URBS

(Unified **R**iver **B**asin **S**imulator**)**

A
Rainfall Runoff Routing Model
for
Flood Forecasting & Design

Version 5.00

by

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PREFACE

The URBS model has been under development over the past 30 years. Its technical basis is in the work carried out by Laurenson & Mein and later as WT42 developed by the Queensland Department of Natural Resources and Mines. The primary focus of its development has been flood forecasting and design flood hydrology. Central to its development is the philosophy that the model is a tool that can be readily employed by flood forecasting practitioners and design flood hydrologists. This demanded a modular approach - one that facilitates good data management and interfacing with external inputs and outputs.

The URBS model includes the following features:

- (a) Calculated water levels as well as discharges using uniform/dependent rating curves
- (b) Integration with third party applications e.g. FEWS, AWBM etc.
- (c) Automatic generation of AR&R design storms for any Zone
- (d) Automatic collation of design storm results for various ARIs and durations
- (e) Integrated Monte-Carlo design storm results management routines
- (f) Both event and continuous modelling/simulation
- (g) Better modelling of hydrological behaviour through:
  - (i) splitting the catchment and channel routing components,
  - (ii) introducing more sophisticated event loss models,
  - (iii) in-built continuous loss modelling (Recovering Initial Loss Model)
  - (iii) splitting of loss model into pervious and impervious components, and
  - (iv) better accounting for the effects of urbanisation and de-forestation.
- (h) Sediment wash off and deposition modelling
- (i) Traffic disruption costs due to flooding
- (j) On-site detention analysis
- (k) Assessment of the impacts of roofwater retention.
- (l) Detention basin design
- (m) Allowance for channel transmission losses
- (n) Incorporation of a simple dam operating rule (non-operational)
- (o) Hotstart capabilities for flood forecasting operations
- (p) Batch processing to minimise runtime and maximise review time

The URBS model and associated utilities contain approximately 30,000 lines of code in which there are software bugs. The user is advised to check all results using basic continuity principles, comparative analysis, peer review, literature findings etc. The user is also advised that all risk associated with the use of the model and its utilities lies with the user. Accordingly, the author makes no representations concerning the suitability of this software for any particular purpose. It is provided "as is" without expressed or implied warranty of any kind. If you or your company do not accept all risk in its usage then you and your company should not use the model.

I would like to thank the following people for their assistance in the development of the URBS model; Mr Warren Shallcross, Queensland Department of Primary Industries- Water Resources, who developed WT42, Mr Michael Della who rigorously tested earlier versions of the model, Mr Terry Malone for his flood forecasting methodologies and operational in-sights, Dr. Sharmil Markar for his advice on command line interfacing, recovering loss concepts and hotstart approach, Dr. Tam Hoang for her advice regarding statistical reporting and presentation, Mr. Tony Aitken for his advice on the development of the sedimentation and traffic modules, to Mr. Bill Meynink for his insights regarding baseflow modelling, to Dr Ataur Rahman and Mr. Erwin Weinmann for their advice regarding deploying the CRC-CH and Total Probability Theorem Monte Carlo methodologies respectively and to Mr Michel Raymond for his insights into non-linear channel routing. Finally, and not least, I wish to thank the Hydrology and Hydraulics Staff at University College Galway, Ireland where I received my foundation training.

Pluralitas non est ponenda sine necessitate, William of Ockham, 14^{th} Century.

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1. INTRODUCTION

There are many catchment variables and model parameters values to choose from when modelling the runoff response for a catchment. What variables to choose and what parameter values to select are totally at the modeller's discretion. The modeller should always strive to minimise the number of parameters used. Further, the modeller should always check all results for sensibility and sensitivity. The URBS model therefore should be seen merely as a tool to produce results that are in line with those expected by an experienced hydrologist/engineer and reported in relevant literature.

If catchment changes are to be investigated, for example, changes in the extent of urbanisation, forestation, or channelisation, then the relevant variables should be included in the modelling process.

This manual is a user manual and is not intended to explain basic hydrological concepts, other than their application in the model. The reader is referred to AR&R (1987) for a better understanding of these concepts, particularly Chapters 6 7 & 9 that refer to the runoff routing concepts and processes. However, new concepts, not employed in traditional runoff routing models are explained.

Section 2 of the manual deals with runoff routing models, Section 3 with rainfall runoff model or loss models. Section 4 discusses ancillary models. Section 5 outlines data requirements for URBS; Section 6 discusses links with third party systems. Section 7 discusses URBS environment variables and Section 8 details how to run the model. Section 9 details URBS' utilities and Section 0 outlines how to run URBS in batch mode. Section 11 discusses future directions for URBS. Sections 12 and 13 contain listings of model errors and warnings.

2. RUNOFF ROUTING MODELS

URBS is a runoff-routing networked model of sub-catchments based on centroidal inflows. Two runoff routing models are available to describe catchment and channel storage routing behaviour. These are the URBS Basic and Split routing models.

The Basic model is a simple RORB-like model (Laurenson & Mein, 1990) where stream length (or derivative) is assumed to be representative of both catchment and channel storage. The Split Model separates the channel and catchment storage components of each sub-catchment for routing purposes. Irrespective of the model used, each storage component is conceptually represented as a non-linear storage.

The derived or assumed model parameters are set at the sub-catchment level and can be compared directly with similar catchments without requiring a re-scaling of calibrated parameters. This is unlike other models where calibrated parameters are expressed as a function of the outlet/calibration point catchment characteristics e.g. length, area, slope etc..

Interpolation, i.e. deriving flood hydrographs for points upstream of the calibration point, is achieved using "un-scaled" calibration parameters, however, the user should always ensure there is adequate definition of the upstream catchment i.e. the minimum number should be five sub-catchments as recommended by Boyd (1985).

It is worth noting that when calibration is achieved for a gauged location within the catchment, calibration of the summation of upstream flows is achieved, but to say any individual contribution is calibrated is fraught with danger. Extrapolation can also be carried out without changing calibration parameters however, care should be taken where there are wide downstream floodplains that will invariably increase storage availability and thereby decrease downstream flow rates.

Where hydraulic studies have been carried out (i.e. using the St. Venant equations), the URBS model should be calibrated to the results of the hydraulic model. This is particularly so where there are wide floodplains downstream of the calibrated point. A full description of integrated hydrologic and hydraulic modelling is described by Carroll & Collins (1993).

The routing variables used by URBS are, stream length, catchment area, channel slope, catchment slope, fraction urbanised (various degrees), fraction forested and channel roughness. The model requires that at least stream length be specified to define the extent of catchment and/or channel routing. All other variables are included optionally in the modelling process at the discretion of the modeller.

2.1. Basic Model

The Basic model assumes that the catchment and channel storage for each sub-catchment is lumped together and represented as a single non-linear reservoir. The model is similar to the RORB model (Laurenson & Mein, 1990).

Each conceptual non-linear reservoir is represented by the storage-discharge (S-Q) relationship:

$$S = k_c^1 \; Q^m \qquad (1)$$

k_c^1 is the non-linear routing constant for a single reservoir and is a function of the sub-catchment and channel storage characteristics. The Basic model includes these characteristics by replacing k_c^1 to give the following storage equation:

$$S = \left\{ \frac{\alpha f L n (1+F)^2}{\sqrt{S_c}(1+U)^2} \right\} Q^m \qquad (2)$$

where
- S = catchment and channel storage [m^3h/s]
- α = storage lag parameter
- f = reach length factor
- L = length of reach [km]
- U = fraction urbanisation of sub-catchment
- F = fraction of sub-catchment forested
- n = channel roughness or Manning's n
- S_c= channel slope [m/m]
- Q = outflow [m^3/s]
- m = catchment non-linearity parameter

By introducing these catchment characteristics, the routing constant (k_c^1) is reduced to the parameter α, which for a chosen set of catchment characteristics is assumed to be constant for all sub-catchments. The parameter is more familiar to RORB users when expressed as k_c divided by d_{av}. This is the case when stream length alone (minimum requirement) is used to characterise catchment and channel storage. d_{av} is the average stream length distance to the calibration point or outlet.

Incorporating the fraction urbanisation (**U**) reduces the routing lag (and accordingly catchment and channel storage) by reducing the reach length or derivative by a factor of $\mathbf{(1+U)^2}$. The exponent 2 was adopted as it approximates the value obtained by many researchers, in particular, Aitken (1975a) who derived a value of 1.97 from a set of urbanised Australian catchments. It is recognised however, that this reduction is only applicable to the sewered component of the catchment, which once surcharged, the storage discharge relationship tends to return to its pre-urbanisation characteristics. This results in a diminishing effect of urbanisation with increasing event magnitude. How this effect is incorporated into the model is discussed in Section 4.1.1 of this manual.

The fraction forested (**F**) affects the routing by increasing reach length (and therefore catchment and channel storage) by $\mathbf{(1 + F)^2}$. This factor was derived by SMEC (1990) from studies undertaken in PNG. It assumes dense forest and care should be taken when used to Australian conditions.

The Manning's **n** value should be used with caution and if used should not be combined with the urbanisation and/or forestation factors which already include the effects of channelisation and dense channel growth respectively.

It is interesting to note that equation (2) resembles the kinematic wave time of travel (Ragan & Daru, 1972) when **m** is set to 0.6 and the variables, $\mathbf{L/\sqrt{S_c}}$ and **n** are raised to the power of m. How to raise L, Sc and n and other variables to the exponent m is explained later. The catchment lag is often assumed by modellers to be 0.6 times the Kinematic wave travel time or time to equilibrium, e.g. Schroeter & Watt, (1983).

When stream length alone is used to represent catchment and channel storage, the default values of α and **m** adopted by URBS are 1.2 and 0.8 respectively. These values have been found to be typical for catchments in South-East Queensland (McMahon & Muller, 1986).

The Basic model can also be used to match the results of a calibrated hydraulic model by adjusting the parameter α to give a good overall fit, and then fine tuning the calibration by altering the value of **f**, the reach length factor, at strategic points.

2.1.1. Model Definition and Stability Issues

At least five sub-catchments are required upstream of a calculation point (Boyd, 1985) when estimating flows for internal model nodes, Without the required upstream model sub-division, calculated hydrographs will not have the appropriate shape, and peak flow rates tend to be under-estimated.

Calculation instability can occur where the sub-catchment lag divided by the chosen time interval ($k^1_c/\delta T$) becomes too small i.e. close to zero. The URBS model uses the following criterion as a base control of instability;

$$\frac{k_c^{\,1}}{\delta T} \leq 0.01 \qquad (3)$$

However, instability can still occur, and when it does, either larger sub-catchment sizes should be used, or the more common approach; the time step i.e. δT should be reduced. Calculation instability can be readily identified by plotting the calculated hydrographs using the URBS plotting module WinPLOTU. How to use WinPLOTU is discussed in Section 9.1 of this manual.

To overcome some of these problems, the RORB model for example, increases each sub-catchment lag by averaging sub-catchment rainfall over two time steps, i.e. the rainfall for the current time step is the average of the recorded rainfall for the current time and the previous time-step. This effectively increases the sub-catchment lag by δT/2, thereby reducing instability problems.

The URBS model can use the RORB approach by setting the environment variable URBS to RORB, i.e. by typing **set URBS=RORB** at the command line. The full range of URBS' environment variables and their meaning are described in Section 7 of this manual.

As an alternative to the RORB approach, URBS adopts a pseudo-physical approach, where the rainfall is lagged by an amount that is a function of the sub-catchment characteristics. This approach has the added advantage that it also reduces the number of sub-catchments required to adequately define a node calculation point (RORB requires a minimum 5 sub-catchments as already discussed). The exact reduction has not as yet been researched. The sub-catchment lag in units of hours is defined as;

$$Lag = \frac{1}{2}\ 0.76\ A^{0.38}\frac{(1 + F)^2}{(1 + U)^2} + \frac{U}{6} \qquad (4)$$

The first part of this equation is the time of concentration to the sub-catchment centroid i.e. the sub-catchment lag. It is based on the well known Pilgrim time of concentration equation given in the AR&R. The factor ½ is applied to represent time of travel to the centroid rather than outlet. The user can scale this factor by setting the value of the variable V on the DEFAULT PARAMETERS line of the catchment definition file. How to do this is described in Section 5.1 of this manual. The default value for V is 1 i.e. no scaling. The second component of equation (4) represents the time of entry for urbanised catchments, i.e. for a fully urbanised catchment 10 minutes is added to the travel time to account for entry time.

It is acknowledged that this approach has many conceptual flaws; for example the appropriateness of Pilgrim's equation in this context, the assumption that lag is ½ the time of concentration, and thirdly that the urbanisation and forestation factors have the same impact irrespective of event intensity and/or duration i.e. no account for less impact with increasing event magnitude. Nevertheless is does provide a useful technique for generating more realistic hydrographs at the sub-catchment level, without significantly affecting downstream peak flow rates.

Inclusion of the method is invoked by adding the R keyletter to the USES line in the catchment definition file. This is described in detail in Section 5.1.

2.1.2. *Fitting Model Parameters for the BASIC Model*

As the Basic model closely resembles the RORB model, a discussion of parameter fitting is warranted. For the same value of m, the catchment non-linearity parameter, the fundamental relationship between URBS' α and RORB's k_c is:

$$k_c = \alpha \; f_{av} \qquad (5)$$

f_{av} is calculated by URBS and reported to the user each run.

It is evaluated using the following formula:

$$f_{av} = \sum_{i=0}^{n} \frac{f_i \; A_i}{A} \qquad (6)$$

where A_i is the area of the i^{th} of n sub-catchments. f_i is the sum of routing constants e.g. L_i , $L_i/\sqrt{Sc_i}$ etc, along the routing path from the centroid of the sub-catchment (area A_i) to the outlet. When f_i is specified as stream length alone, ($f_i = L_i$) then f_{av} is equal to the well known d_{av}.

For example, a regional equation for k_c based on rural non-forested catchments gives a value of 3.8. The f_{av} value calculated by URBS is 54.28 assuming zero urbanisation and forestation. Stream length (L) and Channel Slope (Sc) are used to characterise the routing process. The value of α is then given as 3.8/54.28 = 0.07. This value of α should then be adopted for the URBS model and doing so will give similar results to the RORB model (the results will be identical if the RORB model uses the same variables i.e. L, Sc to characterise the storage behaviour of the catchment). Urbanisation and/or forestation effects can be taken into account by simply incorporating the extent of urbanisation/forestation for each sub-catchment into the model.

2.1.3. *Estimating k_c or α and m from a given set of events*

Much work has been carried out in this area in particular by Weeks (1980) through the use of interaction diagrams. Yu (1993) has also carried some further work based on channel characteristics which is promising and can be used to confirm the adopted set of calibration parameters. A third complementary method is as follows:

For each recorded event calculate the catchment lag and the maximum catchment storage. URBS calculates these two values with every run and are recorded in a ".o" output file. The different types of output files are discussed in Section 5. A log-log plot of lag (h) versus maximum catchment storage (cumec-h) is then carried out. The behaviour of the catchment lag with storage should be obvious from the plot (data timing errors and lack of rainfall definition are usually the cause of outliers). Decreasing lag with storage indicates a value of m less than 1, increasing lag with storage indicates a value of m greater than 1.

From the plot calculate the regression coefficients a,b of the equation:

$$\ln(lag) = a + b \ln(S) \qquad (7)$$

$$or \quad lag = c\ S^b,\ where\ c = e^a \qquad (8)$$

$$m = \frac{1}{(1-b)} \qquad (9)$$

It can be shown by comparing equation (7) with the storage equation for a single reservoir (equation (1)) that

$$and \quad k_c^1 = \alpha\ f_{av} = c^m \qquad (10)$$

However, equation (10) is not strictly correct, as calculation of catchment lag, which is an integral value, is carried out over the total range of discharge values, whereas S_{max} is a point estimate, which for a single reservoir is uniquely equal to $k_c^1 Q_{max}^m$. To correct this it is necessary to scale the k_c^1 value by the factor m. The factor was found experimentally. Equation (10) now more correctly becomes:

$$k_c^1 = \alpha\ f_{av} \approx m\ c^m \qquad (11)$$

By assuming that the total catchment can be represented as a single non linear storage, it has been found that k_c^1 (i.e. based on a single storage) is highly correlated with k_c (based on a well sub-divided catchment) as both represent the lag of the total catchment. Accordingly the following has been assumed:

$$k_c \approx k_c^1 \qquad (12)$$

The difference between the two lag estimates is mostly accounted for by the extent of catchment subdivision and degree of non-linearity. It should be noted that when m = 1, i.e. for a linear catchment k_c^1 is identical to k_c.

Fine tuning of the value of k_c can then be achieved by inter-event comparison, adopting the value of m calculated from equation (9) for all events.

It should be noted that it is not necessary to use URBS to determine the lag and maximum storage series for a set of events. The formulae, shown on the next page, are simple and may be implemented quite easily on a spreadsheet. They are given as follows:

Using the usual definitions:

$$S(t) \approx S_i = \delta T \sum_{i=1}^{\infty} (Q_i - I_i) \text{ where } \sum_{i=1}^{\infty} Q_i = \sum_{i=1}^{\infty} I_i \qquad (13)$$

from which S_{max} can be determined.

It can be shown that

$$Lag = \frac{\int_0^{\infty} S(t)dt}{\int_0^{\infty} Q(t)dt} \approx \frac{\delta T \sum_{i=1}^{\infty} S_i}{\delta T \sum_{i=1}^{\infty} Q_i} \qquad (14)$$

Higher moments can also be easily determined by further integration of equation (14).

It is interesting to note that for a single non-linear reservoir ($S = k_c^1 Q^m$), equation (14) can be expressed as:

$$\frac{k_c^1}{Lag} = \frac{\sum_{i=1}^{\infty} Q_i^m}{\sum_{i=1}^{\infty} Q_i} \qquad (15)$$

which can therefore be used to estimate the value of k_c via equation (12). However, for a well sub-divided catchment (greater than 20 sub-catchments) it has been empirically found that k_c is over-estimated for values of m less than 1, and under-estimated for values of m greater than 1. The difference is explained by the degree of catchment non-linearity and catchment sub-division.

Finally, equation (15) can also be used to explore, how k_c varies with m for a given event by assuming that the measured event lag should remain constant for each k_c/α-m calibration pair.

2.2. Split Model

The Split Model separates catchment and channel routing in each sub-catchment. First, the rainfall on a sub-catchment is routed through the catchment to the creek/river channel. This inflow from the sub-catchment into the channel is assumed to occur at the centroid of the sub-catchment. The lag of the sub-catchment storage is assumed proportional to the square root of the sub-catchment area. Next, the inflow is routed along a reach using a non-linear Muskingum method, whose lag time is assumed proportional to the length (or derivative) of the reach.

The Split Model is similar to the Watershed Bounded Network Model or WBNM (Boyd, 1987), except the WBNM model assumes the channel storage is proportional to sub-catchment area rather than channel length.

2.2.1. Catchment Routing

The catchment routing component of this model has been modified to include (optionally) the effect of catchment slope (CS) on the catchment response.

If the catchment slope (CS) is specified on the USES: command line (explained in Section 5.1), the rainfall is first routed through a catchment time-area diagram, similar to that as defined by Cordery & Webb (1974) i.e. a right hand sided triangle. This shape is the theoretical time-area diagram of a circular sub-catchment whose flows are directed to its centroid at a constant velocity.

The time (T) it takes (in hours) to travel from the sub-catchment perimeter to the centroid (i.e. the base length of the time-area diagram) is:

$$T = \frac{\sqrt{A / \pi}}{v} \qquad (16)$$

where A is the area of the sub-catchment (in square kilometres) and v is the velocity of the flow (in kilometres per hour)

The flow velocity, v is given in AR&R Volume 1 (1988) for various reliefs or catchment slope types. Values for differing catchment relief types are given in Table 1. This table was developed by the Bridge Branch of the Department of Transport, Queensland.

Table 1: Flow Velocities for Various Reliefs (QLD DoT)

Terrain Type	v (km/h)
Flat (0 - 0.015)	1.1
Rolling (0.015 - 0.04)	2.5
Hilly (0.04 - 0.08)	3.2
Steep (0.08 - 0.15)	5.4
Mountainous (> 0.15)	10.8

The time T (h) is the time the runoff has spent in concentrated flow throughout the sub-catchment.

If the sub-catchment is sewered, i.e. urbanised, the travel time is reduced by a factor of $(1+U)^2$. If the catchment is forested the travel time is increased by $(1+F)^2$. A time of entry (h) equal to U/6 is added for urbanised catchments. Inclusion of these factors in this component of the routing process is arguable, particularly for rare events, and more research is required in this area.

Once the rainfall has been routed using the time-area diagram, it is routed through a non-linear reservoir. The storage-discharge relationship for this reservoir is:

$$S_{catch} = \left\{ \frac{\beta\sqrt{A}(1+F)^2}{(1+U)^2} \right\} Q^m \qquad (17)$$

where S_{catch} = catchment storage [m^3h/s]
β = catchment lag parameter
A = area of sub-catchment [km^2]
U = fraction urbanisation of sub-catchment
F = fraction of sub-catchment forested.
m = catchment non-linearity parameter

The non-linear catchment routing parameter m is typically between 0.6 and 0.8.

Placing an asterisk (*) after the SPLIT keyword (explained later) on the MODEL definition line in the catchment definition file will include, as with the BASIC Model, the variables within the exponent m.

Finally, it is noted that the effects of urbanisation and forestation are applied to the catchment routing component. Therefore through flows are unaffected by local sub-catchment urbanisation or forestation. Accordingly this model is more suitable for large creeks and rivers where the main channel hydraulic properties are largely unaffected by the extent of catchment urbanisation or forestation.

2.2.2. Channel Routing

Channel routing is based on the non-linear Muskingum model as is given as:

$$S_{chnl} = \alpha f \frac{n\,L}{\sqrt{S_c}}(xQ_u + (1-x)Q_d)^n \qquad (18)$$

Where:

S_{chnl} = channel storage [m^3h/s]
α = channel lag parameter
f = reach length factor
L = length of reach [km]
S_c= channel slope [m/m]
Q_u = inflow at upstream end of reach (includes catchment inflow)
Q_d = outflow at downstream end of the channel reach [m^3/s]
x = Muskingum translation parameter
n = Muskingum non-linearity parameter (exponent)
n = Manning's n or channel roughness

It is noted that setting Muskingum n = m, x = 0 and β = 0, the Split Model reduces to the Basic model, or the simplest form of the RORB model. Setting β =0 and n = 1, the model reduces to the Muskingum Model.

Setting Muskingum n to a value other than 1, assumes the non-linear Muskingum model which allows the model to vary lag with flow; a value less than 1 implies a decrease in lag with increasing flow, whereas a value greater than 1 implies vice versa. A value of n = 1 is recommended as this has been supported through calibration to the results of hydrodynamic models, and secondly using the usual variable definitions and adopting a simplistic expression for channel storage (S_{chnl}), the following relationship can be derived;

$$S_{chnl} = L\ A_{ave} = \frac{L}{V}\ Q = \frac{n\,L}{\sqrt{S_0}}\ \frac{Q}{R^{2/3}} \qquad (19)$$

The rate of change of R with A is approximately inversely proportional to the value of the wetted perimeter i.e. as the perimeter increases R tends to approach a constant viz. channel velocity approaches a constant.

2.2.3. Parameter Estimation

2.2.3.1. <u>Interaction Diagrams</u>

It is possible when using the Split Model to undertake an α-β interaction analysis. The modeller should vary α and β to achieve calibration for each event and plot the α-β interaction curve for each event. Good calibration can be achieved where there is a defined intersection region from which α and β can be selected. This type of analysis is similar to that proposed by Weeks who investigated interaction between RORB k_c and m parameters.

2.2.3.2. Comparison with WBNM Model

Boyd (1986) uses the split model concept for the WBNM model, however, the relationship assumes (i) the same degree of non-linearity for channel and catchment storage and (ii) that the relationship between the channel and catchment storage constants is fixed through an empirical relationship (Pilgrim, 1982) i.e. $k_{channel}=0.6\ k_{catchment}$.

Using Boyd's relationship and comparing equations (17) and (18) (assuming stream length (L), and area (A) alone adequately describe the routing behaviour) gives for a single sub-catchment:

$$\alpha L = \alpha d_{av} = 0.6 \beta \sqrt{A} \qquad (20)$$

For catchments in the Brisbane area, the average value of $\sqrt{A}/d_{av} \approx 1/\sqrt{2}$, however, this value varies widely. Substituting into equation (20) gives :

$$\beta \approx 3\alpha \qquad (21)$$

Thus once, α has been determined, β can be calculated using equation 21. It should be noted that both catchment and channel storage share the same degree of non-linearity.

Using Recorded Hydrograph Field data and/or Hydraulic Models

α can be estimated from upstream and downstream hydrograph from which the flood wave celerity/speed can be estimated. α is the inverse of the average wave speed (km/h) when n, the channel linearity parameter is assumed to be 1 and stream length alone is used to characterise the routing process. However if the channel is highly subdivided then the effect of this model sub-division will be to introduce lag through numerical diffusion. This will require the modelled α to be less than the calculated α to compensate, the degree to which requires further research.

Alternatively the results of model Muskingum routing could be matched to the output of a rigorous hydraulic model to establish the value of α, (e.g. Della & McGarry, 1993).

Once α and n have been calibrated, β and m are calibrated through matching recorded events.

2.2.3.3. Using Calibrated Model parameters from other catchments

The Australian Bureau of Meteorology (BoM) has used the URBS Split model for many catchments. The parameters adopted by the BoM may be available to the user upon request to the BoM.

3. RAINFALL RUNOFF – LOSS MODELS

The determination of rainfall losses is critical to determination of accurate flow peaks. It is an area that requires more research to complement the significant research into runoff-routing models over the past decade.

URBS adopts two rainfall loss approaches; event based and continuous modelling.

3.1. Event Based Rainfall Loss Modelling

Unlike continuous modelling, event based modelling requires the user to specify the rainfall lost to the catchment before surface runoff occurs. This loss is commonly called the initial loss. Various loss models can then be used to estimate rainfall losses during the event.

The URBS model models rainfall losses for impervious and pervious areas separately[1]. The user however has the option of specifying loss parameters that represent both impervious and pervious areas if so required. However, the former approach is preferred.

3.1.1. Impervious Loss Model

For impervious areas, the URBS model assumes by default that there is no initial loss and 100% runoff. Recent research seems to suggest an initial loss of approximately 1 to 2 mm and a runoff proportion between 90% and 100% to be more appropriate. Furthermore, some researchers, e.g. Boyd et al, 1993, adopt an effective fraction impervious to represent the directly connected impervious components of the catchment. A value between 0.7 and 0.9 is often used.

The user can change the impervious initial loss and runoff proportion on the DEFAULT PARAMETERS line in the catchment definition file. The effective impervious area can be adjusted by multiplying the I keyletter by the chosen factor on the USES key line in the catchment definition file, eg I*0.7. This is explained more fully in Section 5.1.

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1 It should be noted that this approach is not to be confused with separate pervious and impervious area routing as used by some runoff routing models eg. RAFTS-XP (WP, 1988). This model assumes different lag coefficients for both types of catchment - a much shorter lag is assumed for impervious areas calculated by dividing the pervious area lag by $(1 + U)^2$. For fully urbanised areas U is set to 2 which translates to a dividing factor of 9. The U value of 2 is an extrapolation based on fraction impervious.

The URBS does not employ the split routing approach as it is considered that this may tend to over-estimate peak flow rates for fully urbanised sub-catchments, particularly for high rainfall (rare) events. This is a tentative assessment and is based on the premise that research to date has not used an extrapolated U value to assess the effects of urbanisation ie U values have been restricted to a maximum value of 1. Previous research also lumped both non-urbanised and urbanised areas from which the $(1 + U)^x$ lag reduction factor has been derived. Accordingly to apply this reduction factor to a split routing model, may not be in line with the findings of the original research. It is obvious that further research work is required in this area to determine the relative advantages/disadvantages of spilt routing models and associated lag parameters. In the meantime the URBS adopts the lumped routing approach at the sub-catchment level.

3.1.2. Pervious Loss Models

The URBS model has 3 types of pervious loss models. These are:

(i) Continuing Loss Model (rainfall is lost on all parts of the catchment)

This model assumes that there is an initial loss of *il* millimetres before any rainfall becomes effective. After this, a continuing loss rate of *cl* millimetres per hour is applied to the rainfall.

(ii) Proportional Runoff Model (only part of the catchment contributes to runoff)

This model assumes that there is an initial loss of *il* millimetres before any rainfall becomes effective. After this, a proportional amount of runoff of *pr* is assumed.

(iii) Manley-Phillips Loss Model. (Rainfall is lost on all parts of catchment)

Once the initial loss has been satisfied, Phillips equation is used to calculate rainfall losses. Application of Phillips equation is based on Manley (1974) who developed a set of physically based coefficients for Phillip's Equation. The model assumes a loss rate based on the following equation:

$$f_t = \frac{1}{2}(2kP)^{1/2} t^{-1/2} + k \qquad (22)$$

where f_t = loss rate after time t [mm/h]
t = time [h]
P = capillary suction head [mm]
k = saturated loss rate [mm/h]

This model reduces to a uniform loss rate of k when P = 0.

The default values assumed by URBS for each loss model are:

Continuing Loss Model:	IL = 0 mm	CL = 2.5 mm/h	
Proportional Loss Model:	IL = 0 mm	PR = 1.0 (i.e. all runoff)	
Manley-Phillips Loss Model:	IL = 0 mm	P = 0 mm	k = 2.5 mm/h

3.1.3. Including Spatial Variability Effects in Loss Model parameters

The URBS adopts a statistical distribution approach to account for the spatial variability of soil loss model parameters, specifically maximum soil storage capacity. This approach determines that when infiltration into the pervious areas has reached x mm, say, one can expect that y fraction of the catchment is contributing to runoff. The statistical approach is used by many models throughout the world, more notably, the Stanford rainfall runoff model.

The URBS model assumes the simplest model i.e. a straight-line distribution. The model is therefore defined by the equation;

$$f_{eff} = f_u + \frac{F_t}{F_{\max}}(1 - f_u), \quad \mathrm{Max}(f_{ect}) = 1 \qquad (23)$$

where f_{ect} = the effective impervious area. f_u is the existing impervious area. F_t is the cumulative infiltration into the pervious area (mm) after time t, and F_{max} is the maximum soil storage capacity of the catchment.

Figure 1 describes the URBS catchment infiltration model.

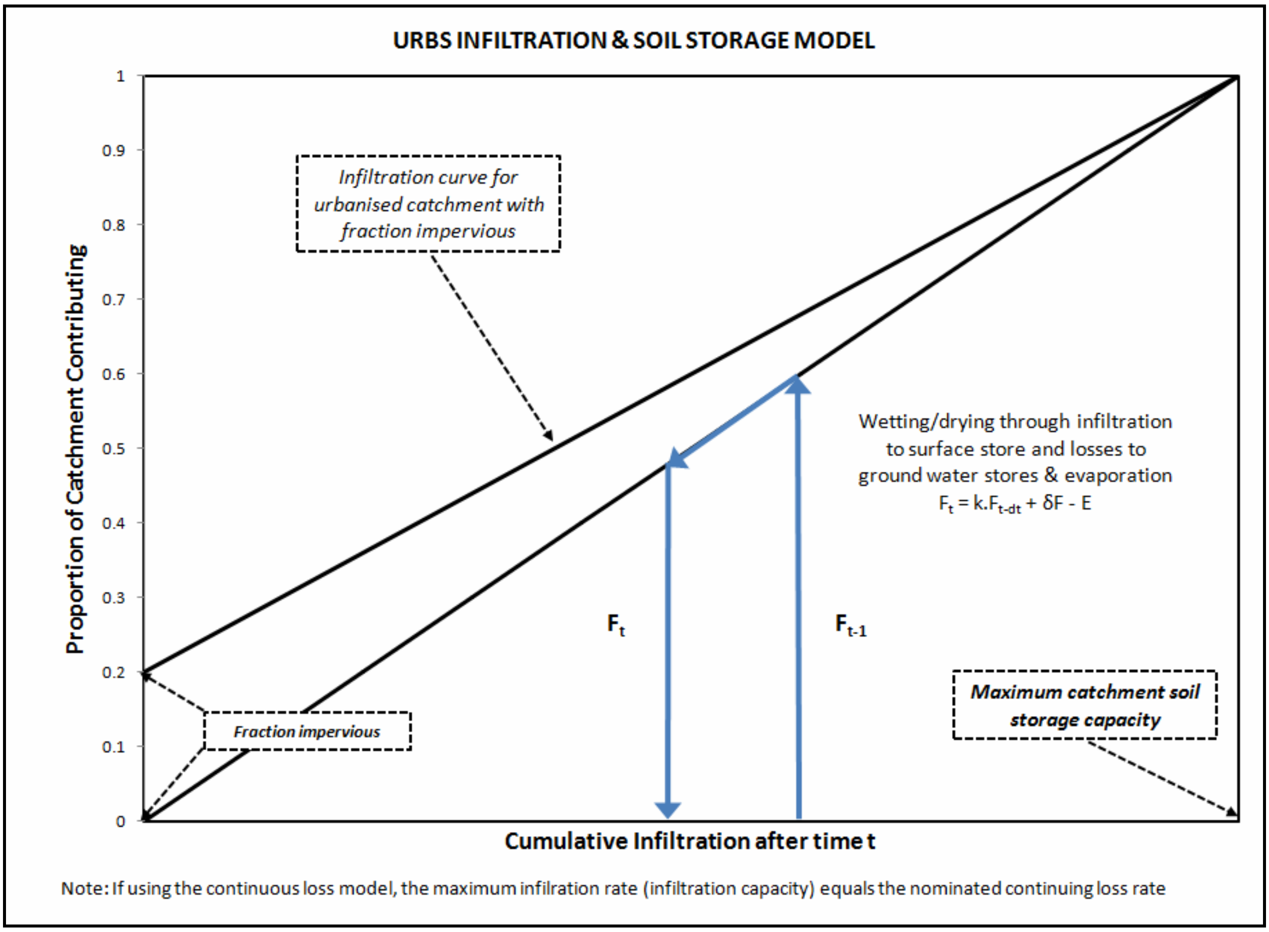

Figure 1: URBS Spatial Infiltration Model based on effective impervious areas

Rainfall for each time period is calculated from;

$$R_i = f_{eff} \; C_{imp} \; R_i^{tot} + (1 - f_{eff}) \; R_i^{per} \qquad (24)$$

where R_i^{tot} is the incident or total rainfall depth, C_{imp} is the impervious runoff coefficient (default is 100%), and R_i^{per} is the pervious excess rainfall depth calculated via any one of the of pervious loss models (viz. proportional, continuing, Phillips etc).

