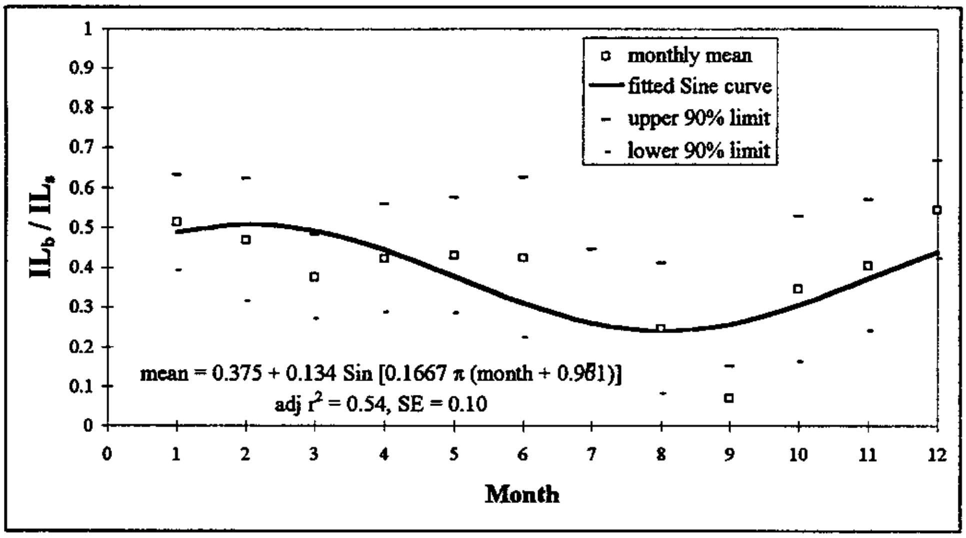

Figure C.4 Monthly Variation of *IL$_b$/IL$_s$* for 6 hour Duration Bursts

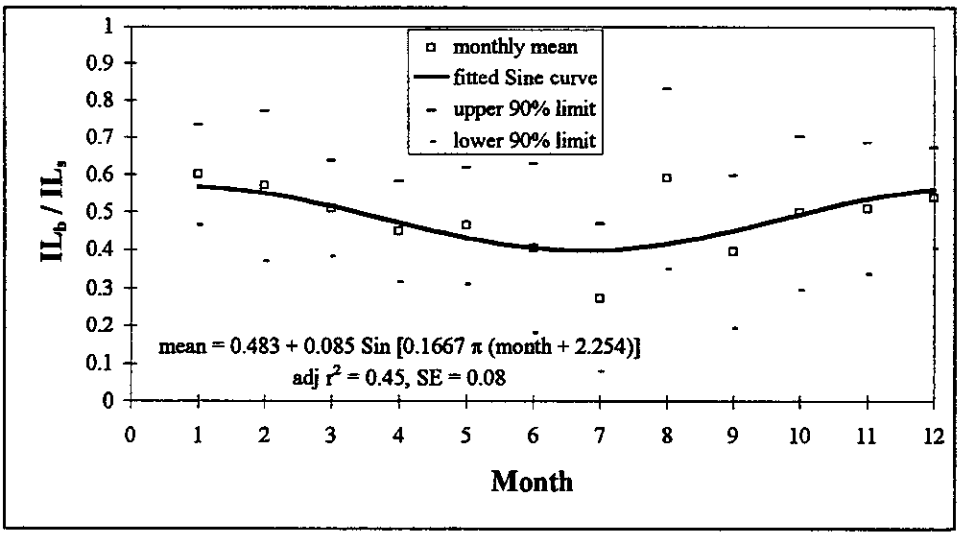

Figure C.5 Monthly Variation of *IL$_b$/IL$_s$* for 12 hour Duration Bursts

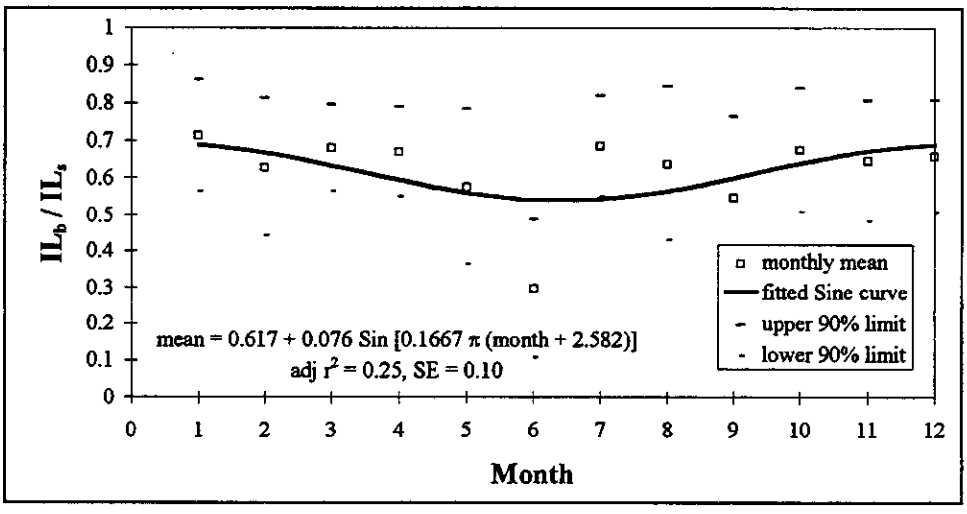

Figure C.6 Monthly Variation of *IL$_b$/IL$_s$* for 24 hour Duration Bursts

Appendix C

Appendix D

VARIATION OF LOSSES WITH SEVERITY

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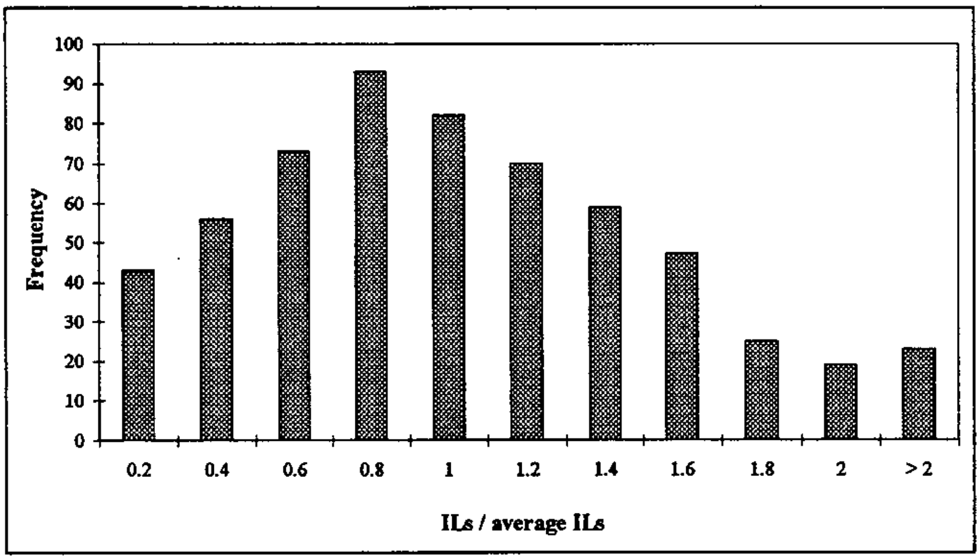

Figure D.1 Distribution of Standardised IL_s for ARIs of 1 to 2 years

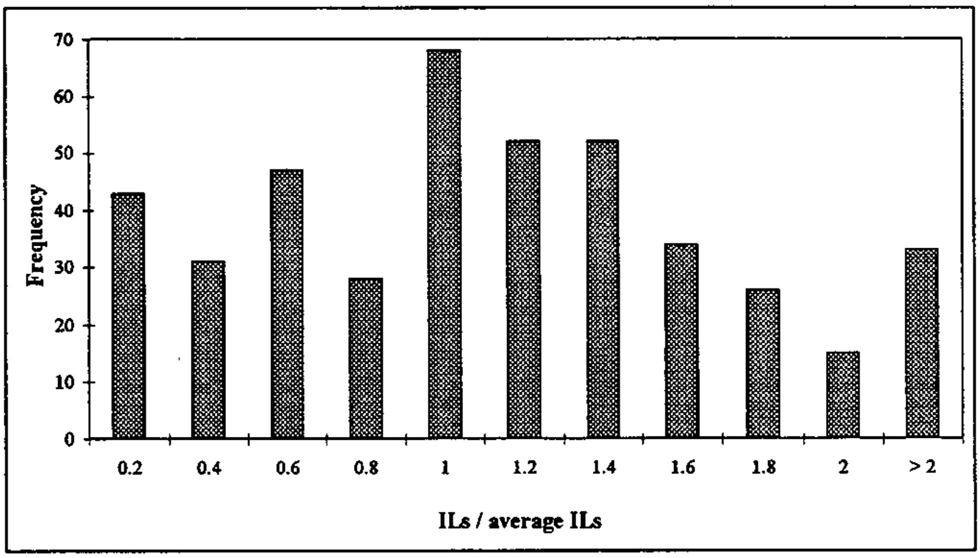

Figure D.2 Distribution of Standardised IL_s for ARIs of 2 to 20 years

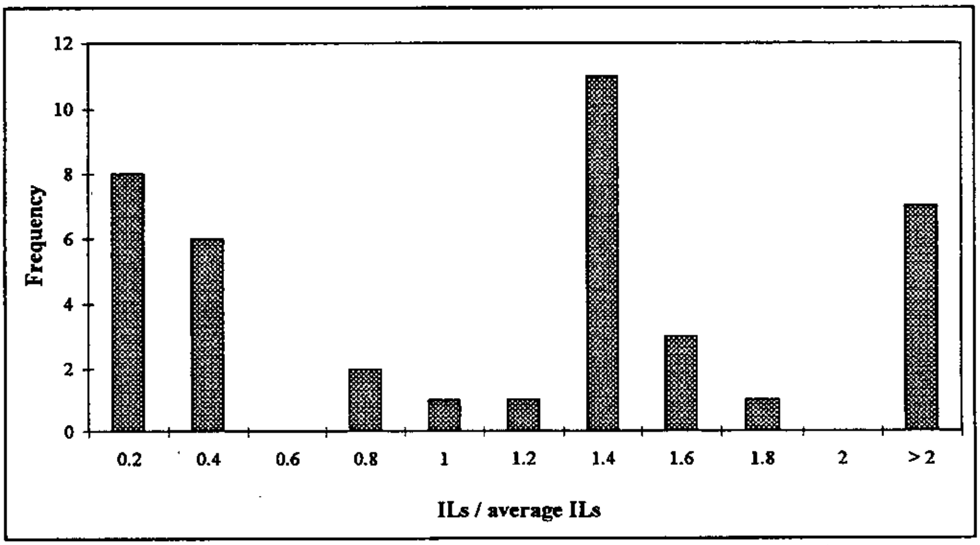

Figure D.3 Distribution of Standardised IL_s for ARIs of greater than 20 years

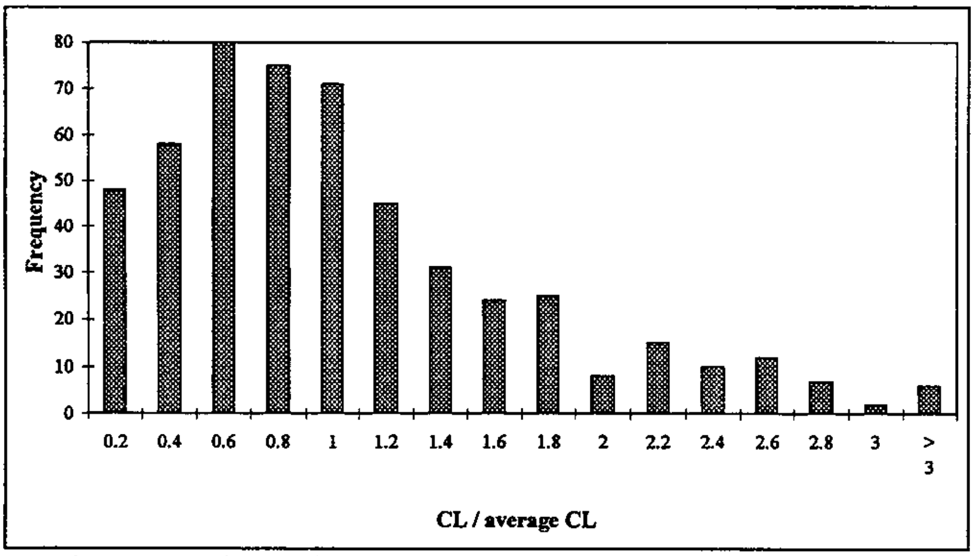

Figure D.4 Distribution of Standardised *CL* for ARIs of 1 to 2 years

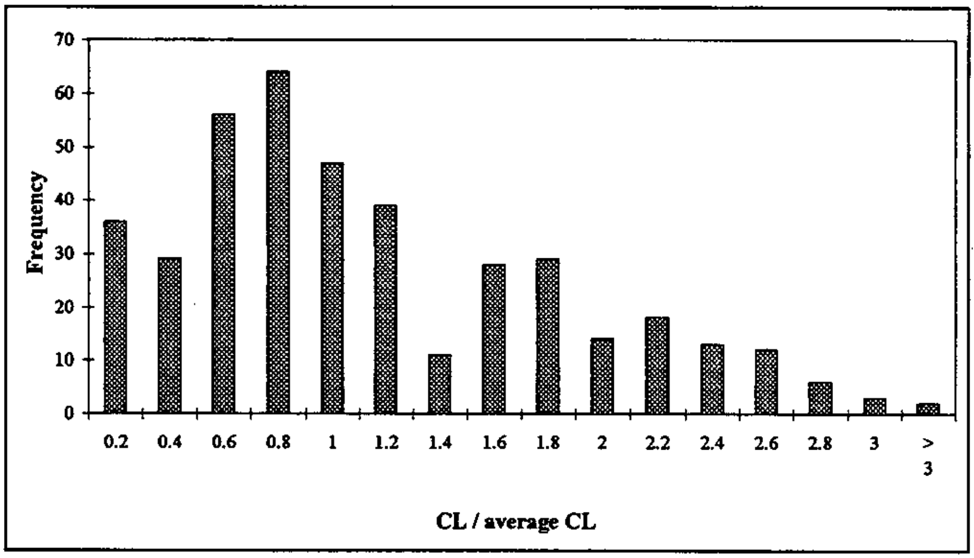

Figure D.5 Distribution of Standardised *CL* for ARIs of 2 to 20 years

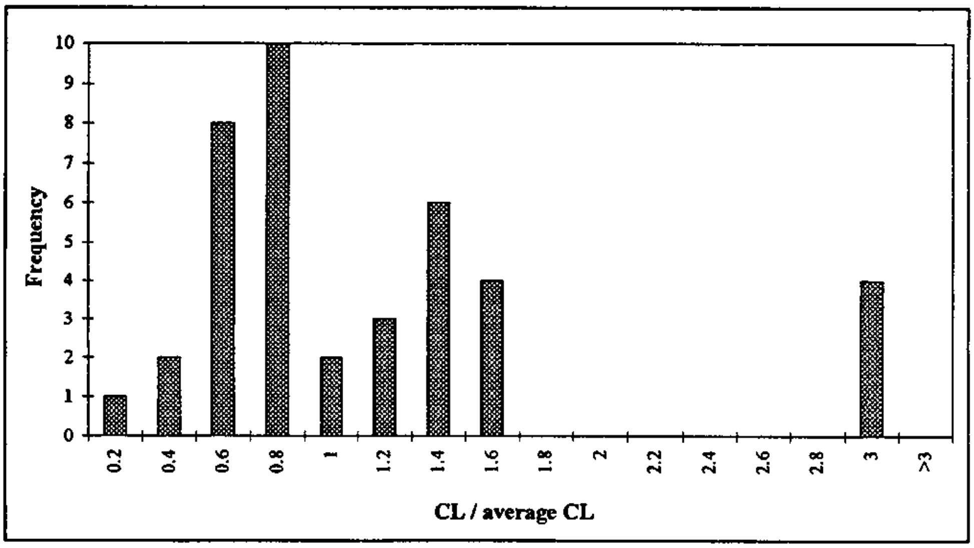

Figure D.6 Distribution of Standardised *CL* for ARIs of greater than 20 years

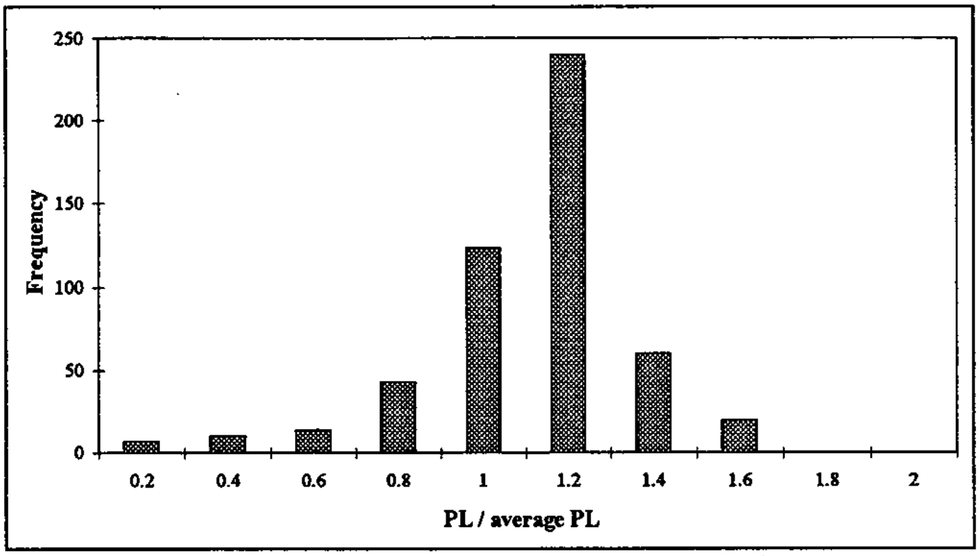

Figure D.7 Distribution of Standardised *PL* for ARIs of 1 to 2 years

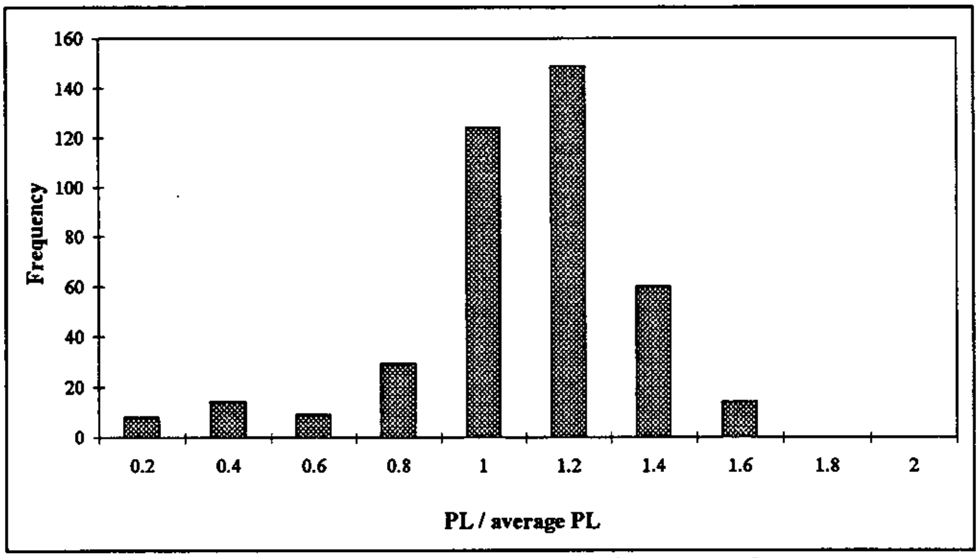

Figure D.8 Distribution of Standardised *PL* for ARIs of 2 to 20 years

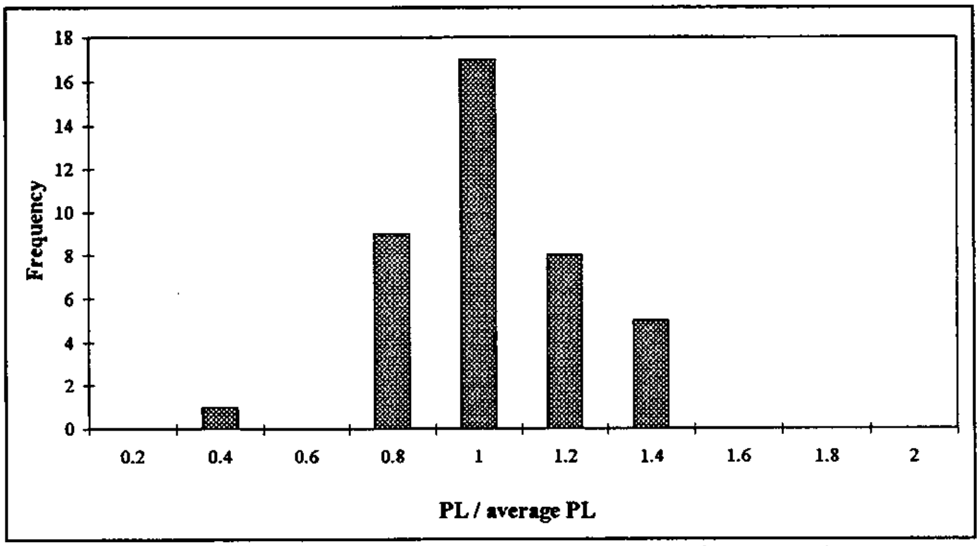

Figure D.9 Distribution of Standardised *PL* for ARIs of greater than 20 years

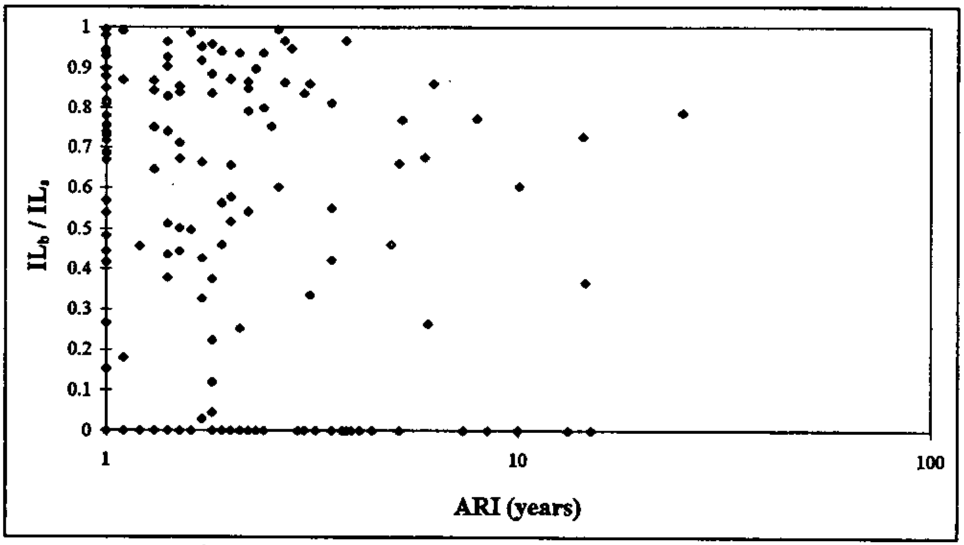

Figure D.10 *IL_b/IL_s* vs ARI for 2 hour duration

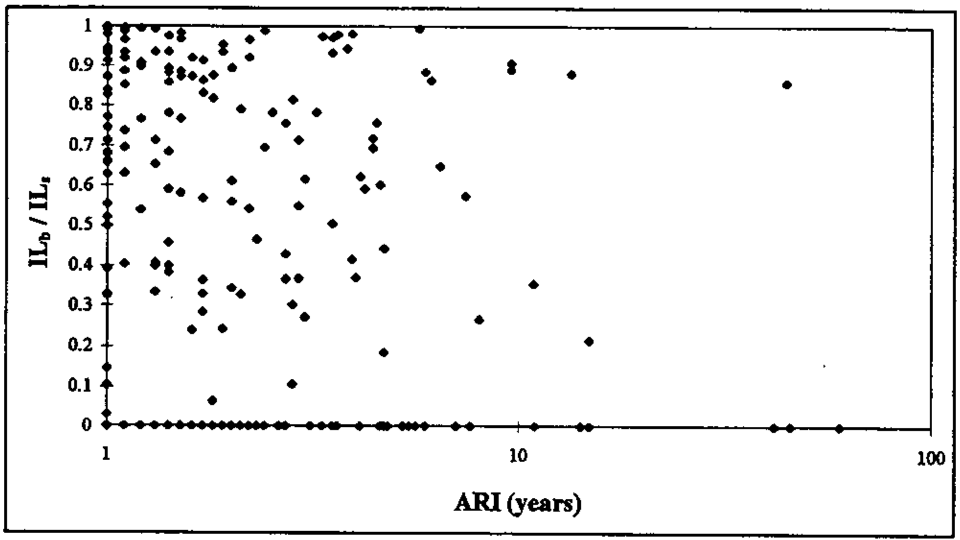

Figure D.11 *IL_b/IL_s* vs ARI for 6 hour duration

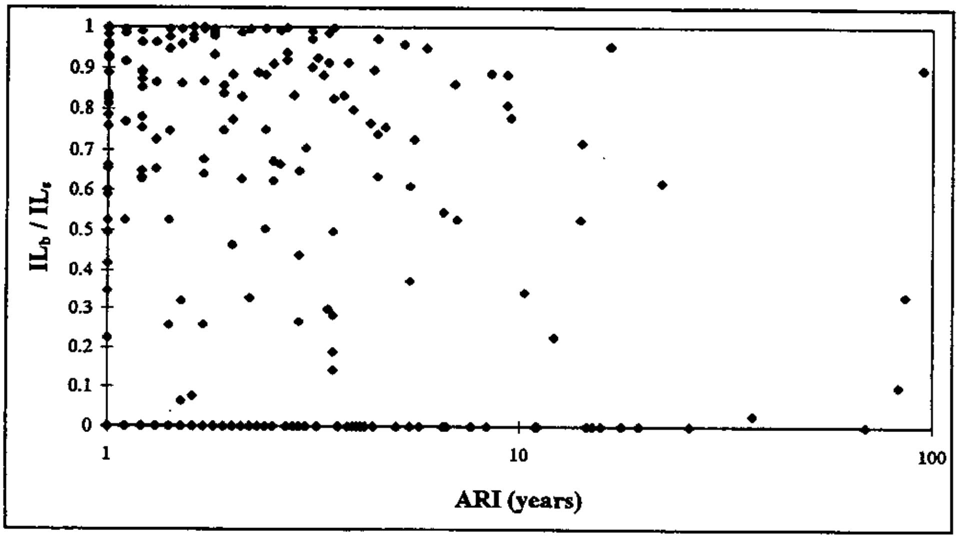

Figure D.12 *IL_b/IL_s* vs ARI for 12 hour duration

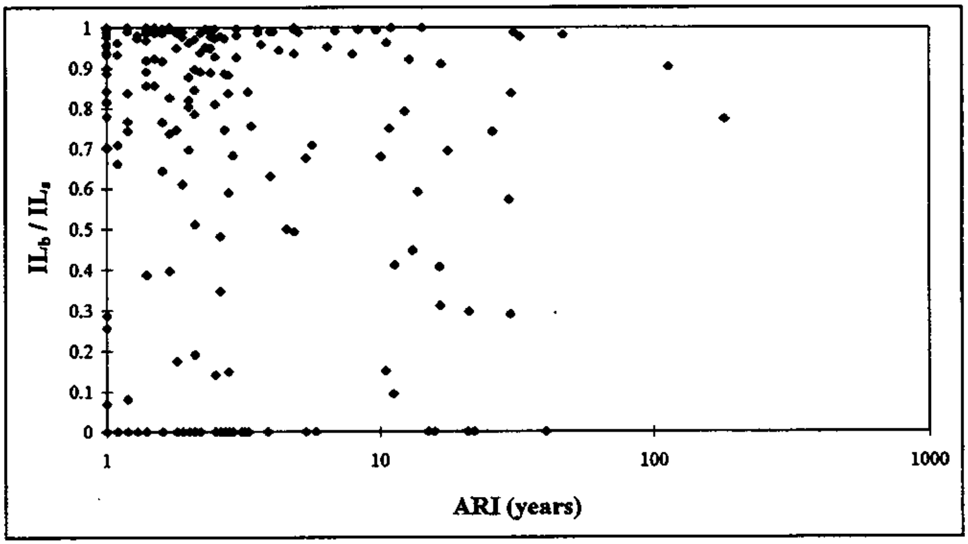

Figure D.13 *IL$_b$/IL$_s$* vs ARI for 24 hour Duration

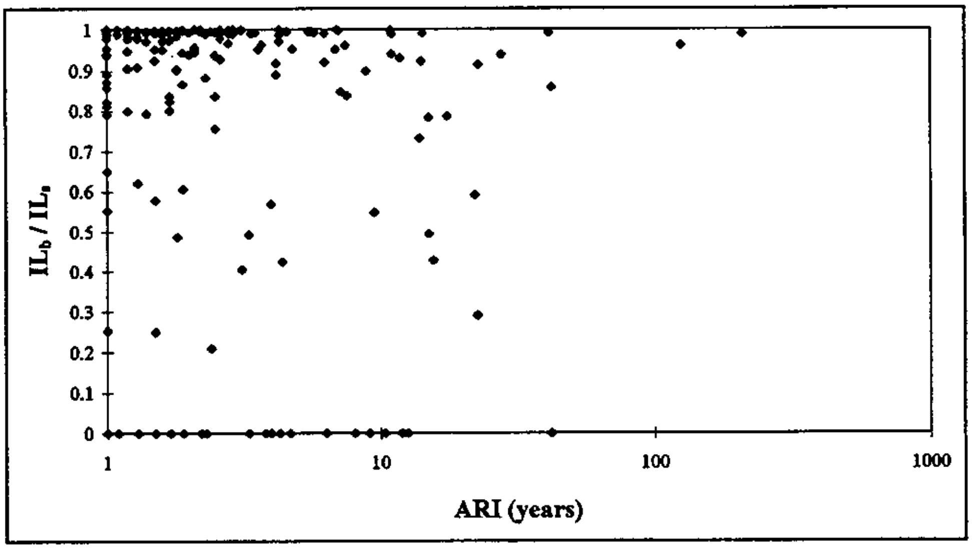

Figure D.14 *IL$_b$/IL$_s$* vs ARI for 48 hour duration

Appendix E

SELECTION OF SURFACE RUNOFF THRESHOLD

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Sensitivity of Mean Losses to Runoff Threshold

The selection of events for analysis on the basis of rainfall bursts means that loss parameters need to be estimated for events with very small volumes of surface runoff, or even no surface runoff at all. This, and the need to automate the calculation of losses, makes it necessary to use a threshold surface runoff to indicate the 'start of surface runoff'.

For events with no surface runoff, or surface runoff less than the threshold, the storm initial loss is simply the total rainfall depth. Thus, calculated losses are sensitive to the choice of the surface runoff threshold. To determine this sensitivity, losses were calculated for surface runoff thresholds of 0.01 mm/h, 0.05 mm/h and 0.10 mm/h; the effect on the calculated mean loss is shown in Tables E-1, E-2 and E-3 and Figures E-1, E-2 and E-3.