Recovery is included by reducing the amount infiltrated after every time step as follows.

$$F_t = k_{\delta T} F_{t1}, \; k_{\delta T} = k^{\frac{\delta T}{24}} \qquad (25)$$

The reduction coefficient $k_{\delta T}$ is based on the 24 hour coefficient k_{24} which is entered by the user in the DEFAULT PARAMETERS line of the catchment definition file. Evaporation also can be specified which will further reduce the contents of the soil water store.

Using this approach is optional, however if used, it is best coupled with Proportional Runoff model. In this case, the chosen proportion runoff coefficient for each sub-catchment should be considered as an initial value. Continuous rainfall will increase the runoff proportion through increasing the effective impervious area of the catchment. Inclusion of the recovery coefficient k_{24} will reduce the effective impervious area over time, - given a cessation of rainfall.

3.2. Rainfall-Runoff Models / Continuous Loss Modelling

URBS has two methods that be used to include the results (excess rainfall) of continuous rainfall runoff modelling. The user can elect to use URBS' simple recovering initial loss rainfall runoff model or can opt to integrate the results from a third party water model such as the AWBM (Boughton, 1993) model.

3.2.1. URBS Recovering Initial Loss Models (RILM)

Whereas continuing loss or proportional loss can be recovered as outlined in Section 3.1.3, recovery of the initial loss after a substantial dry period is not possible. The RILM is a model that recovers initial loss. It can be used with either the continuing loss or proportional loss models.

Essentially the RILM is a simple initial loss single bucket model – once rainfall is less than potential loss, the deficit is made up in part from the initial loss store. The capacity of the Initial loss store (IL_{max}) is specified by the user. If it is not specified, it is assumed to be the initial loss specified for the first event. This means that that the first event should commence after a significantly dry period.

3.2.1.1. <u>Continuing Loss Model</u>

A simple model was developed to allow recovery of the initial loss:

The initial loss is recalculated after every time step using the equation:

$$IL_{(i+1)} = IL_i, \qquad R_i > clr_i \,.\, \delta t$$

$$IL_{(i+1)} = IL_i + f\,.(clr_i\, \delta t - R_i), \qquad Ri \le clr_i \,.\, \delta t$$

$$IL_{(i+1)} = IL_{\max}, \qquad IL_i > IL_{\max}$$

where R_i is the rainfall series and clr_i is the continuing loss rate series, δt is the model time interval and f is user selected calibration parameter and represents the fraction of continuing loss deficit that contributes to the initial loss recovery. A value of f between 0.1 and 0.5 has been reported by Markar (2001).

This model can be combined with the infiltration model described in Section 3.1.3 to provide both variable initial and continuing loss rates. How to apply this model is described in Section 5.1 of this manual.

3.2.1.2. Proportional Loss Model

A simple model was developed to allow recovery of the initial loss:

The initial loss is recalculated after every time step using the equation:

$$IL_{(i+1)} = IL_i, \quad pr\,R_i > rlr.\delta t$$
$$IL_{(i+1)} = IL_i + rlr.\delta t - R_i, \quad Ri \le rlr.\delta t$$
$$IL_{(i+1)} = IL_{\max}, \quad IL_i > IL_{\max}$$

where R_i is the rainfall series and pr is the proportional runoff coefficient, rlr is the recovering loss rate. When the rainfall rate is less than this rate, the initial loss can be recovered. δt is the model time interval.

This model can be combined with the infiltration model described in Section 3.1.3 to provide both variable initial and proportional loss rates.

How to apply this model is described in Section 5.1 of this manual.

3.2.2. Third party water balance models.

A water balance model such as the AWBM model (Boughton, 1993) may be used to determine the losses for a given event. These models generally produce un-routed runoff or rainfall excess to a gauged location (called a rainfall runoff station). The URBS model can access these data and disaggregate the excess for each upstream sub-catchment based on the volume of total rainfall that fell on each sub-catchment. When this loss model is used you should ensure that the parameters for the event based loss models (i.e. either uniform, proportional or Manley-Phillips) are set so that there is no generated loss.

Section 5.7 how to include the results from third party rainfall runoff (or water balance) models into URBS.

4. ANCILLARY MODELS

4.1. Modelling Land Use Changes

4.1.1. Urbanisation

There are two effects of urbanisation; decreased lag and increased runoff volume. Both effects diminish with event magnitude. URBS uses the fraction urbanised variable U (fraction of catchment sewered (pipe/channelised)) to determine the decrease in lag and the fraction imperviousness (I) to determine the increased runoff volume. A full description of the effects of catchment urbanisation is given in a paper titled "*Assessment of the effects of Urbanisation on Peak Flow rates*" prepared by the author at the second International Stormwater Management Conference, Melbourne 1995.

The effect of urbanisation on peak flow rates due to channelisation should be modelled where possible using rigorous hydraulic models. These models should use hydrological inputs modified to reflect catchment urbanisation through use of the urbanisation index (U) (to quicken catchment runoff) and the impervious fraction index (I) (to increase runoff volumes). The hydrologic model for the main channel, where possible, should be calibrated to the hydraulic model by altering calibration parameters and the reach length factor f.

4.1.1.1. URBS Urbanisation Indices

The URBS model provides the user with the following urbanisation indices:

UL	(Urban Low density), fraction impervious is ULI (17% by default)
UM	(Urban Medium density), fraction impervious is UMI (33% by default)
UH	(Urban High density), fraction impervious is UHI (50% by default)
U	same as UH
UR	(Urban Rural) rural land in urban area with good cover (default)
UD	(Urban Disturbed) land with no cover and/or under development
UF	(Urban Forest) land covered by tropical forest
F	same as UF
I	fraction Impervious
UI	threshold Urban Impervious fraction above which land is considered as UH (50% by default)

The user can assign a fraction impervious to the UL, UM and UH land use categories or adopt the default values as given above. Changing the default impervious fractions is done via the DEFAULT PARAMETERS line in the catchment definition file using the UHI, UMI, and ULI variables. How to do this is discussed in Section 5.1. The user can also specify the threshold imperviousness (UI) above which all areas with an imperviousness fraction in excess of this value are considered to be fully urbanised. The default value is 50%.

Using the above index definitions, the urbanisation index (U) adopted for reducing catchment and/or channel lag is calculated as;

$$U = \tfrac{0}{UI}(UR + UD + UF) + \tfrac{UMI}{UI}UL + \tfrac{UMI}{UI}UM + \tfrac{UHI}{UI}UH \qquad (27)$$

Should any of the "U?I/UI" ratios exceed 1, then they are set to 1, as per the definition of the threshold impervious fraction variable (UI). The above approach differs from that adopted by the RAFTS-XP model, where 100% impervious fraction catchments are assumed to have an extrapolated U value of 2. The maximum URBS U value is 1. There is insufficient research data to determine which is the better approach.

The urbanisation indices are also used for sediment wash-off and deposition modelling described in Section 4.4 of this manual.

In determining the increase in runoff volume, URBS will calculate the fraction impervious based on the above definitions, or alternatively the user can explicitly assign the fraction impervious for each sub-catchment. How the impervious fraction increases runoff has been discussed in Section 3.1.1. Implementation is discussed in Section 5.1.

4.1.1.2. Factors Affecting the Impact of Urbanisation

(i) Connectivity

A factor that affects the impact of urbanisation is the degree of "connectivity" of the sewered system. The factor $(1+U)^{-2}$, when applied to routing and lag parameters assumes a well-connected system based on results obtained of many westernised cities.

However, in developing countries the degree of connectivity is often less than that of developed countries. Accordingly a factor "e" (for efficiency) ranging from 0 to 1 has been included to account for the degree of connectivity. The $(1+U)^{-2}$ factor was then modified to read;

$$1 - e\,(1 - (1 + U)^{-2}) \qquad (28)$$

How to enter the value of "e" into the URBS model is described in Section 5.1 of this manual.

(ii) Event Magnitude

The current literature also indicates that the greatest effects are for flows of smaller return periods (increases of up to 4 times for in-bank discharges for small catchments) to relatively small effects at high flows (in excess of 20 years ARI). To include this effect the following storage-discharge relationship has been assumed (assuming e = 1):

$$\begin{aligned} Q < Q_{cap},\ S &= k_c^1 (1+U)^{-2}\ Q^m \\ Q > Q_{cap},\ S &= k_c^1\ Q^m - (1 - (1+U)^{-2})\ k_c^1\ Q_{cap}^m \end{aligned} \qquad (29)$$

Q_{cap} represents the capacity of the sewered drainage system. Once this capacity is exceeded, it is assumed that storage discharge relationship reverts to its pre-urbanisation characteristics. The constant $((1-(1+U)^{-2})k_c{}^1Q_{cap}{}^m)$ represents the maximum storage lost due to catchment urbanisation. How to include the capacity for a given reach or for an entire catchment is described in Section 5.1 of this manual.

Figure 2 explains the maximum storage lost concept.

Simulating the effect of decreasing urbanisation effect with increasing event magnitude is not so much an issue for the downstream calculation points of an URBS Split Model, as the effect of urbanisation is limited to sub-catchment inflows. However, its effectiveness of simulating the diminishing effect depends on the relative magnitude of catchment to channel storage. Accordingly it is still recommended that the maximum capacity of the minor system for each sub-catchment be identified and included in the model.

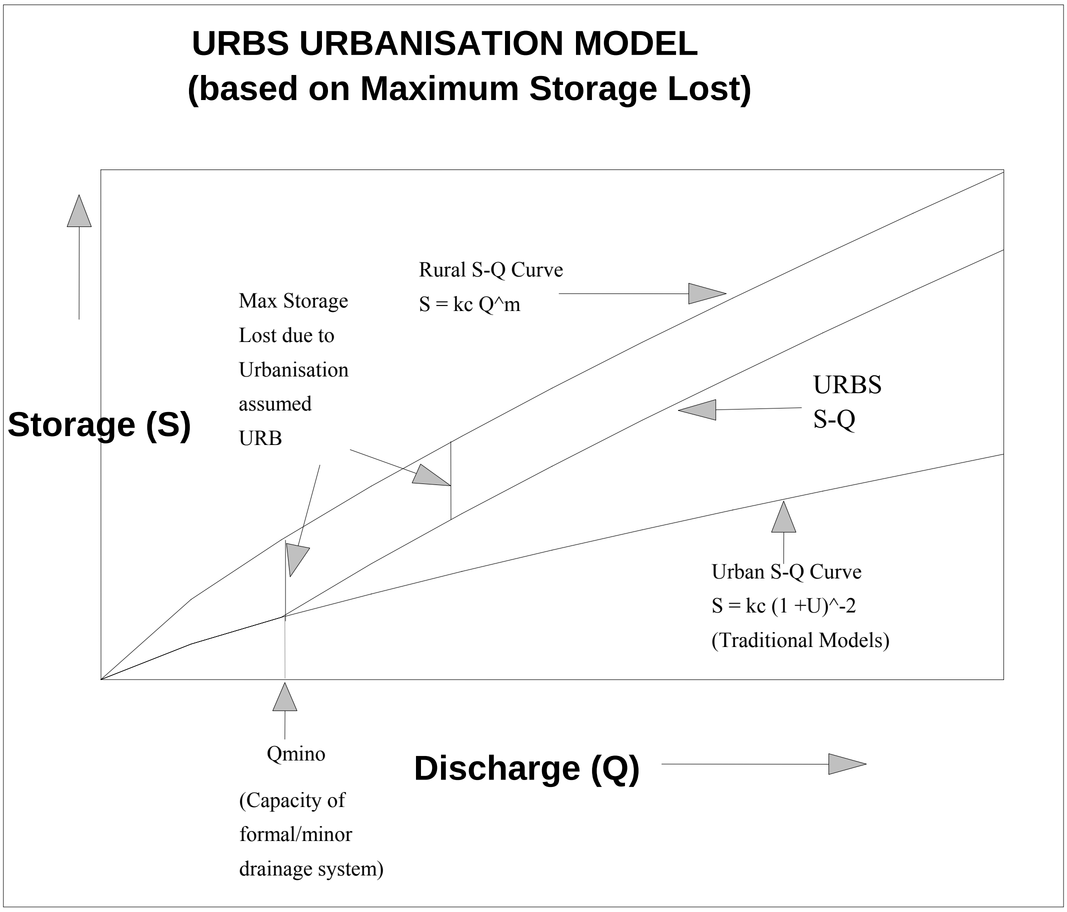

Figure 2: URBS's Urbanisation Model
Incorporating the Diminishing Effect of Urbanisation with Event Magnitude

4.1.1.3. Increasing Lag with Increasing Event Magnitude

This has been included indirectly by the maximum storage loss concept as described in the last section. Simple mathematics shows that for this method the urban lag differs from the rural lag by an amount S_{max}/Q. As Q becomes large, the difference between the urban and rural lag approaches zero.

An alternative approach under investigation by the author involves assuming that for each sub-catchment the lag approaches a constant with increasing event magnitude, irrespective of its dominant land use. This constant lag is independent of catchment urbanisation which only affects the minor floodwater system.

Adopting the URBS' Basic model the idea can be easily expressed by the following equation:

$$Lag = \gamma \frac{n\,L}{\sqrt{S_c}} + \alpha \frac{n\,L}{\sqrt{S_c}} \frac{(1+F)^2}{(1+U)^2} Q^{m-1} \qquad (30)$$

from which the storage equation for a single reservoir can be generalised as:

$$S = Lag\,Q = (K + k_c^1\ Q^{m-1})\,Q \qquad (31)$$

The first component of the lag equation (K) is the linear term and dominates the routing process at high flows, the second component is the non-linear term ($k_c^1 Q^{m-1}$) whose influence declines with increasing flow, assuming m, the catchment non-linearity parameter, is less than 1.

When stream length alone is used to define channel routing, then gamma (γ) is the inverse of the asymptotic wave celerity (km/h). How to incorporate it into the URBS model is explained in Section 5.1 of this manual. However, it is not recommended that this parameter be included for design purposes until further research is carried out and reviewed by the engineering community. Research by the author is currently underway and will be reported in later versions of URBS.

4.1.1.4. Modelling Approach

As a general rule, the Basic Model is only suitable for small urban catchments whose main channel has been modified, if not lined, to accommodate the increased flows.

The Split Model is suitable for medium to large river systems where the channel routing component is a major influence on the calculated peak discharges, and where increased flows due to urbanisation in natural channels have to be assessed. Using this model, urbanisation affects catchment routing only as routing of through flow is not affected by sub-catchment urbanisation.

4.1.2. Forestation/de-Forestation

The relationship between catchment lag and extent of catchment forested has not been well documented or researched. However, SMEC (1990) has produced relationships from Papua New Guinea data which are used by the URBS model. The effect is to increase the routing constant and therefore lag time by a factor of $(1 + F)^2$. Losses are increased (scaled) by a factor $1/(1 - F/2)$. The latter modification to losses is at best notional and was chosen to complement the factor used to account for the effects of urbanisation, i.e. equal areas of forest and urbanisation will cancel each other's effects as is the case for catchment lag.

It is likely that the effect of forestation will also decrease with event magnitude, the extent of this decrease is unknown. Accordingly great care needs to be taken when applying forestation indices for rare events.

Another point for consideration is the type of forest; e.g. tropical, open, pine forests etc., each of which has different effects on catchment lag. Recent model studies of Queensland catchments undertaken by the author have used a factor of 0.4 to 0.5 for open forest and a factor of 0.1 to 0.2 for pine forests. These factors are an assessment of the equivalent area of tropical forest, the basis for the original SMEC equation. The factors adopted are not based on any research. However, tree density and understorey growth are key factors in their determination.

Recent catchment management studies have necessitated estimating the effects of catchment afforestation - as a measure to control the effects of urbanisation. The approach adopted has been to select the Split Model, which allows catchment inputs to be modified by increasing catchment lags by the ratio $(1+F)^2$. Channel flows on the other hand should be modified, by adjusting the Manning's n value to reflect any increased riparian vegetation. These control measures increase catchment storage, thereby reducing downstream peak flow rates and to some degree compensating for storage lost through urbanisation.

It again must be stressed that the assessment of the effects of forestation on catchment flows however, requires further research before any absolute quantitative interpretation can be applied to the results produced by the URBS model. Nevertheless, the URBS model does offer the user a mechanism through which the effects of afforestation can be assessed as a means of controlling catchment urbanisation.

4.2. Baseflow Modelling

The URBS model can incorporate either a constant or variable baseflow into the model. The initial baseflow value at a node may be specified using the BASEFLOW command in the catchment definition file, described later in Section 5.1 or alternatively it can be set as the first value of a recorded input gauging station or inflow hydrograph files described later in Sections 5.5 and 5.6.

For constant baseflow, the value of baseflow remains constant for all time. The calculated direct runoff is added to this value to calculate total flow.

Variable baseflow at a node is calculated using the equation:

$$Qb_i = BR\ Qb_{i-1} + BC\ (Qr)^{BM} \qquad (33)$$

where Qb_i , Qb_{i-1} are the base flow values for time step I and time step I-1 respectively. BR, BC and BM are base flow parameters. These parameters are specified on the DEFAULT PARAMETERS line of the catchment definition file - refer Section 5.1.2. The value of BR is assumed to be a daily recession constant. Its value is adjusted according to the model data time interval. The parameter BM is assumed to be 1, however, recent studies have shown that a value less than 1 to be more appropriate. When BM is 1, BC can be directly related to the base flow index (BFI) as BC=BFI x (1-BR)/(1-BFI). Values of BR, BC and BM can be assumed constant for all nodes or alternatively individually set for each node. Figure 3 illustrates the baseflow model defined by equation 33.

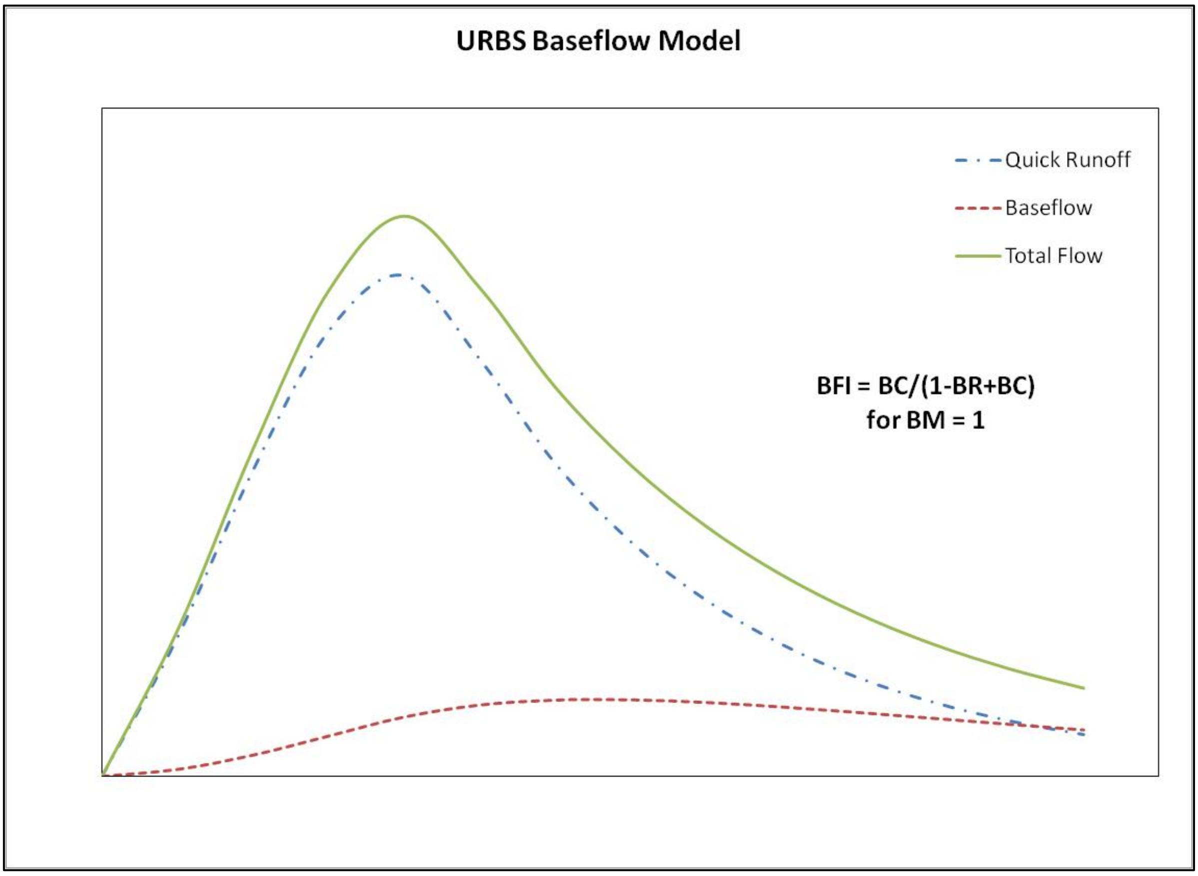

Figure 3: URBS Baseflow modelling

Baseflows are accumulated through the network (not routed as for direct runoff). The baseflow of a downstream node will equal the sum of contributing base flows, unless over-written by an explicit BASEFLOW command in the catchment definition file (see Section 5.1.2).

4.3. On-Site-Detention Modelling

The effects of implementing on-site-detention (OSD) policies on the catchment's runoff response are also incorporated into the URBS model. The model assumes that for each sub-catchment the effect of on-site detention for that catchment can be represented a single reservoir located at the centroid of the sub-catchment. This assumption was found to be valid through work carried by Lees and Leach (1992) of the Upper Parramatta River Catchment Trust (UPRCT).

When OSD analysis is required URBS automatically creates a detention basin (assuming high early discharge (HED)) whose dimensions are based on the inputed on-site-storage parameters (PSD permissible site discharge in l/s per hectare) and SSR (site storage requirement cubic metres per hectare).

A third parameter called TBO (fraction To Be OSD'd) specifies what proportion of area in each sub-catchment to be subject to OSD policies. The parameters SSR, PSD and TBO can be specified globally i.e. for an entire catchment or specified individually for each sub-catchment. However, the global TBO parameter specifies the proportion of urbanised area to be subjected to OSD policies (as opposed to proportion of sub-catchment). How to input these values is described in Section 5.1.2 of this manual.

To assess OSD policy impact assessment the modeller is required to estimate the impact of increased runoff rates due to increased urbanisation, and attempt to reduce this impact through imposition of a catchment wide on-site detention policy. To achieve this, the values of SSR and PSD should be varied for each sub-catchment to assess their sensitivity in reducing downstream peak runoff rates.

The UPRCT carried out such an analysis for the Parramatta River catchment using the RAFTS model. A similar analysis using the URBS model carried for an urban creek in Port Moresby Papua New Guinea is shown below. This latter analysis revealed that the OSD reduction curves collapsed to the same curve, that the PSD is approximately linearly related to the SSR, and that below a target percentage reduction there is no advantage gained by reducing the PSD for an assumed SSR.

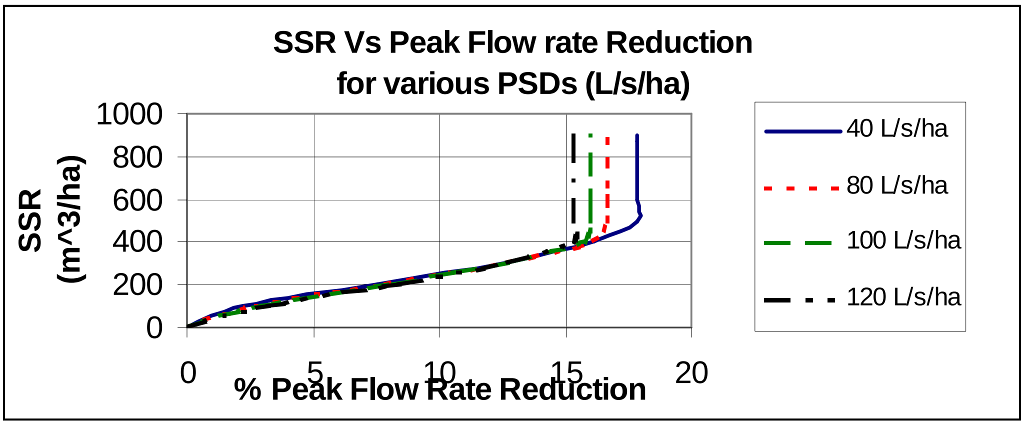

Figure 4: OSD Reduction Curves for Boroko Creek, NCD PNG

4.4. Bulk Sediment Wash-off and Deposition Modelling

Bulk Sediment wash-off and deposition is a very complex process and one which is not fully understood by the industry. Accordingly the URBS model has adopted the simplest of modelling approaches. The problem is to estimate volumes of bulk sediment washed off into the channel system and the amount deposited due to constrictions and/or lack of channel capacity.

4.4.1. Sediment Supply

In Australia the most popular equation for sediment export is

$$E = C\ R^D \qquad (34)$$

where E is the export rate in kg/km^2/day and R is the daily runoff in mm. This type of equation is used by many industry models, e.g. AQUALM-XP (1993). The equation should be thought of the sediment "supply" equation.

From the equation it is seen that the rate of supply is a function of the rate of runoff. Aitken (1975) describes the more rigorous SWMM model which assumes that the export rate is a function of the runoff rate and the amount of remaining sediment supply. However, it we assume that there is always adequate supply then the simpler equation can be used.

The following simple dimensional transformation of equation (34) enables a "sediment" graph to be calculated from a given discharge hydrograph.

$$E = \frac{C}{1000} \left(\frac{86.4}{A}\right)^{D-1} Q^D \qquad (35)$$

where E is now in kg/s, A is the catchment area in km^2 and Q is the instantaneous discharge in cumecs. Once the sediment graph has been calculated using this equation, the volume of sediment can be calculated by "integrating under the curve".

For D greater than 1, which is usually the case for sediment export, the volume of sediment contained in the discharge hydrograph will be less than the volume calculated using the "rainfall excess" or un-routed hydrograph.

The model assumes that using the rainfall excess hydrograph estimates the potential wash-off into the channel system, whereas calculation based on the routed discharge hydrograph represents the actual wash-off, assuming in both instances, infinite channel capacity to carry the sediment. This assumption to some degree mimics the behaviour of the SWMM model, and given the overall uncertainty of the process is assumed adequate for the URBS model.

The URBS Model however, allows the user to calculate all sediment wash-off volumes based on rainfall excess by setting an environment variable called URBS_SEDD to FALSE. How to do this is described in Section 7.

D, in the literature has been estimated to be 1.4. (Goyen, 1991). For UH, (Urban High) the coefficient C has been estimated to be 1000, for developing or disturbed areas, the value of C is 2500. However, because calibration of C values has been based on daily models, the value of the coefficient may be somewhat smaller for event based models because of time scale differences. Secondly this coefficient applies to course sediment including bed load. Therefore application to suspended solids alone will require a significant reduction in the C coefficient. Furthermore it is likely that for application to suspended solids the exponent D will approach unity, which has been found to be typical for constituents which are "suspended" or diluted (such as nutrients). This is supported by Wicks' study of export loads of nutrients and suspended solids from two small urban Brisbane catchments using the URBS model (Wicks, 1995).

The coefficient (C) has been standardised based on UH and is calculated for a given land use mix as follows:

$$C = C_{UH} \; (0.0F + 0.15UR + 0.5UL + 0.75UM + 1.0UH + 2.5UD) \qquad (36)$$

The bracketed term is called the erodibility factor (EF) for the purpose of this manual. The definitions for the various U types are given in Section 4.1.1. F is the fraction forested. The weighting or export coefficients i.e., 0, 0.15, 0.5 etc. qualifying each land use can be altered by the user. How to do this is described in Section 5.1 of this manual.

The values of C_{UH} and D are the basic parameters of the supply model. The default parameters are C_{UH} = 1000 and D = 1.4. These are parameters for bulk sediment. Values for finer material would be an order of magnitude less.

4.4.2. Sediment Deposition

Deposition is assumed to occur where (i) there is in-adequate capacity to carry the sediment (ii) where pondage occurs on a small scale as in the case of a sediment trap or (iii) on a large scale such as a major dam (iv) where there is a major constriction in the waterway e.g. undersized road crossing, which would reduce velocities and cause the sediment to fall out, and (v) deposition based on a detailed sediment grading curve analysis. There is no account of sediment won from in-bank erosion which occurs when capacity (or demand) exceeds supply, e.g. downstream of a retention basin.

The algorithm for the sediment deposition component of the model is as follows:

For a given Node (point deposit)
    Add up all upstream deposits
    Calculate potential sediment graph at node
    Deduct by scaling to account for upstream deposits
    Deposit Sediment greater than capacity (i)
    Deposit Sediment as specified (ii)
    Deposit Sediment in Volume as specified (iii)
    Deposit Sediment using threshold analysis (iv)
    Deposit Sediment using grading analysis (v)
    Calculate Actual Sediment Deposited
    Calculate bypass
Do next Node.

From the algorithm, it is seen that there are five possible mechanisms of how sediment may be deposited at a given location. Each of these mechanisms is discussed in turn.

(i) Supply Exceeding Demand.

The demand equation can be derived from a whole host of sediment equations eg. the Engelund-Hansen equation, one of many equations recommended by the ASCE (1977). However for URBS the equation must be expressed as a power law of discharge i.e.

$$D = C_{ap} \; Q^{n} \qquad (37)$$

where Demand (D) is given as Kg/s. n=0 is the default, where C_{ap} becomes a threshold demand given in Kg/s.

Where the demand exceeds supply, no account is taken of potential erosion of the watercourse.

(ii) Deposition into Sediment Traps (SBF) tonnes.

The is the sediment which is trapped (if it can be supplied) and subtracted from the sediment graph (eg. a GPT) One parameter called SBF or Sediment Before Full measured in tonnes is used to describe this deposition process. For example a 20 cubic metre sediment trap will trap approximately 30 tonnes of sediment (assuming a density is 2.65 tonnes/cubic metre, voids about 0.4). If a value of SBF = 30 is specified and it can be supplied then 30 tonnes will be removed from the rising limb of the sediment graph.

(iii) Deposition of sediment in a specified volume of water.

A volume of water is specified which is then subtracted from the discharge hydrograph (as for dams below spillway level). The sediment contained in this volume is calculated and subtracted from the sediment graph. This type of deposition is specified using one parameter called (VBF) which is the volume before full in Megalitres (ML).

(iv) Threshold Analysis.

This type of analysis is useful for estimating the deposition which occurs due to constrictions such as undersized culverts. The analysis consists of three parameters which are:

Threshold (T), cumecs
Factor Above Threshold (FAT)
Factor Below Threshold (FBT)

How the threshold algorithm works is as follows: for a given discharge hydrograph if the flow rate is below T cumecs, then FBT times the sediment contained in the flow below T cumecs will be deposited otherwise FAT times the sediment contained in flow above T cumecs will be deposited. This is a very crude model particularly as the sediment build-up will affect the threshold value(T).

(v) Sediment Deposition based on sediment grading analysis

Deposition is based on the Pemberton-Lara equation i.e.

$$F_i = (1 - e^{1.0548 u_s L/q}) \qquad (38)$$

where F_i is the fraction deposited, u_s is the settling velocity, q is the discharge per unit width and L is the length of the trap. This equation has been generalised (and the 1.055 factor dropped) to read;

$$F_i = (1 - e^{u_s A_t/Q_t}) \;,\; where \; A_t = \frac{\partial S}{\partial Q} \frac{\partial Q}{\partial h} \qquad (39)$$

$\partial S/\partial Q$ is simply the slope of the storage-discharge curve, whereas $\partial Q/\partial h$ is the slope of the outflow rating curve. (Note the sediment load in determined by the inflow hydrograph, the amount deposited is dependent of the characteristics of the storage and the outflow hydrograph.) Alternatively A_t can be specified explicitly.

The depth of the trap (D) is also specified to determine when the trap is full of sediment. Once full no more sediment can be deposited in the trap.

Settling velocity is calculated using the well known Rubey's equation.

Equation (39) is then applied to each representative fraction as specified in the input grading curve. The calculated sediment deposited for each representative sediment size fraction is summed up to calculate the total amount deposited.

How to apply this to the URBS model is described in Section 5.

Any combination of the five specified deposition mechanisms can be used by specified, however, the order in which they operate on the sediment graph is as listed above.

The URBS Sediment Deposition model can also be used for estimating the annual average sediment deposition/yield for a specified location. The procedure is to run the URBS model for a range of return periods from 1 to 100 year ARI for all possible storm durations and plot the resulting maximum deposition volumes against their associated exceedence probabilities. Integrating under the probability curve and adding sediment deposition from minor within year events should give the modeller an estimate of the annual deposition or yield rate. Rates of between 2000 and 3600 kg/hectare per year have been used to design gross pollutant traps (GPTs) in coastal eastern Australia.

4.5. Traffic Disruption due to Flooding Modelling

Often the modeller is required to assess the economic justification for upgrading under-sized road crossings. One economic impact is the effect of road closures. The URBS model includes a crude model to assist in estimating annual average traffic disruption costs.

The model is quite simple, the length of time a particular flood (typically a design flood) is above the crossing's flood capacity (eg. culvert capacity) is calculated (TAQ, or Time above threshold discharge). Buffers can be added to either end of this time to calculate the total time the crossing is closed (e.g. for official warnings prior to closure or clearing of traffic after re-opening.)

Once the closure time is known, the delay time for each vehicle is estimated to be half the closure time. The cost of delaying each vehicle by one hour is then multiplied by the total delay time to calculate the cost per vehicle due to the road closure.

The cost of the closure is then calculated by multiplying the number of vehicles delayed by the cost of delaying each vehicle. This calculation assumes that drivers are warned about the crossing and do not attempt the crossing until notified. However, to allow for the intrepid, a "leakage" factor (L) has been included which reduces the extent of delayed traffic.

There are six parameters which define the model. These are;

- (i) The cost is cost per vehicle hour delay (C)
- (ii) The vehicles arrival rate per hour (VPH)
- (iii) The threshold discharge (Q) above which the road becomes impassable
- (iv) The Before Closure Time, is the time in hours which traffic will avoid crossing before commencement of road flooding (default zero)
- (v) The After Closure Time (ACT), is the time in hours after road flooding ceases which traffic resumes across the crossing (ACT)
- (vi) Leakage, (L) is the fraction of traffic which finds alternative routes

The equation for the cost of traffic disruption is given as:

$$Cost\ of\ Disruption\ =\ C\ \frac{(TAQ + BCT + ACT)^2}{2}\ VPH\ (1 - L) \qquad (40)$$

A more rigorous analysis is described by Parker et alia (1987) where traffic network models are used to compare traffic flows under "dry" and "wet" scenarios. The cost of disruption is then estimated by comparing resource and delay costs between the two traffic conditions. They suggest that unless the crossing is frequently flooded and traffic loadings are high (in excess of 250 vph in both directions) then the cost of traffic disruption is likely to be small. The reader is referred to the above reference for more information.

Annual average disruption costs can be estimated by running URBS for a range of design flood events from 1 to 100 years ARI for each storm duration. The maximum disruption cost for each ARI should be calculated. Finally these costs should be plotted against their associated exceedence probabilities and the area under the curve calculated to estimate the annual average traffic disruption cost.

4.6. Modelling Looped Rating Curves

When "calibrating" the URBS model to the results of a hydraulic model, users have requested that URBS include the capability of simulating looped rating curves produced by the hydraulic model.

The author has developed a technique for doing this which it must be added has little theoretical basis, other than its ability to replicate the looped rating curve behaviour of rigorous hydraulic models. The method is as follows:

Assume that the relationship between height (h) and discharge (Q) is

$$h = f\,(Q - K\frac{\partial Q}{\partial t})\,, K \geq 0 \qquad (41)$$

Replacing the derivative with the backward difference operator it can be shown that:

$$Q - K\frac{\partial Q}{\partial t} \approx (1 - \frac{K}{\delta T})\,Q_t + \frac{K}{\delta T}\,Q_{t-\delta T} \qquad (42)$$

Therefore, given K, δT, Q_t, $Q_{t-\delta T}$, h can be calculated.

To determine Q, given h, the stream height, the following reciprocal method is used:

$$Q^* = (1 - \frac{K}{\delta T})\; Q_t + \frac{K}{\delta T}\; Q_{t-\delta T} = f^{-1}(\,h) \qquad (43)$$

or

$$Q_t = \frac{Q^* - \dfrac{K}{\delta T}Q_{t-\delta T}}{1 - \dfrac{K}{\delta T}} \qquad (44)$$

As can been seen, incorporation of looped rating curves is a very simple process, only requiring inclusion of only one parameter, K. How to enter this value into the URBS model is explained in Section 5.1.3 of this manual.

4.7. Detention Basin Modelling

Detention basins are still the most common management tool used to control the adverse effects of urbanisation. The URBS model has 4 ways of incorporating detention basins into its model structure. These are (i) via a storage discharge table "hardwired" into the catchment definition file, (ii) via an external file which contains a storage-discharge table, (iii) via a simple power law equation relating storage to discharge and (iv) via input of a single pair of maximum storage and discharge values.

Modellers will find the last approach the most useful for preliminary sizing of basins. The maximum storage corresponds to the volume of the storage between the outlet invert and the spillway crest (road crown or shoulder). The peak discharge corresponds to a pre-development or target peak flow rate which has to be matched under developed conditions. This approach assumes a straight line relationship between storage and discharge, although there is a facility to introduce a power law relationship. The straight line relationship is appropriate for shallow basins whose cross-sectional shape is approximately parabolic. However, for deep basins, where the outlet flow rate becomes a function of the square root of head, a power law based on an exponent in excess of 2 would be most appropriate.

A program called DETAIN accompanies the URBS model to assist the modeller in preparing storage discharge files for association with a chosen catchment definition file. The program reads as input, the basin characteristics (either storage versus height or area versus height), a weir profile and details of the outlet configuration. These data are combined to derive the characteristic storage discharge curve for the site.

The generated storage discharge file is then accessed by the URBS model through inclusion of the storage discharge file name in the catchment definition file. Discharge is calculated using Boyd's equations for inlet control for box and piped culverts (Boyd 1986). Outlet control (based on inlet, barrel and outlet losses) is also calculated.

The mechanism (inlet or outlet control) which gives the higher headwater levels is chosen. While this approach is conservative and appropriate for determining road inundation frequencies, in some instances it is not conservative when designing detention basins, particularly where tailwater levels exceed the downstream obvert of the outlet pipe, drowning out the inlet critical flow regime, causing the headwater level to fall. This reduction in headwater level results in lesser upstream storage which causes higher downstream peak flow rates that what would have been otherwise expected. This is particularly true for the lower ARIs or higher frequency floods. This effect has not been included in the DETAIN module of the URBS model.

The DETAIN Module is described in detail in Section 9.12 of this manual.

4.7.1. Stability and Detention basin/ Dam routing.

The modeller is always advised to check the calculated outputs from modelled detention basins. Plotting the output using the WinPLOTU module will quickly reveal any instabilities. Instabilities are usually caused by a very steep gradient in the storage discharge curve - this is characteristic of weir flow over a wide road. When this occurs inflows tend to approach outflows.

The problem of instability may be overcome by flattening the gradient of the storage discharge curve above weir level eg by increasing storage values. A second cause for instability is where the URBS model extrapolates the storage discharge table. This problem can usually be overcome by ensuring that storage associated with the maximum inflow peak discharge can be interpolated from the table. Where all else fails, an environment variable called URBS_SMTH can be used to invoke URBS' smoothing routine. This method should only be used as a last resort. If employed, the modeller should always check his/her output for inflow/outflow volume consistency, as there are circumstances where the continuity equation is not obeyed by the smoothing routine.

4.8. Roofwater Storage Modelling

The use of roofwater tanks is a catchment management tool used to reduce downstream flow volumes and peaks. Their effectiveness however very much depends on the assumed initial tank contents i.e. full no effect, empty maximum effect. The assessment of roof water tanks is carried out by including two additional parameters in the URBS model. These are RD and RF.

RD is the rainwater depth to be stored in the roof water tank in mm. For example if RD is set at 25 mm and a typical roof area is 200 sq. metres, then the volume of tank required is 5 cubic metres. Often at the start of an event, the tank is likely to be partly full. A value of 50% full is adopted as a "best guess". In the above example, therefore, a volume of 10 cubic metres is required. URBS does not include a factor to account for the level of water in the tank. This is done is the conversion of RD into roof tank volume.

RF is the roof fraction. It represents the fraction of impervious area which is roofed. Typically for a residential area this value is 50%.

Roofwater tanks are incorporated into the URBS model as an increased initial loss for impervious areas. Normally initial loss for impervious areas is 1 to 5 mm. Introducing roofwater tanks can increase this to 6 to 12 mm depending on the initial contents of the tanks as already discussed.

Model studies to date have shown that some reduction is achievable up to a 2 year ARI event, however, for rarer events there is little benefit gained.

The RF and RD parameters are entered into URBS via the DEFAULT PARAMETERS line in the catchment definition file. The default values for RF and RD are both zero, i.e. no roof water tank storage.

5. URBS FILES

URBS requires at least two input files. These are:

(i) catchment definition file, and
(ii) rainfall definition file.

These files are arranged such that the catchment definition file contains all the data which are "static" for the catchment, and the rainfall definition file contains all the data which are "dynamic" in the catchment.

Static data are that data which do not change for the catchment. These include the routing path in the catchment, catchment geometry, rating curves available at points along the creek, and pluviograph and gauging station locations.

Dynamic data are that data which cause or measures flow in the catchment. These data include the run duration, storm pluviograph(s), external inflows into the catchment, and recorded flows or heights.

Comments may be located anywhere in either of these files. The comments must be contained between braces, i.e. { }.

The commands which make up the catchment and rainfall definition files are described in Sections 5.1 and 5.2. Items contained between square brackets [...] are optional.

Besides the two necessary files, data files containing

(i) rating curves,
(ii) pluviograph information,
(iii) recorded flows or heights at gauging stations,
(iii) inflow hydrographs
(iv) excess rainfall depths (from water balance models)
(vi) sub-catchment land use, relief and capacity data
(vii) storage discharge files
(viii) storage-elevation files
(ix) grading curve files

can be used. The format for these files is given in Sections 5.1.3-5.1.8.

Comment lines can be placed in all files by putting an asterisk (*) in the first column, except for rainfall and flow data files which have three comment lines as shown in Sections 5.4-5.7.

5.1. Catchment Definition File

5.1.1. Catchment Schematisation

The catchment should be divided into at least 20 sub-catchments. Where possible sub-catchments should be of similar size and elongated or skewed sub-catchments shapes are best avoided. At least 5 catchments should be defined to the first calculation point. Where skewed shapes cannot be avoided, the modeller should assign a sub-catchment node away from the through channel, and route sub-catchment inflows to the connecting internal junction within the sub-catchment.

RORB modellers generally route from node to node, URBS modellers are advised to route from node to sub-catchment boundary to node. The author has found that has several advantages; additional calculation points are easily incorporated into model without requiring cross boundary routing paths to be split, secondly, it provides a better hydrograph shape by the addition of extra routing nodes and thirdly, it allows the characteristics of each sub-catchment to be attached to each routing reach. This is particularly important for assessing urbanisation and forestation effects. Where reaches are not split, the cross boundary routing reaches have to be adjusted to accommodate the effects of both sub-catchments' influence on its routing characteristics. The URBS methodology for doing this is described in Section 7. However, as already discussed, its application is not advised and best avoided by simply ensuring that there are no cross boundary routing reaches.

5.1.2. Catchment Definition

<u>(i) Assignment of Model Parameters</u>

The first line of the catchment definition file contains a heading or description of the catchment. This line is echoed in all of the output files.

The next line, which is optional, is of the form:

MODEL: BASIC | SPLIT

This line indicates which model you want to use. If this line is not specified the model assumed will be based on the parameters specified on the DEFAULT PARAMETERS line described below. Placing an asterisk after the BASIC or SPLIT model types will result in the exponent of the storage equation including the values of the sub-catchment variables.

The next line, again optional, is of the form

USES: L [,U[*|+nn]] [,Sc] [,CS] [,F[*|+nn]] [,N] [,Q] [,I[*|+nn]] [,R] [,E[*nn]]

and specifies which catchment variables are to be used in the model. L is to use channel length (mandatory), U and/or F to use Urbanisation and Forest indices, Sc to use the channel slope, CS to use catchment slope for sub-catchment time-area routing, n to use channel roughness, Q to use channel/urban drainage capacity data, I to use explicit impervious fraction data and R to use the Rational Method approach for sub-catchment routing. E is specified to use the evaporation data (provided in the rainfall definition file). The user can specify either a space or a comma to separate the variable names.

The U, F, I and E variables can be globally adjusted by using the + (except E) or * operators. The + operator adds a fraction *nn* of the area non-urbanised, de-forested or pervious to each sub-catchment, eg, specifying U+0.25 will increase a sub-catchment's urbanisation index of 0.6 to 0.7. The '*' operator multiplies each sub-catchment's U, F or I values, should this scaling result in value greater than 1, the index (U,F or I) is reset to 1, eg. U*1.5 will increase a sub-catchment's urbanisation index of 0.5 to 0.75. Evaporation data is simply scaled by the inputed factor.

The next line, again optional, is of the form

DEFAULT PARAMETERS: alpha=*aa* m=*mm* [[[beta=*bb*] x=*xx*] n=*nn*] [gamma= *gg*] [C=*cc*] [D=*dd*] [SSR=*ss*] [PSD=*pp*] [TBO=*tt*] [Q=*qq*] [RD=*rd*] [RF=*rf*] [II=*ii*] [IP=*ip*] [IF=*if*] [K=*kk*] [IL=*il*] [ULI=*uli*] [UMI=*umi*] [UHI=*uhi*] [UI=*ui*] [V=*vv*] [BR=*br*] [BC=*bc*] [BM=*bm*] [TL=*tl*]]

where *aa* = the default value of α
mm = the default value of m
bb = the default value of β
xx = the default value of Muskingum x
nn = the default value of Muskingum n
gg = the default value of γ
cc = the default value of the Sediment Export Coefficient C
dd = the default value of the Sediment Export Coefficient D
ss = the global site storage requirement (SSR) (m^3/ha)
pp = the global permissible site discharge (PSD) (l/s per ha)
tt = the fraction of urbanised area to be included in the OSD analysis
qq = the global value for capacity of the urbanised waterway system
rd = the rainfall depth which can be stored in a roofwater tank (mm)
rf = the proportion of roofed to total impervious area
ii = the initial loss impervious areas (mm)
ip = the impervious area runoff coefficient
if = the maximum soil storage capacity for the catchment (mm)
kk = the daily infiltration recovery value
il = Maximum Initial Loss across the catchment
uli = the fraction impervious for the UL land use category
umi = the fraction impervious for the UM land use category
uhi = the fraction impervious for the UH land use category
ui = the threshold fraction impervious for U definition
vv = scaling factor for the Rational Method approach.
br = daily baseflow recession factor
bc = baseflow constant applied to runoff
bm = baseflow exponent applied to runoff
tl = transmission loss (ML/km)

There is no restriction on the number of sequential DEFAULT PARAMETERS lines. However the parameters α, β, m and n must be entered on the **first** DEFAULT PARAMETERS line. This is to ensure compatibility with earlier versions of URBS. A full explanation for each of the parameters is given in Section 2.

If the DEFAULT PARAMETERS line is omitted, the default parameters are taken as α = 1.2, m = 0.8, β=0, x=0, n = 1, γ= 0, CUH = 1000 and D= 1.4, SSR = 0, PSD = infinity, Q = infinity, RD = 0, RF = 0, II = 0, IP = 1, IF = infinity, IL = [IL for first event], ULI = 0.16666, UMI = 0.33333, UHI = 0.5, UI = 0.5, BR = 0.0, BC = 0.0, BM = 1.0, TL = 0.0.

If the MODEL keyword is not used then if β is specified, it should be set to zero and the Basic Model is used. This effect can be overwritten by setting the environment variable URBS_SPLT equal to TRUE (see Section 7). This will cause the Split Model to be used. The default values of α, m, and β may be overwritten by specifying new parameters in the opening command line or in an initialization file (see Section 8). If the Muskingum x or x and n are specified, Muskingum routing equations will be used.

The next line which is optional, is of the form

EXPORT COEFFICIENTS: UF = *uf* UR = *ur* UL = *ul* UM = *um* UH = *uh* UD = *ud*

This line specifies the coefficients to be used in the Sediment wash-off/deposition model as given in equation (35) in Section 4.4. If this line or any parameter is not specified the default parameter(s) are: UF = 0, UR= 0.15, UL = 0.5, UM =0.75, UH = 1.0 and UD = 2.5.

The next line specifies the sub-catchment data/areas of the model. Data can be entered in two ways; (a) via a file or (b) "hardwired" into the catchment definition file.

(a) via an external file called a catchment data file (preferred).

The next line should be in the form:

CATCHMENT DATA FILE = *filename*

The catchment data file is a text comma delimited file. Its format is detailed in Section 5.8. The data consists of sub-catchment reference number, the area, land use fractions and catchment slope. If you have opted to specify these variables in the catchment data file there is no need to specify them on the routing command lines.

(b) "hardwired" into catchment definition file.

The next line should be of the form:

n **SUB-CATCHMENTS OF AREA:**
a_1 a_2 a_3 a_4 .... a_n

where n is the total number of sub-catchments contained in the catchment, and a_i is the area of the ith ranked sub-catchment in the catchment in square kilometres. These areas are listed in ascending order based on the sub-catchment area number, unlike RORB which lists sub-catchments from upstream to downstream along the specified routing path.

Using this option the land use and catchment slope (if specified) information is entered on the individual routing command lines.

It is preferable to use a catchment data file as it allows easy assessment of land use changes by simply replacing the catchment data file name in the catchment definition file.

After the above parameter assignment lines are entered, command lines are used to define the routing extent and path of the catchment model. They are described next.

<u>(ii) Routing and Printing Commands.</u>

(1) **RAIN** #*i* L= *ll* [*] [U=*uu*] [F=*ff*] [I=*ii*] [Sc=*ss*] [CS=*cc*] [n=*nn*] [SSR=*ss*] [PSD=*pp*] [TBO=*tt*] [Q=*qq*] [IF = *if*]

This command attaches rainfall to sub-catchment number *i* and routes the rainfall through a conceptual storage, whose magnitude is determined by the inputed catchment characteristics. This routing process determines the hydrograph at the downstream end of the reach. It is preferable to locate the downstream reach at the catchment boundary. If the fractions urbanised (U) forested (F) or impervious (I) are omitted, their values are assumed to be zero. The value of Sc is used if specified on the USES keyword line (see previous page). CS (catchment slope) is used with Split Model and also must be specified on the USES keyword line. The value of CS can be specified as *flat, rolling, hilly* etc as given in Section 2.2.1. Alternatively, a numerical value may be specified, the units are m/m. n is Manning's n and is best used with the Split Model. SSR (m^3/hectare), PSD (l/s/hectare) and TBO (fraction of sub-catchment to be subject to OSD policies) are also optional parameters. The default is for no OSD i.e. SSR = 0. Q is entered in cumecs and represents the maximum capacity of the sewered system. IF in mm is the maximum infiltration capacity for the sub-catchment (mm). Infiltration capacities are assumed to vary linearly from 0 to this value throughout the catchment. The default value is infinite capacity.

If the optional asterisk is included after the reach length value, the reach length will be factored by $(1+U)^{-2}$ and/or $(1+F)^{2}$. This option is only available when the Split Model is being used. This command is used when there is no sub-catchment upstream of the current one. The sub-catchments can be given any number, provided that a number is not assigned to two different sub-catchments.

The parameters may be specified in any order but must all be contained on the same line.

(2) **ADD RAIN** #i L= *ll* [*] [U=*uu*] [F=*ff*] [I=*ii*] [Sc=*ss*] [CS=*cc*] [n=*nn*] [SSR=*ss*] [PSD=*pp*] [TBO=*tt*] [Q=*qq*] [IF = *if*]

This command is very similar to the RAIN command, but is used when there are sub-catchments upstream of the current one. Thus rainfall is applied to sub-catchment number *i*, and the runoff hydrograph is ADDed to the current (running) hydrograph. This combined hydrograph is routed through a conceptual storage as described above.

(3) **ROUTE** [THRU #*i*] L=*ll*[*] [U=*uu*] [F=*ff*] [I=*ii*] [Sc=*ss*] [n=*nn*] [Q=*qq*]IF = *if*]

This command routes the current hydrograph through a conceptual storage, along the specified reach, using the specified parameters. The reach length may be factored if the asterisk is included (see RAIN for details). If you use the THRU option (recommended), this specifies which sub-catchment the flood hydrograph is being routed. When specified the routing process inherits the characteristics of the nominated sub-catchment, and there is no need to specify the sub-catchment data (eg urbanisation, forestation and catchment slope) on the remainder of the command line.

(4) **STORE.**

This command stores the current hydrograph, indicating that the following commands, until a GET command, relate to a tributary of the current channel.

(5) **GET.**

This command gets the previously stored hydrograph and adds it to the current hydrograph. It indicates the end of the current tributary. STORE and GET commands can be nested to signify tributaries of tributaries.

(6) **PRINT.** *Location* [*]*[:BR = n.n BC = n.n BM = n.n]*

This command writes the hydrograph to an output file. This file shows a table of the hydrograph values for each time interval, for each PRINT location. The optional asterisk immediately after the location name requests that the calculated flow results for this location also be printed to a separate file. URBS uses a file name based on the location name. Optionally baseflow parameters can be specified – refer Section 4.2 for details. Note the use of the colon to separate the location name and the baseflow parameters.

(7) **PLOT.** *Location* [*]

This command plots the hydrograph at this location in text mode on the screen. The optional asterisk requests that the calculated flow results for this location also be printed to a separate file. URBS uses a file name based on the location name.

(8) **P&P.** *Location* [*]

This command PRINTs and PLOTs the hydrograph, as described in the above PRINT and PLOT commands. The optional asterisk requests that the calculated flow results for this location also be printed to a separate file. URBS uses a file name based on the location name.

(9) **FACTOR =** *ff*

This command factors all the ensuing reach lengths by *ff*. This is used to account for various creek elements, such as overland flow paths, bypasses, steep terrain, lined channels, etc. If *ff* is greater than one, the reach lengths are increased. If *ff* is less than one, the lengths are decreased. Increasing the factor will increase the lag time and storage in the creek. The opposite is true for a reduction in the factor.

(10) **TRANSMISSION LOSS FACTOR =** *tlf*

This command factors the nominated transmission loss (as specified on the DEFAULT PARAMETERS line) for all the ensuing reach lengths by *tlf*. It is assumed that baseflow does not fill in-stream storages that account for the transmission losses.

(11) **MUSKINGUM x =** *xx*

This command changes the default or current value of x in Muskingum's Equation to *xx*. All ensuing route calculations will use this value, until it is changed again.

(12) **DAM ROUTE**: There are four possible configurations for the DAM ROUTE command line. These are;

(a) **DAM ROUTE VBF=***volume / label* **NUMBER=***n* [**EVAP =** *nn.nn*]

s_1 q_1
s_2 q_2
.. ..
.. ..
s_n q_n

The volume below full supply (VBF) is the volume available in the storage which must be filled before discharge will occur. The VBF parameter can either be specified in the catchment file as a *volume* (in megalitres) or given the name of a *label* which contains the volume. The label is set as an environment variable (see Section 7). If the value specified is negative, then it is assumed that the dam is full and the value is the initial discharge in cumecs over the spillway. This discharge is then assumed to be operational for all points downstream, except where intercepted by a downstream dam.

The number entered after the NUMBER keyword specifies the number of storage discharge pairs. Each subsequent line contains a pair of values. Storage is given in ML. Discharge is given in cumecs.

EVAP specifies the daily evaporation loss in ML/day.

(b) **DAM ROUTE VBF=***volume / label* **FILE** = *<filename>* [**EVAP =** *nn.nn***]**

This command line is identical to (a) except that the storage discharge is read from an external file rather than being hardwired into the catchment definition file. The default extension for this file is ".sq". The format for the file is described in Section 5.9. This command line is useful for accessing files generated by external modules, eg DETAIN described in Section 9.12.

(c) **DAM ROUTE VBF=***volume / label* **A=***a* **B=***b* [**EVAP =** *nn.nn***]**

This method is based on the relationship $S = a\ Q^b$. S (storage) is in ML. Q (discharge) is in cumecs. The values of *a* and *b* can be determined as follows: Plot storage (above full supply) against discharge on log-log graph paper and draw a straight line of best fit. The slope of this line gives the value of *b*. Extrapolation to find the value of storage where Q=1 cumec gives the value of *a*.

(d) **DAM ROUTE VBF=***volume / label* **SMAX=***ss* **QMAX=***qq* [**N**=*nn*] [**EVAP =** *nn.nn***]**

This command line requires input of the maximum storage (SMAX) in ML (eg between the outlet invert and road crest or shoulder level) and the discharge capacity of the outlet structure at this storage (QMAX in cumecs).

This method is very useful for preliminary sizing of a detention basin. QMAX is usually specified as the target pre-development discharge, whereas SMAX is a trial storage which is iterated until the target outflow discharge is obtained. The optional *nn* value specifies the interpolation exponent for the storage-discharge table. A value of 1 is the default i.e. linear interpolation.

Alternatively, if the modeller requires the URBS model to calculate the **VBF** from a storage elevation table for the storage, the **VBF** specification should be replaced on the **DAM ROUTE** line with:

FSL = *nn.nn* **Datafile** = *damdatafile* **IL** = *nn.nn* Location = <*locationName[*]*>

Where **FSL** is the Full Supply Level in metres. The **DataFile** keyword specifies the file that contains the storage elevation data and **IL** specifies the Initial storage level in metres. The format for the storage level data file is given in Section 5.10. Location is the name that is used for model results and if followed by an asterisk the model results will be 'matched' to the recorded dam levels in the file *locationName.g*. Model results are printed to a file named *locationName_cal.o.* They are also listed in the '.h' and 'csv' files - see Section 8.3. If the **Location** is not specified then the location name is taken from the **DataFile** name excluding its suffix.

The **IL** may also be specified using a label, in which case the operating system's environment space is scanned for a variable named as the label, and the value set for that environment variable is assigned as the **IL**.

It should be noted that these three parameters i.e. **FSL**, **Datafile, IL** and **Location** must be kept together and in order as they are a replacement for the **VBF** specification**.**

If the **EVAP** keyword is also specified then its value is mm/day (as opposed to ML/day when the **VBF** is specified). The evaporation loss volume is estimated using area data contained in the storage elevation data file.

(13) **OPERATE DAM H =** *nn.nn* **Q =** *nn.nn* ***T*** = *nn.nn*

The **OPERATE DAM** command line should follow immediately after a **DAM ROUTE** statement block. **H** specifies the target elevation (metres) e.g. the level at which control gates are set, and **Q** (cumecs) is the maximum release e.g. the maximum control gates release. **T** specifies the number of hours it takes to release the maximum release rate. This last parameter (**T**) is often required to prevent 'hunting' of release rates and promotes stability. Note this command should only be used for design purposes and should not be used operationally.

(14) **ORWB H** = *nn.nn* **W=** *nn.nn* **C =** *nn.nn* **A** = *nn.nn* **B** = *nn.nn* **IL =** *nn.nn* **offset =** *nn.nn* **Evap =** *nn.nn* **Location =** *location* **StorageFile =** *filename* **D** = *nn.nn* **P** = *nn.nn*

The **ORWB** command indicates that there is an Off-River-Water-Body (ORWB) storage. This storage is filled or spills into the river depending on the relative river and ORWB water levels. Flow is either regulated by a side weir or a more generalised approach by using an equation to estimate flows to and from the off river water body.

The side weir formula adopts the broad crested weir formula and is as follows:

$$Q = Sf\ C W\ (H - H_0)^{1.5}$$

where Sf is the submergence factor, C is the weir coefficient (default is 1.7), W is the side weir length, H is the upstream water level and H0 is the crest level. Use the keywords **C** and **W** and **H** to specify C W and H_0 in the above equation. The user can optionally specify a **P** keyword to specify the maximum proportion of river flow available to be spilled over the side weir.

The more generalised flow formula is given as:

$$Q = A\,(wH_R + (1-w)H_L)^B\ \Delta H^{0.5}$$

where A and B are constants, (wH_r + $(1\text{-}w)H_l$) is a weighted river (H_R) and lake (ORWB) level (H_L). The weighting factor w should be between 0 and 1. ΔH is the absolute difference in water level between the river and ORWB. This equation is based on work undertaken for the Tonle Sap Off River Water Body located in the southern end of the Mekong River basin.

Use the keywords **A**, **B** and **W** to specify A, B and w is the above equation. The **H** keyword should be specified at the level at which the exchange of flows begins to occur.

IL specifies the Initial off river body storage level in metres.

The river level is determined using the rating curve specified using the **location** keyword. If the location is not specified then the most upstream rating curve location is used. If the ORWB datum differs from the rating curve height data, then a correction must be provided through using the **offset** keyword. The offset value is added to the rating curve height to adjust it to the ORWB datum.

The storage characteristics of the Off-River-Body-Storage are specified using the **StorageFile** keyword. This keyword specifies the file containing the storage data. It should have an 'els' extension and contain at least elevation and storage volume data. The format for the storage level data file is given in Section 5.10.

Average evaporation from the ORWB is specified using the **Evap** keyword. The value is either mm/day or ML/day depending whether area information is provided in the storage data file.

If the tie channel between the river and the ORWB is of sufficient length that causes delayed arrival and routing of flows to and from the off river water body, the keyletter **D** should be specified. The keyletter **D** specifies the number of days that the exchange flows are to be lagged by.

Two additional files are created when using the ORWB feature. These are *filename*_ORWB.o and *filename*_FLOW.o. The *filename* prefix is taken as the storage file name. These files contain the calculated ORWB lake levels and exchange flows between the ORWB and the river respectively.

(15) **INPUT.** *location* [: [A=*aa*] [Dav=*dd]* [U=*uu*] [F=*ff*] [E=*ee*] [CS=*cc*] [I=*ii*] [PSD=*pp*] [PSD=*pp*] [TBO=*tt*] [IF=*if*]]

This command indicates that a hydrograph is to be added to the current (running) hydrograph at this point in the catchment. The input hydrograph can be entered in the rainfall definition file (see Section 5.2), as an input data file (see Section 5.6) or from a bypass node upstream - see LOSS command, described next. The optional data after the *location* name contains the area *aa*, average distance of travel *dd*, the fraction urbanisation *uu,* fraction forestation *ff*, catchment slope *cc*, average erodibility factor *ee* of the inflow catchment, the average fraction impervious *ii*, the average PSD *pp*, and average fraction of urbanised area OSD'ed *tt*, and the average maximum infiltration depth *if*. These values can be entered in any order and are added to the running totals of the main catchment.

(16) **LOSS C=***cc* **F=***ff* **Q**=*qq* [**Bypass** = *location [* nn.nn* + *nn.nn]*]

This command is used as follows;

(1) subtracts a uniform loss of *cc* cumecs from the current hydrograph;
(2) subtracts a uniform fraction *ff* from the resultant hydrograph for discharge values greater than *qq*

Mathematically the loss algorithm is defined as;

$$Q_i^1 = Q_i - cc\,, \quad Q_i > cc$$
$$Q_i^2 = (1 - ff)\,(Q_i^1 - qq) + qq\,, \quad Q_i^1 > qq$$

A bypass location can optionally be specified via the **bypass** keyword. If specified then lost flow is diverted to this location. The receiving node is specified using the same location name after the **INPUT** command. The receiving INPUT node should not be upstream of the LOSS node. If it located upstream, a warning is issued and the command ignored.

The extent of lost flow diverted can be controlled by two values. The first parameter (after the '*' character) specifies the proportion of lost flow to be diverted. The second parameter (after the '+' character) specifies the time of travel in hours between the LOSS node location and the bypass location ie the lost flow hydrograph is delayed by the specified number of hours.

The **LOSS** command is useful for preparing split flow models. As already discussed, the amount lost can be diverted to a downstream location within the catchment using the INPUT command.

An example of a typical split flow scenario is; say low flows up to 5 cumecs are to be diverted from a watercourse, then the coefficients to use on the **LOSS** command line are *cc* = 5, *ff* = 0 and *qq* = 0 to calculate the resultant hydrograph. The low flow hydrograph is calculated by setting *cc* = 0, *ff* = 1 and *qq* = 5.

Note either *cc* or *ff* may be zero or negative. Negative values will cause an increase in discharge.

(17) BASEFLOW = *bb*

This command sets the baseflow in the creek to *bb* cumecs. This command overwrites the baseflow set by gauging station or inflow files (see Sections 5.5 & 5.6). However, the baseflow set by this command can be overwritten by matching the flow at a location to a recorded hydrograph (see Section 5.1.2), or by using another BASEFLOW command. Baseflow is not routed along a creek. It stays at a constant level, except for dams where it forms part of the inflow.

(18) EXPONENT N = *nn*

This command is similar to behaviour to the FACTOR command, in that the value set is current until the next occurrence of the EXPONENT N command. The exponent n refers to the non-linear Muskingum coefficient. It is assumed to be equal to 1, however some users have reported values of both less than and greater than 1. It should be used with care.

The final line of the catchment definition must be:

END OF CATCHMENT DATA.

which marks the end of the routing commands.

After these commands, information relating to

(i) rating curves,
(ii) pluviograph sites,
(iii) gauging stations, and
(iv) rainfall-runoff stations
(v) sediment deposition locations
(vi) traffic disruption locations

follows and may be entered in any order. These data requirements are described next.

5.1.3. Rating Curve Data

If rating curves are going to be used, the first necessary line is:

n RATING CURVES:

where *n* is the number of rating curves in the catchment. These rating curves can either be entered into the catchment file as described below, or in a data file (see Section 5.1.3). For each rating curve, the following line is required in the catchment file:

LOCATION. *location* [/ *dsLocation* = *h* [+ *timeOffset*]]

where *location* is the location of this rating curve.
dslocation is the name of the downstream location upon which this rating is dependant. *timeOffset* is the travel time in hours between this rating curve location and its dependent location.
h = the water level at the downstream location.

The next optional line specifies the value of K, the looped rating curve constant - see Section 4.6. The line is of the form:

K = *kk*

If a rating curve file exists, no more data lines are required in the catchment file for this location. If the rating curve data for this location is to be entered in the catchment file, the following lines are needed:

The first line should specify the number of h-Q data pairs and is of the form:

pp PAIRS:
$h_1\ q_1\quad h_2\ q_2\ \ ....\ \ h_{pp}\ q_{pp}$

where *pp* is the number of (h,q) coordinates that are listed. The first discharge value, q_1, must be zero.

A rating curve enables the stream heights to be calculated at the specified *location* if a discharge hydrograph has been requested by a "PRINT." command.

The optional data is required if the rating curve at the specified *location* depends on the water level, *h*, at a point downstream, *dslocation*. Thus, a series of rating curves for the given *location*, which are dependent on different downstream water levels, can be used. For example assuming ½ hour time delay between the rating curve locations:

LOCATION. Lytton Rd / Outlet = 1.0 + 0.5
..
LOCATION. Lytton Rd / Outlet = 1.5 + 0.5
..

At the conclusion of the rating curve data, the following line is required:

END OF RATING CURVE DATA.

5.1.4. Pluviograph Data

If more than one pluviograph is used in the catchment, the first necessary line is:

n PLUVIOGRAPHS:

where *n* is the number of pluviographs relating to the catchment.

For each pluviograph, the following lines are required:

LOCATION. *name* [/ *backup*][* *scale*]
j SUB-CATCHMENTS:
$a_1\ \ a_2\ \ ....\ \ a_j$

where *name* is the pluviograph which relates to sub-catchments a_1, a_2, ... a_j. If a sub-catchment is not assigned a pluviograph, it uses the next pluviograph it finds downstream of the current sub-catchment.