Table E-1 Mean Storm Initial Loss for Different Surface Runoff Thresholds

Catchment	code	Mean IL$_S$ (mm) for different thresholds					
		0.01 mm/h		0.05 mm/h		0.10 mm/h	
		N	mean	N	mean	N	mean
Tidbinbilla Ck @ Mountain Creek	TI	31	12	32	32	33	41
Chapple Ck @ Chapple Vale	CH	23	29	24	39	24	45
Goodman Ck above Lerderderg Tunnel	GO	19	35	20	42	19	44
Campaspe River @ Ashbourne	CA	7	47	8	60	9	65
Tarwin River East Branch @ Mirboo	TA	5	20	5	34	5	36
Ginninderra Ck u/s Barton Highway	GI	20	35	21	29	21	42
Snobs Ck @ Snobs Ck Hatchery	SN	12	7	13	23	14	29
Myers Ck @ Myers Flat	MY	9	29	12	33	12	35
Jerrabomberra Ck @ Four Mile Creek	JE	35	27	33	36	32	36
Ford River @ Glenaire	FO	23	22	24	35	21	43
Glenelg River @ Big Cord	GL	17	23	14	51	15	54
Warrambine Ck @ Warrabine	WA	17	35	17	37	17	39
Spring Ck @ Fawcett	SP	17	28	16	35	17	35
La Trobe River @ Near Noojee	LA	7	18	7	33	7	40
Orroral River @ Crossing	OR	36	23	36	51	36	58
Aire River @ Wyelangta	AI	17	17	16	32	16	43
Moonee Ck @ Lima	MO	28	19	25	33	28	42
Cobbannah Ck @ Bairnsdale	CO	13	55	13	63	12	67
Boggy Ck @ Angleside	BO	33	22	33	31	34	38
Wanalta Ck @ Wanalta	WN	24	33	23	34	23	35
Tarwin R East Branch @ Dumbalk Nth	TE	5	34	5	45	5	49
Lerderderg River @ Sardine Ck	LE	9	31	9	40	8	44

Table E-2 Mean Continuing Loss for Different Surface Runoff Thresholds

Catchment	code	Mean CL (mm/h) for different thresholds					
		0.01 mm/h		0.05 mm/h		0.10 mm/h	
		N	mean	N	mean	N	mean
Tidbinbilla Ck @ Mountain Creek	TI	31	9.4	28	8.0	26	9.3
Chapple Ck @ Chapple Vale	CH	23	3.0	22	2.2	21	2.0
Goodman Ck above Lerderderg Tunnel	GO	13	3.7	12	3.1	10	3.2
Campaspe River @ Ashbourne	CA	3	5.8	3	3.5	3	2.9
Tarwin River East Branch @ Mirboo	TA	5	4.5	5	1.7	5	1.5
Ginninderra Ck u/s Barton Highway	GI	14	8.2	14	7.2	14	7.0
Snobs Ck @ Snobs Ck Hatchery	SN	12	11.5	10	9.2	8	10.0
Myers Ck @ Myers Flat	MY	7	3.4	5	2.7	5	2.7
Jerrabomberra Ck @ Four Mile Creek	JE	31	5.0	28	3.9	23	5.3
Ford River @ Glenaire	FO	23	3.2	22	2.3	19	1.7
Glenelg River @ Big Cord	GL	17	5.8	10	1.5	8	1.6
Warrambine Ck @ Warrabine	WA	8	2.1	7	2.0	6	1.8
Spring Ck @ Fawcett	SP	12	4.7	10	1.8	5	2.0
La Trobe River @ Near Noojee	LA	5	4.7	3	2.1	2	2.6
Orroral River @ Crossing	OR	36	8.7	27	5.4	25	5.0
Aire River @ Wyelangta	AI	17	5.4	14	3.7	14	2.5
Moonee Ck @ Lima	MO	28	6.7	19	6.1	17	5.0
Cobbannah Ck @ Bairnsdale	CO	12	2.1	11	2.0	9	2.1
Boggy Ck @ Angleside	BO	33	5.6	28	5.1	24	4.7
Wanalta Ck @ Wanalta	WN	11	2.2	7	2.6	5	1.4
Tarwin R East Branch @ Dumbalk Nth	TE	5	2.5	5	1.2	5	1.2
Lerderderg River @ Sardine Ck	LE	7	2.3	7	1.1	6	0.9

Table E-3 Mean Proportional Loss for Different Surface Runoff Thresholds

Catchment	code	Mean PL for different thresholds					
		0.01 mm/h		0.05 mm/h		0.10 mm/h	
		N	mean	N	mean	N	mean
Tidbinbilla Ck @ Mountain Creek	TI	31	0.87	28	0.84	26	0.82
Chapple Ck @ Chapple Vale	CH	23	0.75	22	0.70	21	0.65
Goodman Ck above Lerderderg Tunnel	GO	13	0.65	12	0.59	10	0.56
Campaspe River @ Ashbourne	CA	3	0.68	3	0.58	3	0.55
Tarwin River East Branch @ Mirboo	TA	5	0.67	5	0.58	5	0.57
Ginninderra Ck u/s Barton Highway	GI	14	0.66	14	0.61	14	0.56
Snobs Ck @ Snobs Ck Hatchery	SN	12	0.90	10	0.87	8	0.85
Myers Ck @ Myers Flat	MY	7	0.80	5	0.74	5	0.68
Jerrabomberra Ck @ Four Mile Creek	JE	31	0.59	28	0.49	23	0.48
Ford River @ Glenaire	FO	23	0.72	22	0.66	19	0.67
Glenelg River @ Big Cord	GL	17	0.87	10	0.59	8	0.55
Warrambine Ck @ Warrabine	WA	8	0.53	7	0.47	6	0.69
Spring Ck @ Fawcett	SP	12	0.73	10	0.53	5	0.47
La Trobe River @ Near Noojee	LA	5	0.88	3	0.80	2	0.72
Orroral River @ Crossing	OR	36	0.86	27	0.79	25	0.76
Aire River @ Wyelangta	AI	17	0.70	14	0.65	14	0.60
Moonee Ck @ Lima	MO	28	0.89	19	0.86	17	0.84
Cobbannah Ck @ Bairnsdale	CO	12	0.64	11	0.59	9	0.58
Boggy Ck @ Angleside	BO	33	0.81	28	0.78	24	0.74
Wanalta Ck @ Wanalta	WN	11	0.57	7	0.56	5	0.51
Tarwin R East Branch @ Dumbalk Nth	TE	5	0.62	5	0.53	5	0.50
Lerderderg River @ Sardine Ck	LE	7	0.50	7	0.36	6	0.31

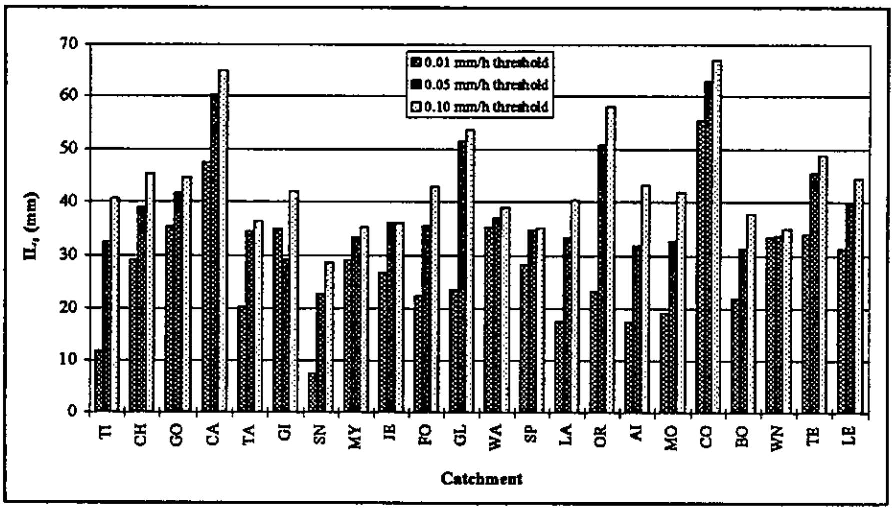

Figure E-1 Effect of Surface Runoff Threshold on Mean Storm Initial Loss (by catchment)

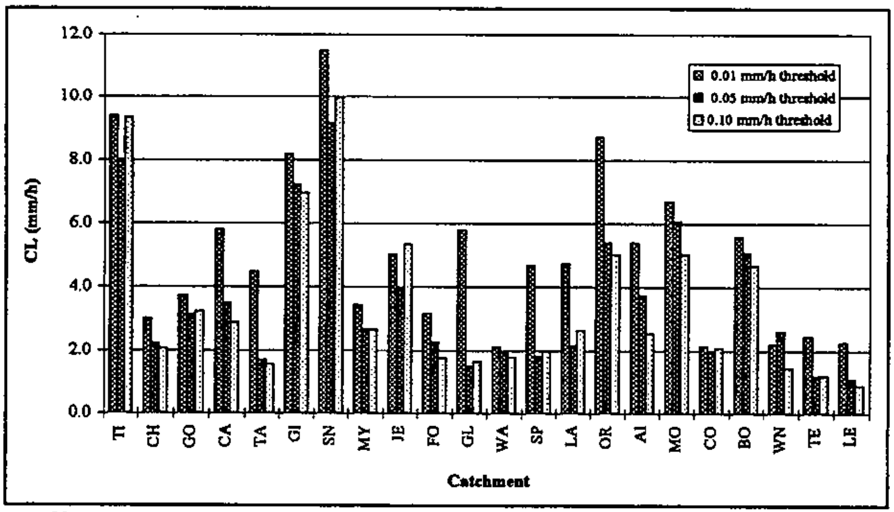

Figure E-2 Effect of Surface Runoff Threshold on Mean Continuing Loss (by catchment)

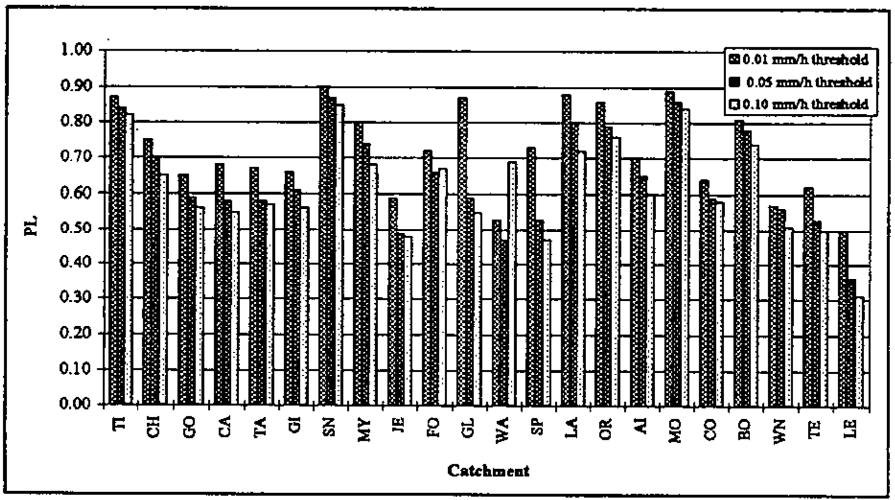

Figure E-3 Effect of Surface Runoff Threshold on Mean Proportional Loss (by catchment)

For a given event, increasing the surface runoff threshold results in increased initial loss, and thus reduced continuing and proportional losses. The mean losses in Figure E-1, E-2 and E-3 show this trend, except for a few catchments such as Ginninderra Ck (GI). These anomalies are produced by a different number of events being included in the average; for some events, the change of threshold results in continuing losses outside of the acceptable range (0-20 mm/h) and hence they are excluded from the average.

The number of excluded events was also considered as an indicator of the most suitable threshold. As shown in Figure E-4, increasing the surface runoff threshold results in more events which are considered to have "data errors" because of negative continuing losses. Decreasing the surface runoff threshold results in more events with very high continuing losses (greater than 20 mm/h) and excluded from the analysis.

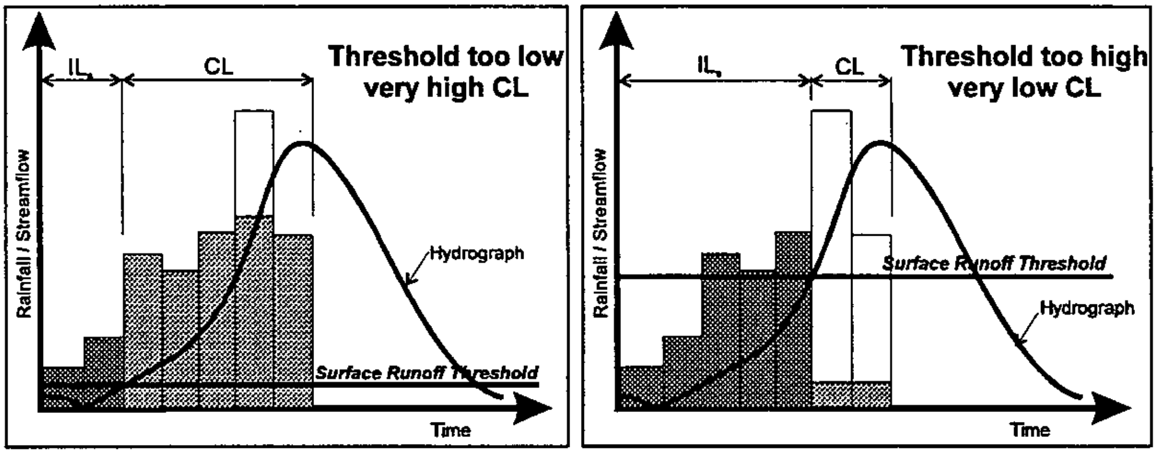

Figure E-4 Effect of Surface Runoff Threshold on Calculated Continuing Loss

The total number of events which were considered to have data errors (continuing loss too high or too low) is shown in Table E-4 for each of the thresholds. For some catchments the number of data errors increases with the surface runoff threshold and for other catchments the opposite is true. When all 22 catchments are considered, there is little difference between the total number of events with data errors (103, 109 and 104). The number of events excluded as data errors was approximately 10 percent of all of the events.