The pluviograph information is contained in either the rainfall definition file (see Section 5.2), a pluviograph data file (see Section 5.1.4).

The first part of the optional data specifies a backup pluviograph. If the program cannot access pluviograph *name*, it looks for pluviograph *backup* (if specified). If URBS cannot access pluviograph *name* or pluviograph *backup* (if specified), it will look for a default pluviograph (see Section 5.1). If a default pluviograph is required and cannot be accessed, the program is aborted. The backup pluviograph for a given station must be specified at the first reference to that station.

As mentioned above, the pluviograph information can be contained in any of three locations. The order in which URBS looks for the pluviograph information is:

(i) in the rainfall definition file (Section 5.2)
(iii) in a pluviograph data file (Section 5.4)

The second part of the optional data specifies a scale. This scale is the amount by which this pluviograph data will be factored on the sub-catchments specified. If pluviograph data at a given station is to be factored for some sub-catchments but not for others, two references are needed for the given pluviograph location: one reference with a scale and the relevant sub-catchment numbers; and the other with no scale and the sub-catchment numbers where the pluviograph data is not scaled.

An example of assigned sub-catchment numbers to pluviographs is given as follows.

```
4 PLUVIOGRAPHS:
LOCATION. Corinda / Calamvale * 1.5
{Gauge unrepresentative of mountainous area}
5 SUB-CATCHMENTS:
1 2 3 4 5
LOCATION. Corinda
{Default scale = 1.0}
4 SUB-CATCHMENTS:
6 7 8 9
LOCATION. Calamvale / Richlands
4 SUB-CATCHMENTS:
10 11 12 13
LOCATION. TheGap
7 SUB-CATCHMENTS:
14 15 16 17 18 19 20
```

At the conclusion of the pluviograph data, the following line is required:

```
END OF PLUVIOGRAPH DATA.
```

5.1.5. Gauging Station Locations

Gauging stations may be used for two purposes:

(i) to store recorded data for use in calibrating a model, or
(ii) to contain downstream boundary data.

If recorded data (i.e. heights or rated flows) are available from gauging stations included in the model, these data can be accessed to enable a comparison with calculated flows or heights. If no rating curve is specified at a gauging station location, the recorded values must be entered as flows (unless for the most downstream location (catchment outlet) and some of the values are negative (i.e. tidal values) then it is assumed to be heights).

If a rating curve is specified for a location, the recorded values must be entered as heights. These values are entered in either the rainfall definition file (see Section 5.1) or in a gauging station data file (see Section 5.5). The order in which URBS looks for this information is the same as for the pluviograph data (see Section 5.1.4).

A gauging station also can be used to account for tidal influences, or to set the downstream water level to a given value. This is most useful where water levels upstream are dependant on a downstream tailwater level, but no rating curve exists for the downstream boundary, e.g. creek/river outlets. These levels can be entered in either the rainfall definition file (see Section 5.2) or a gauging station file (see Section 5.5). The final water level given in the gauging station data is used for the remainder of the run. Therefore a constant downstream water level can be set by entering only one number.

For either of these uses, the first necessary line is:

n GAUGING STATIONS:

and each of the *n* locations require the line:

LOCATION. *location* [*]

If an asterisk is entered after the *location* name, URBS matches the calculated hydrograph to the recorded hydrograph at this gauge, thereby affecting downstream calculations. This option is useful when calibrating a catchment with multiple gauging stations.

At the conclusion of the gauging station data, the following line is required:

END OF GAUGING STATION DATA.

5.1.6. Rainfall-Runoff Locations

Generally, the runoff depths at nominated locations have been modelled using a soil moisture accounting model such as Boughton's AWBM model (1993). These models output the un-routed excess runoff to the nominated location. URBS scales all upstream pluviograph data to balance the volume of rainfall from all pluviographs to the un-routed runoff volume at the gauge. It is assumed that the runoff depths represent the average depths upstream of the gauge.

The first necessary line is:

> *n* RUNOFF STATIONS:

and each of the *n* locations require the line:

> LOCATION. *location*

At the conclusion of the rainfall-runoff station data, the following line is required:

> END OF RUNOFF STATION DATA.

5.1.7. Sediment Deposition Locations

The parameters characterising the sediment deposition process are described in Section 4.4. A sediment deposition location should at least be specified at the outlet.

The first line necessary is:

> *n* SEDIMENT DEPOSITION LOCATIONS:

and each of the *n* locations require the line:

> LOCATION. *location*

The next line specifies the sediment deposition parameters for that station and is of the form:

> [SBF = *ss*] [T = *tt*] [FAT = *fa*] [FBT= *fb*] [CAP = *cc*] [n = *nn*] [VBF= *vv*]

Where sediment grading information is available, then for major storages the following variables should be included;

> [gradefile=*gradeFileName*] [DSL = *dsLocation*][SF = *storageFile*]

gradeFileName specifies the file name that contains the sediment grading information. The format for this file is described in Section 5.11. *dsLocation* specifies the location where a rating curve is given. *storageFile* specifies the storage file which contains the storage discharge information. The format for this file is described in Section 5.9. If the storage file name is not specified, then the file name will be constructed from *dsLocation*.

The default extension for the storage discharge file is .sq. The default file location is in the rating curve directory (the default rating curve directory is the current directory). Alternatively the following variables should be used for fixed area storages eg. Gross Pollutant Traps;

[gradefile=*gradeFileName*][A = *aa*] [DEPTH = *dd*]

aa specifies the area of the trap. *dd* specifies the trap depth.

At the conclusion of the sediment deposition data, the following line is required:

END OF SEDIMENT DEPOSITION DATA.

5.1.8. Traffic Disruption Locations

The parameters required to use this model are described in Section 4.5.
The first line necessary is:

n TRAFFIC DISRUPTION LOCATIONS:

and each of the *n* locations require the line:

LOCATION. *location*

The next line specifies the traffic disruption parameters for that location and is of the form:

[C= *cc*] [VPH = *vv*] [Q= *qq*] [BCT= *bb*] [ACT= *aa*] [L= *ll*]

At the conclusion of the traffic disruption data, the following line is required:

END OF TRAFFIC DISRUPTION DATA.

5.2. Rainfall Definition File

The first line of the rainfall definition file contains a heading, describing the type of storm affecting the catchment. This line is echoed in the output files.

The second line must be one of:

DESIGN RUN
or **SIMULATION RUN**
or **FORECAST RUN**
or **MATCHING RUN**

indicating the type of model run.

A DESIGN RUN indicates that the event being modelled has no real-time significance. The rainfall definition usually details a design storm, perhaps from AR&R, and the results are output at time increments measured from t=0 (i.e. the start of the design storm).

A SIMULATION run models a historical event whereas a FORECAST RUN models a real-time event. The SIMULATION run should be used to event calibrate a model based on historical rainfall and gauging station data. The FORECAST run should be used for forecasting stream flows/heights during a rainfall event.

For both run types, the results are output at time increments measured from the date and time specified using the URBS_DATE and URBS_TIME environment variables (see Section 7).

A MATCHING RUN is the same as a FORECAST RUN with one exception. It forces or matches the calculated flow at an independent gauging station to equal the recorded flow at that point, affecting calculations downstream. (An independent gauging station is one which there are do dependent downstream rating curves - see Section 5.1.3).

The next line must be:

TIME INCREMENT: *tt* HOURS

where *tt* is the time step which the model will use to calculate and output results.

The next line must be:

RUN DURATION: *rr* HOURS

where *rr* is the length of time for which the model will run.

Alternatively the user can specify a forecast duration. This duration is added to the time specified by the END_DATE and END_TIME environment variables – or from the present time if not specified to form the run duration.

FORECAST DURATION: *ff* HOURS

The next line, which is optional, is:

STORM DURATION: *ss* HOURS

where *ss* is the duration of the storm, which must be less than or equal to the RUN DURATION.

Any pluviograph data in excess of *ss* hours after the starting time will be ignored. If this line is omitted, *ss* = *rr*.

The following lines contain the pluviograph information. For each pluviograph being used, the first necessary line is:

PLUVIOGRAPH. [*name*]

where *name* is the location name of this pluviograph. This name should match one of those listed in the pluviograph data in the catchment definition file. If no location *name* is specified, the pluviograph is the **default** pluviograph for the catchment. If a location *name* is specified, the pluviograph data is applied on those sub-catchments listed in the pluviograph data in the catchment definition file for this pluviograph *name*.

The pluviograph information may be either entered directly into the rainfall definition file (as described below) or as a separate pluviograph data file (see Section 5.4).

If a pluviograph file exists, no more lines of data are required in the rainfall definition file. If the data is to be entered in the rainfall definition file, the following line(s) are required:

[Data Interval : *hh*]
p_1 p_2 p_3 ... p_n

If the Data interval for the data is specified then you must specify the data interval in hours after the colon. If the data interval is not specified then a data interval equal to the time increment is assumed.
p_i is either:

(i) the proportion of rainfall which fell between t = i-1 and t = i, or
(ii) the actual amount of rainfall, in millimetres (mm), which fell between t = i-1 and t = i.

The number of pluviograph values (*n*) required in the rainfall definition file must at least equal the storm duration (*ss*) divided by the time increment (*tt*).

Following all the pluviograph information the next line, which is optional, is:

RAIN ON SUB CATCHMENTS: r_1 r_2 r_3 ...

where r_i is the total amount of rain, in millimetres (mm), which fell on the ith ranked (least to highest) sub-catchment number listed in the catchment definition file. The last rainfall value which is specified is used on all ensuing sub-catchments. Thus, if only one rainfall value is given, it is used on all of the sub-catchments. This command will factor the pluviograph values such that the total depth of rain which falls on sub-catchment *i* will be r_i. The rainfall pattern however is based on the pluviograph data.

The following line(s) define the loss model (and parameters, if necessary) required by URBS (see Section 3). The line defining the loss model must be one of:

LOSS: UNIFORM CONTINUING [* [*factor*]]
LOSS: VARIABLE CONTINUING [* [*factor*]]
LOSS: UNIFORM PROPORTIONAL[*[*recovery rate*]]
LOSS: VARIABLE PROPORTIONAL [*[*recovery rate*]]
LOSS: UNIFORM MANLEY-PHILLIPS
LOSS: VARIABLE MANLEY-PHILLIPS [*]

If a UNIFORM loss model is used, the uniform parameters can be specified on the next lines. If they are not specified the default values are used (see Section 3.1). The values can be **altered** by specifying different parameters in the opening command line (see Section 8). Uniform model parameters are affected by the levels of urbanisation and forestation specified for the catchment.

If a VARIABLE loss model is used, parameters are required for each sub-catchment. These variable values will be **factored** by the loss parameters if they are specified in the opening command line (see Section 8). If the optional asterisk is specified then the specified loss parameters will be for pervious areas only. Loss parameters for impervious areas are entered on the DEFAULT PARAMETERS line of the catchment definition file (see Section 5.1.2).

If you want to use URBS initial loss recovery model (RILM) for the continuous loss models specify a factor between 0.0 and 1.0 after the asterisk. Setting the factor to zero [the default] will prevent the initial loss from recovering – a value of 1 will allow the initial loss to be drawn down by an amount equal to the continuing loss less rainfall per period. A value of between 0.1 and 0.5 has been found to provide satisfactory recovery (Markar, 2001). Likewise set the recovering loss rate after the asterisk if you want the initial loss to recover when using the proportional loss model.

The necessary lines are:

(i) Continuing Loss Model:

Variable Model

IL: il_1 il_2 il_3 ...
CL: cl_1 cl_2 cl_3 ...

Uniform Model (optional)

IL: *il*
CL: *cl*

(ii) Proportional Loss Model:

Variable Model

IL: il_1 il_2 il_3 ...
PR: pr_1 pr_2 pr_3 ...

Uniform Model (optional)

IL: *il*
PR: *pr*

(iii) Manley-Phillips Loss Model:
(note: earlier versions did not include an initial loss)

Variable Model

IL: il_1 il_2 il_3 ...
K: k_1 k_2 k_3 ...
P: p_1 p_2 p_3 ...

Uniform Model (optional)

IL: *il*
K: *k*
P: *p*

where il_i is the initial loss in the ith ranked sub-catchment
cl_i is the continuing loss rate in the ith ranked sub-catchment
pr_i is the proportional amount of runoff in the ith ranked sub-catchment
p_i is the capillary suction head in the ith ranked sub-catchment
k_i is the saturated loss rate in the ith ranked sub-catchment

For any of the three variable loss models, the last value specified for each parameter is used on all ensuing sub-catchments. For example, if only one initial and one continuing loss value is given for a VARIABLE CONTINUING loss model, these are used on all of the sub-catchments, thereby achieving a UNIFORM CONTINUING loss model, without, however, the effects of catchment urbanisation and forestation taken into account - unless of course an asterisk has been placed on the loss model specification line. This asterisk specifies that separate loss models be used for pervious and impervious areas, and the listed parameter values are for the pervious areas only. Impervious loss parameter values are entered in the DEFAULT PARAMETERS key line in the catchment definition file.

If the user is undertaking continuous modelling then it will be necessary to include evaporation data after the loss data. These are included as follows:

EVAPORATION: e_1 e_2 e_3 e_4 e_5 e_6 e_7 e_8 e_9 e_{10} e_{11} e_{12}

Where e_i are the average monthly evaporation depths beginning in January. Evaporation is subtracted from the infiltrated store (see Figure 1) – thus drying out the catchment faster than if it was not included.

If BASEFLOW commands have been used in the catchment file, they can be altered by the command:

BASEFLOW FACTOR: *bf*

where *bf* is the factor by which the baseflow will increase (if *bf*>1) or decrease (if *bf*<1).

If GAUGING STATION's have been specified in the catchment file, URBS will look for the recorded data in the rainfall definition file (see below) and then in a data file (see Section 5.5). If the recorded data is contained in a data file, no commands are required in the rainfall definition file for the gauging station. If the recorded data for a gauging station is to be entered in the rainfall definition file, the following lines are required:

> **GAUGING STATION.** *Location*
> *[Data interval: hh]*
> $r_0 \; r_1 \; r_2 \; ... \; r_n$

If the data interval is specified then you must specify the data interval for gauging station in hours after the colon. If the data interval is not specified, then the model assumes that the data interval is specified by the time increment.

r_i is the recorded hydrograph ordinate at time t = *i* at the specified gauging station *location*.

The *location* specified must agree with that given in the catchment definition file. The recorded data starts at t=0, and is in time increments of *tt* hours (as specified in line 3 of the rainfall file). If a rating curve is used at this *location*, the hydrograph of stream heights is required. If no rating curve is specified, a discharge hydrograph is required.

If INPUT commands have been used in the catchment file, URBS will look for the inflow hydrographs in the rainfall file (see below), and then in a data file (see Section 5.6). If an inflow hydrograph file exists, no commands are required in the rainfall file for this inflow. If the inflow hydrograph data is to be entered in the rainfall file, the following lines are required:

> **INPUT.** *location*
> $i_0 \; i_1 \; i_2 \; ... \; i_n$

where i_j is the inflow hydrograph ordinate at time t=*j* at the specified inflow *location*.

The *location* specified must agree with that given in the catchment file. The hydrograph data starts at t=0, and is in time increments of *tt* hours (as specified in line 3 of the rainfall file). If a rating curve is used at this *location*, the hydrograph of stream heights is required. If no rating curve is specified, a discharge hydrograph is required.

If RUNOFF STATIONs have been specified in the catchment definition file, URBS will look for the rainfall-runoff data in the rainfall file (see below), and then in a data file (see Section 5.7). If a rainfall-runoff station file exists, no commands are required in the rainfall file for this station. If the rainfall-runoff station data is to be entered in the rainfall file, the following lines are required:

> **RUNOFF STATION.** *location*
> $e_1 \; e_2 \; ... \; e_n$

where e_i is the depth of excess rainfall which fell between t = i-1 and t = i upstream of the specified *location*.

The *location* specified must agree with that given in the catchment definition file. The rainfall-runoff data starts from t=0, and is in time increments of *tt* hours (as specified in line 3 of the rainfall file).

5.3. Rating Curve Files

The name of a rating curve data file must be the same as the *location* specified in the catchment definition file (or its first eight letters, whichever is the shorter), followed by a ".rat" extension.

Apart from the necessary lines, comment lines may be inserted anywhere. A comment line is defined by an asterisk (*) in the first column.

The first necessary line is a heading line, usually describing the location of the rating curve.

The next lines are:

[/ *dslocation* = *h* [+*timeOffset]*]
[k = *kk*]
pp PAIRS:
h_1 q_1
h_2 q_2
..
..
h_{pp} q_{pp}

where *dslocation* is the name of the downstream location upon which this rating is dependant (dependant rating curves only) and optionally *timeOffset* is the travel time between the two stations
h is the water level at the downstream location (dependant rating curves only).
pp is the number of (h,q) coordinates that are listed in the file.
h_i q_i are the (h,q) coordinates on the rating curve

Only one pair of (h,q) values can be specified on each line.

If this is a dependant rating curve, this block of data can be repeated as many times as required in this file to define the rating curve for different downstream water levels. The forward slash (/) prior to the downstream location *dslocation* must be in column one.

5.4. Pluviograph Files

The name of a pluviograph data file must be the same as the location *name* specified in the catchment and rainfall definition files (or its first eight letters, whichever is the shorter), followed by a ".r" extension.

The format of the pluviograph data file is:

heading line
comment line
comment line
comment line
t_{start} t_{inc} n
p_1
p_2
..
..
p_n

where t_{start}= the time (in SECONDS) from the starting time to the time when the pluviograph data starts.
t_{inc}= the time increment (in SECONDS) of the pluviograph data. This value can be different to the time increment specified in the rainfall file.
n = the number of pluviograph values, p_n. These values will be factored by a RAIN ON SUB-CATCHMENTS command if used in the rainfall definition file.

For a DESIGN run, the starting time is at t = 0. For a FORECAST or MATCHING run:

(a) if t_{start} is less than one year (31 536 000 seconds), the starting time is relative to the date and time set by the environment variables URBS_DATE and URBS_TIME (see Section 7).
(b) if t_{start} is greater than one year, the starting time is:
 (i) in DOS or UNIX/XENIX - the time in SECONDS since GMT 1/1/1970 (10:00am EST);
 (ii) in QNX - the time in SECONDS since 1/1/1980 (local time).

The pluviograph value p_i is the depth of rainfall, in millimetres, which fell between t = i-1 and t = i.

5.5. Gauging Station Files

The name of a gauging station file must be the same as the *location* specified in the catchment definition file (or its first eight letters, whichever is the shorter), followed by a ".g" extension.

The format of the gauging station file is:

heading line
comment line
comment line
comment line
t_{start} t_{inc} n
h_0
h_1
h_2
..
..
h_n

where t_{start}= the time (in SECONDS) from the starting time to the start of the gauging station data, h_0

t_{inc} = the time increment (in SECONDS) of the gauging station data. This value can be different to the time increment specified in the rainfall file.

n = the number of recorded hydrograph values, h_n.

For a DESIGN run, t_{start} is the time from t = 0. For a FORECAST or MATCHING run:

(a) if t_{start} is less than one year (31 536 000 seconds), the starting time is relative to the date and time set by the environment variables URBS_DATE and URBS_TIME (see Section 7).

(b) if t_{start} is greater than one year, the starting time is:
  (i) in DOS or UNIX/XENIX - the time in SECONDS since GMT 1/1/1970 (10:00am EST);
  (ii) in QNX - the time in SECONDS since 1/1/1980 (local time).

If a rating curve is used at this *location*, the hydrograph values must be stream heights. If no rating curve is specified, a hydrograph of discharges is required.

The recorded hydrograph value h_i is the flow/height at t = i.

The first hydrograph ordinate, h_0 will be converted to a discharge (if not already) and this will be taken as the value of baseflow at this *location*. This value will overwrite the baseflow already in the catchment. This effect can be switched off however by setting the URBS_BASF environment variable to FALSE (see Section 7).

5.6. Inflow Hydrograph Files

The name of an inflow hydrograph file must be the same as the *location* specified in the catchment definition file (or its first eight letters, whichever is the shorter), followed by a ".i" extension.

The format of the inflow hydrograph file is:

heading line
comment line
comment line
comment line
t_{start} t_{inc} n
i_0
i_1
i_2
..
..
i_n

where t_{start}= the time (in SECONDS) from the starting time to the start of the inflow hydrograph data, i_0
t_{inc}= the time increment (in SECONDS) of the inflow hydrograph data. This value can be different to the time increment specified in the rainfall file.
n = the number of inflow hydrograph values, i_n.

For a DESIGN run, t_{start} is the time from t = 0. For a FORECAST or MATCHING run:

(a) if t_{start} is less than one year (31 536 000 seconds), the starting time is relative to the date and time set by the environment variables URBS_DATE and URBS_TIME (see Section 7).
(b) if t_{start} is greater than one year, the starting time is:
  (i) in DOS or UNIX/XENIX - the time in SECONDS since GMT 1/1/1970 (10:00am EST);
  (ii) in QNX - the time in SECONDS since 1/1/1980 (local time).

The hydrograph values must always be discharges, not heights.

The inflow hydrograph value i_j is the flow/height at t = j.

The first hydrograph ordinate, i_0 will be converted to a discharge (if not already) and this will be taken as the value of baseflow from this inflow. This value will be added to the baseflow already in the catchment. This effect can be switched off however by setting the URBS_BASF environment variable to FALSE (see Section 7).

5.7. Rainfall-Runoff Files

The name of a rainfall-runoff data file must be the same as the *location* specified in the catchment definition file (or its first eight letters, whichever is the shorter), followed by a ".rrf" extension.

The format of the rainfall-runoff data file is:

heading line
comment line
comment line
comment line
t_{start} t_{inc} n
e_1
e_2
..
..
e_n

where t_{start}= the time (in SECONDS) from the starting time to the time when the rainfall-runoff data starts.

t_{inc}= the time increment (in SECONDS) of the rainfall-runoff data. This value can be different to the time increment specified in the rainfall file. If t_{inc} exceeds the time increment *tt* specified in the rainfall file by a factor of four, the rainfall will be distributed according to the relevant pluviograph pattern.

n = the number of rainfall-runoff values, e_n. These values will be altered by the loss parameters specified.

For a DESIGN run, the starting time is at t = 0. For a FORECAST or MATCHING run:

(a) if t_{start} is less than one year (31 536 000 seconds), the starting time is relative to the date and time set by the environment variables URBS_DATE and URBS_TIME (see Section 7).

(b) if t_{start} is greater than one year, the starting time is:
   (i) in DOS or UNIX/XENIX - the time in SECONDS since GMT 1/1/1970 (10:00am EST);
   (ii) in QNX - the time in SECONDS since 1/1/1980 (local time).

The rainfall-runoff value e_i is the amount of excess rainfall, in millimetres, which fell between t = i-1 and t = i.

5.8. Catchment Data Files

A catchment data file contains sub-catchment land use and relief data. Each line of data lists data for a sub-catchment identified by its area reference number or index. This index is given in the catchment definition file (specified by a RAIN or ROUTE command). The data listed is the area reference number, the sub-catchment area, the fractions I, F, UL, UM, UH, UR and UD, and the average sub-catchment slope. The three OSD analysis parameters, PSD, SSR and TBO, capacity parameter Q and maximum infiltration parameter IF can also be optionally included. The file is a text comma delimited file (for spreadsheet access) and its format is as follows:

The first line of the file must be of the form:

"Index", "Area", "UL", "UM", "UH", "UD", "UR", "UF", "CS", "SSR", "PSD", "TBO", "Q","I","IF"

A detailed explanation of each variable is as follows:

Index:	Number assigned to a sub-catchment - any order, but must be unique
Area:	Sub-catchment area in km^2
UL:	Low density Urban fraction
UM:	Medium density Urban Fraction
UH:	High density Urban Fraction
UD:	fraction of sub-catchment disturbed for urban development
UR:	fraction of sub-catchment with rural land (cleared but not forested)
UF:	Fraction of sub-catchment forested.
CS:	Catchment slope (m/m)
SSR:	Site Storage Requirement (m^3/hectare) for sub-catchment
PSD:	Permissible Site Storage (L/s/hectare) for sub-catchment
TBO:	fraction of sub-catchment to be OSD'd
Q:	maximum capacity of sub-catchment minor drainage system (m^3/s)
I:	fraction of catchment impervious
IF	Maximum Infiltration capacity of sub-catchment (mm).

The only restrictions are that the index field must be first column and that the area column must be specified. The remaining columns (variables) are optional and can be specified in any order.

The following lines list the values separated by commas in the same variable order specified in the first line.

It is not essential that each area reference number listed refers to a sub-catchment of the catchment under investigation. The only requirement is that all references in the catchment definition file are resolved. This implies that it is possible to have a catchment data file which contains the data for a whole city or district, within which there are many defined catchments.

Comments can be placed in the file by typing an asterisk (*) in the first column.

5.9. Storage Discharge Files

Storage Discharge files are used to replace "hardwired" storage discharge tables in the catchment definition file. This facility also allows the results from third party software to be incorporated into the URBS model. The URBS model comes with its own utility named DETAIN. This program is described in Section 9.12 of this manual. Storage Discharge files are also required when sediment deposition modelling is undertaken for dams - see Section 4.4.

The format for a storage discharge file is;

Line 1: Title
Line 2: n No of Storage-Discharge pairs
Line 3: S_1 q_1
Line 4: S_2 q_2
. . .
. .
Line n: S_n q_n

The unit for storage values is ML. Discharge values are in cumecs.

Comments can be placed in the file by typing an asterisk (*) in the first column.

The default extension for a storage discharge file is **.sq**.

5.10. Storage Elevation Data Files

The format of the elevation storage file is as per CSV files and is as follows:

Line 1: EL,A,V,P
Line 2: *nn.nn, nn.nn, nn.nn, nn.nn*
Line 3: *nn.nn, nn.nn, nn.nn, nn.nn*

etc.

EL specifies the elevation in metres. **A** specifies the storage area at that elevation in hectares. **V** specifies the storage volume in megalitres at that elevation. **P** specifies the non-exceedence probability (expressed as a fraction) of a level been less than or equal to the specified elevation. This is used in Monte Carlo studies and is optionally included.

The default extension for an elevation storage data file is **.els**

5.11. Sediment Grading Files

Sediment grading files are used to assess the extent of deposition for a given sediment size distribution in sediment trap, retention basin or reservoir. The file is accessed by specifying the file name as one of the parameters used for sediment wash-off and deposition modelling - see Section 4.4.

The format of the file is;

Line 1: Heading
Line 2: n number of data points
Line 3: s_1 pp_1
Line 4: s_2 pp_2
. . .
. . .
Line n: s_n pp_n

s_i is the sieve size in mm. These should be listed in decreasing order. pp_i is the percentage of material passing the corresponding sieve size s_i.

Comments can be placed in the file by typing an asterisk (*) in the first column.

The default extension for a storage discharge file is **.sgf**.

5.12. Size Limits

There are no practical limits to the number of areas, nodes and dams that can be modelled in an URBS model. However, the total number of dam storage-discharge ordinates has been limited to 500 ordinates. The number of pluviographs and rating curves has been limited to 150. The maximum number of rating curve dependencies has been limited to 10.

The amount of rainfall data is dependent on the amount of RAM available after allocation of memory for node, area, dam and associated information.

5.13. Units

The following table shows the units to be used for input data:

Table 2. Input Data Units

QUANTITY	UNITS
Rainfall	mm
Initial Loss	mm
Catchment Slope	m/m
Channel Slope	m/m
Continuing Loss Rate	mm/h
Proportion of Runoff	Fraction
Capillary Suction Head	mm
Saturated Loss Rate	mm/h
Discharge	m^3/s
Forestation	Fraction
Flow Height	m
Area (sub-catchment)	km^2
Area (storages)	ha
Reach Length	km
Average Distance	km
Urbanisation	Fraction
Volume, Storage	ML
Storm Duration	H
Run Duration	H
Time Increment (Rainfall File)	H
Time Increment (Pluviograph Data File)	S
Sediment	Tonnes
Export Rates	$kg/km^2/yr$
Site Storage Requirement	m^3/ha
Permissible Site Discharge	l/s/ha
Sewered Channel Capacity	m^3/s
Max Infiltration Capacity	mm
Impervious fraction	fraction

6. LINKS WITH THIRD PARTY SOFTWARE SYSTEMS

6.1. HYMODEL (BoM)

URBS has been linked to the several software systems developed by the Australian Bureau of Meteorology. The main system used is a web based interface named HYMODEL that uses specially developed modules by the Bureau to run the URBS software. These modules are not provided with this model.

6.2. ENVIROMON

The Australian Bureau of Meteorology has developed a software package named ENVIROMON that monitors and captures data from ALERT reporting systems. The URBS model has been modified to incorporate ENVIROMON files through use of an interfacing module named c2u. How to use this utility is described in Section 9.16.

6.3. CATCHMENTSIM

CatchmentSim developed by Catchment Simulation Solutions P/L can automatically generate URBS vector files (as well as for other runoff routing models) using inputed raster DEM's.

6.4. FEWS

The FEWS flood forecasting system is developed by Deltares, Netherlands. Its input and output files are based on an XML schema issued by Deltares. A pre-adapter and post adapter has been prepared to facilitate running the URBS model within FEWS. These are not provided with the URBS software and can be obtained by contacting the author.

7. ENVIRONMENT VARIABLES

The URBS model can access 40 different environment variables, including those specified in DAM ROUTE commands. They can be set by typing:

(i) in Windows DOS: (no spaces)
SET *environment variable=value*

(ii) in UNIX/XENIX:
setenv *environment variable value*
(where *environment variable* must be in capital letters)

(iii) in QNX (make sure the "envmgr" task has been executed):
setenv *environment variable=value*
(where *environment variable* must be in capital letters)

(iv) in an initialisation file named *basename*.ini, where *basename* is the name used to define the catchment definition file.

A list of the current values of all of the environment variables (except DAM ROUTE variables) can be obtained in any operating system by typing:

URBS32 -e

The command also generates a file called urbs.ini, which can be modified and renamed as *basename*.ini. The renamed file would then be accessed by the next *basename* model run, and the values of the set environment variables contained in the model applied to the model.

The environment variables are:

(a) Model Parameters:

(1) URBS=*value*

Value can be either URBS (default) or RORB. If URBS=URBS, the rainfall hyetograph is read in as discrete blocks of data. This is the correct way to interpret rainfall. If URBS=RORB, the hyetograph is assumed to be linearly interpolated between data points. This has the net effect of delaying the calculated runoff by half a time increment. Setting URBS=RORB will achieve the exact same results as running a RORB model.

(2) URBS_MUSK=*value*

Value can be either TRUE or FALSE (default). If URBS_MUSK=TRUE, the Split Model will be used. If values of Muskingum x and Muskingum n have not been specified in the catchment file, the default values will be used. If these values have been specified in the catchment file, the Split Model will be used regardless of whether URBS_MUSK is set to TRUE or FALSE.

(3) URBS_SPLT=*value*

Value can be either TRUE or FALSE (default). This parameter will determine whether or not the Split Model is used, i.e. whether the catchment and channel storages are "split" and defined by separate equations, or combined in one equation. If URBS_SPLT=TRUE, URBS will use the Split Model. If URBS_SPLT=FALSE, URBS will use the Basic or Combined Model, depending on the parameters specified.

(4) URBS_SCAL=*value*

Value can be either TRUE or FALSE (default). This environment variable only applies when URBS is performing a MATCHING RUN (see Section 5.1.2). When URBS_SCAL=FALSE, URBS matches the calculated hydrograph to the recorded values at each gauging station location only. If URBS_SCAL=TRUE, URBS will scale all hydrograph values upstream of a gauging station location in proportion to the ratio of recorded to calculated hydrograph values at the gauging station.

(5) URBS_PROP=*value*

Value can be either TRUE (default) or FALSE. This environment variable is only applicable when the BASIC model is used. If TRUE, then should the urbanisation index not be given for a route statement which crosses a catchment sub-catchment boundary, or the route statement has not specified a THRU area option, then URBS will estimate its index by proportioning the indices of adjoining sub-catchments based on their relative sub-catchment areas. Otherwise, the index specified on the route command line or assigned via the THRU area option is used. Using the usual definitions the proportioning equation is:

$$U_{ROUTE} = \frac{A_{u/s}\ U_{u/s} + A_{d/s}\ U_{d/s}}{A_{u/s} + A_{d/s}}$$

(6) URBS_RATM=*value*

Value can be either TRUE (default) or FALSE. Setting URBS_RATM to TRUE has the same effect as including the R keyletter on the USES line of the catchment definition file. This invokes the rational method based sub-catchment smoothing routine described in Section 2.2.1 of this manual.

(7) URBS_SMTH=*value*

Value can be either TRUE (default) or FALSE. Setting this environment variable to TRUE requests the URBS model to invoke the smoothing routing for DAM routing. This variable should be used with caution, as the causative factors behind the model instability should be first identified and understood.

(b) Data Parameters:

(8) URBS_BASF=*value*

Value can be either TRUE (default) or FALSE. If URBS_BASF=TRUE, the first discharge value of the inflow or recorded hydrographs is assumed to be the value of baseflow. If URBS_BASF=FALSE, the first discharge value is assumed part of the normal creek flow, and will be routed normally.

(9) URBS_CONE=*value*

This *value* specifies the degree of connectivity of the urban drainage system. The value is given as a fraction ranging from 0 to 1. The default value is 1.

(10) URBS_CONN=*value*

Value can be either TRUE (default) or FALSE. If URBS_CONN to TRUE, then the connectivity index specified by the URBS_CONE variable is used, else full connectivity or e = 1 is assumed.

(11) URBS_INFR=*value*

This *value* specifies the maximum infiltration capacity for the modelled catchment. The default value is infinity. This value can also be entered on the DEFAULT PARAMETERS line of the catchment definition file. Its value is in mm.

(12) URBS_INTR=*value*

Value can be either TRUE or FALSE (default). If URBS_INTR=FALSE, the rainfall-runoff values specified apply to the entire catchment upstream of a rainfall-runoff station. If URBS_INTR=TRUE, the rainfall-runoff values specified only apply to the catchment downstream of other rainfall-runoff stations.