Table E-4 Number of Data Errors for Different Surface Runoff Thresholds

Catchment	code	Area (km²)	Number of Errors for threshold 0.01 mm/h	0.05 mm/h	0.10 mm/h
Tidbinbilla Ck @ Mountain Creek	TI	25	13	10	10
Chapple Ck @ Chapple Vale	CH	28	5	5	4
Goodman Ck above Lerderderg Tunnel	GO	32	1	0	2
Campaspe River @ Ashbourne	CA	33	15	9	3
Tarwin River East Branch @ Mirboo	TA	43	0	0	0
Ginninderra Ck u/s Barton Highway	GI	48	2	0	1
Snobs Ck @ Snobs Ck Hatchery	SN	51	4	2	1
Myers Ck @ Myers Flat	MY	55	11	4	4
Jerrabomberra Ck @ Four Mile Creek	JE	55	6	11	13
Ford River @ Glenaire	FO	56	1	0	9
Glenelg River @ Big Cord	GL	57	0	10	3
Warrambine Ck @ Warrabine	WA	57	4	4	4
Spring Ck @ Fawcett	SP	60	4	5	5
La Trobe River @ Near Noojee	LA	62	0	0	0
Orroral River @ Crossing	OR	90	7	8	11
Aire River @ Wyelangta	AI	90	8	6	6
Moonee Ck @ Lima	MO	91	0	8	0
Cobbannah Ck @ Bairnsdale	CO	106	1	1	2
Boggy Ck @ Angleside	BO	108	9	10	8
Wanalta Ck @ Wanalta	WN	108	11	15	16
Tarwin R East Branch @ Dumbalk Nth	TE	127	1	1	1
Lerderderg River @ Sardine Ck	LE	153	0	0	1
ALL CATCHMENTS			103	109	104

Sensitivity of Design Flood Peaks to Runoff Threshold

From the previous section, it is evident that calculated mean losses are sensitive to the choice of runoff threshold. Because a change in the runoff threshold has an opposite effect on the initial loss as on (both) the continuing and proportional losses, it is not clear what effect the choice of runoff threshold has on the design peak flow.

Design peak flows were calculated using calibrated RORB models for 6 catchments (a subset of the 22 catchments used in the derivation of design losses). These are listed in Table E-5; a description of the RORB models and their calibration is given in Hill et al. (1996a).

Table E-5 Catchments used for Testing the Sensitivity of the Design Peak Flows to Runoff Threshold

Catchment	Code	Area (km^2)	Mean Annual Rainfall (mm)
Goodman Ck above Lerderderg Tunnel	GO	32	800
Ford River @ Glenaire	FO	56	1520
Orroral River @ Crossing	OR	90	750
Aire River @ Wyelangta	AI	90	1880
Moonee Ck @ Lima	MO	91	1060
Wanalta Ck @ Wanalta	WN	108	540

The design rainfall information was taken from AR&R and the mean IL_s, CL, PL, were calculated for each of the 3 surface runoff thresholds. The variation of burst initial loss was also calculated for each threshold using an equation of the form of Equation E.1. The fitted parameters are shown in Table E-6.

$$IL_b = IL_s \left\{ 1 - \frac{1}{1 + \alpha \dfrac{(duration)^{\beta}}{MAR^{\delta}}} \right\} \tag{E.1}$$

The fitted parameters for the 0.01 mm/h threshold are slightly different from those in Section 6.3 because only non-zero values of mean IL_b/IL_s were used in the analysis. The fitted parameters in Section 6.3 should be used in preference to those in Table E-6.

Table E-6 Fitted Parameters for Equation E.1

	Surface Runoff Threshold (mm/h)		
parameter	0.01	0.05	0.10
α	142	90	41
β	0.4	0.4	0.5
δ	0.8	0.7	0.6

Design peak flows were calculated for each catchment and threshold using both the initial loss-continuing loss and the initial loss-proportional loss models, and with unfiltered temporal patterns and the areal reduction factors recommended in AR&R. The choice of areal reduction factors and the filtering of temporal patterns is discussed in Hill et al. (1996a).

The effect of the choice of surface runoff threshold on the design peak flow is shown in Figure E-5 to E-12. It is clear from these figures that the design peak flow is relatively insensitive to the choice of surface runoff threshold. Thus, the increase in initial loss and the corresponding decrease in the continuing or proportional loss tend to be compensatory. It is also clear that, when compared to the flood frequency analysis (FFA), design flows estimated using the IL-PL model are consistently underestimated. On the other hand, the design flows estimated using the IL-CL model are much closer to those obtained from the flood frequency analysis.

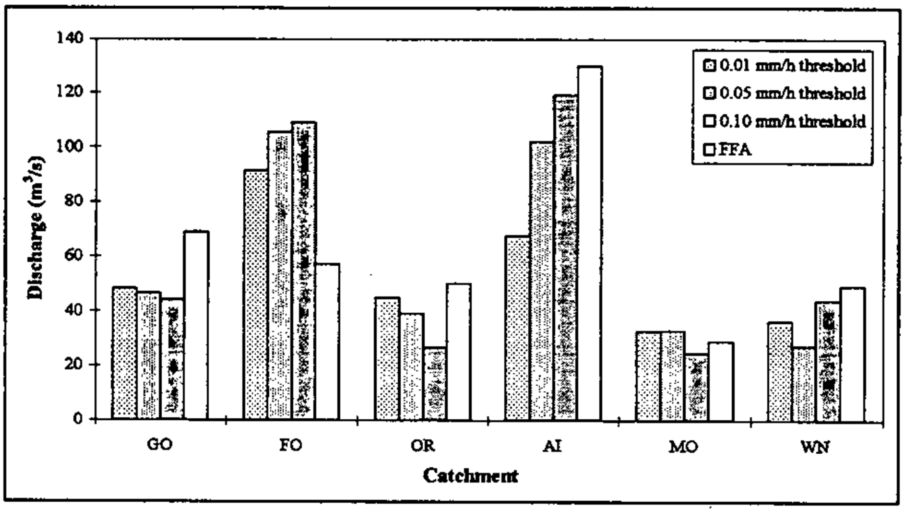

Figure E-5 Sensitivity of 1 in 10 AEP Design Peak Flow to Threshold for IL/CL

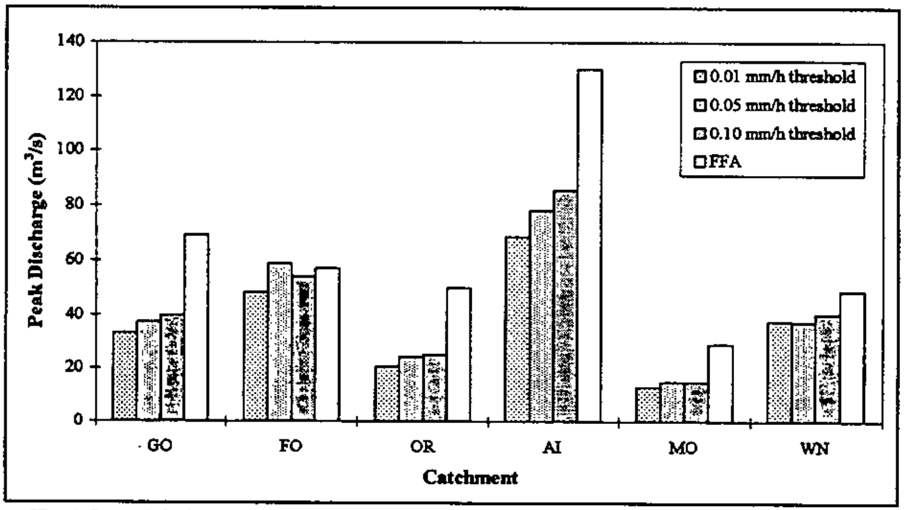

Figure E-6 Sensitivity of 1 in 10 AEP Design Peak Flow to Threshold for IL/PL

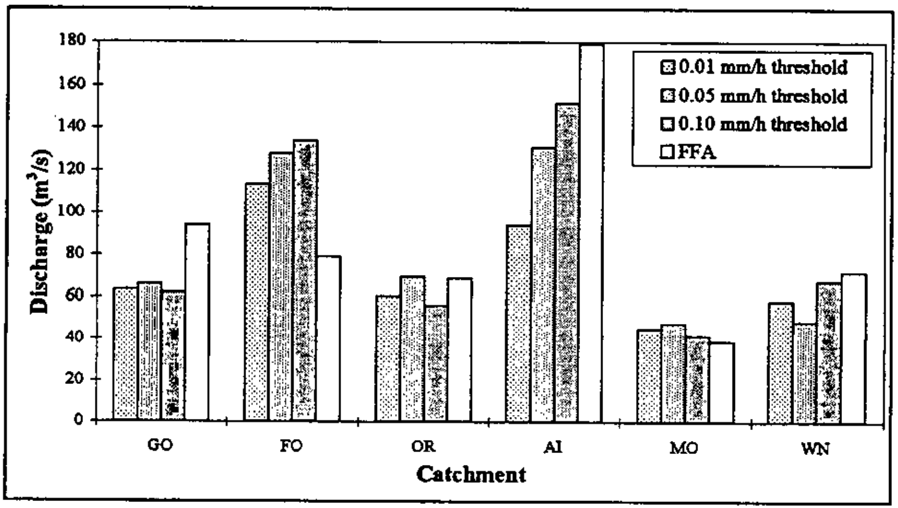

Figure E-7 Sensitivity of 1 in 20 AEP Design Peak Flow to Threshold for IL/CL

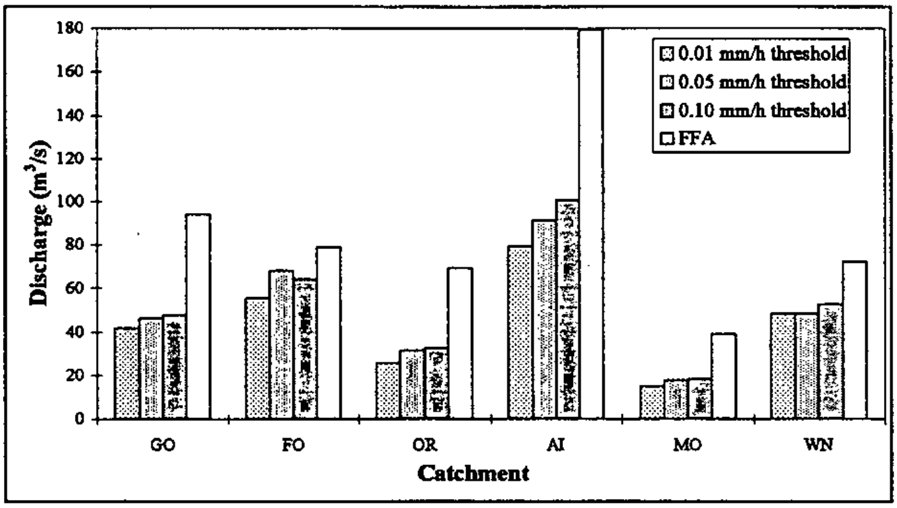

Figure E-8 Sensitivity of 1 in 20 AEP Design Flood Peak to Threshold for IL/PL

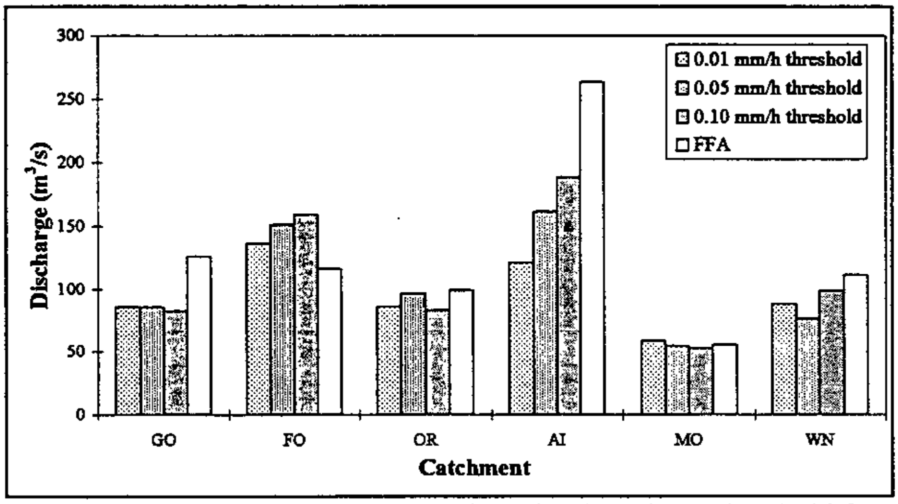

Figure E-9 Sensitivity of 1 in 50 AEP Design Flood Peak to Threshold for IL/CL

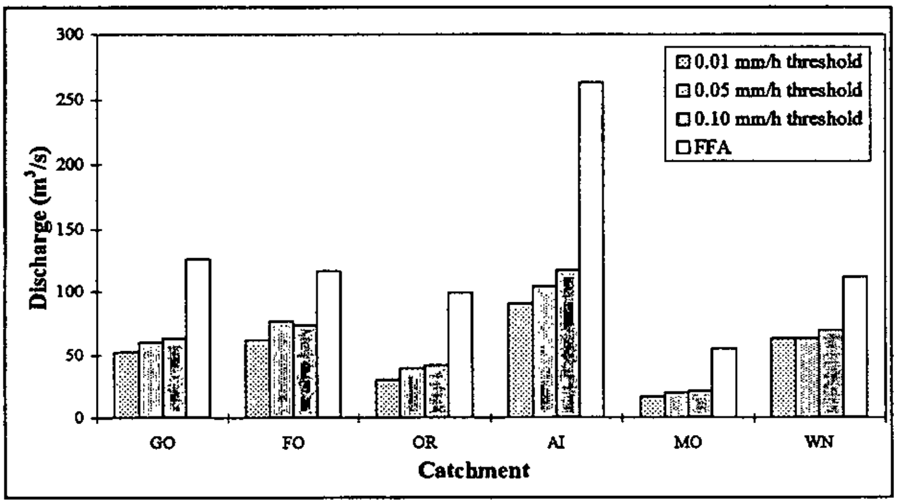

Figure E-10 Sensitivity of 1 in 50 AEP Design Flood Peak to Threshold for IL/PL

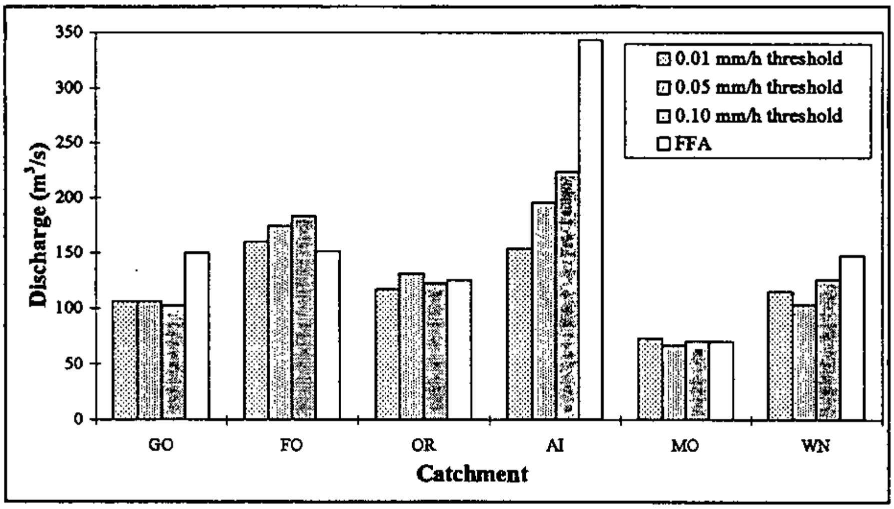

Figure E-11 Sensitivity of 1 in 100 AEP Design Flood Peak to Threshold for IL/CL

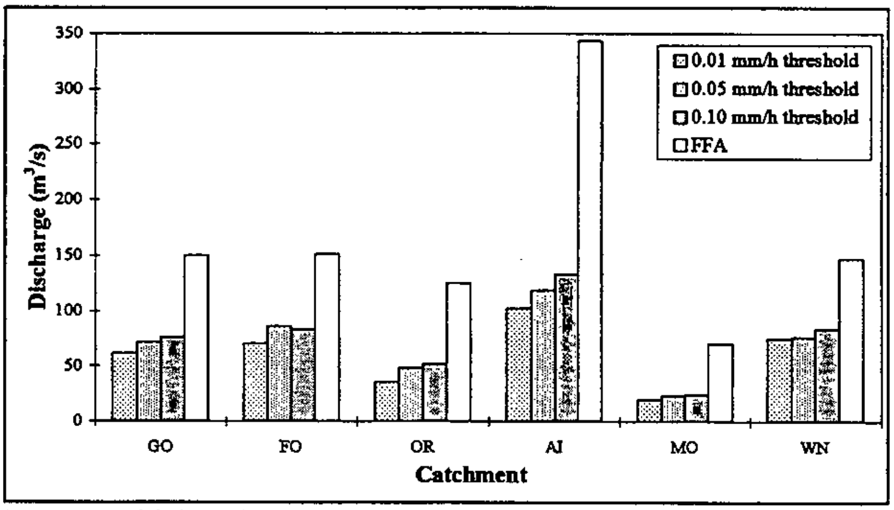

Figure E-12 Sensitivity of 1 in 100 AEP Design Flood Peak to Threshold for IL/PL

The results from the IL-CL model indicate that the use of a surface runoff threshold of 0.01 mm/h produces design peak flows which are closer to those from the flood frequency analysis than does the use of either of the other thresholds. However, the results from the IL-PL model would indicate a preference for a surface runoff threshold of 0.10 mm/h.

From a consideration of the number of data errors and the effect of the surface runoff threshold on the design flows, a surface runoff threshold of 0.01 mm/h was adopted. The choice of threshold is somewhat arbitrary and it could be argued other thresholds may have been suitable. It is reassuring to note however that the design peak flow is relatively insensitive to the choice of surface runoff threshold.

Appendix E

Appendix F

CATCHMENT CHARACTERISTICS

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Table F.1 Textural Classification of Soils for Study Catchments

Catchment	Code	description	Permeability Index
Tidbinbilla Ck @ Mountain Creek	Gn2.14	acid, leached red and yellow earths (red earths, gradational texture)	3
	Dr2.41	hard acidic red soils and hard acidic yellow and yellow mottled soil (hard setting loamy soils with red clayey subsoil)	3
Chapple Ck @ Chapple Vale	Dy3.21	hard acidic yellow mottled soils, unbleached A2 horizon (hard setting loamy with mottled yellow clayey subsoil)	3
	Uc2.3	leached sand with a compact of pan-like layer below the bleach (leach sand soils)	4
Goodman Ck above Lerderderg Tunnel	Uc6	shallow grey-brown, sandy soils (coherent), usually underlain by weathered rock	4
	Dy3.41	hard acidic, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
Campaspe River @ Ashborne	Dr2.21	hard acidic red soils. pedal subsoils (hard setting loamy soils with red clayey subsoil)	2
Tarwin River East Branch @ Mirboo	Gn4.11	Friable (highly structured) porous earths (red loams, podzoli soils, solodic soils)	
Ginninderra Ck u/s Barton Highway	Dy3.42	hard neutral yellow mottled soils with yellow earths, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
Snobs Ck @ Snobs Ck Hatchery	Gn4.31	brown friable porous earths, no A2 horizon	4
	Um7.11	organic loamy soils having A1 horizon	4
Myers Ck @ Myers Flat	Dr2.32	hard neutral red soils; sporadically bleached A2 horizon (hard setting loamy soils with red clayey subsoils)	1
Jerrabomberra Ck @ Four Mile Creek	Dy3.42	hard neutral yellow mottled soils with yellow earths, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
	Gn2.15	neutral leached red earths, yellow earths and yellow leached earths associated with hard neutral and/or alkaline yellow mottled soil, small areas of rock outcrops.	3
Ford River @ Glenaire	Dy3.21	hard acidic yellow mottled soils, unbleached A2 horizon (hard setting loamy with mottled yellow clayey subsoil)	3

Glenelg River @ Big Cord	Dy3.41	hard acidic, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
	Dy5.42	sandy, neutral, yellow mottled soil, bleached A2 horizon	1
Warrambine Ck @ Warrambine	Dy3.41	hard acidic, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
Spring Ck @ Fawcett	Dy3.41	hard acidic, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
La Trobe River @ Near Noojee	Gn4.14	red friable porous earths with an A2 horizon (red loams)	4
Orroral River @ Crossing	Gn2.14	acid, leached red and yellow earths (red earths, gradational texture)	3
Aire River @ Wyelangta	Dy3.21	hard acidic yellow mottled soils, unbleached A2 horizon (hard setting loamy with mottled yellow clayey subsoil)	3
Moonee Ck @ Lima	Dy3.42	hard neutral yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoils)	1
	Dr2.21	hard acidic red soils, pedal subsoils (hard setting loamy soils with red clayey subsoil)	2
Cobbannah Ck @ Bairnsdale	Dr2.21	Hard, acidic, red soils, pedal subsoils (hard setting loamy soils with red clayey subsoil)	2
Boggy Ck @ Angleside	Dy3.43	hard, alkaline, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
	Gn4.14	red friable porous earths with an A2 horizon (red loams)	4
Wanalta Ck @ Wanalta	Dr2.32	hard neutral red soils; sporadically bleached horizon (hard setting loamy soils with red clayey subsoils)	1
	Dr2.22	hard neutral red soils, unbleached A2 horizon (hard setting loamy soils with red clayey subsoils)	2
Tarwin R East Branch @ Dumbalk Nth	Gn4.11	friable (highly structured) porous earths (red loams, podzoli soils, solodic soils)	4
	Dy3.41	hard acidic, yellow mottled soils, bleached A2 horizon (hard setting loamy soils with mottled yellow clayey subsoil)	1
Lerderderg River @ Sardine Ck	Dr2.21	hard, acidic, red soils, pedal subsoils (hard setting loamy soils with red clayey subsoil)	3
	Gn4.11	friable (highly structured) porous earths (red loams, podzoli soils, solodic soils)	4