(13) URBS_JCNS=*value*

Value can be either TRUE or FALSE (default). If URBS_JCNS=FALSE, then distances, slopes, manning n, if specified, are assigned to the next downstream location, otherwise they are specified to the next downstream junction. This information is given the ".hc" output file which is detailed in Section 8 of this manual.

(14) URBS_MINQ=*value*

The *value* specifies a global catchment value for the maximum discharge capacity of the minor system (piped and channelised system). The value can also be entered in the DEFAULT PARAMETERS line of the catchment definition file. Its default value is infinity. Its value is in cumecs.

(15) URBS_PSD=*value*

The *value* specifies a global catchment value for the permissible site discharge for OSD analysis. The value should be given in litres/second per hectare.

(16) URBS_SSR=*value*

The *value* specifies a global catchment value for the site storage requirement for OSD analysis. The value should be given in cubic meters per hectare.

(17) URBS_TRLS=*value*

The value specifies the transmission loss that is to be applied to reach. The units are ML/km. The value can also be entered in the DEFAULT PARAMETERS line of the catchment definition file. Its default value is 0.

(18) URBS_UIMP=*value*

The *value* specifies the threshold fraction impervious, which when exceeded defines the extent of urbanised area. The value can also be entered in the DEFAULT PARAMETERS line of the catchment definition file. Its default value is 50%. Its value is given as a fraction.

(19) URBS_ZERO=*value*

Value can be either TRUE or FALSE (default). If URBS_ZERO=TRUE, URBS will match all recorded data (including zero values) to recorded data if a match is required, otherwise only recorded values greater than zero will be matched.

(c) Real Time Parameters:

(20) URBS_REAL=*value*

Value can be either TRUE (default) or FALSE. If URBS_REAL=TRUE, the URBS_FORE variable takes effect starting at the present time. If URBS_REAL=FALSE, the URBS_FORE variable takes effect starting *offset* hours after the time and date specified by the URBS_DATE and URBS_TIME variables, where *offset* is the value of URBS_OFFS in hours (see below).

(21) URBS_DATE=*dd/mm/yy*

dd/mm/yy is the date (eg 25/9/91) from which the URBS files measure their start date. This variable is used in conjunction with URBS_TIME to define a starting time and date for the model run. The default value of URBS_DATE is today's date.

(22) URBS_TIME=*hh*:*mm*:*ss*

hh:mm:ss is the time on a 24 hour clock (eg 15:30:00) from which the URBS files measure their start time. This variable is used in conjunction with URBS_DATE to define a starting time and date for the model run. The default value of URBS_TIME is midnight (00:00:00).

(23) END_DATE= *dd*/*mm*/*yy*

dd/mm/yy is the end date (eg 25/9/91) to which data is extracted from URBS data files. It is only valid for forecast runs as specified in the rainfall definition file.

(24) END_TIME= *hh*:*mm*:*ss*

hh:mm:ss is the time on a 24 hour clock (eg 15:30:00) and is the end time to which data is extracted from URBS data files. It is only valid for forecast runs as specified in the rainfall definition file and is used in conjunction with END_DATE.

(25) URBS_FORE=*aa*,*bb* [,*cc, dd*]

If only two parameters are specified, URBS adds another *aa* millimetres of rainfall to the catchment over the next *bb* hours. If three parameters are specified, URBS distributes rainfall of intensity *aa* times that which fell in the previous *bb* hours over the next *cc* hours. If *cc* is set to zero then the two parameter specification applies. The fourth parameter is a delay parameter that is used to delay the forecast rainfall by *dd* hours.

The rainfall for either use of URBS_FORE is distributed in proportion to the rainfall history for each sub-catchment if the forecasted depth is greater than half the recorded average depth. If this is not the case, the forecast rainfall is distributed uniformly. When rainfall-runoff data is used and URBS_REAL=TRUE, the forecast rainfall will be proportioned according to the ratio of actual volume of runoff prior to the start of the forecast rainfall to the recorded volume.

(26) URBS_OFFS=*offset*

This variable only has an effect when URBS_REAL=FALSE. When this is the case, the forecast rainfall defined by the URBS_FORE variable starts *offset* hours after the time and date specified by URBS_TIME and URBS_DATE. The default value of URBS_OFFS is 0 hours.

(27) URBS_PROF=*value* ***[no longer used]***

Value can be either TRUE (default) or FALSE. If URBS_PROF=TRUE, then the URBS model will attempt to access the host machines Prophet database for data. Otherwise no access is made.

(d) URBS Directories:

(28) URBS_RAIN=*directory*

The specified *directory* is where URBS will look for the pluviograph files. The default *directory* is the current directory.

(29) URBS_RATS=*directory*

The specified *directory* is where URBS will look for the rating curve files. The default *directory* is the current directory.

(30) URBS_GAUG=*directory*

The specified *directory* is where URBS will look for the gauging station files. The default *directory* is the current directory.

(31) URBS_INFS=*directory*

The specified *directory* is where URBS will look for the inflow hydrograph files. The default *directory* is the current directory.

(32) URBS_RUNF=*directory*

The specified *directory* is where URBS will look for the rainfall-runoff station files. The default *directory* is the current directory.

(33) URBS_RETS=*directory*

The specified *directory* is where URBS will place the results files. The default *directory* is the current directory.

(e) DAM ROUTE Labels:

(34) *label*=*volume*

Volume is the volume below full supply in the dam which must be filled before discharge will occur. The name of the *label* must agree with that given in the DAM ROUTE command in the catchment definition file.

(35) *label*=*level*

Level is the water level of the storage at the onset of the event or at the start of the simulation. The name of the label must agree with that given in the DAM ROUTE command in the catchment definition file.

(36) label=**RANDOM**

This is used to allow the URBS model select a random starting water level for the simulation. An ‘els’ file must be available and include a column specifying the non-exceedence probabilities for all elevations.

(f) Hot Start Environment Variables

Hot Start files are files that contain model results at a particular point in time, that can be subsequently used as initial conditions by another model run. When hot start environment date and time variables are set, a hot start file is created containing model results for that date and time. Another environment variable is set to tell the URBS model to use this file in a later run using the hot start file for initial conditions.

The following is a description of the associated environment variables.

(36) UHST_DATE =dd/mm/yy

dd/mm/yy specifies the date (eg 25/9/91) that model results should be written to a hot start file. This variable is used in conjunction with UHST_TIME to define the hot start date and time.

(37) UHST_TIME=*hh*:*mm*:*ss*

hh:mm:ss is the time on a 24 hour clock (eg 15:30:00) and is used to define the hot start time for which model results are written to a hot start file.

(38) URBS_HOTS=*value*

The value is either TRUE or FALSE. If it is TRUE data from a hot start file will be used at the model initial conditions.

If a hot start file is used the URBS_DATE and URBS_TIME should be set to the hot start date and time - these variables are sometimes used by data extraction processes that generate the relevant input files that are offset from URBS_DATE and URBS_TIME. If the model finds that they are different it sets the URBS_DATE and URBS_TIME to the hot start date and time with a warning re data abstraction.

(39) URBS_MVBF=*value*

The value is either TRUE (default) or FALSE. When set to TRUE the URBS_MVBF environment variable the modelled storage volumes deficits are used at the start of the run otherwise the VBF values as set in the new run. This allows dam levels to be set every run.

(f) URBS Matching

(40) URBS_MATCH= *locationName*

Matched locations can be set using the URBS_MATCH variable. Up to 5 locations can be specified (repeat the URBS_MATCH assignment) and the *locationName* must match the location identifier in the catchment definition file as specified by a PRINT statement,

8. RUNNING PROGRAM URBS

This section describes how URBS is run as a stand alone module. Section 10 describes how the model can be run in batch mode. Developers should refer to both this Section and Section 10 to assist in their interface development for URBS.

Before running your model, you should test the catchment definition file which you have assembled. This is done by typing at the command line:

URBS32 *catchmentFile*

This will report any errors which you may have included in your file. If the run was successful, a cc file (catchment characteristic file) is created. The name of the file is *catchmentfile.cc*. The file is a text comma delimited file suitable for import into spreadsheets. Each line of the file lists the catchment characteristics for each location nominated in your catchment definition file (via a PRINT, P&P or PLOT command line). The characteristics listed are; d_{av}, L, Drainage Density DD= ΣL/A, %Urbanised (U%), %Impervious (I%), %Forested (F%), % Channel Slope (S_c%), % Catchment Slope (So% or CS%), and EF, the catchment erodability factor - see equation (36).

The URBS model will also output important statistics to the screen, these are; total catchment area A, d_{av}, f_{av}, the average channel slope, Sc_{av}. These factors should be noted if regional parameters for α, m etc. are used - see Section 2. Furthermore third party programs can access the catchment characteristics file to estimate design discharges using alternative techniques such as the rational or a regional equation method.

If you wish to calculate flows through assigning a rainfall definition file to the catchment definition file then the opening command line to run program URBS has the following format:

URBS32 *catchmentFile rainfallFile* [*newBaseName*]]
where *catchmentFile* is the catchment file.
rainfallFile is the rainfall file.
newBaseName is the default base name for output files. If this option is not used, the default base name for the output files is the base name of catchment definition file.

How URBS parameters are set is discussed in the next section.

8.1. Setting URBS Parameters

There are three ways of setting URBS parameters. These are in order of precedence:

- Command Line interface (either numeric or alpha mode)
- Via the "Ini" File
- Via the catchment definition or rainfall definition file

Each method is discussed in turn in the following sections and is summarised in Table 3.

Table 3: Parameter Specification Methods

Parameter	**Cmd line - Numeric (1)**	**Command Line – alpha (1)**	**INI FILE (2)**	**Default (3)**	**Affects**	**Typical Range**
Alpha	4th parm	Alpha=n.n	URBS_ALPHA	Alpha=n.n (CDF)	Channel|Catchment routing	0.1 – 0.3
N	N/A	N=n.n	URBS_N	N=n.n (CDF)	Channel routing exp 1/(km/h)	0.8 - 1.2
M	5th parm	M=n.n	URBS_M	M=n.n (CDF)	Catchment routing exponent	0.6-1
Beta	6th parm	Beta=n.n	URBS_BETA	Beta=n.n (CDF)	Catchment Routing	1 – 9
Il	7Th parm	IL=n.n	URBS_IL	Il=n.n (RDF)	Initial Loss mm	0-150
IlMax	N/A	ILmax=n.n	URBS_ILMX	N/A	Maximum Initial Loss mm	0-150
Cl	8th parm	Cl=n.n | lp=n.n	URBS_CL	Cl=n.n (RDF)	Continuing loss mm/hr	0-5
Rf	9th parm	Rf= n.n	URBS_RF	Rf= n.n (RDF)	Recovery Factor	0-1
If	N/A	IF= n.n	URBS_IF	IF= n.n (CDF)	Maximum Soil Storage (mm)	0-500
X Factor	N/A	XF=n.n	URBS_XF	N/A	Muskingum x scaling factor	> 0
Bf	N/A	Bf=n.n	URBS_BF	Bf=n.n (C|RDF)	Baseflow scaling factor	> 0
Kd	N/A	Kd=n.n	URBS_IFRF	Kd=n.n (CDF)	Daily Infiltration Recovery factor	0.5-1
TL	N/A	Tf = n.n | Tl = n.n	URBS_TRLS	Tl = n.c (CDF)	Transmission Loss ML/km	Varies
hotStartFile	N/A	HotStartFile=<filename>	N/A	Basename.hst	Hot Start File	N/A

Notes:
- Hierarchy (highest to lowest): Command->ini file -> default parameters
- Parameters are case insensitive
- Either the numeric or the alpha command line mode can be used – they cannot be mixed
- In the alpha command mode, parameters and values must be separated by =. Spaces are allowed. Any order is permitted.
- n.n denotes a value. N/A denotes not available. | means either specification is allowed,
- CDF catchment definition file, RDF rainfall definition file

8.1.1. Command Line Interface

Setting parameters using the command line interface has the highest precedence ie the values specified overwrite parameters specified in the 'ini' file, the catchment definition file or the rainfall definition file.

There are two modes which parameters can be specified -a numeric model or an alpha mode.

Numeric Mode.

Three routing parameters; α, m, β and two loss parameters; *IL, lp* parameters are specified after the output file name on the command line i.e.

URBS32 *catchmentFile rainfallFile* [*newBaseName*]] α *m* β *IL lp*

The order which they specified must be adhered to.

α ,***m****,* and β have the usual meanings*.* ***IL*** is the initial loss and ***Ip*** is the continuing loss rate when the continuing loss model is used or the runoff proportion when the proportional loss model is used. If a VARIABLE loss model is specified in the rainfall definition file, the loss parameters are average values. This is achieved by re-scaling the values for each sub-catchment.

Alpha Mode

The alpha mode is more versatile than the numeric mode. When using the alpha mode, parameters and values must be separated by =. Spaces are allowed. Any order is permitted and any number of parameters may be specified. The parameters that can be specified are: alpha, n, m, beta, Initial loss, Maximum initial loss, continuing loss, recovery factor, Infiltration capacity, Muskingum X scaling factor. Baseflow scaling factor , Infiltration recovery factor and Transmission loss. In addition the name of the hot start file that the model should read can also be specified. The default is the run basename with the suffix .hst.

The command line specification is as follows

URBS32 *catchmentFile rainfallFile* [*newBaseName*]] [*alpha=n.n] [N = n.n] [M =n.n] [beta = n.n] [IL= n.n] [Ilmax= n.n] [CL|LP = n.n] [RF = n.n] [IF = n.n] [XF=n.n] [BF= n.n] [Kd= n.n] [Tf = n.n] [hotStartFile = <filename>]*

8.1.2. Ini File

The 'ini' file is a parameter file that contains environment variable settings as well as parameter specifications. Parameters set the in the ini file override those specified in the catchment definition and rainfall definition file, but are overwritten by command line parameters. The parameters that can be specified in the ini file are identical to those that can be set using the alpha mode for the command line mode, with the exception of the hot start file specification. However, the names of the parameters are different to reflect the names of other environment variables that can be specified in the ini file - ie the names are preceded with URBS_ eg. URBS_ALPHA. The list of ini file variable names are given in Table 3.

8.1.3. Catchment Definition and Rainfall Definition Files

Catchment Definition File

Parameters are specified on the DEFAULT PARAMETERS line as outlined in Section 5.1. These parameters are overwritten by those specified in the 'ini' file, which are in turn overwritten by those specified on the command line.

Rainfall Definition File

The loss parameters and or baseflow are specified in the rainfall definition file as specified in Section 5.2. These parameters are overwritten by those specified in the 'ini' file, which are in turn overwritten by those specified on the command line.

8.2. URBS Input Files

As mentioned in Section 5, URBS can access nine different input files besides the necessary catchment definition and rainfall definition files. A summary of the file types is shown in Table 4. The base name of these files is specified in the catchment or rainfall definition file.

Table 4. Input File Types

EXTENSION	FILE CONTENTS
.rat	Rating Curve
.r	Pluviograph Information
.g	Gauging Station Recorded Heights or Rated Flows
.i	Inflow Hydrograph
.rrf	Rainfall-Runoff Station Data
.cdf	Catchment data file
.sq	Storage Discharge File
.els	Storage Elevation File
.sgf	Sediment Grading Curve data

8.3. URBS Output Files

After running program URBS, up to twenty-three different output files will be created. The base name for most of these files is the same as the catchment file base name, unless a *newBaseName* is specified in the opening command line. The files created are:

(i) *basename*.a is a list of the average depths of rainfall which fell in each time increment during the model run. The depths are the average over the entire catchment in that time increment. The format of this file is the same as for a pluviograph data file (see Section 5.4).

(ii) *basename*.b is a binary plot file that is no longer used.

(iii) *locationName*.bf is a baseflow series that be requested for any location by appending an asterisk after the location name on the PRINT statement in the catchment definition file.

(iv) *basename*.cc is text comma delimited file containing the catchment characteristics for each nominated PRINT and/or PLOT command.

(v) basename.csv is a CSV file containing all the model run results for each nominated location. These include gross and excess rainfall, water level and discharge data.

(vi) *basename*.e is a list of the average excess depths of rainfall which fell in each time increment during the model run. The depths are the average over the entire catchment in that time increment. The format of this file is the same as for a rainfall-runoff data file (see Section 5.7).

(vii) *basename.fs* is a file that contains a series of values of the fraction of catchment saturated over time.

(viii) *basename*.h is a table of calculated and recorded stream heights for each time increment. Stream heights are only calculated at PRINT locations where a rating curve exists. Recorded values are given if a gauging station is present at the PRINT location.

(ix) *basename*.hst file contains the hot start data using model results for a specified date and time. The date and time is specified using the UHST_DATE and UHST_TIME variables - see Section 7.

(x) *basename*.hc is the catchment's hydraulic connectivity file. It lists for each PRINT and/or PLOT location, the next downstream PRINT and/or PLOT location including the channel length (metres) and channel slope (%) and manning's n between the two locations. If the URBS_JCNS environment variable is set to TRUE, then the downstream location is relaced with the next downstream junction. This file is generally used as input for hydraulic analyses programs.

(xi) *basename*.log contains all the run information generated by the model.

(xii) *basename*.o is a discharge hydrograph file calculated at a nominated PRINT location. This file can be used as an inflow hydrograph file if it forms a tributary of another larger catchment. The format of this file is therefore the same as for an inflow hydrograph file (see Section 5.6). The location specified at the last PRINT location is automatically printed. Other locations can be printed by placing an asterisk after the location name.

(xiii) *damLocation_cal.o* contains modelled stage data for a storage. For this file to be written you must specify elevation storage data see Sectons 5.1 and 5.10.

(xiv) *basename*.osd tabulates the OSD parameters for each PRINT and/or PLOT location. The file lists the PSD, the SSR, fraction urbanisation (U) and the fraction urbanisation subject to OSD policies (TBO).

(xv) *basename*.p is table of the calculated peak discharges and stream heights at each PRINT location, and the time that they occur. Stream heights are only calculated at those location where a rating curve also exists.

(xvi) *basename.prm* is a file that contains the parameters that were in the model run

(xvii) *basename.pqh* is a file that contains modelled flow volumes and peaks and coefficient of efficiencies (Nash-Sutcliffe) for locations where data is available.

(xviii) *basename*.q is a table of calculated and recorded discharges for each time increment. Recorded values are given if a gauging station is present at the PRINT location. The last line contains the total volume of the hydrograph.

(xix) *basename*.s contains all the sediment wash-off and deposition results.

(xx) *basename*.t contains all the traffic disruption due to flooding results.

(xxi) *basename*.vbf file contains the volume before full for each dam as the date and time specified by UHST_DATE and UHST_TIME environment variables - see Section 7.

(xxii) urbsQlog.csv is a csv file that contains a record of peak flows and volumes for all locations for each URBS run. It is primarily used in Monte Carlo analysis.

(xxiii) urbsHlog.csv is a csv file that contains a record of peak levels for all locations for each URBS run. It is primarily used in Monte Carlo analysis.

The user is advised that when running multiple instances of the model within one location the last two files will be written by the separate processes. This issue will be addressed in future editions of the model.

A summary of these file types is given in Table 5.

Table 5. Output File Types

EXTENSION	FILE CONTENTS
.a	Average Rainfall per Period on Catchment
.b	Binary Plot File no longer used
.cc	Catchment Characteristics results
.csv	All the results for spreadsheet import (3 files)
.e	Average Excess Rainfall per Period on Catchment
.fs	Average catchment fraction saturation time series
.h	Table of Calculated & Recorded Heights
.hst	Hot start file contain model results at a specified date
.hc	Hydraulic connectivity file
.log	Run log file
.o	Discharge Hydrograph at PRINT Location
_cal.o	Modelled Storage Results
.osd	Results of OSD analysis
.p	Table of Calculated Peak Discharges & Heights
.pqh	Statistics of calculated results (peaks, volumes, etc.)
.prm	File listing parameters used in the run
.q	Table of Calculated & Recorded Discharges
.s	Sediment Wash-off and Deposition results
.t	Traffic Disruption Costs results
.vbf	File containing air space data for storages

9. URBS UTILITIES

There are nineteen utilities provided to assist the modeller in plotting, collating and comparing URBS' results. Each utility is discussed in turn.

9.1. WinPLOTU

WinPLOTU is the URBS hydrograph and hyetograph plotting module. It obtains the results from URBS's csv file and has the following capabilities:

(i) Plots discharge hydrographs at the PRINT locations specified in the catchment definition file;

(ii) Plots stage hydrographs at the PRINT locations specified if a rating curve also exists for that location.

(iii) Plots Gross and Excess hyetographs of average rainfall to each location.

(iv) Plots Minor, Moderate and Major Flood for specified locations

(v) Tabulates all result data facilitating copying and pasting to third party applications.

The WinPLOTU module can be invoked by clicking on the WinPLOTU executable or from the command line as follows:

WinPLOTU [*filename.csv*] [*filename.mmm*]

The *filename.csv* file is created by the URBS32 module. It is a CSV file containing 5 sequential sections; Gross Rainfall, Excess Rainfall, River Levels and Flow Rates for each specified location (as per the PRINT statements in the catchment vector file) and a Run Parameters section that lists the parameters used in the run as well as the run date.

The second file is a user created csv file that specifies Minor, Moderate and Major Levels for those locations for which river level is available. These threshold levels are plotted as horizontal lines on the corresponding river levels plot. An example of this file follows:

```
"Thresholds", "Wigley_g",  "ANZAC"
"Minor",          3.0,      2.7
"Moderate",       4.0,      3.1
"Major",          5.5,      3.5
```

Note all text fields are enclosed with double quotes (“) and comma’s separate the field values.

If the “*.mmm*” file is not specified WinPLOTU will look for a file with the same base name as the csv file in the same directory and if found will use this file to plot to the threshold levels.

Inclusion of thresholds was a requirement of Melbourne Water and their contribution to improving WinPLOTU is gratefully acknowledged.

The following is an example output from the WinPLOTU module:

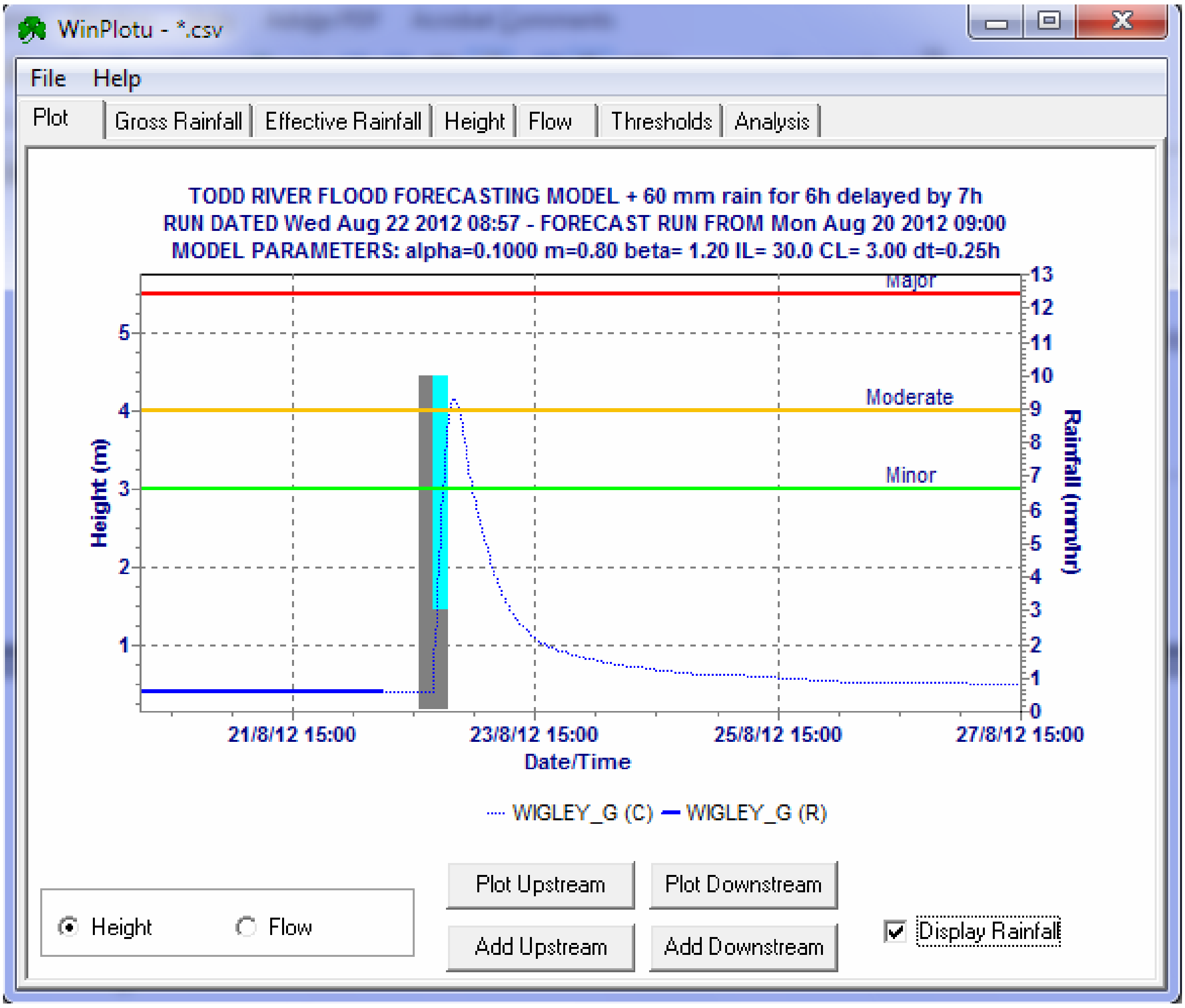

Figure 5: Sample WinPLOTU Plot

The dark blue line is recorded height data, where as lighter dotted blue line is the calculated heights or in this instance forecast river levels. Rainfall is represented by two colors; light blue for excess and grey for rainfall loss. In this case the rainfall is assumed forecast rainfall as detailed in the Figure's heading text. Threshold levels are represented by green, orange and red for minor, moderate and major respectively.

The above figure in addition to the plot results shows six information tabs. The next 4 tabs provide the tabular data upon which all plot results are based. The threshold tab echoes the data in the ".mmm" or thresholds file, whereas the analysis tab provided statistics relating to the exceedences of these thresholds.

In addition to the tabs, Plot/Add Upstream/Downstream buttons are provided to allow single and overlays of plots for other locations for comparative purpose. Plot Upstream/Downstream proceeds to the next upstream and downstream location respectively. Add Upstream/Downstream overlays the next upstream or downstream location respectively.

Rainfall data can be omitted from the plot by unchecking the "Display Rainfall" box in the lower right hand corner. Rated Flows can be plotted by selecting the flow radio button located in the lower left hand corner.

9.2. MAXQ

MAXQ is a utility which determines the peak flow rates for the PRINT and/or PLOT locations listed in the catchment definition file. This is done by accessing ".p" files generated by URBS for a series of design storms. It is primarily used in DESIGN analysis, when the modeller is requested to determine peak flows for a series of catchment locations.

It is used as follows:

MAXQ [file1.p] [file2.p] .... [filen.p] [-ofilename.mq]

where file1.p, file2.p etc are ".p" or profile files calculated for different duration from the same catchment. The output file has a default extension of ".mq" and may be specified using the "-o" switch with the last command line parameter. This file lists for each location the calculated peak flow rate and associated critical duration.

9.3. MAXMAXQ

This utility reads output files generated by the MAXQ utility (".mq" files) to generate a list of peak flows for a range of ARIs as defined in each ".mq" file. The output file has a default "amq" extension. Typically you would use this utility to generate a list of peak flow rates for a series of ARIs for all catchment locations.

It is used as follows:

MAXMAXQ [file1.mq] [file2.mq] ......[filen.mq] [-ofilename.amq]

where file1.mq, file2.mq etc are ".mq" files generated by the MAXQ utility. The output file has a default extension of ".amq" and may be specified using the "-o" switch with the last command line parameter.

MAXMAXQ accesses the file name for each ".mq" file to collate the results in the ".amq" file.

9.4. MAXMAXC

This utility reads output files generated by the MAXQ utility (".mq" files) to generate a list of critical durations for a range of ARIs as defined in each ".mq" file. The output file has a default "amc" extension. Typically you would use this utility to list the critical durations for a series of ARIs for all catchment locations.

It is used as follows:

MAXMAXC [file1.mq] [file2.mq] ......[filen.mq] [-ofilename.amc]

where file1.mq, file2.mq etc are ".mq" files generated by the MAXQ utility. The output file has a default extension of ".amc" and may be specified using the "-o" switch with the last command line parameter. MAXMAXC accesses the file name for each ".mq" file to collate the results in the ".amc" file.

9.5. MAXS

MAXS is a utility which determines the peak sediment deposition volumes for PRINT and/or PLOT locations listed in the catchment files. This is done by accessing ".s" files generated by URBS using a series of durations for a chosen ARI. It is primarily used in DESIGN analysis, when the modeller is required to determine sediment deposition volumes for a series of catchment locations.

It is used as follows:

MAXS [file1.s] [file2.s] .... [filen.s] [-ofilename.ms]

where file1.s, file2.s etc are ".s" or sediment deposition files calculated for different duration from the same catchment. The output file has a default extension of ".ms" and may be specified using the "-o" switch with the last command line parameter. This file lists for each location the calculated maximum sediment deposition volume and associated storm duration.

9.6. MAXMAXS

This utility reads output files generated by the MAXS utility (".ms" files) to generate a list of maximum sediment deposition volumes for a range of ARIs as defined in each ".ms" file. The output file has a default "ams" extension. Typically you would use this utility to list the maximum sediment deposition volumes for a series of ARIs for all catchment locations.

It is used as follows:

MAXMAXS [file1.ms] [file2.ms] ......[filen.ms] [-ofilename.ams]

where file1.ms, file2.ms etc are ".ms" files generated by the MAXS utility. The output file has a default extension of ".ams" and may be specified using the "-o" switch with the last command line parameter.

MAXMAXS accesses the file name for each ".ms" file to collate the results in the ".ams" file.

9.7. MAXT

MAXC is a utility which determines the maximum traffic disruption costs for the PRINT and/or PLOT locations listed in the catchment definition file. This is done by accessing ".t" files generated by URBS using a series of durations for a chosen ARI. It is primarily used in DESIGN analysis, when the modeller is required to determine traffic disruption costs for a series of catchment locations.
It is used as follows:

MAXT [file1.t] [file2.t] .... [filen.t] [-ofilename.mt]

where file1.t, file2.t etc are ".t" or traffic disruption costs files calculated for different durations from the same catchment. The output file has a default extension of ".mt" and may be specified using the "-o" switch with the last command line parameter. This file lists for each location the calculated maximum traffic disruption costs and associated storm duration.

9.8. MAXMAXT

This utility reads output files generated by the MAXT utility (".mt" files) to generate a list of maximum traffic disruption costs for a range of ARIs as defined in each ".mt" file. The output file has a default "amt" extension. Typically you would use this utility to list the maximum traffic disruption costs for a series of ARIs for all catchment locations.

It is used as follows:

MAXMAXT [file1.mt] [file2.mt] ......[filen.mt] [-ofilename.amt]

where file1.mt, file2.mt etc are ".mt" files generated by the MAXT utility. The output file has a default extension of ".amt" and may be specified using the "-o" switch with the last command line parameter.

MAXMAXT accesses the file name for each ".mt" file to collate the results in the ".amt" file.

9.9. RatARR

This utility was written to assist designers compares their URBS peak flow estimates with those derived using the ARR rational method. The program accesses the catchment characteristics file generated by the URBS file to determine catchment parameters used in the ARR rational method. It also accesses a specified Intensity Frequency Duration (IFD) file to calculate rainfall intensities. The format for this file is a comma/quote delimited ASCII file also suitable for import into spreadsheets. A sample file for Brisbane is given in Table 6.

The command line format for RatARR is as follows:

RatARR <file.cc> <file.ifd> [-n] [-m[l]] [-p] [-tARI] [-vn.n] [-ofilename]

The -p switch tells the program to use Pilgrim's equation to determine the time of concentration (ARR, 1987). The result of this calculation is factored by $(1 + U)^{-2}$ to account for urbanisation. If the channel slope is specified in the catchment characteristics file, then the Ramsay-Kirpich formula is used. It too is scaled by the $(1 + U)^{-2}$ factor to account for the reduction in time of concentration due to urbanisation. A time of entry of U/6 is added to the calculated time of concentration.

The -m switch is used to tell the program to apply Carroll's modification (increase) in travel times for higher ARIs (Carroll 1995). The additional *l* switch ensures that the increased time of concentration cannot exceed its rural equivalent. The -t switch defines the design ARI for the minor system. The default value is 2 years. The higher this value is, the less reduction in urbanisation effects at the higher ARIs is achieved.

The -v switch followed by a numeric instructs the program to use a time of concentration based on channel velocity. Its value is given in m/s. There should be no spaces between the -v switch and the velocity value.

The [-o] switch specifies the basename for the two output files; a peak flow rate file (extension .rq) and a time of concentration file (extension .rtc) for each location specified in the catchment characteristics file for all ARIs specified in the ifd file.

Table 6: Typical IFD file generated for Brisbane CBD

"dur",	"I1",	"I2",	"I5",	"I10",	"I20",	"I50",	"I100"
0.083h,	117,	151,	191,	215,	248,	291,	324
0.1h,	110,	141,	179,	202,	232,	273,	304
0.167h,	89.7,	116,	147,	167,	192,	227,	253
0.333h,	66.0,	85.3,	110,	125,	145,	172,	193
0.5h,	53.8,	69.6,	90.3,	103,	120,	142,	160
1.0h,	35.9,	46.7,	61.1,	69.9,	81.6,	97.4,	110
2.0h,	22.5,	29.4,	38.7,	44.5,	52.2,	62.5,	70.6
3.0h,	16.8,	22.0,	29.1,	33.5,	39.3,	47.2,	53.4
6.0h,	10.1,	13.2,	17.7,	20.4,	24.0,	28.9,	32.8
12.0h,	6.25,	8.19,	11.0,	12.7,	15.0,	18.0,	20.5
24.0h,	4.06,	5.32,	7.10,	8.21,	9.66,	11.6,	13.2
48.0h,	2.68,	3.50,	4.64,	5.34,	6.26,	7.52,	8.50
72.0h,	2.01,	2.62,	3.46,	3.97,	4.65,	5.57,	6.30

9.10. IFD

This utility accesses a ASCII comma/quote delimited text file of rainfall intensities to calculate the rainfall intensity for a chosen ARI (years) and duration (minutes). It is primarily used to check the ifd file used by the RatARR program.