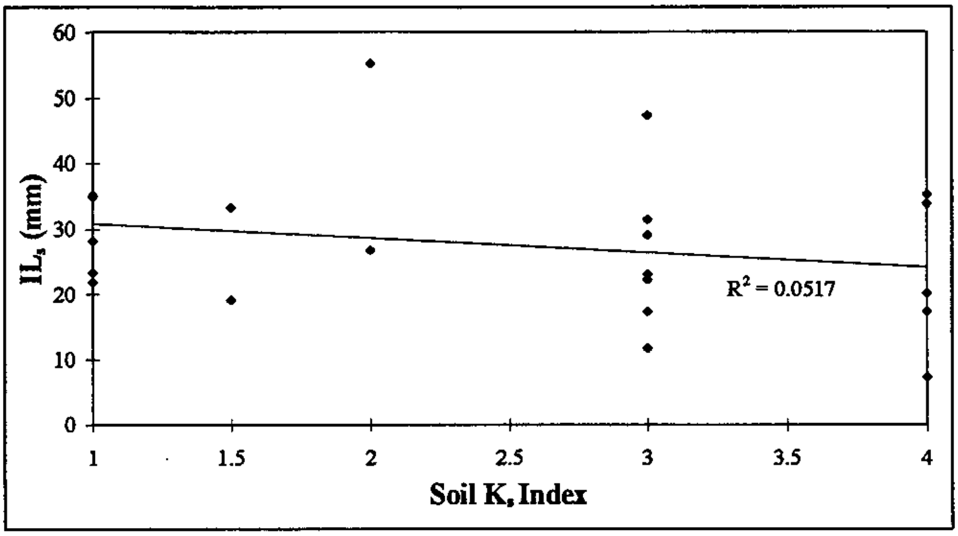

Figure F.1 Storm Initial Loss versus Soil K_s Index

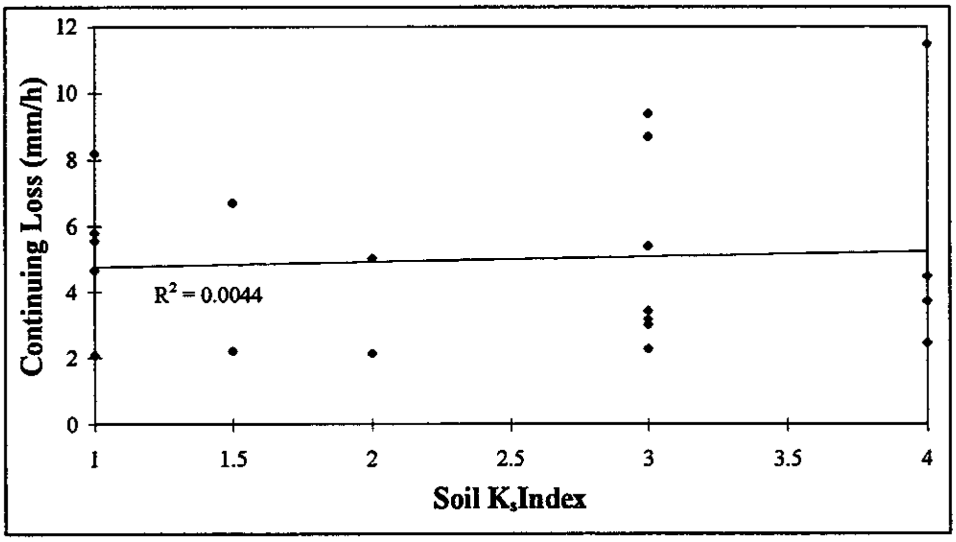

Figure F.2 Continuing Loss versus Soil K_s Index

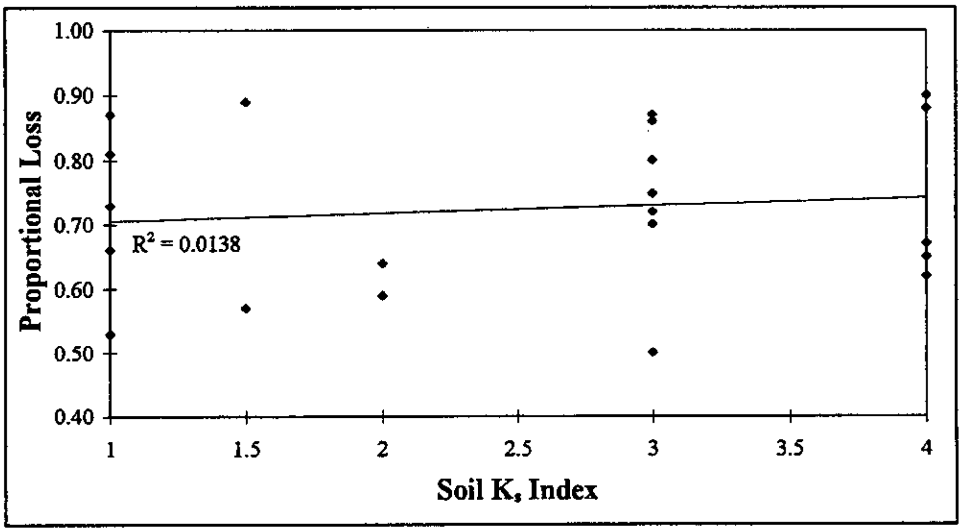

Figure F.3 Proportional Loss versus Soil K_s Index

Appendix G

DEVELOPMENT OF REGIONAL LOSS PREDICTION EQUATIONS

List of Tables

Table G.1 Seasonally Adjusted Storm Initial Loss

		adj. IL_s (mm)			IL_s (mm)			
Catchment	N	mean	std.err.	90% limits	mean	std.err.	90% limits	IL_s/ adj.IL_s
Tidbinbilla Ck @ Mountain Creek	31	11	1	± 3	12	2	± 3	1.09
Chapple Ck @ Chapple Vale	23	28	3	± 5	29	3	± 6	1.04
Goodman Ck above Lerderderg Tunnel	19	32	2	± 4	35	3	± 5	1.12
Campaspe River @ Ashborne	7	44	10	± 19	47	12	± 23	1.08
Tarwin River East Branch @ Mirboo	5	18	2	± 5	20	4	± 8	1.15
Ginninderra Ck u/s Barton Highway	20	30	4	± 7	35	4	± 7	1.16
Snobs Ck @ Snobs Ck Hatchery	12	7	1	± 2	7	1	± 2	1.05
Myers Ck @ Myers Flat	9	28	4	± 8	29	5	± 10	1.04
Jerrabomberra Ck @ Four Mile Creek	35	23	2	± 3	27	3	± 4	1.16
Ford River @ Glenaire	23	21	2	± 4	22	3	± 5	1.09
Glenelg River @ Big Cord	17	23	4	± 7	23	4	± 7	1.00
Warrambine Ck @ Warrabine	17	34	5	± 8	35	5	± 9	1.04
Spring Ck @ Fawcett	17	24	3	± 4	28	3	± 5	1.20
La Trobe River @ Near Noojee	7	15	2	± 4	18	2	± 4	1.16
Orroral River @ Crossing	36	20	2	± 4	23	3	± 5	1.18
Aire River @ Wyelangta	17	15	2	± 3	17	2	± 4	1.15
Moonee Ck @ Lima	28	19	2	± 4	19	3	± 5	1.01
Cobbannah Ck @ Bairnsdale	13	55	7	± 13	55	9	± 15	1.00
Boggy Ck @ Angleside	33	23	3	± 5	22	4	± 7	0.95
Wanalta Ck @ Wanalta	24	34	2	± 4	33	3	± 5	0.99
Tarwin R East Branch @ Dumbalk Nth	5	30	6	± 13	34	8	± 17	1.15
Lerderderg River @ Sardine Ck	9	31	6	± 11	31	8	± 15	1.02
							average	**1.08**

Table G.2 Seasonally Adjusted Continuing Loss

		adj. CL (mm/h)			CL (mm/h)			
Catchment	N	mean	std.err.	90% limit	mean	std.err.	90% limits	CL/ adj.CL
Tidbinbilla Ck @ Mountain Creek	31	8.5	0.71	± 1.2	9.4	0.88	± 1.5	1.10
Chapple Ck @ Chapple Vale	23	3.0	0.34	± 0.6	3.0	0.38	± 0.7	1.01
Goodman Ck above Lerderderg Tunnel	13	3.1	0.86	± 1.5	3.7	1.11	± 2.0	1.19
Campaspe River @ Ashborne	3	6.2	3.28	± 9.6	5.8	3.06	± 8.9	0.93
Tarwin River East Branch @ Mirboo	5	4.0	1.02	± 2.2	4.5	1.50	± 3.2	1.11
Ginninderra Ck u/s Barton Highway	14	6.9	1.65	± 2.9	8.2	1.97	± 3.5	1.19
Snobs Ck @ Snobs Ck Hatchery	12	9.9	0.95	± 1.7	11.5	1.10	± 2.0	1.16
Myers Ck @ Myers Flat	7	3.9	0.88	± 1.7	3.4	0.81	± 1.6	0.88
Jerrabomberra Ck @ Four Mile Creek	31	4.3	0.69	± 1.2	5.0	0.81	± 1.4	1.16
Ford River @ Glenaire	23	3.0	0.38	± 0.7	3.2	0.47	± 0.8	1.05
Glenelg River @ Big Cord	17	5.9	1.28	± 2.2	5.8	1.34	± 2.3	0.98
Warrambine Ck @ Warrabine	8	2.2	0.67	± 1.3	2.1	0.68	± 1.3	0.95
Spring Ck @ Fawcett	12	3.9	0.89	± 1.6	4.7	1.17	± 2.1	1.21
La Trobe River @ Near Noojee	5	4.3	2.17	± 4.6	4.7	2.66	± 5.7	1.09
Orroral River @ Crossing	36	7.6	0.67	± 1.1	8.7	0.89	± 1.5	1.14
Aire River @ Wyelangta	17	4.8	1.30	± 2.3	5.4	1.44	± 2.5	1.11
Moonee Ck @ Lima	28	6.8	0.68	± 1.2	6.7	0.71	± 1.2	0.98
Cobbannah Ck @ Bairnsdale	12	2.2	0.59	± 1.1	2.1	0.70	± 1.3	0.97
Boggy Ck @ Angleside	33	6.1	0.61	± 1.0	5.6	0.67	± 1.1	0.91
Wanalta Ck @ Wanalta	11	2.4	0.91	± 1.7	2.2	0.75	± 1.4	0.91
Tarwin R East Branch @ Dumbalk Nth	5	2.3	0.78	± 1.7	2.5	1.04	± 2.2	1.06
Lerderderg River @ Sardine Ck	7	2.4	0.80	± 1.6	2.3	0.83	± 1.6	0.96
							average	**1.05**

Table G.3 Seasonally Adjusted Proportional Loss

Catchment	N	adj.PL	PL	PL/ adj.PL
Tidbinbilla Ck @ Mountain Creek	31	0.84	0.87	1.03
Chapple Ck @ Chapple Vale	23	0.76	0.75	0.99
Goodman Ck above Lerderderg Tunnel	13	0.63	0.65	1.03
Campaspe River @ Ashborne	3	0.72	0.68	0.95
Tarwin River East Branch @ Mirboo	5	0.66	0.67	1.01
Ginninderra Ck u/s Barton Highway	14	0.64	0.66	1.04
Snobs Ck @ Snobs Ck Hatchery	12	0.87	0.90	1.03
Myers Ck @ Myers Flat	7	0.83	0.80	0.96
Jerrabomberra Ck @ Four Mile Creek	31	0.57	0.59	1.04
Ford River @ Glenaire	23	0.71	0.72	1.01
Glenelg River @ Big Cord	17	0.87	0.87	1.00
Warrambine Ck @ Warrabine	8	0.53	0.53	1.01
Spring Ck @ Fawcett	12	0.69	0.73	1.06
La Trobe River @ Near Noojee	5	0.86	0.88	1.02
Orroral River @ Crossing	36	0.83	0.86	1.03
Aire River @ Wyelangta	17	0.69	0.70	1.02
Moonee Ck @ Lima	28	0.92	0.89	0.97
Cobbannah Ck @ Bairnsdale	12	0.64	0.64	0.99
Boggy Ck @ Angleside	33	0.86	0.81	0.94
Wanalta Ck @ Wanalta	11	0.61	0.57	0.94
Tarwin R East Branch @ Dumbalk Nth	5	0.63	0.62	0.99
Lerderderg River @ Sardine Ck	7	0.52	0.50	0.96
			average	**1.00**

Table G.4 Selected Catchment Characteristics for Study Catchments

Catchment	Area (km²)	Slope %	BFI	Forest %	dense+ pine%	Infilt. 1	Infilt. 2	MAR (mm)	${}^{1}I_{2}$	${}^{1}L_{48}$	${}^{50}I_{2}$	${}^{50}I_{72}$	${}^{1}L_{48}$ ${}^{1}I_{2}$	${}^{50}I_{72}$ ${}^{50}I_{2}$	PET (mm)	MAR-PET (mm)	Wet days	MARdays	RAIN Var	Ks index
TI	25	1.3	0.52	95.8	94.3	288	221	1120	12.66	1.73	33.43	3.48	0.14	0.10	1410	-290	142	7.89	2.11	3
CH	28	1.9	0.50	91.2	70.9	274	144	1520	9.59	2.01	26.68	3.20	0.21	0.12	1050	470	264	5.76	2.52	3
GO	32	2.4	0.13	86.8	85.0	347	148	800	9.95	1.34	28.16	2.72	0.13	0.10	1080	-280	213	3.76	1.88	4
CA	33	0.7	0.32	98.5	75.5	295	416	960	10.07	1.34	27.88	2.65	0.13	0.10	1100	-140	212	4.53	2.17	3
TA	43	0.9	0.41	100.0	39.2	400	440	1140	9.83	1.53	27.17	3.16	0.16	0.12	1000	140	204	5.59	2.11	4
GI	48	0.7	0.19	34.0	1.9	34	46	640	10.78	1.22	28.75	2.42	0.11	0.08	1608	-968	95	6.74	1.87	1
SN	51	4.1	0.72	92.0	92.0	368	89	1660	10.15	1.70	27.72	2.05	0.17	0.07	1025	635	212	7.83	4.27	4
MY	55	0.3	0.15	89.5	38.6	268	789	520	9.38	0.96	25.23	1.87	0.10	0.07	1175	-655	150	3.47	1.88	3
JE	55	1.1	0.15	29.0	5.6	58	53	620	10.89	1.27	27.36	2.18	0.12	0.08	1608	-988	98	6.33	2.17	2
FO	56	3.3	0.58	66.9	53.8	201	61	1520	9.59	2.01	26.68	3.20	0.21	0.12	1050	470	264	5.76	2.52	3
GL	57	1.5	0.56	100.0	93.4	100	67	680	9.11	1.05	27.60	2.20	0.12	0.08	1010	-330	156	4.36	4.52	1
WA	57	1.0	0.09	0.0	0.0	0	0	660	8.41	0.93	25.59	1.96	0.11	0.08	1075	-415	147	4.49	1.86	1
SP	60	1.2	0.25	52.8	7.3	53	46	720	9.92	1.32	26.11	2.55	0.13	0.10	1050	-330	145	4.97	2.02	1
LA	62	0.8	0.81	98.8	98.8	395	488	1480	10.48	1.65	26.69	3.20	0.16	0.12	1000	480	231	6.41	2.35	4
OR	90	1.0	0.54	88.4	88.3	265	27	740	11.81	1.63	32.93	3.32	0.14	0.10	1410	-670	129	5.74	1.77	3
AI	90	0.9	0.58	79.5	48.0	239	254	1880	11.32	2.53	28.55	3.72	0.22	0.13	1050	830	278	6.76	2.69	3
MO	91	2.5	0.65	99.8	86.6	150	59	1060	12.20	1.56	29.40	2.59	0.13	0.09	1125	-65	159	6.67	2.80	1.5
CO	106	1.3	0.14	99.5	99.5	199	158	840	10.94	1.77	31.16	3.44	0.16	0.11	1025	-185	201	4.18	1.78	2
BO	108	1.5	0.55	97.8	59.6	98	65	1080	10.51	1.23	27.54	2.19	0.12	0.08	1130	-50	164	6.59	2.83	1
WN	108	0.2	0.08	100.0	0.0	150	1000	540	9.77	1.04	26.09	1.86	0.11	0.07	1175	-635	153	3.53	3.50	1.5
TE	127	0.4	0.39	52.7	16.0	211	555	1140	9.83	1.53	27.17	3.16	0.16	0.12	1000	140	188	6.06	1.74	4
LE	153	0.9	0.41	99.4	90.1	298	343	1080	10.02	1.43	28.39	2.65	0.14	0.09	1100	-20	192	5.63	2.32	3
minimum	25	0.15	0.08	0.0	0.0	0	0	520	8.41	0.93	25.23	1.86	0.10	0.07	1000	-988	95	7.89	1.74	1
maximum	153	4.12	0.81	100.0	99.5	400	1000	1880	12.66	2.53	33.43	3.72	0.22	0.13	1608	830	278	3.47	4.52	4

Table G.5 Correlation between Catchment Characteristics

	Dense+Pine	Area	BFI	${}^{1}I_{2}$	${}^{1}I_{48}$	${}^{50}I_{2}$	${}^{50}I_{72}$	Forest	Infilt_1	Infilt_2
Dense+Pine	1.00	-0.02	0.60	0.36	0.37	0.53	0.40	0.73	0.61	-0.16
Area	-0.02	1.00	0.02	0.08	0.01	0.07	0.01	0.13	-0.14	0.26
BFI	0.60	0.02	1.00	0.33	0.55	0.22	0.39	0.45	0.42	-0.19
${}^{1}I_{2}$	0.36	0.08	0.33	1.00	0.43	0.82	0.48	0.27	0.13	-0.15
${}^{1}I_{48}$	0.37	0.01	0.55	0.43	1.00	0.35	0.82	0.25	0.42	-0.19
${}^{50}I_{2}$	0.53	0.07	0.22	0.82	0.35	1.00	0.54	0.29	0.17	-0.23
${}^{50}I_{72}$	0.40	0.01	0.39	0.48	0.82	0.54	1.00	0.24	0.44	-0.09
Forest	0.73	0.13	0.45	0.27	0.25	0.29	0.24	1.00	0.65	0.36
Infilt_1	0.61	-0.14	0.42	0.13	0.42	0.17	0.44	0.65	1.00	0.37
Infilt_2	-0.16	0.26	-0.19	-0.15	-0.19	-0.23	-0.09	0.36	0.37	1.00
MAR	0.38	-0.02	0.75	0.17	0.85	0.04	0.56	0.28	0.51	-0.15
MAR_PET	0.41	0.05	0.69	-0.05	0.74	-0.12	0.49	0.35	0.53	-0.07
MARdays	0.18	-0.04	0.72	0.59	0.51	0.39	0.32	-0.03	0.12	-0.39
MRIndex	0.24	0.01	0.43	-0.15	-0.02	-0.17	-0.37	0.37	0.00	-0.04
Slope	0.42	-0.28	0.45	0.05	0.34	0.06	0.00	0.12	0.18	-0.57
PET	-0.28	-0.16	-0.28	0.48	-0.21	0.40	-0.14	-0.36	-0.35	-0.13
${}^{1}I_{48}/{}^{1}I_{2}$	0.28	-0.04	0.49	0.08	0.93	0.06	0.72	0.17	0.42	-0.17
${}^{50}I_{72}/{}^{50}I_{2}$	0.24	-0.02	0.38	0.21	0.81	0.20	0.93	0.16	0.44	-0.02
Ks_index	0.38	-0.13	0.33	0.05	0.46	0.08	0.47	0.34	0.90	0.33
Wet_days	0.39	-0.04	0.46	-0.18	0.71	-0.18	0.52	0.38	0.58	0.05

Table G.5 Correlation between Catchment Characteristics (cont.)

	MAR	MAR_PET	MARdays	MRIndex	Slope	PET	$^{1}I_{48}/^{1}I_{2}$	$^{50}I_{72}/^{50}I_{2}$	Ks_index	Wet_days
Dense+Pine	0.38	0.41	0.18	0.24	0.42	-0.28	0.28	0.24	0.38	0.39
Area	-0.02	0.05	-0.04	0.01	-0.28	-0.16	-0.04	-0.02	-0.13	-0.04
BFI	0.75	0.69	0.72	0.43	0.45	-0.28	0.49	0.38	0.33	0.46
$^{1}I_{2}$	0.17	-0.05	0.59	-0.15	0.05	0.48	0.08	0.21	0.05	-0.18
$^{1}I_{48}$	0.85	0.74	0.51	-0.02	0.34	-0.21	0.93	0.81	0.46	0.71
$^{50}I_{2}$	0.04	-0.12	0.39	-0.17	0.06	0.40	0.06	0.20	0.08	-0.18
$^{50}I_{72}$	0.56	0.49	0.32	-0.37	0.00	-0.14	0.72	0.93	0.47	0.52
Forest	0.28	0.35	-0.03	0.37	0.12	-0.36	0.17	0.16	0.34	0.38
Infilt_1	0.51	0.53	0.12	0.00	0.18	-0.35	0.42	0.44	0.90	0.58
Infilt_2	-0.15	-0.07	-0.39	-0.04	-0.57	-0.13	-0.17	-0.02	0.33	0.05
MAR	1.00	0.94	0.60	0.23	0.47	-0.43	0.87	0.65	0.54	0.81
MAR_PET	0.94	1.00	0.37	0.28	0.45	-0.71	0.83	0.63	0.52	0.90
MARdays	0.60	0.37	1.00	0.13	0.36	0.28	0.34	0.23	0.18	0.04
MRIndex	0.23	0.28	0.13	1.00	0.43	-0.27	0.03	-0.35	-0.16	0.14
Slope	0.47	0.45	0.36	0.43	1.00	-0.22	0.40	-0.01	0.17	0.35
PET	-0.43	-0.71	0.28	-0.27	-0.22	1.00	-0.41	-0.33	-0.28	-0.71
$^{1}I_{48}/^{1}I_{2}$	0.87	0.83	0.34	0.03	0.40	-0.41	1.00	0.81	0.50	0.85
$^{50}I_{72}/^{50}I_{2}$	0.65	0.63	0.23	-0.35	-0.01	-0.33	0.81	1.00	0.52	0.69
Ks_index	0.54	0.52	0.18	-0.16	0.17	-0.28	0.50	0.52	1.00	0.57
Wet_days	0.81	0.90	0.04	0.14	0.35	-0.71	0.85	0.69	0.57	1.00

Table G.6 Geology-Vegetation Index (Lacey, 1996b)

Group	Geology	Ecological Vegetation Classes	Baseflow Index
A	Devonian rhyodacite	(a) Wet Forest; (b) Damp Forest; (c) Montane Wet Forest; (d) Montane Damp Forest; (e) mix of Damp Forest & Shrubby Foothill Forest.	0.79
B	Tertiaty basalt	Damp Forest.	0.66
C	Devonian granite	(a) Wet Forest; (b) Damp Forest; (c) Montane Wet Forest; (d) mix of Montane Wet Forest & Sub-alpine Woodland; (e) mix of Montane Wet Forest & Montane Dry Woodland; (f) mix of Damp Forest with Herb-rich Foothill Forest or Shrubby Foothill Forest.	0.70
D	Silurian or Devonian granite	(a) Herb-rich Foothill Forest; (b) Shrubby Foothill Forest; (c) Shrubby Dry Forest; (d) Grassy Dry Forest; (e) Granitic Hills Woodland.	0.42
E	Tertiary unconsolidated	(a) Damp Forest; (b) Herb-rich Foothill Forest.	0.44
F	Upper Ordovician sedimentary	(a) Mix of Montane Damp Forest & Sub-alpine Woodland; (b) Herb-rich Foothill Forest; (c) Shrubby Foothill Forest; (d) Grassy Dry Forest.	0.54
G	Upper Ordovician metamorphic	(a) Mix of Herb-rich Foothill Forest with Shrubby Dry Forest or Grassy Dry Forest; (b) Grassy Dry Forest.	0.46
H	Silurian or Devonian sedimentary	Mix of Wet Forest & Damp Forest.	0.60
I	Silurian or Devonian sedimentary	(a) Mix of Damp Forest with Shrubby Foothill Forest, Herb-rich Foothill Forest or Heathy Foothill Forest; (b) mix of Herb-rich Foothill Forest & Grassy Dry Forest; (c) Heathy Dry Forest; (d) Grassy Dry Forest.	0.36
J	Cambrian or Lower Ordovician sedimentary	(a) Shrubby Foothill Forest; (b) Grassy Dry Forest.	0.33
K	Lower Cretaceous sedimentary	Wet Forest.	0.57
L	Lower Cretaceous sedimentary	Mix of Wet Forest & Damp Forest.	0.38

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