It is used as follows:

IFD [filename.ifd] [ARI] [Duration]

9.11. UNIXTIME

This utility is used to convert date and time into unix time ie seconds since 1 January 1970 12:00 am GMT. The default time zone has been set for Eastern Australian Time ie GMT less 10 hours. This default can be overridden using the operating system time zone environment variable TZ. This utility is mainly used by modellers to check unix datestamps in URBS and AWBM input and output files.

It is used as follows:

UNIXTIME [dd/mm/yyyy] [hh:mm:ss]

The result is seconds since midnight (GMT) 1/1/1970.

9.12. DETAIN

The DETAIN program or module was written to generate storage discharge files for the URBS model. The program uses Boyd's (1985) equations for inlet control. Outlet control is calculated from calculated inlet, barrel and outlet losses. The higher headwater is adopted. This, as already discussed, is not a conservative approach as a lower headwater will result in a lesser storage volume for a given outflow rate. This is most likely to occur when the critical flow at the inlet becomes drowned by the rising downstream tailwater. Once drowned a decrease in headwater occurs. This effect however diminishes with increasing headwater.

The modeller is strongly advised that for detailed design, reference be made to various nomographs eg FHWA charts. Tailwater conditions should also be investigated in detail and if found they can influence the hydraulic behaviour of the outlet, a detailed analyses should be undertaken either by constructing a physical model or preparing a numerical model such as the US Army Corp of Engineers HEC-RAS model.

DETAIN uses information on basin characteristics, weir profile, outlet configuration and downstream tailwater levels (either a fixed tailwater or a rating curve) to create the storage discharge file. The required information is collated in a series of input files. These are a parameter file (extension .prm), a storage height or an basin area height file and a weir profile file (extension .w). The parameter file is the control file.

The command line to use DETAIN is:

DETAIN -p<*filename.prm*> [-g]

filename.prm is the parameter file name. The -g switch requests the output be plotted to the screen. The keywords used is this file is described next;

loc = *location*

The keyword **loc** specifies the location name. This name will be used as the base name for all output files.

sf = *filename*

The keyword **sf** specifies the file name that contains the storage information for the basin. The data contained in this file may be specified either as height - area information or alternatively height - storage information. The format for a storage height file is;

Line 1: Comment line { place asterisk in first column }
Line 2: "S", "H"
Line 3: S_1, h_1
Line 4. S_2, h_2
etc.

The "S" and "H" key characters may be interchanged, however, the following data must be in the same order as the key characters. The unit for storage value is cubic metres (note not ML). Height values are given in metres.
The format for the alternate area-height file is;

Line 1: Comment line { place asterisk in first column }
Line 2: "A", "H"
Line 3: A_1, h_1
Line 4. A_2, h_2
etc.

As for the storage-height file, the "A" and "H" key characters may be interchanged, however, following data must be in the same order as the key characters. The units for basin areas are square metres. Height values are given in metres.

wf = *filename.w*

The keyword **wf** specifies the weir file name. This file contains the xy co-ordinates for the weir - typically a road profile. The format for the file is;

Line 1: Heading
Line 2: n , the number of xy pairs
Line 3: x_1 y_1
Line 4: x_2 y_2
. . .
. . .
Line n: x_n y_n

wo = *nn.nn*

The keyword **wo** specifies a weir offset. This offset is added to each vertical ordinate specified in the weir file. Its value is given in metres. This keyword is often used when designing the crest level for a proposed basin.

L = *ll*

The keyword **L** specifies the length of the weir in the direction of flow. Its value should be given in metres.

C = *cc*

The optional keyword **C** specifies the weir coefficient. The default value is 1.70.

rf = *filename.rat*

The **rf** keyword specifies the downstream rating curve to be used for determining tailwater effects on the upstream storage discharge relationship. This is an alternative approach to specifying a constant tailwater level. The file format for a rating curve file is given in Section 5.3. The default file extension is .rat.

TWL = *nn.nn*

The keyword **TWL** specifies the tailwater level to be used for all outflow flow calculations. The value should be given in metres.

The next set of keywords define the outlet configuration.

Type= *type [,type2, type3, …]*

The **Type** keyword specifies the type of culvert. At this stage only a box or a pipe is permitted, eg Type = box for a box culvert. The type for more sets of culverts can be included on this line.

NC = *n [, n_2, n_3 …]*

The keyword **NC** specifies the number of culverts. You can specify several sets of culverts by specifying the number of culverts associated with each set.

D = *nn.nn [, $nn.n_2$, $nn.n_3$ …]*

The keyword **D** specifies the diameter for a pipe culvert or the height for a box culverts. The value of **D** (nn.nn) should be given in metres. You can also specify the diameters for additional culvert sets. The order must be in the same order as specified on the **NC** line.

W = *nn.nn[, $nn.n_2$, $nn.n_3$ …]*

The keyword **W** specifies the width of a box culvert. The value of **W** (nn.nn) should be given in metres. You can also specify the widths for additional culvert sets. The order must be in the same order as specified on the **NC** line.

IL = *nn.nn[, $nn.n_2$, $nn.n_3$ …]*

The keyword **IL** specifies the invert level at the upstream end of the culvert. Its value should be given in metres. You can also specify the widths for additional culvert sets. The order must be in the same order as specified on the **NC** line.

S = *nn.nn[, $nn.n_2$, $nn.n_3$ …]*

The **S** keyword specifies the slope of the culvert. Its value is given in metre/metre. The slope is used to calculate the downstream invert of the outlet. You can also specify the slope for additional culvert sets. The order must be in the same order as specified on the **NC** line.

CL = nn.nn*[, $nn.n_2$, $nn.n_3$ …]*

The **CL** keyword is used to specify the culvert length in the direction of flow. Its value should be given in metres. You can also specify the lengths for additional culvert sets. The order must be in the same order as specified on the **NC** line.

k = *nn.nn*

The **k** keyword specifies the additional velocity head coefficient to be added to the inlet loss coefficient. The DETAIN model uses a inlet loss coefficient of 0.5. This is typical for most applications (see various culvert handbooks). However where additional inlet losses are suspected due to poor geometry etc, the user should specify an additional loss be included in the calculations, eg, if an inlet loss coefficient is assessed at 0.9, then the value of k should be set at 0.4.

9.13. RAINURBS

The RAINURBS utility generates AR&R based design rainfall files or Monte Carlo generated rainfall files compatible with the input requirements of URBS. The command line to use RAINURBS is:

RAINURBS *-p<filename.prm> [-h]*

Filename.prm is RAINURBS' parameter file. The optional [-h] switch is used to interpret all durations specified in the IFD files in units of hours. The parameter file contains a series of keywords which defines the required data. Details of each keyword follow:

9.13.1.Keywords for AR&R Rainfall Files

Time Increment = *tt*

The time increment specifies the model time interval. It value should be in hours.

label = *name*

This label is prepended to all generated design rainfall files. RAINURBS will only read the first 5 characters, the remaining characters will be discarded. The default value is 'ari' eg. ari100.60m.

Zone = *zz*

The **zone** keyword specifies which zone should be used. These zones are based on those defined in the AR&R, eg Zone 3 is used for SE Queensland. Zone 3 is the default. This value defines the temporal patterns which will be used. The temporal patterns are located in a zone?.pat file.

IFD = *filename.ifd [,AreaNo$_i$-AreaNo$_j$, AreaNo$_k$, AreaNo$_l$, ….]*

The **IFD** keyword specifies the IFD table to be used to generate the design rainfall data. The format for this table is identical to that required by the RatARR and IFD utilities -see Section 9.9.

If you optionally specify sub-catchment area numbers after the IFD filename (separated by commas) then that IFD file will be assigned to those areas. Several IFD lines may therefore be required be assign an IFD table to all sub-catchments. A range of sub-catchments may be specified by place a dash between area numbers eg. 3-23, or alternatively they may be specified separately delimited by commas.

Model = *modelType [*]*

The **model** keyword specifies the type of loss model that is to be used for the run. The value of *modelType* can be either Continuing Loss, Proportional Loss or the Manley-Phillips equation. The optional [*] placed after the *ModelType* value, indicates that the loss parameters are for pervious areas only i.e. a split loss model for impervious and pervious area is to be used - see Section 3.1 for further explanation. The default is the Continuing loss model.

LossType = *Uniform* | *Variable*

This specifies whether a uniform or a variable loss model is to be used – see Section 3.1 for further details.

ARI = ari_1, ari_2, ari_3 ....

The **ARI** keyword specifies the ARI's to be used in the design rainfall generation. ARI values should be separated by a comma or a space. If this line is not specified, the ARIs nominated in the IFD file will be used. Their order however will be sorted to read from least to highest.

DUR = dur_1, dur_2, dur_3 ....

The **DUR** keyword specifies the Durations to be used in the design rainfall generation. Duration values should be separated by a comma or a space. If this line is not specified, the Durations nominated in the IFD file will be used. Their order however will be sorted to read from least to highest. Duration values can be either in min or hours. However to specify hours a 'h' should immediately follow the duration value eg. 3h.

FAF = faf_1, faf_2, faf_3 ……….

This **FAF** keyword specifies the frequency adjustment factor to be used. Typically it is used for climate change studies where rainfall intensities need to be adjusted depending on the chosen planning horizon. Each rainfall value in the design rainfall files is scaled by this value. Each FAF value is assigned to the ARI as specified on the ARI line.

TAF = *taf*, [,$AreaNo_i$-$AreaNo_j$, $AreaNo_k$, $AreaNo_l$, ….]

The TAF keyword specifies the topographical adjustment factor that is to be applied to each model sub-catchment area. The depth of rainfall of each sub-area is scaled using the specified factor. If you do not specify sub-catchment area numbers then the *taf* value is applied to all sub-catchments.

Several TAF lines may be required be assign rainfall adjustment factors to all sub-catchments. A range of sub-catchments may be specified by place a dash between area numbers eg. 3-23, or alternatively they may be specified separately delimited by commas.

BaseScale = *baseScale*

The BaseScale keyword defines the run duration for each storm. The storm duration is factored by the baseScale value to determine the run duration. The default value is 3, i.e. the run duration is three times the storm duration.

RunDuration = *runDuration*

The RunDuration keyword defines the run duration in hours for all storms. If this duration is less than that determined using the baseScale value then the latter is used.

IL = il_1, il_2, il_3, ………..

The **IL** keyword specifies the initial loss for each of the specified or default ARIs. The values are given in mm and should be separated by a comma or a space. If there are insufficient values to match the number of specified ARIs, then the last value or default value will be assumed. The default initial loss is 0 mm.

CL = cl_1, cl_2, cl_2, ...

The **CL** keyword is used when the Continuing Loss model is selected. It specifies the continuing loss for each of the specified or default ARIs. The values are given in mm/hr and should be separated by a comma or a space. If there are insufficient values to match the number of ARIs, then the last value or default value will be assumed. The default continuing loss is 2.5 mm/h.

PR = pr_1, pr_2, pr_2, ...

The **PR** keyword is used when the Proportion Runoff model is selected. It specifies the proportion of runoff for each of the specified or default ARIs. The values are given as a fraction and should be separated by a comma or a space. If there are insufficient values to match the number of ARIs, then the last value or default value will be assumed. The default proportion runoff is 1.0.

P = p_1, p_2, p_2, ...

The **P** keyword is used when the Manley-Philips model is selected. It specifies the capillary suction head for each of the specified or default ARIs. The values are given in mm and should be separated by a comma or a space. If there are insufficient values to match the number of ARIs, then the last value or default value will be assumed. The default Capillary Suction head is 0 mm.

K = k_1, k_2, k_2, ...

The **K** keyword is used when the Manley-Philips model is selected. It specifies the saturation loss rate for each of the specified or default ARIs. The values are given in mm/h and should be separated by a comma or a space. If there are insufficient values to match the number of ARIs, then the last value or default value will be assumed. The default saturation loss rate is 2.5 mm/h.

Area = *a*

The area specified is the area used in calculation of the areal reduction factor.

Location = state

The location keyword specifies which Australian state or territory is to be used for the calculation of area reduction factor

Interpolate = TRUE|FALSE

The interpolate keyword is used to specify whether the temporal patterns between the 100 years ARI and the third pattern (PMP) list for each duration in the temporal pattern file are to be interpolated.

9.13.2. *Additional Keywords for Monte Carlo simulation files*

URBS can undertake two types of Monte Carlo simulation methodologies; the CRC-CH methodology as developed by Rahman et al (2001) and the Total Probability Theorem Approach as developed by Nathan, Weinmann and Kuczera as detailed in the RORB 5 manual (2005). How to use apply methods is described as follows in turn.

CRC-CH Methodology (Rahman et al)

StormDataFile = *filename*

This keyword specifies the storm data files which are to be used for the analysis. Several files can be specified, but they must be entered one line at a time and be the same format – see **Temporal Pattern Intervals** keyword.

Random Temporal Patterns = *TRUE | FALSE*

The random keyword specifies whether random temporal patterns are to be used. If they are, it should be set to TRUE. The multiplicative cascade model is then used. If it is set to FALSE, then temporal patterns are extracted from the temporal pattern files as specified using the **StormDataFile** keyword.

EventType = core| complete| burst

If the EventType is core (default) then adjustments are made to the generated random initial loss as recommended by Rahman et al (2001). Also if using the Multiplicative Cascade model (see later this section), then a check is made to ensure that the generated temporal pattern does not produce a burst with a higher ARI than the storm event ARI. This is to ensure consistency with the definition of a core storm event as proposed by Rahman et al (2001).

Temporal Pattern Intervals = *nn [[[,aa][, bb]][, cc]]*

The keyword specifies the number of data intervals that the temporal pattern is to be divided into. Aa specifies the minimum duration for sampling (default is 4 hours), bb specifies the upper duration limit. Cc specifies the file format for the temporal file data. Cc set to 0 specifies a text file containing 1 line per storm. The format for each line is:

Duration total_depth d1 d2 d3 d4 d5 d6 d7 d8 d9 d10

Duration is the duration in hours, total_depth is the storm depth in mm. D1 through d10 specifies the depth in each the 10 intervals.

This format is used by Dr. Ataur Rahman’s suite of Monte Carlo simulation programs – refer Rahman et al (2001).

Cc set to 1 specifies a text file where each storm is specified as

Hr day month year n depth rate
D1
D2
D3
.
Dn

Where Hr, day, month year specify the start of the event. N is the number of rainfall depth values. Depth is the rainfall depth in mm, and rate is the intensity rate in mm/hr. D1 through to Dn are the rainfall depths per interval.

This format is used by Dr. Ataur Rahman's suite of Monte Carlo simulation programs.

Cc set to 2 specifies a binary file whose format for each storm is:

Duration total_depth n d1 d2 d3 ….. dn

Where duration is the storm duration, total_depth is the storm depth in mm. N is the number of values and d1 d2 … dn are the rainfall depths in mm.

This file is written by the URBS module named MCURBS – see Section 0.

Duration = Dur_{ave}, *[,*$AreaNo_i$-$AreaNo_j$, $AreaNo_k$, $AreaNo_l$, *….]*

The Duration keyword specifies the mean duration. If area reference numbers are included after this value (separated by commas) then the mean duration specified pertains to those areas only, else it is assumed to be applicable for all sub-catchment areas.

Seed = *nnnnnn*

This Seed keyword is used to assign a seed (integer) for the random number generator. If this is not set then a randomized seed will be used and a different set of random events will be generated with each run.

CV = *cv*

The CV keyword specifies the coefficient of variation for all durations. For some areas the exponential distribution is not suitable as the standard deviation of the durations is significantly different from its mean – generally larger. In this case the gamma distribution is applied.

IL = IL_{ave}, IL_{sd}, IL_{min}, IL_{max}, *[,*$AreaNo_i$-$AreaNo_j$, $AreaNo_k$, $AreaNo_l$, *….]*

The **IL** keyword specifies the initial loss parameters. IL_{ave} is the mean Initial Loss, IL_{sd} is the standard deviation, IL_{min} is the minimum initial loss and IL_{max} is the maximum initial loss. These parameters are used to fit a beta distribution.

The optional area reference numbers that follow these parameters specify which sub-catchment areas these parameters apply.

Duration = *duration, [,AreaNo$_i$-AreaNo$_j$, AreaNo$_k$, AreaNo$_l$, ….]*

The duration is the mean duration. The exponential distribution is applied ie assumes that same standard deviation, unless the CV key is specified – see above.

The optional area numbers that follow these parameters specify which sub-catchment areas these parameters apply.

TCE = *duration, fraction*

Use this keyword when you want to use the two-component exponential distribution to describe the duration distribution. The first parameter is the short mean duration (assumed to be the mean convective storm duration) typically between 1 and 2 hours. The second parameter is the fraction of all storms that can be characterized as convective (short duration) storms. Typically f is between 0.25 and 0.5. These parameters are applied for all sub-catchments.
The long duration component (frontal storms) are specified using the **Duration** keyword as described above and can be varied on a sub-catchment basis. Omitting this keyword assumes the exponential distribution or gamma distribution if the **CV** keyword is specified.

Parameters = *gran, min, max*

Gran is for granularity or the minimum duration increment, eg if set to 1 hour then generated storm durations are rounded to the nearest hour value. *Min* specifies the minimum storm duration i.e. if a generated storm duration is less than this it is reset to the minimum. Likewise *max* specifies the maximum duration that be generated.

CL = CL_{ave}, *[,AreaNo$_i$-AreaNo$_j$, AreaNo$_k$, AreaNo$_l$, ….]*

CL_{ave} is the mean continuing loss. The exponential distribution can be optionally applied, otherwise a constant loss is assumed. If the exponential distribution is assumed its value is calculated by assuming an inverse proportional relationship to the randomly selected duration.

The optional area numbers that follow these parameters specify which sub-catchment areas these parameters apply.

PR = *pr*, *[,AreaNo$_i$-AreaNo$_j$, AreaNo$_k$, AreaNo$_l$, ….]*

Pr_{ave} is the proportional runoff coefficient. The optional area numbers that follow these parameters specify which sub-catchment areas these parameters apply.

Multiplicative Cascade Model = MCM_{ave}, MCM_{sd}, MCM_{min}, MCM_{max}

If the Random Temporal patterns keyword is set to TRUE, then parameters for the multiplicative cascade model (MCM) are specified using the Multiplicative Cascade Model keyword. The beta distribution is assumed. The parameters are: MCM_{ave} which is the mean – typically 0.5. MCM_{sd} is the standard deviation – typically 0.15 to 0.25. MCM_{min} and MCM_{max} are the min and max values. The default values are 0 and 1.

N = *nnnnn*

N is the number of randomly generated storms. Typically n is 10,000 assuming the number of events per years is 5 – this amounts to 2000 years of storm events of various durations and intensities.

Lambda = *lambda*

The sampling ARI for the IFD table is assumed to be 1/(lambda R), where R is the random uniform variate [0-1]. The default value for lambda is 1 which is consistent with the approach adopted by Rahman et al (2001). Alternatively you can specify a value of lambda usually greater than 1, however when adopting this approach the sampled IFD table must be derived using an alternate methodology as explained in detail in a paper by the author, Carroll (2008).

A typical Parameter file prepared to generate 10,000 storm events for Monte Carlo Simulation is given in Figure 4. The reader should note that the N keyword is specified first – this indicates that this is a Monte Carlo simulation and all ensuing parameters are treated in this context.

```
* NUMBER OF RUNS
N=10000
time increment=1
* DURATIONS
* mean core duration, allocate subareas
* 040094
duration=10.5,1,18,19,20,23,24
* 040135
duration=13.6,3,8,10,11,12,21,22,26
* 040677
duration=10.9,2,4,5,6,7,9,13,14,15,16,17,25
* coefficient of variation to correct for qld distribution
cv=1.5
* INTENSITIES
* allocate subareas to ifd stations
ifd=040094.ifd, 1,18,19,20,23,24
ifd=040135.ifd, 3,8,10,11,12,21,22,26
ifd=040677.ifd, 2,4,5,6,7,9,13,14,15,16,17,25
* TEMPORAL PATTERNS (Random = TRUE use MC model else use historical data
random=true
* ave,stdev,min wgt,max wgt
multiplicate=0.5,0.15,0,1
* temporal distribution files from mcurbs
stormdatafile=040094.tpb
stormdatafile=040135.tpb
stormdatafile=040677.tpb
* no of intervals, 4-12hrs,12-00hrs (2 bins),binary=2
temporal pattern interval=8,4,12,2
* INITIAL LOSS
* average,stddev, min, max for seq
IL=45,25,0,150
* CONTINUING LOSS
* prescribed cl mm/hr for all events and sub-catchments
cl=1.5
```

Figure 6: Typical Parameter File (CRC-CH) used with RainURBS Utility

Total Probability Theorem (TPT) Methodology (Nathan et al, RORB 5, 2005)

There are three additional keyword required:

TPT = *TRUE|FALSE*

If TPT is set to TRUE then RAINURBS will generate TPT based design rainfall files.

Intervals = *nn*

The number of intervals that the rainfall depth frequency curve is to be divided for a specified duration.

Samples = *nn*

The number of samples to be taken per interval.

For a detailed description of the methodology the reader is referred to the RORB V5 manual (2005) and in the soon to be published revision of the AR&R.

A sample parameter file follows:

```
* Monte Carlo TPT Parameter File
TPT = TRUE
Label = cur
Intervals = 50
Samples = 20
Seed = TPTRun1
Temporal Pattern Intervals = 100,4,12,2
Event Directory = d:\mc_tpt\storms
RANDOM = TRUE
MULTIPLICATIVE CASCADE = 0.5,0.15,0,1
IFD = SC01.ifd,1
IFD = SC02.ifd,2
IFD = SC03.ifd,3
IFD = SC04.ifd,4
IFD = SC05.ifd,5
IFD = SC06.ifd,6
IFD = sc07.ifd,7
IFD = SC08.ifd,8
IFD = sc09.ifd,9
IFD Directory = d:\mc_tpt\..\design\ifd
PMP = 1e6
Durations = 360,540,720
Time Increment = 0.25
Area = 30
Location =Queensland
BaseScale = 4
IL = 30,30,0,100
CL = 1.0
Model = Continuing
Loss Type = Uniform
```

Figure 7: Typical Parameter File (TPT) used with RainURBS Utility

9.14. MCURBS

MCURBS is a utility to analyse rainfall data to ascertain parameters and data that are later used in a CRC-CH Monte Carlo simulation analysis. The utility provides estimates of the mean duration and associated standard deviation, parameters for the Multiplicative Cascade Model, an IFD table, temporal pattern data as well as several useful statistics. The calculations are based on Rahman et al (2001).

The command line to use MCURBS is:

MCURBS -p<*filename.prm*>

Where *filename.prm* is the parameter file that specifies the run. The keywords used in this parameter file are described next. Keywords are entered on a line by line basis and in any order.

C1 = nn.nn

C2 = nn.nn

The C1 and C2 keywords specify the rainfall rates in mm/hr that are used to eliminate low intensity rainfall at the beginning and end of storms. If the average rainfall is less than C1 mm/hr at the beginning or end of a storm event, then these data are removed from the storm data set. Successive values less than C2 mm/hr are also removed from the beginning and end of a storm data series. The default value for C1 is 0.25 mm/hr. The default value for C2 is 1.25 mm/hr.

F1 = *nn.nn*

F2 = *nn.nn*

The F1 and F2 keywords specify whether a storm is included or not in the analysis. The value of F1 is the fraction of the 2 year storm burst intensity which the storm intensity must exceed for it to be included in the analysis. The duration with the maximum ratio of storm intensity to the 2 year storm burst intensity is known as the storm core. The default value for F1 is 0.4.

F2 is based on the complete storm only i.e. the complete storm intensity must exceed this fraction of the 2 year storm burst to be included in the analysis. The default value for F2 is 0.5.

N = *nn*

N specified the number of temporal pattern intervals i.e. each storm is sub-divided into n intervals. The default value is 10. The minimum value is 4.

Methodology = CRCCH| LUMPED

The **methodology** keyword specifies how the IFD Table is to be generated. Specifying CRCCH requires the methodology as set out by Rahman et al (2001) to be deployed. If CRCCH is specified then when using the RainURBS utility to generate random storm events, lambda should be set equal to 1 (default). Specifying the methodology to be lumped pools all events as described by Carroll (2008). Using this approach an event based IFD table is generated, however, pooling events constrains the shape of the IFD curves which may result in poorer accuracy. When using the lumped approach, the value of lambda set when using the RainURBS utility should be such as to replicate the characteristics of the storm duration distribution ie it is best set to at least the original number of storm events per year used in the MCURBS analysis.

Level = *nn*

Level specifies the level required for the Multiplicative Cascade Model. The default value is 3. This number is applied as an exponent to the base 2 and should not exceed the specified number of temporal pattern intervals eg $2^3 < 10$.

Order = *nn*

The **order** keyword specifies the order of the polynomial that will be fitted to the log intensity – log duration data for a specified ARI. The default value is 2. When the LUMPED model is used, setting the order specifies the fit model for all the intensity-duration data. Setting the order to 1 – invokes the simple Sherman model. The program automatically calculates the duration offset. This can be set to zero by using the offset keyword – described on the next page.

I2H1 = *nn.nn*

I2H12 = *nn.nn*

I2H72 = *nn.nn*

These are the 2 years burst intensities for the 1 hour, 12 hour and 72 hour durations as specified in the 1987 edition of the Australian rainfall and Runoff.

Gap = *nn.nn*

This is the minimum gap in hour between independent storm events. The default value is 6 hours.

Missing years = *nn.nn*

The **Missing Years** keyword specifies the number of missing years in the rainfall data set that is being analysed. The default is 0 i.e. no missing years.

Skew = *nn.nn*

The skew keyword is used to set a fixed skew value for the LP3 distribution if chosen instead of the exponential distribution to fit ranked intensity data for a given duration. The default value is –1 i.e. the skew is calculated from the data.

Offset = *nn.nn*

The **offset** keyword is used to specify an offset in the regression analysis of log intensities on log duration i.e. log (Intensity) = a + b log (Duration + offset). This is the Sherman model and is an alternative to using a polynomial to fit the data – see the **order** keyword above. The default value is –1 i.e. do not use an offset.

Storm = *complete* | *core* | *burst*

The **Storm** keyword specifies which type of analysis is required. If it is set to *complete* then the statistical analysis is based on complete storms. If set to *core* then the analysis is based on core storms i.e. those storms with the greatest **F1** ratio – see the **F1** keyword above. If it set to *burst* then the all bursts within the complete storm is considered. The default is *core*.

Fit = *Least Squares* | *Moments*| LMoments

The **Fit** keyword specifies which parameter estimation technique should be used to calculate the parameters of the chosen distribution for the ranked intensity data of a specified duration. The default is *moments*.

LambdaMax = *nn.nn*

The **LambdaMax** keyword specifies the maximum intensity values per year that should be used in the ranked intensity data for a given duration i.e. if the number exceeds this maximum value then the excess values are discounted beginning with lowest intensity value. The default is not to set a maximum.

Pdf = *exponential* | *GEV* | *Pareto* | *lp3*

The **pdf** keyword specifies which distribution should be used to fit the ranked intensity data for a given duration.

Plotting Position = *Weibull* | *Exponential*

The **Plotting Position** keyword is used to assign which formula to use in assigning plotting positions to the ranked data. These positions are used when the least squares methodology is adopted to estimate the distribution's parameters. The default is *Weibull*.

Distribution Parameters = *n*

The **Distribution Parameters** keyword specifies whether a 2 parameter or a 3 parameter distribution is to be used where applicable. The default is 3.

Set Duration = *TRUE* | *FALSE*

The **Set Duration** keyword is used to set whether to assign durations based on a equal number of storms per duration bin or whether to use a prescribed set of durations. The default is TRUE i.e. the events are assigned such that there are an equal number of storms per duration bin.

OverallSlope = *TRUE* | *FALSE*

The **overallSlope** keyword specifies whether to use the overall slope determined from the regression of the log intensities and log of storm duration to assign storms to nominated duration bins. Otherwise the local slope is used. The default is FALSE i.e. the local slope is used.

HydsysFile = *filename*

The **HydsysFile** keyword specifies the file that contains the input data. The file must be of flat file format. The detailed format is:

StationNo StationType yyyymmddhhmmss data dataCode

For example:

2500 10 19930401100000 0.012 80

There must be no spaces contained in any of the data. At least one space must separate each data value.

IFD = *filename*

The **IFD** keyword is used if an IFD file (based on burst intensities) is specified rather than specifying the I2H1, I212H and I272H intensity values. The format for this table is identical to that required by the RatARR and IFD utilities -see Section 9.9. The default is to use the I2H1, I212H and I272H values.

OutputFile = *filename*

The **OutputFile** keyword specifies the base name for all output files. If this is not specified then a base name from the input hydsys file will be used.

A typical parameter file used with the MCURBS utility is shown below (Figure 5).

```
I2H1= 58.3
I2H12= 18.1
I2H72= 7.2
F1=0.40
F2=0.40
hydsys file = 2500test.flt
output file = mytest.out
n = 10
pdf = exp
storm = core
```

Figure 8: Typical MCURBS Parameter File

A typical output file the MCURBS utility is presented below.

Typical output from the MCURBS Utility.

```
Analysis using file city.out
385 events from 84.00 years
Arrival Time Statistics (days to complete storms)
Mean = 79.72, Stdev = 111.77, skew = 5.30
Complete Storm Duration Statistics
Mean = 18.92, Stdev = 19.74, skew = 1.69
Core Storm Duration Statistics
Mean = 10.25, Stdev = 15.62, skew = 2.75
L-Moments: L-CV= 0.65, L-Skewness= 0.553 L-Kurtosis= 0.274
Generalised Pareto Distribution Parameters for Storm Core Durations
Location = -5.37, Scale = 14.33, Shape = -0.082
Overall Intensity-Duration exponent -0.58 (R2=0.845)

Duration Bin Statistics
Duration = 1.00
   Intensity Statistics for 97 core storm events
   Mean = 32.05, Stdev = 11.89, Skew = 2.243
   Exponential Distribution parameters: (Lambda = 1.15)
   Max Likelihood: b0= 22.00 beta= 10.05
   Least Squares : b0= 20.06 beta= 11.99 R2= 0.972
   Bin Regression: intercept = 0.00 slope = -0.50 (R2= 0.000)
Duration = 2.00
   Intensity Statistics for 96 core storm events
   Mean = 23.15, Stdev = 9.08, Skew = 1.981
   Exponential Distribution parameters: (Lambda = 1.14)
   Max Likelihood: b0= 13.82 beta= 9.33
   Least Squares : b0= 13.92 beta= 9.23 R2= 0.987
   Bin Regression: intercept = 3.40 slope = -0.46 (R2= 0.139)
Duration = 6.00
   Intensity Statistics for 96 core storm events
   Mean = 10.84, Stdev = 3.78, Skew = 2.408
   Exponential Distribution parameters: (Lambda = 1.14)
   Max Likelihood: b0= 7.44 beta= 3.40
   Least Squares : b0= 7.03 beta= 3.82 R2= 0.977
   Bin Regression: intercept = 3.50 slope = -0.65 (R2= 0.470)
Duration = 24.00
   Intensity Statistics for 96 core storm events
   Mean = 5.44, Stdev = 2.38, Skew = 2.218
   Exponential Distribution parameters: (Lambda = 1.14)
   Max Likelihood: b0= 3.05 beta= 2.39
   Least Squares : b0= 3.04 beta= 2.40 R2= 0.970
   Bin Regression: intercept = 3.48 slope = -0.58 (R2= 0.415)


ARI Intensity - Duration Analysis
ARI = 0.2        years
   Log(I) 2OP C0= 0.524 C1=-1.837 C2=0.789 (R2=0.836)
ARI = 1.0        years
   Log(I) 2OP C0= 3.095 C1=-0.583 C2=-0.003 (R2=0.999)
ARI = 2.0        years
   Log(I) 2OP C0= 3.434 C1=-0.625 C2=0.016 (R2=0.996)
ARI = 5.0        years
   Log(I) 2OP C0= 3.756 C1=-0.654 C2=0.028 (R2=0.993)
ARI = 10.0       years
   Log(I) 2OP C0= 3.945 C1=-0.667 C2=0.034 (R2=0.991)
ARI = 20.0       years
   Log(I) 2OP C0= 4.104 C1=-0.677 C2=0.038 (R2=0.990)
ARI = 50.0       years
   Log(I) 2OP C0= 4.282 C1=-0.685 C2=0.042 (R2=0.988)
ARI = 100.0      years
   Log(I) 2OP C0= 4.398 C1=-0.690 C2=0.044 (R2=0.987)
ARI = 500.0      years
   Log(I) 2OP C0= 4.625 C1=-0.699 C2=0.048 (R2=0.986)
ARI = 1000.0     years
   Log(I) 2OP C0= 4.709 C1=-0.701 C2=0.049 (R2=0.985)
ARI = 1000000.0  years
   Log(I) 2OP C0= 5.297 C1=-0.714 C2=0.054 (R2=0.982)
```

Typical output from MCURBS Utility - Continued

```
Temporal Pattern Analysis 4-12, 12-OO, 4-OO
4-12 hour statistics for 87 events
Stats       1      2      3      4      5      6      7      8      9     10
Mean    0.102  0.107  0.096  0.091  0.089  0.095  0.105  0.107  0.105  0.104
Stdev   0.056  0.054  0.052  0.045  0.046  0.049  0.051  0.051  0.053  0.061
Skew    1.449  1.085  0.582  0.387  0.146 -0.325  0.048  0.060  1.027  1.627
Min     0.043  0.011  0.001  0.003  0.000  0.000  0.000  0.000  0.015  0.040
Max     0.268  0.291  0.259  0.213  0.209  0.191  0.248  0.248  0.288  0.328
Lag1 = 0.39, Stdev = 0.25, Skew = -1.16
12-OO hour statistics for 97 events
Stats       1      2      3      4      5      6      7      8      9     10
Mean    0.115  0.090  0.081  0.088  0.087  0.094  0.104  0.099  0.122  0.120
Stdev   0.063  0.056  0.050  0.065  0.058  0.065  0.067  0.063  0.081  0.058
Skew    1.329  0.809  0.866  1.024  1.335  0.661  0.557  0.878  0.852  1.152
Min     0.040  0.001  0.000  0.003  0.000  0.000  0.000  0.009  0.004  0.041
Max     0.318  0.245  0.227  0.301  0.350  0.251  0.286  0.280  0.375  0.322
Lag1 = 0.17, Stdev = 0.26, Skew = -0.03
4-OO hour statistics for 184 events
Stats       1      2      3      4      5      6      7      8      9     10
Mean    0.109  0.098  0.088  0.089  0.088  0.094  0.104  0.103  0.114  0.112
Stdev   0.060  0.055  0.052  0.057  0.052  0.058  0.060  0.058  0.070  0.060
Skew    1.387  0.878  0.714  0.884  0.960  0.398  0.419  0.566  1.060  1.327
Min     0.040  0.001  0.000  0.003  0.000  0.000  0.000  0.000  0.004  0.040
Max     0.318  0.291  0.259  0.301  0.350  0.251  0.286  0.280  0.375  0.328
Lag1 = 0.27, Stdev = 0.28, Skew = -0.44


Level 3 Cascade Multiplicative Analysis 4-12, 12-OO, 4-OO
4-12 hour statistics for 87 events
Stats      W1     W2     W3     W4     W5     W6     W7   Mean
Mean    0.504  0.527  0.465  0.485  0.502  0.496  0.489  0.495
Stdev   0.153  0.162  0.170  0.112  0.120  0.161  0.145  0.146
Skew    0.983  0.719  0.005  0.535  0.032  0.613 -0.264  0.375
Min     0.216  0.212  0.000  0.218  0.011  0.000  0.000  0.000
Max     0.996  0.987  1.000  0.962  0.980  1.000  1.000  1.000
Parameters of Beta Distribution: alpha = 5.29, Beta = 5.39
12-OO hour statistics for 97 events
Stats      W1     W2     W3     W4     W5     W6     W7   Mean
Mean    0.494  0.554  0.473  0.563  0.499  0.499  0.501  0.512
Stdev   0.145  0.155  0.196  0.180  0.216  0.216  0.212  0.189
Skew    0.249  0.414  0.061  0.356 -0.052  0.207 -0.153  0.154
Min     0.228  0.181  0.011  0.191  0.000  0.000  0.000  0.000
Max     0.838  0.978  0.917  0.997  0.942  0.998  0.899  1.000
Parameters of Beta Distribution: alpha = 3.09, Beta = 2.94
4-OO hour statistics for 184 events
Stats      W1     W2     W3     W4     W5     W6     W7   Mean
Mean    0.499  0.541  0.469  0.526  0.500  0.498  0.495  0.504
Stdev   0.148  0.159  0.184  0.156  0.177  0.192  0.183  0.171
Skew    0.624  0.546  0.048  0.678 -0.055  0.332 -0.147  0.289
Min     0.216  0.181  0.000  0.191  0.000  0.000  0.000  0.000
Max     0.996  0.987  1.000  0.997  0.980  1.000  1.000  1.000
Parameters of Beta Distribution: alpha = 3.79, Beta = 3.73
End of Analysis
```

9.15. CRCFREQ

The CRCFREQ utility is used to derive a frequency curve for prescribed ARI’s for an assumed rainfall duration for the Monte Carlo TPT analysis. A non-parametric frequency analysis is undertaken.

The command line to use CRCFREQ is:

CRCFREQ –p[parameterfile] –[q|h]

The parameter file is a file that contains the keywords such as the ARI’s that are required to be estimated.

A sample parameter file is as follows:

** Monte Carlo CRCFREQ Parameter File*
N = 1000
Lambda = 4
ARI = 2,5,10,20,50,100,500

N and Lambda are as defined in the RAINURBS parameter file used to generate the CRC-CH Monte Carlo rainfall files.

The –q or –h switch indicates what type of analysis is to be carried out i.e. peak flow or peak height frequency analysis respectively. The CRCFREQ utility accesses the urbsQlog.csv file for peak flow and volume analysis and urbsHlog.csv for peak level analysis. The output file for peak flow analysis is named MC_CRC_Q.csv, for volume analysis (in ML) the file is named MC_CRC_V.csv and MC_CRC_H.dur for peak level analysis.

A sample output file for peak flow rates follows:

"Location",ARI2,ARI5,ARI10,ARI20,ARI50,ARI100
"CAMBERRA",121.8,156.8,201.7,233.0,278.9,341.7
"NICOLLS",135.4,171.5,207.2,253.7,280.6,355.5
"TH_CATOUT",184.0,228.8,273.6,325.6,425.8,533.3

9.16. TPTFREQ

The TPTFREQ utility is used to derive a frequency curve for prescribed ARI’s for an assumed rainfall duration for the Monte Carlo TPT analysis. The frequency analysis methodology is that as outlined in the RORB 5 (2005) manual.

The command line to use TPTFREQ is:

TPTFREQ -p[parameterFileName] –[q|h]

The parameter file is a file that contains the keywords such as the ARI’s that are required to be estimated.

A sample parameter file is as follows:

** Monte Carlo TPTFREQ Parameter File*
ARI = 2,5,10,20,50,100,500
Intervals = 50
Samples = 20

The intervals and samples keyword are as used in the RAINURBS parameter file to generate the TPT Monte Carlo rainfall files.

The –q or –h switch indicates what type of analysis is to be carried out i.e. peak flow or peak height frequency analysis respectively. The TPTFREQ utility accesses the urbsQlog.csv file for peak flow analysis and urbsHlog.csv for peak level analysis. The output file for peak flow analysis is named MC_TPT_Q.dur and MC_TPT_H.dur for peak level analysis. The file suffix ',dur' is the duration in hours e.g. MC_TPT_Q.9H are the frequency results for the 9 hour TPT run.

A sample output file follows:

"Location",ARI2,ARI5,ARI10,ARI20,ARI50,ARI100,ARI500
"CAMBERRA",101.7,141.8,177.4,218.2,265.9,307.7,401.1
"NICOLLS",130.6,179.3,220.3,273.0,332.9,384.9,507.2
"TH_CATOUT",192.3,261.9,321.8,393.8,486.1,563.9,782.1

9.17. TPTSUM

The TPTSUM utilities analyses the TPT frequency analysis for the selected durations and determines the peak flow rate or level for the specified ARI's and locations.

The command line is: **TPTSUM** [file1] [file2] [file3] ……

Where file1,2,3 etc are files generated by the TPTFREQ utility, each file containing results for an assumed duration. These files must of the same type i.e. all Q's or H's.

TPTSUM MC_TPT_H.6H MC_TPT_H.9H MC_TPT_H.12H
TPTSUM MC_TPT_Q.6H MC_TPT_Q.9H MC_TPT_Q.12H

TPTSUM creates two output files viz. summary.amq or summary.amh and summary.amc. These files contain the peak flow rates or levels and associated critical durations for the specified ARI's and locations.

9.18. C2U

The C2U utility converts asynchronous rainfall or river level data to either synchronous or 'regularised' URBS '.r', and '.g' files or HYDSYS files.

The command line to use C2U is:

C2U [filename] [-1] [-2] -d[nn] [-e] [-f] [-g] [-h] -i[n.n] [-l] [-n] –p[filename] -q[n] -r[n.n] [-t]

Filename specifies the input data file name i.e. the data file that contains the asynchronous rainfall data. The format for this file is either in Enviromon text file data format (as adopted by the Bureau of Meteorology) or alternatively as a raw data file format specified by three fields per line i.e. *Date Time dataValue*. Each field must not contain any spaces. At least one space must separate each field data item.

Command line switches (case sensitive):

-1 The –1 switch informs the C2U program not to assume an increment after a reset has occurred. The default is to increment the data. Applied to ALERT rainfall only.

-2 The -2 switch indicates that there are 2 comment lines in the data file – rather than the default 1 comment line. 2 Comment lines is the older format still used by some users.

-b[n] input data file is in Enviromon format. If 'n' is specified after the –b switch (no spaces) then the output data will be produced up to the current time. Note the program determines from the file whether the data is rainfall or river level data.

-dnn The –d switch specifies the maximum value **nn** between successive readings before a reset is initiated. This is applied to rainfall files only that contain ALERT data.

-e The –e switch tells the utility to use the URBS environment variables to specify the starting and end time for the data extraction ie URBS_DATE and URBS_TIME and END_DATE and END_TIME,

-f forces the C2U program to use the directories as specified by the URBS directory variables in particular URBS_RAIN i.e. output files will be written to the directory specified by the URBS_RAIN environment variable.

-g specifies that the data contained in the raw data input file is gauge level data.

-h The –h switch forces the program to also write a HYDSYS flat file as well an URBS '.r' file.

-I[n.n] The –I switch specifies the increment *n.n* in hours for the synchronous or regularised data i.e. it is the data increment.

-l The –l switch informs the program to assume that the file listed on the command file is a list file rather than a data file. If the file is a list file it contains a list of files (one per line) that should be processed. The format for the list file is: inputDataFile, outputDataFile. If the output file contains a '.r' suffix it is assumed that the inputDataFile contains asynchronous rainfall data. Otherwise gauge level data is assumed.

-n The –n switch forces the C2U program to write data to the current date and time.

-q[nn] The –q switch specifies what quality code *nn* is to be placed after the data in the requested HYDSYS file.

-p[filename] The –p switch followed immediately with the name of the project file (.prj) as generated by the URBS' controlCentre interface is used to constrain the generation of regularized data to between the start and finish dates contained in this file. If you do not use the –p switch the utility, you can specify the –e switch as described above to set the start and end dates for the analysis.

-r[n.n] The –r switch specifies the maximum rate *n.n* of rainfall in mm/hr before a reset is initiated.

-t The –t switch specifies that the input data file is in raw text file format. When this format is used, it is assumed that the data is rainfall data, unless the –g switch is set.

9.19. SUBRAIN

The purpose of the utility is to create a virtual pluviograph for each URBS' sub-area based on n nearest pluviograph stations.

The methodology is based on the BoM methodology as developed by Mr. Terry Malone. Preparation of this utility has been greatly assisted by reference to the RAINAL utility prepared by Mr. Warren Shallcross of SunWater Queensland, Australia and is gratefully acknowledged.

Subrain assigns rainfall depth to each URBS sub-area based on a weighted average depth calculated using nearest pluviograph station data. The user selects n nearest recording stations and weights are calculated based on the inverse square of the distance between the pluviograph station and the sub-area centroid. Sub-area centroids and pluviograph station locations are specified in latitude and longitude. This weighted average depth for each sub-area is distributed in time according to a prescribed methodology. These methods will be discussed later.

The utility can optionally modify an existing URBS catchment definition or vector file to include the assignment table for the virtual pluviographs as well as output a rainfall definition file ('.rdf') for use with the catchment definition or vector file. In essence all the files necessary to undertake an URBS run can be created using this utility. The utility also creates Google Earth kml files to facilitate visualization of the calculated sub areas rainfall depths and rainfall station depths.

Using SUBRAIN

The Command line to run SUBRAIN is as follows:

SUBRAIN filename.net filename.sub [-switches].

The Network File (.net)

Filename.net contains a list of pluviograph stations including their locations specified in longitude and latitude. Filename.sub contains a list of URBS' sub-areas and their centroids specified in longitude and latitude.

The format for the 'net' or network file is as follows:

Line 1: Header/ Title
Line 2: n stations :
Line 3: StationNo StationText StationLongitude StationLatitude StationType Depth
Line 4 StationNo StationText StationLongitude StationLatitude StationType Depth
.
.
Line n: End of Rainfall Stations.

The header or title line should describe the region where the following pluviograph stations are located. The next line should contain the number of stations terminated by a colon. The following lines contain the station data as follows. The Station No is the number assigned to the station by the monitoring agency e.g. The Australian Bureau of Meteorology. The station text describes the location of the station. Please avoid inserting numbers into this text as it will trigger reading the next field which is the station longitude. The station longitude and latitude are the next two fields and are specified in degrees minutes and seconds. The numbers should read as a single number and should not be separated by spaces or colons. For longitude 3 digits are required for degrees, 2 for minutes and 2 for seconds. For latitude 2 digits are expected for degrees, 2 for minutes and 2 for seconds. The last line of the file should be 'End of rainfall stations.'. Note the full stop

The StationType field specifies whether the station is a pluviograph (p) or daily read (d). If it is a daily read station then its depth is included in the weighted averaged depth calculation for associated sub-areas – however it is not used in the temporal distribution of that depth for the associated sub-areas.

The Depth field is usually specified as –99 i.e. no value. This value will be replaced by the depth recorded for the period specified in the results file. A later feature will be to allow the user to specify this depth so as to override the recorded depth.

If you do not wish a station to be included in the analysis simply put a " in the first column of the station data line. Although this station has been commented out in terms of the analysis it is still included in the number of stations specified in the second line of the station network file.

An example file is as follows:

Rainfall Stations for Altona region
6 stations:
586006 Mitcham RG 1451125 -374918 p -99
586023 Notting Hill RG 1450741 -375407 p -99
586176 Surrey Hills RG 1450627 -374935 p -99
"587047 Altona RG 1444724 -375214 p -99
231105 Rockbank RG 1443928 -374160 p -99
587004 Sunshine North RG (at CWW office) 1444915 -374603 p -99
End of rainfall stations.

The Sub-Area File (.net)

The format for '.sub' or subarea file is as follows:

Line 1: Header or Title
Line 2: n subarea :
Line 3: subareaNo Longitude Latitude
Line 4: subAreaNo Longitude Latitude
.
.
Line n: End of sub-areas.

Line 1 should describe the specific URBS model for which the following data are relevant. Line 2 specifies the number of sub-areas. Note the terminating colon. The following lines specify the location data for each sub-area as follows: The subAreaNo is the number of the subarea as specified in the URBS catchment definition or vector file. The longitude and latitude fields are specified in the '.net' file. The last line of the file is 'End of sub-areas.'. Again note the terminating full stop.

An Example of this file is as follows:

My catchment.
10 Sub-areas:

1	*1454138*	*-374501*
2	*1454420*	*-374553*
3	*1454416*	*-374359*
4	*1454329*	*-374202*
5	*1454626*	*-374331*
6	*1455107*	*-374608*
7	*1454937*	*-374259*
8	*1455342*	*-374516*
9	*1455031*	*-374111*
10	*1454727*	*-374140*

End of Sub-areas.

Switches

Switches are used to specify the utility's options. They are as follows:

-b for the BoM format
-c<n.n> continuing loss
-d<directory for all data input and output files>
-e use URBS start time and endtime variables environment
-i<n.n> data interval in hours
-l<label> label for output rainfall files
-n<nn> -> use the nn nearest stations
-m<nn> -> 1 for column method and 2 for row method (default)
-o<output file name>
-p<project file name>
-r<rainfall Directory with input raw data>
-s<n.n> run Scale
-t<n.n> iniTial loss
-u<Urbs catchment definition file name>
-w<rainfall directory for output rainfall data>

Each switch is described in detail.

-b Switch

Adoption of the Australian Bureau of Meteorology format is set using the –b switch. Its specifies how the 'net' or network file is formatted. The description of the network file above assumes use of this switch and is recommended. The alternative format is to place the station text as the last field of each station description line i.e.

Line i: StationNo StationLongitude StationLatitude StationType Depth StationText.

This gives the added flexibility of including digits in the text description – however its use is not recommended.

-c<n.n> Switch

The SUBRIN utility creates the rainfall definition file (.rdf) that specifies the files that contain the virtual pluviograph data for each sub-area, as well as information on the initial loss and continuing loss that should be used for the URBS's run. This switch is used to set the continuing loss rate. If you do not specify a number after this switch then a default 2.5 mm/hr will be used. If you wish to change this simply specify the desired continuing loss rate immediately after the switch (no spaces) e.g. –c1.0.

-d<directory for all input and output files> Switch

Using this switch specifies the directory location that contains all input (pluviograph station data) and where output files e.g. the virtual subarea pluviographs should be placed. The default is the current directory unless the –e or the –p switch has been activated. This –e switch is discussed next.

-e Switch

The –e switch tells the utility to use the URBS environment variables to specify (a) the starting and end time for the data extraction i.e. URBS_DATE and URBS_TIME and END_DATE and END_TIME, and (b) the directory for the source and output data as set using the URBS_RAIN environment variable. The directory information specified by the –e switch can be overwritten by using the –d, -r and –w switches. The –r specifies the input data directory and the –w specifies the output data directory. These switches are described later. Should the URBS' start date and time environment variable not be specified then the SUBRAIN utility will use the earliest start time and latest end time identified in the pluviograph data files.

-i<n.n> Switch

The –i switch specifies the data interval that the data contained in the virtual sub-area pluviograph should be tabled. The default is one hour. If you wish to change this interval simply specify the interval immediately after the –i switch (no spaces) e.g. –i3.0.

-l<label> Switch

The –l switch specifies the label that will be used to name the virtual sub-area pluviograph files. Each file is labelled as *labelnnn.r*, where label is the specified label and nnn is the sub-area number. For example *yar005.r*, yar is the label and 005 is the sub-area number. Note the sub-area number is restricted to three characters and padded with left hand zeroes as required. The default is label is "sa" if a project file is not specified. The project file is specified using the '-p' switch and is discussed later.

-n<nn> Switch.

This switch specifies how many nearest pluviograph stations should be used for the calculation of the sub-area virtual pluviograph. The default is to use 4 stations.

-m<n> Switch

The –m switch specifies the methodology that should be used in the calculation of the sub-area virtual pluviograph. Two methodologies are available. Methodology 1 or **column** method specifies that the rainfall for each time period should be allocated as per the temporal pattern of the nearest pluviograph station. Methodology 2 or **row** method specifies that the rainfall for each time interval should be weighted according to the weights determined for each of the n nearest pluviograph station. The default is the column method i.e. –m1. To change to the row method simply specify –m2.

-o<filename> Switch

The –o switch specifies the name of the results file. The results file contains the run analysis. It has a '.res' suffix.

-p<project file name> Switch

The –p switch specifies the URBS ControlCentre project file. This file has a '.prj' suffix and contains all the relevant information for executing your URBS model through the ControlCentre. This file is accessed by the SUBRAIN utility for information regarding input and output directory locations and secondly for start and end dates and times for the abstraction analysis. This information can however be overwritten by use of the –e switch as described above.

-r<rainfall Directory with input raw data> Switch

The –r switch specifies the directory that contains the pluviograph station data. The directory specified using this switch overrides the directory specifies using the –e switch i.e. using the URBS' environment variable URBS_RAIN.

-s<n.n> Switch.

The –s switch specifies the run duration as set in the rainfall definition file. Its default value is 3 times the rainfall duration. To change this value simply specify the multiplier immediately after the –s switch (no spaces) e.g. –s4.0.

-t<n.n> Switch

The SUBRIN utility creates a rainfall definition file (.rdf) that specifies those files that contain the virtual pluviograph data for each sub-area, as well as information on the initial loss and continuing loss that should be used for the URBS's run. This switch specifies the initial loss to be used. If you do not specify a number after this switch then a default initial loss 0 mm/hr will be used. If you wish to change this simply specify the desired initial loss immediately after the switch (no spaces) e.g. –t30.0.

-u<URBS filename> Switch

The –u switch specifies the URBS catchment definition or vector file that should be used as the basis of creating an updated file that contains the assignment table of virtual pluviograph for each sub-area. The SUBRAIN utility removes the previous assignment table (starts with "nn PLUVIOGRAPH stations:" and ends with "End of PLUVIOGRAPH assignment data.") from the specified URBS vector file and replaces it the newly generated assignment tables. Please note the updated file will have '.u' suffix.

Therefore the specified base file should have a different suffix such as '.cdf' so as to avoid it being overwritten. If you do not specify this option the utility creates a '.paf' or pluviograph assignment file that you can use later to update your URBS' vector file.

-w<output rainfall directory> Switch

The –w switch specifies the directory that will be used to contain the virtual sub-area pluviograph. The directory specified using this switch overrides the directory specifies using the –e switch i.e. using the URBS' environment variable URBS_RAIN.

Output Results File

A typical output results file (.res) created by the SUBRAIN utility (with permission of Melbourne Water) is as follows:

```
MWC Rainfall Stations
130 RAINFALL STATIONS:
 229249      Brushy Creek at Moor    1451823    -374655    p     62.5
"230101      Emu Creek at Clarkef    1444553    -372951    p    -99.0
"230103      Jacksons Creek at Ro    1443408    -372825    p    -99.0
"230104      Jacksons Creek at Su    1444431    -373457    p    -99.0
 229627      Merri Creek at Craig    1445755    -373425    p     27.7
"229402      Merlynston Ck at Faw    1445708    -374258    p    -99.0
 229645      Merri Creek at Bell     1445846    -374433    p     39.0
 229603      Merri Creek at Coope    1445822    -373845    p     26.2
 228603      Clayton South Drain     1450648    -375605    p     60.2
"228379      Mordialloc Creek at     1451037    -380156    p    -99.0
 229672      Olinda Creek at Lily    1452110    -374537    p     57.2
 .
 .
 .
 229620      Arthurs Creek RG        1451222    -373454    p     31.9
 586146      Wallan RG               1445857    -372514    p     29.1
 586185      Oakleigh South RG (a    1450455    -375521    p     61.0
END OF RAINFALL STATIONS.

Low Yarra
26 SUBAREAS:
  1   1445522   -374912    33.1   230106
  9   1451257   -374717    54.1   229200B
 10   1450809   -374259    40.9   229614
 11   1450950   -374527    49.5   229200B
 12   1451120   -374336    44.4   229200B
 .
 .
 27   1450455   -374606    44.4   229614
 28   1450404   -374406    39.1   229614
 29   1450657   -374515    43.9   229614
 30   1450223   -374752    44.0   229143
 31   1450003   -374752    40.6   229143
 32   1450021   -374930    36.5   229621
 33   1445913   -374953    36.5   229621
END OF SUBAREAS.
```

Note the right hand column in the sub-area file lists the closest pluviograph station for that sub-area.

You should examine this file together with the KML outputs to ensure the analysis has been undertaken correctly and that erroneous data has been removed. Examples of KML plots are provided on the next page.

SubRain KML Plots

SubRain creates two sets of KML files; a station depth file and a sub-area depth file. The sub-area file also contains weights to the nearest ‘n’ stations as specified on the Sub-Rain command line. These files can be plotted using Google Earth. Examples of both files are shown below:

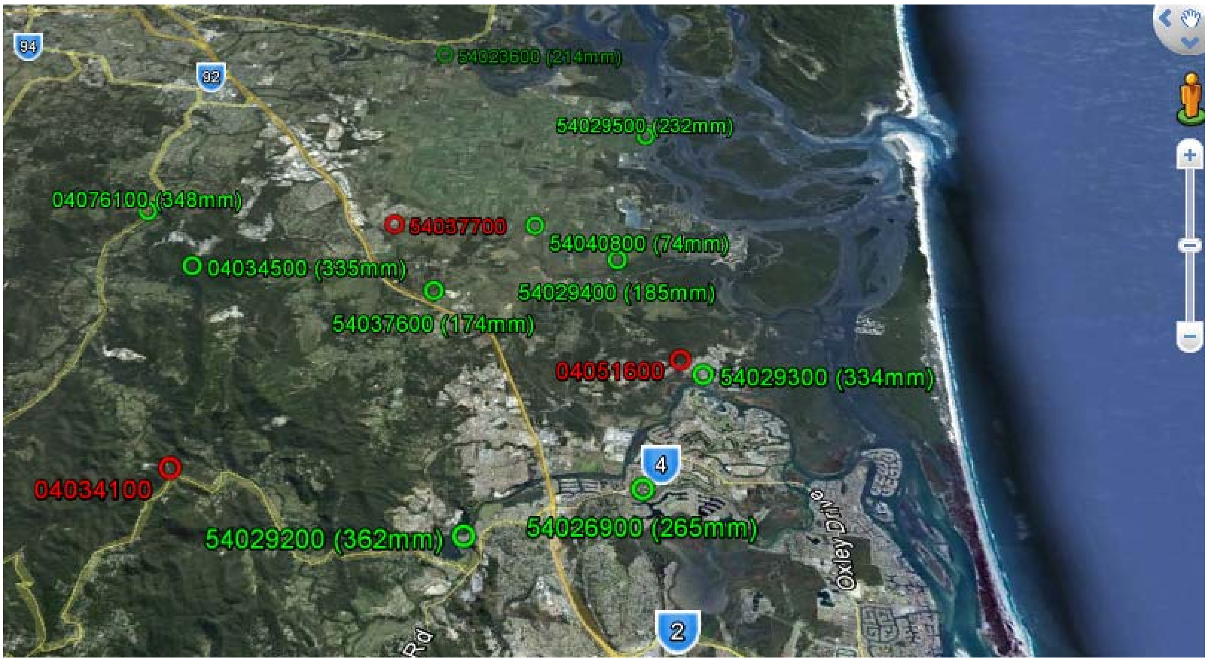

Figure 9: SubRain KML file showing rainfall depths for a Gold Coast Catchment (Note stations colored as red indicates that no data from these stations was provided for the analysis)

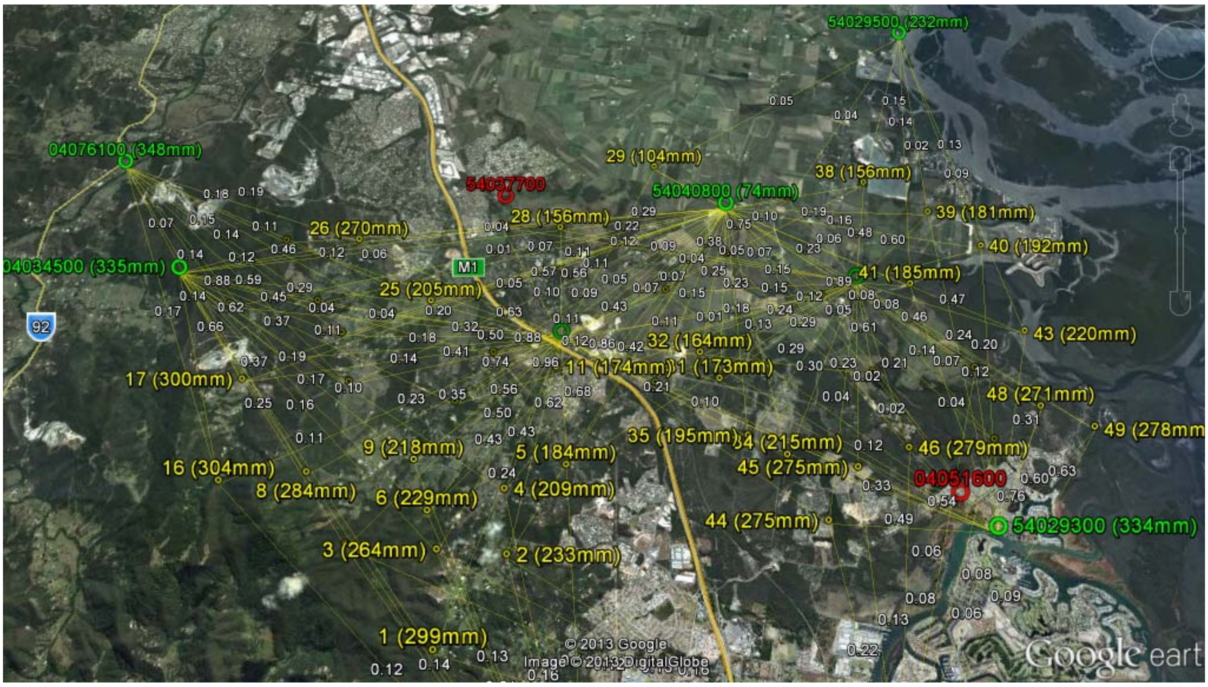

Figure 10: Sub Area rainfalls also showing nearest stations and assigned weights

10. RUNNING URBS IN BATCH MODE

Probably the most useful feature of the URBS model is its batch mode processing facilities. This allows third parties to incorporate the model into their systems. The user can also use the ControlCentre as provided with the software to generate these batch files automatically, however it is important to understand the contents of the batch files so as to be able to bypass the ControlCentre if required or alternatively incorporate the model into third party systems.

10.1. Design Event Approach

Current hydrologic modelling practice requires the model to be run for design storms of various durations for a given ARI. The duration which gives the peak flow rate is adopted. This storm duration is called the critical duration. For 7 ARIs and 15 durations, this amounts to 105 model runs. Sifting through the results files is then required to prepare a table of peak flow rates and associated critical durations for each location.

The URBS model provides the user with sufficient tools for this process to be automated. This automation does not diminish the responsibility of the modeller to systematically check through the results for any anomalies or instabilities which may occur. The results produced by this process are in ASCII comma/quote delimited formatted suitable for import into a spreadsheet for final formatting and plotting.

The most common utilities used by URBS to do this are MAXQ, MAXMAXQ and MAXMAXC. These are described in Section 9 of this manual.

The following is an excerpt from a batch file used to run these utilities.

```
SET URBS=RORB
rem 1 year runs
rem  .....
Rem these are the 100 year runs
urbs32 myCatch.u ari100.10m m10010
urbs32 myCatch.u ari100.15m m10015
urbs32 myCatch.u ari100.20m m10020
urbs32 myCatch.u ari100.25m m10025
urbs32 myCatch.u ari100.30m m10030
urbs32 myCatch.u ari100.45m m10045
urbs32 myCatch.u ari100.60m m10060
urbs32 myCatch.u ari100.90m m10090
urbs32 myCatch.u ari100.2h  m1002h
urbs32 myCatch.u ari100.3h  m1003h
urbs32 myCatch.u ari100.6h  m1006h
urbs32 myCatch.u ari100.12h m10012h
urbs32 myCatch.u ari100.24h m10024h
urbs32 myCatch.u ari100.48h m10048h
urbs32 myCatch.u ari100.72h m10072h
maxq   m10010 m10015 m10020 m10025 m10030 m10045 m10060 m10090 m1002h
       m1003h m1006h m10012h m10024h m10048h m10072h -om100.mq
maxmaxq m1 m2 m5 m10 m20 m50 m100 -omyCatch.amq
maxmaxc m1 m2 m5 m10 m20 m50 m100 -omyCatch.amc
```

These batch commands are repeated for the 1, 2, 5, 10 and 50 years events.

An important feature of the batch process is the naming convention. The design rainfall files are immediately recognisable from their names eg. ari100.60m is the 100 year storm event of 60 minutes duration. The base name for each run is also named in a similar manner; eg m10090 represents the output from the 100 year storm of 90 minutes duration. While this naming convention is not mandatory, the author has found that it will help the modeller in managing the data output.

Naming the MAXQ output file (.mq extension) is critical to the successful collation of the results by the MAXMAXQ and MAXMAXC utilities. These last two utilities read the numeric part of the output file name and assign the run ARI to this number. In the above example the file name adopted is m**100**.mq. The MAXMAXQ and MAXMAXC utilities on reading this file name will conclude that the results contained in this file are the results for the 100 year design runs. If these utilities fail to recognise a number in the filename, then a -1 value is assigned to the ARI and this will be output in the summary table.

Sample MAXMAXQ and MAXMAXC output files are given in Tables 7 and 8 respectively.

Table 7: Sample MAXMAXQ output file

```
"StructureID", "Q1", "Q2", "Q5", "Q10",  "Q20", Q50", "Q100
"L_154   ",      5.1,     8.6,     12.8,    15.1,    17.9,    21.5,    24.7
"L_254   ",    2.9,    4.6,    6.7,    8.2,    9.6,    11.5,    13.1
"L_153   ",    7.1,   11.0,   15.7,   17.8,   20.6,     24.2,     27.3
"L_159_I ",     16.4,     24.8,     33.7,     39.1,     44.9,     51.4,     57.7
"L_159_O ",     11.8,     17.8,     25.2,     29.5,     36.4,     45.4,     54.8
"L_156   ",     4.5,      6.9,      9.8,     11.3,     13.2,     15.0,     16.3
"L_157   ",     17.0,     24.5,     32.5,     37.6,     43.3,     52.8,     58.8
"L_160   ",     17.5,     24.5,     32.6,     37.9,     43.9,     52.8,     60.3
"L_250   ",     1.9,      3.0,      4.7,      5.9,      7.1,      8.7,     10.0
"L_162   ",     4.2,      7.0,     11.0,     13.5,     15.7,     17.9,     20.5
"L_158   ",     6.0,     10.1,     14.8,     17.0,     19.7,     22.9,     25.5
"OUTLET_I",     22.5,     29.9,     39.8,     47.9,     55.8,     66.9,     76.9
"OUTLET_O",     17.0,     23.7,     31.9,     37.7,     49.8,     60.1,     70.6
```

Table 8: Sample MAXMAXC output file

```
"StructureID", "Q1",     "Q2",     "Q5",     "Q10",    "Q20",    "Q50",    "Q100
"L_154   ",    "1H",     "1H",    "25M",    "20M",    "20M",    "20M",    "20M"
"L_254   ",    "1H",    "25M",    "25M",    "20M",    "20M",    "20M",    "20M"
"L_153   ",    "1H",     "1H",    "25M",    "25M",    "25M",    "20M",    "20M"
"L_159_I ",    "1H",     "1H",    "25M",    "25M",    "25M",    "25M",    "25M"
"L_159_O ",    "1H",     "1H",     "1H",     "1H",     "1H",    "45M",    "25M"
"L_156   ",    "1H",    "25M",    "25M",    "25M",    "25M",    "20M",    "20M"
"L_157   ",    "1H",     "1H",     "1H",     "1H",     "1H",    "45M",     "1H"
"L_160   ",    "1H",     "1H",     "1H",     "1H",     "1H",    "45M",     "1H"
"L_250   ",    "2H",     "1H",    "20M",    "20M",    "20M",    "20M",    "20M"
"L_162   ",    "2H",     "1H",    "25M",    "25M",    "25M",    "20M",    "20M"
"L_158   ",    "2H",     "1H",     "1H",    "25M",    "25M",    "25M",    "25M"
"OUTLET_I",    "1H",     "1H",     "1H",     "1H",     "1H",     "1H",     "1H"
"OUTLET_O",    "1H",     "2H",     "2H",     "2H",     "1H",     "1H",     "1H"
```

10.2. Joint Probability/Monte Carlo Approach

10.2.1.TPT Methodology

Though more complex than the Design Event Approach, it is simpler process to batch a Monte Carlo TPT run. A typical batch file for 3 duration runs (3, 6 and 9 hour) is as follows:

```
rem Run Urbs runs using generated rainfall files
PATH="c:\program files\urbs 2002"
set TZ=EST-10
d:
cd d:\urbs\myCatch\mc_tpt\run
del d:\urbs\myCatch\urbserr.log
del d:\urbs\myCatch\urbsout.log
del d:\urbs\myCatch\counter
Set URBS=URBS
set URBS_RATS=d:\urbs\myCatch\mc_tpt\..\rating
set URBS_LOGF=TRUE
set URBS_LOGD=d:\urbs\myCatch
Rem 3 hour run
del urbsQlog.csv
del urbsHlog.csv
del d:\currum\counter
for /L %%I in (1,1,1000) do (
   urbs32.exe curru_01.u d:\urbs\myCatch\mc_tpt\storms\TPT%%Icur.3H cur 0.14 0.65 1.8
   echo U>>d:\currum\counter
   Rem Insert another post-process here as required
)
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini -q
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini –h
Rem 6 Hour
del urbsQlog.csv
del urbsHlog.csv
del d:\currum\counter
for /L %%I in (1,1,1000) do (
   urbs32.exe curru_01.u d:\urbs\myCatch\mc_tpt\storms\TPT%%Icur.6H cur 0.14 0.65 1.8
   echo U>>d:\currum\counter
   Rem Insert another post-process here as required
)
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini -q
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini –h
Rem 9 hour
del urbsQlog.csv
del urbsHlog.csv
del d:\currum\counter
for /L %%I in (1,1,1000) do (
   urbs32.exe curru_01.u d:\urbs\myCatch\mc_tpt\storms\TPT%%Icur.9H cur 0.14 0.65 1.8
   echo U>>d:\currum\counter
   Rem Insert another post-process here as required
)
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini –q
TPTFREQ -pd:\currum\mc_tpt\run\TPTFreq.ini -h
TPTSUM MC_TPT_H.3H MC_TPT_H.6H MC_TPT_H.9H
TPTSUM MC_TPT_Q.3H MC_TPT_Q.6H MC_TPT_Q.9H
```

The TPTFREQ and TPTSUM utilities are discussed in Section 9 of this manual.

10.2.2.CRC-CH Methodology

The following is a batch file used to undertake the CRC-CH Monte Carlo analysis.

```
PATH="c:\program files\urbs 2002"
set TZ=EST-10
d:
cd d:urbs\myCatch\mc_crcch\run
del d:\urbs\myCatch\urbserr.log
del d:\urbs\myCatch\urbsout.log
del d:\urbs\myCatch\counter
del urbsQlog.csv
del urbsHlog.csv
del urbsVBF.log
Set URBS=URBS
set URBS_RATS=d:\urbs\myCatch\mc_crcch\..\rating
set URBS_LOGF=TRUE
set URBS_LOGD=d:\myCatch\myCatch
for /L %%I in (1,1,8000) do (
   urbs32.exe curru_01.u d:\urbs\myCatch\mc_crcch\storms\%%ICur.uef Cur 0.14 0.65 1.8
   echo U>>d:\urbs\myCatch\counter
  Rem Insert another post-process here as required
)
crcFreq -pd:\urbs\myCatch\mc_crcch\run\crcfreq.ini -q
crcFreq -pd:\urbs\myCatch\mc_crcch\run\crcfreq.ini –h
```

10.3. Using the ControlCentre

The ControlCentre is a Windows based URBS interface that generates and executes batch files as described in the previous sections. It does not however provide the User will full access to URBS model features, nevertheless it meets the requirements of the majority of users. It must be remembered that the ControlCentre in itself does not undertake any analysis – this is done using the utilities as discussed in Section 9. Use of the ControlCentre is self explanatory and all fields are help context sensitive. However the following pointers are provided to prospective users prior to using the ControlCentre.

Organize your directory structure first – the ControlCentre will require a root directory for the project – all other directories will be subdirectories to the root directory. The ControlCentre will create these directories as you have specified in the requested fields under the ‘Common Settings’ tab. If you are using rating curves with your model – use the same rating curve directory for the DEA and JPA/Monte Carlo analyses so as to avoid duplication of files. You will then need to populate these directories with the requisite files using Windows Explorer. For example place the catchment definition and data files in the run directories and the IFD files in the specified ifd directories. Note if applying both the DEA and the TPT approach, place the IFD files in the DEA IFD directory and ensure that that the TPT IFD directory points to this directory. The CRC-CH method will require its own event based IFD files. The temporal pattern design zone file will also have to be placed in the Design ARR directory.

In terms of running the model wait until the analysis is finished before interrogating output files. When generating rainfall files, be they DEA or Monte Carlo files, always check that the files have actually been generated – use the file datestamp to do this. Always save your changes prior to running the model. When the model has finished its run, check the log files (both error and run) for any error or warnings. You can then plot the results by selecting the ‘plot’ CSV file option. Do not run multiple instances of the same project – run one at a time.

Monte Carlo analysis should only take about 20 to 40 minutes for a medium to large sized catchment. The DEA approach is generally finished in less than 1 to 5 minutes minute. Calibration runs are close to instantaneous for small catchments and up to 5 minutes for large catchments with several sub-models.

An overview of the ControlCentre follows together with examples of its use in various modes. The ControlCentre has 4 modes; Design, Calibration, Monte Carlo-TPT and Monte Carlo CRC-CH.

The ControlCentre will be listed as a module in your URBS 2002 program list. Alternatively you can invoke the ControlCentre by clicking on the ControlCentre executable or invoking it on a command line.

Using the File option, the user can select an existing project or create a new one. If a new project is being created then the directories as specified in the common setting page will be created. There are 5 primary directories under the project root director; these are by default "cal" for the calibration directory (this directory will contain sub-directories for each calibration event, "design" for the design directory – this directory will likely have subdirectories containing run files, ifd files and design rainfall files, "fcst: for forecast runs; "mc_crcch" for the CRCCH Monte Carlo runs and "mc_tpt" for the Monte Carlo Total Probability runs. The information specified in the common settings tab and indeed all other tabs are stored in text file in the project directory with a suffix of ".prj". Other fields include specification of the threshold file (".mmm") and the time zone for plotting of the data. You should always "save" your changes upon changing any of the field.

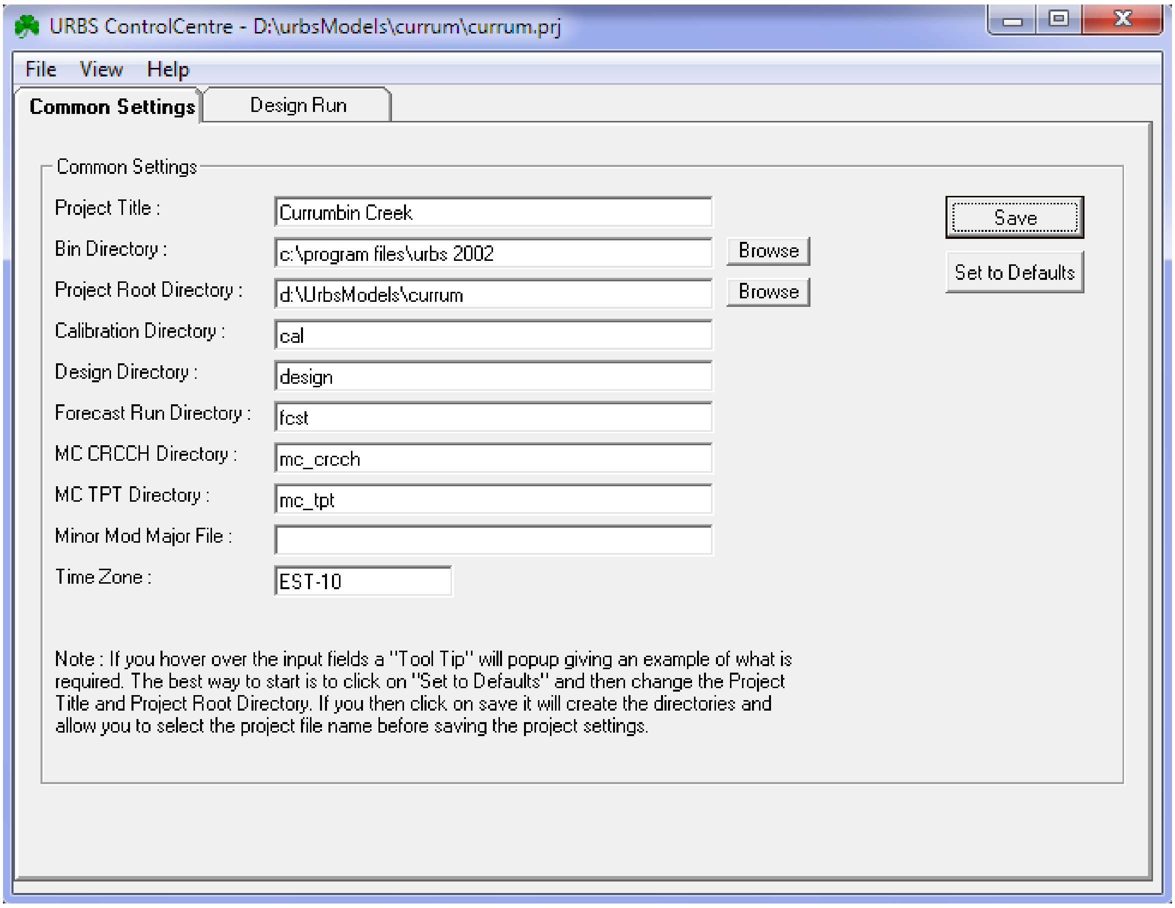

Figure 11: ControlCentre Common Settings Interface

Figure 12 shows the ControlCentre inputs for a design run. It should be noted that the temporal pattern file should be placed in the ARR directory. IFD tables for the catchment should be placed in the IFD directory and the catchment definition and data files placed in the run directory. Rating tables should be available in the rating directory (..\rating) which in this case is located one level up from the design directory i.e. at the project directory level. In so doing this facilitates access to these tables by all model modes.

The process for running the Design analysis is to Save the data entered, then generate the design storms (these will be placed in the arr directory) and run the model. The model will be run in this case 35 times i.e. 7 ARI's by 5 durations. The results of these runs will be collated by the MAX routines as described in Section 9 of this manual. The results can be interrogated by accessing the results files from the Output Files button on the bottom right of the form.

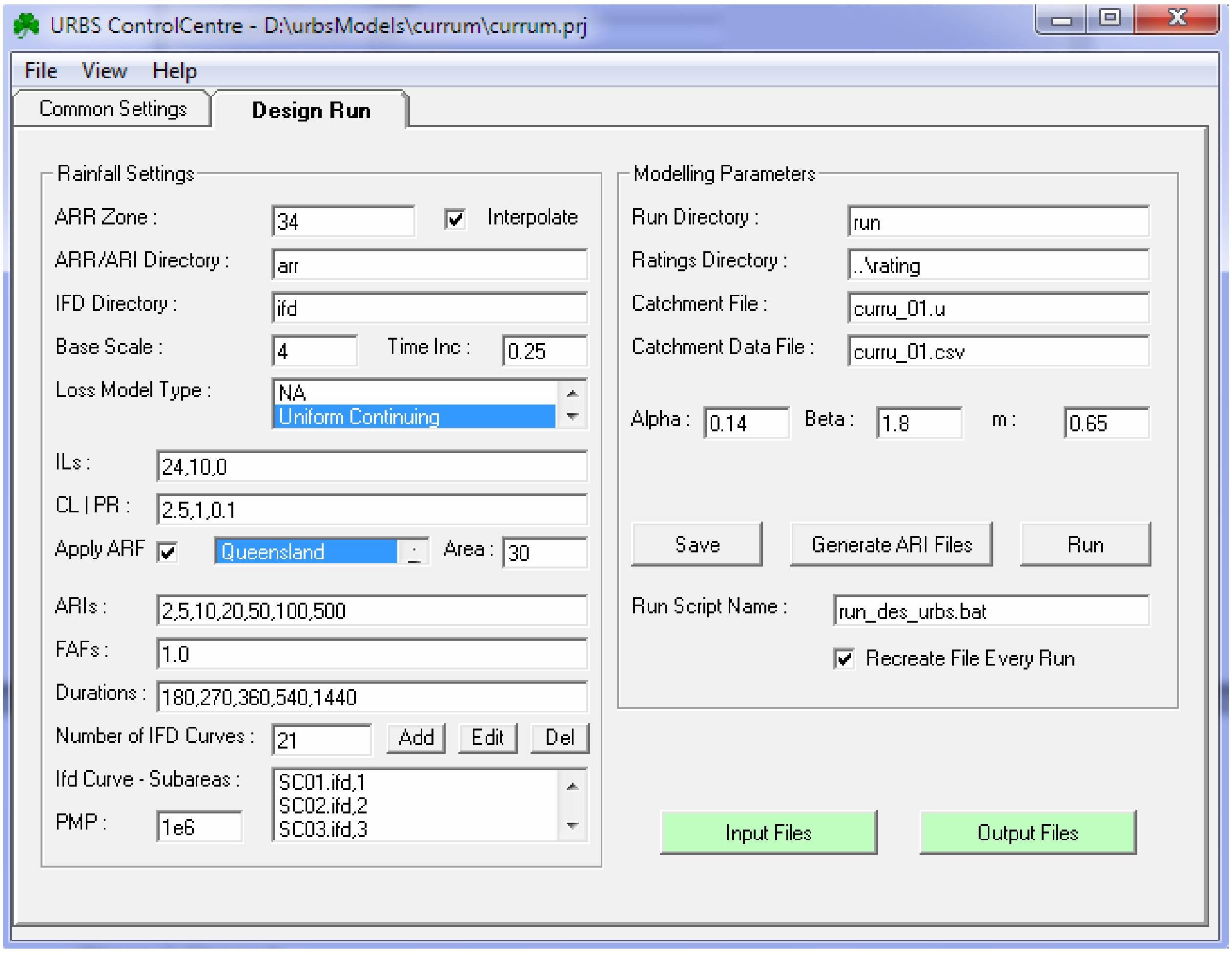

Figure 12: ControlCentre Design Interface

Figure 13 shows the ControlCentre Monte Carlo TPT design run form. As with the previous design run interface, the catchment definition and data files should be located in the run directory. The IFD tables directory should be same as used for the previous design run (i.e. as in ..\design\ifd). Temporal pattern file(s) should be located in the temporal pattern directory (in this case tp) and the spatial pattern file should be located in the spatial pattern directory (in this case spatial). The spatial pattern file is created using the UBSRAIN utility which collates spatial distributions from sub-area rainfall depth estimates for calibration events.

For this run, for each duration the rainfall depth frequency curve is segmented into 50 intervals, each of which is sampled 20 times i.e. a 1000 runs per duration. As there are 4 durations, 4,000 runs will be undertaken and the results collated by the TPT utilities as described in Section 9 of this manual.

The overall process is to generate the TPT rainfall files first using the “Generate Storm Files” button. Check that the files have been created. Run the model using the Run button. Wait until all 4000 runs are completed and view the results by clicking the Output Files button on the bottom right of the TPT interface form.

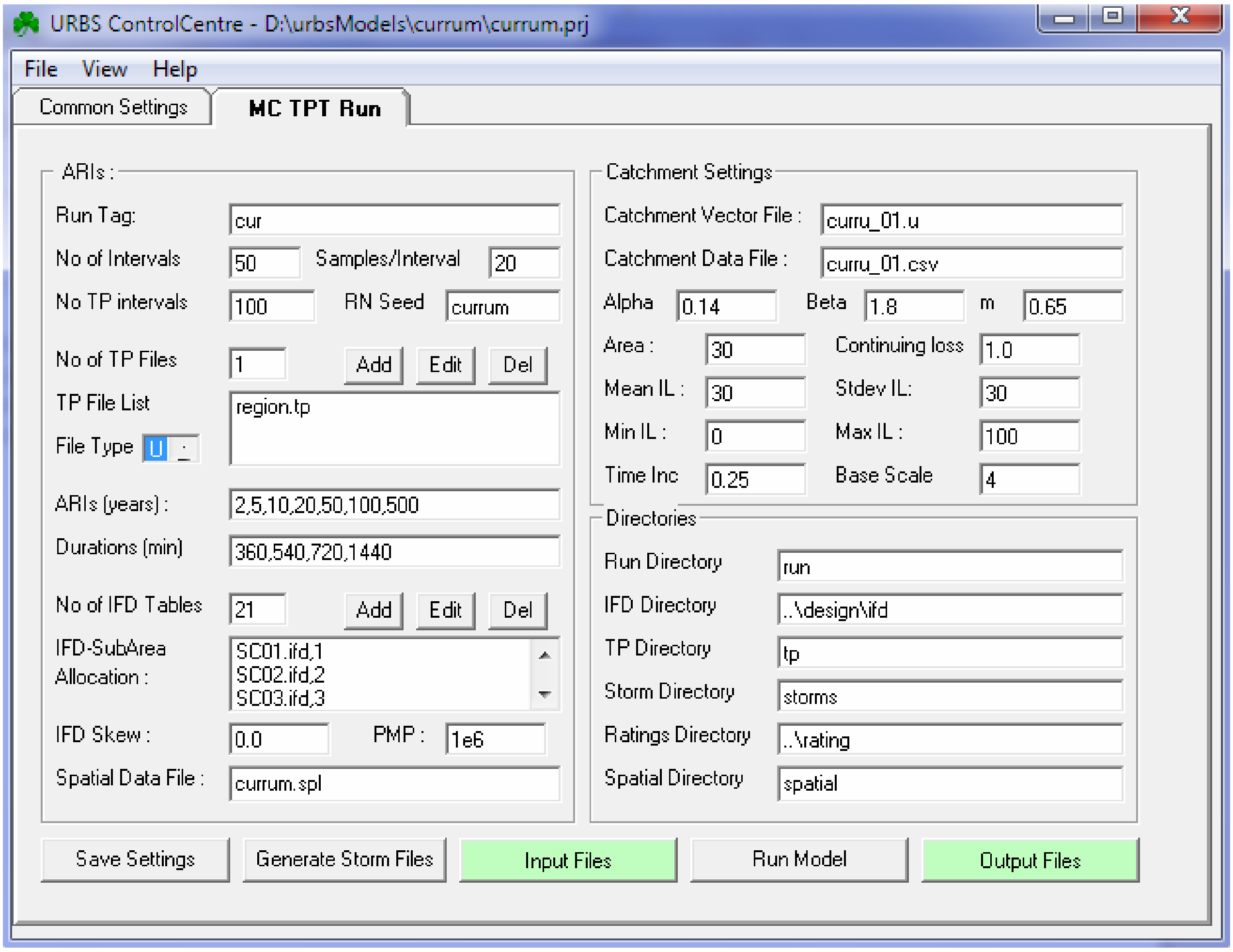

Figure 13: The ControlCentre TPT Interface

Figure 14 shows the ControlCentre interface for a calibration run. This interface form is split into two. The right half of the form deals with individual calibration events whereas the left hand side deals with running all events with either global or local parameters. Deciding which parameters to use can be done by ticking the relevant parameter check box.

The process for undertaking a calibration run is to add an event using the “Add” button on the top left side of the form. Then on the right hand side of the form populate the required fields with directory names, titles etc. Each calibration event is stored in its own directory. Most users use the date of the event to specify this directory name. The catchment definition and data files together with the event rainfall definition file should be placed in this directory. It is best to place the event data (.r and .g files) in a sub-directory to the event directory as shown in the example below. Where possible rating curves used for the run should be common to all modes and accessed from a sub directory to the project directory as shown in the example below. When undertaking a run for particular event, all input and output files associated with that event are in context. For example in the Figure below, all input and output files pertaining to Event4 are in context as this is the event highlighted in blue in the event selection menu on the top right side of the calibration interface form. Calibration statistics for each event is reported in the “.pqh” file which can be accessed using the Output Files button on the bottom left hand side of the Calibration interface form. You should always save your settings prior to running a event. Likewise when running all events (from the left hand side of the interface form).

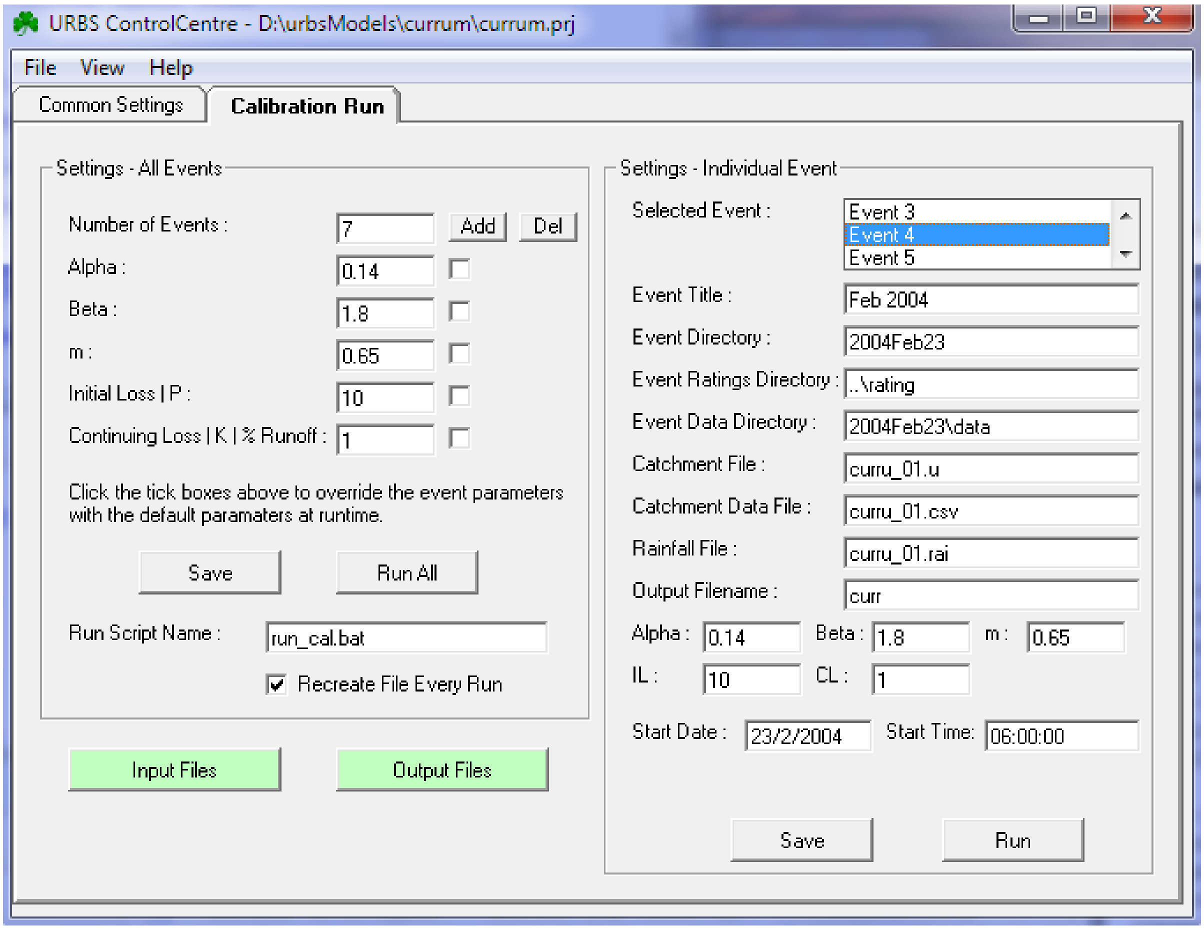

Figure 14: ControlCentre Calibration Interface Form

11. FUTURE DIRECTIONS

The URBS model has been under development for more than 20 years. The model is reasonably well proven in terms of bugs (undocumented features) and robustness, nevertheless bugs are still present and the user is advised to always check the results.

The author has developed a simple Windows interface for the model called “ControlCentre” for managing URBS input and output files. This interface has extensive plotting routines, and includes a facility to perform Monte Carlo design simulation. However the primary focus of development has been enhancing the urbs32 and associated utilities – and allowing users to develop their own interfaces if they so wish. Web interfaces developed for the Yangtze River flood forecasting system and the Australian Bureau of Meteorology’s Hymodel are excellent cases in point. Future development of the model will be focused on developing the modules and not the interface.

Modification to these modules will be based to meet the needs of several flood forecasting agencies. These changes, in particular, enhanced data management facilities – XML interfacing will be included in future releases.

The effects on flood flows (peaks and volumes) of afforestation and riparian vegetation establishment are currently not well researched. Once more literature is published in this area, inclusion of various types of forest and vegetation will be included in the model - not unlike that currently used to define various degrees of urbanisation. Specifying various degrees of forestation and vegetation will facilitate the modeller to better prepare his/her recommendations regarding catchment afforestation and revegetation, however it must be backed up by relevant peer reviewed literature.

The URBS model will continue to be developed over the coming years, however, its successful development is at the behest of its users. Much of the improvements carried out on the model over the years have been as a direct result of user feedback, particularly from the Australian Bureau of Meteorology and Queensland Government agencies. Accordingly I am always keen to receive suggestions and ideas for improvement. I can be contacted on 61-7-31239129 alternatively you can email me, my email address is doncarroll@urbs.com.au.

12. URBS ERROR MESSAGES

The following is a list of the error messages which may occur when running program URBS. The errors are listed alphabetically.

? Bad reference levels for dependent rating curve location for location *location* - aborted
The same downstream water level was listed more than once for the specified dependent rating curve *location* in the catchment file.

? Bad URBS_FORE parameters - aborted
The format of the "URBS_FORE" environment variable was incorrect.

? Cannot allocate memory for average rainfall data - aborted
Insufficient memory existed to store the average rainfall data in the .a file.

? Cannot allocate memory for downstream boundary data - aborted
Insufficient memory existed when the downstream boundary gauged data was read.

? Cannot allocate memory for gauging station data - aborted
Insufficient memory existed when a gauging station hydrograph was read.

? Cannot allocate memory for gauging station file data - aborted
Insufficient memory existed to store the gauging station data from the .g file.

? Cannot allocate memory for input hydrograph data - aborted
Insufficient memory existed when an input hydrograph was read.

? Cannot allocate memory for input hydrograph file data - aborted
Insufficient memory existed to store the input hydrograph from the .i file.

? Cannot allocate memory for plot hydrograph data - aborted
Insufficient memory existed to store the calculated hydrographs.

? Cannot allocate memory for pluviograph data - aborted
Insufficient memory existed when pluviograph information was read.

? Cannot allocate memory for pluviograph file data - aborted
Insufficient memory existed to store the pluviograph data from the .r file.

? Cannot allocate memory for rating curve - aborted
Insufficient memory existed when the rating curve data was read.

? Cannot allocate memory for runoff station data - aborted
Insufficient memory existed when rainfall-runoff data was read.

? Cannot allocate memory for runoff station file data - aborted
Insufficient memory existed to store the rainfall-runoff data from the .rrf file.

? Cannot allocate memory for sub-catchment rainfall data - aborted
Insufficient memory existed when the rainfall data was distributed.

? Cannot allocate memory to read catchment file - aborted
Insufficient memory existed when the catchment file was read.

? Cannot allocate memory to read rainfall file - aborted
Insufficient memory existed when the rainfall file was read.

? Cannot have two successive STOREs in catchment file - aborted
Two successive STORE commands were found in the catchment file. This is not a valid routing procedure.

? Cannot open average rainfall file *filename* - aborted
Insufficient space was available on disk to write the average rainfall file.

? Cannot open backup pluviograph file *filename* - aborted
The backup pluviograph file *filename* could not be accessed.

? Cannot open catchment file *filename* - aborted
The catchment filename specified was not found in the current directory.

? Cannot open discharge file *filename* - aborted
Insufficient space was available on disk to write the discharge file.

? Cannot open height file *filename* - aborted
Insufficient space was available on disk to write the height file.

? Cannot open outlet discharge file *filename* - aborted
Insufficient space was available on disk to write the outfall file.

? Cannot open PLOTU binary file *filename* - aborted
Insufficient space was available on disk to write the binary file.

? Cannot open pluviograph file *filename* - aborted
The rainfall file specified was not found in the current directory.

? Cannot open profile file *filename* - aborted
Insufficient space was available on disk to write the profile file.

? Consistency problems for rating curve location *location* - aborted
No independent downstream location was found for the specified dependent rating curve *location* in the catchment file.

? Dam instruction incorrect - aborted
The format of a DAM ROUTE command was invalid.

? Downstream rating curve location *Dslocation* invalid - aborted
The upstream rating curve location *Uslocation* was specified as dependant on the downstream location *Dslocation*, but no rating curve was given for *DSlocation* in the catchment file.

? Error in capillary suction head - aborted
No capillary suction head values were specified correctly in the rainfall file for a VARIABLE loss model.

? Error in continuing loss - aborted
No continuing loss values were specified correctly in the rainfall file for a VARIABLE loss model.

? Error in gauge file *filename* - aborted

The specified gauging station file did not follow the required format.

? Error in initial loss - aborted

Initial loss values were specified in correctly in the rainfall definition file for a VARIABLE loss model.

? Error in input discharge - aborted

An input hydrograph was listed in the rainfall definition file, but no hydrograph ordinates were specified.

? Error in input file *filename* - aborted

The specified input hydrograph file did not follow the required format.

? Error in pluviograph file *filename* - aborted

The specified pluviograph data file did not follow the required format.

? Error in proportional runoff coefficient - aborted

No proportional runoff coefficients were specified correctly in the rainfall definition file for a VARIABLE loss model.

? Error in rainfall-runoff file *filename* - aborted

The specified rainfall-runoff station file did not follow the required format.

? Error in recorded data - aborted

A gauging station was listed in the rainfall file but no recorded data was specified.

? Expecting either INPUT or GAUGE keywords - aborted

The command after the loss model in the rainfall file was not valid. The program expects either an "INPUT HYDROGRAPH" or a "GAUGING STATION" command.

? Illegal area number found at *number* - aborted

A sub-catchment was specified as the number. Each sub-catchment number must be a positive integer.

? Illegal pluviograph area number reference - aborted

A pluviograph location was specified for an incorrect sub-catchment in the catchment file. Each sub-catchment specified must be a positive integer less than or equal to the total number of sub-catchments.

? Loss model must be one of the following types
Uniform|Variable Continuing Loss Model
Uniform|Variable Proportional Loss Model
Uniform|Variable Manley-Phillips Model

The loss model specified in the rainfall file was not a valid type, or was not located properly.

? Mismatch of dependent rating curve locations for location *location* - aborted

The specified rating curve *location* was listed as dependent on two different downstream locations in the catchment file.

? Missing = after dependent rating curve location name - aborted

An "equals" sign (=) was not found after the downstream location for a dependent rating curve in the catchment file.

? Missing backup pluviograph name - aborted

A backup pluviograph was not specified where required in the pluviograph information in the catchment file.

? Missing BASEFLOW factor - aborted

No factor was specified after the "BASEFLOW FACTOR:" command in the rainfall file.

? Missing comment terminator character } - aborted

A comment did not finish with a right brace, i.e. }.

? Missing END statement in catchment file - aborted

The catchment file did not finish with the command "END." This must be the final command.

? Missing LOCATION keyword - aborted

The required keyword "LOCATION." was missing for either the rating curve, pluviograph, or gauging station information in the catchment file.

? Missing location name after INPUT instruction - aborted

No location was specified after the keyword "INPUT." in the catchment file.

? Missing location name after P&P instruction - aborted

No location was specified after the keyword "P&P." in the catchment file.

? Missing location name after PLOT instruction - aborted

No location was specified after the keyword "PLOT." in the catchment file.

? Missing location name after PRINT instruction - aborted

No location was specified after the keyword "PRINT." in the catchment file.

? Missing name after gauge LOCATION keyword - aborted

No location was specified for a gauging station in the catchment file after the keyword "LOCATION."

? Missing name after pluviograph LOCATION keyword - aborted

No location was specified for a pluviograph in the catchment file after the keyword "LOCATION."

? Missing name after rating curve LOCATION keyword - aborted

No location was specified for a rating curve in the catchment file after the keyword "LOCATION."

? No data for downstream gauging station *location* - aborted

No water levels were found for the downstream boundary.

? No downstream gauging station has been specified - aborted

Upstream water levels were specified as dependant on those at the most downstream location, but no gauged data was entered for this location in the catchment file.

? No rainfall data after RAIN keyword - aborted

No rainfall volume was specified after the command "RAIN ON SUB-CATCHMENTS:" was specified.

? Number of areas = 0 - aborted

No areas were specified for one of the pluviographs in the catchment file.

? Number of areas do not match up - found *number* - aborted

The number of areas specified in the catchment file preceding the "SUB-CATCHMENT OF AREA:" command did not equal the *number* which were found.

? Number of pairs in storage-discharge table < 2 - aborted

There were less than two storage-discharge pairs listed in a DAM ROUTE table in the catchment file. The program requires at least two pairs to interpolate other results.

? Number of rating curve pairs < 2 - aborted

There were less than two height-discharge coordinates for one of the rating curves listed in the catchment file. The program requires at least two pairs to interpolate other results.

? Pluviograph data could not be assigned for area *number* - aborted

No pluviograph data was found for this area or any areas downstream of it.

? Pluviograph sum < 0 - aborted

The sum of the pluviograph ordinates in the rainfall file was less than zero.

? Pluviograph sum is zero - aborted

The sum of the pluviograph ordinates in the rainfall file was equal to zero.

? Rating curve discharges not increasing - aborted

The discharges listed in the rating curve data in the catchment file were not monotonically increasing.

? Rating curve heights not increasing - aborted

The heights listed in the rating curve data in the catchment file were not monotonically increasing.

? Runtype must be DESIGN or FORECAST or MATCHING - aborted

The second line of the rainfall file did not specify a proper run type. The line must be either "DESIGN RUN" or "FORECAST RUN" or "MATCHING RUN".

? Storage-Discharge table in error - aborted

The first storage-discharge pair listed in a DAM ROUTE command in the catchment file were not both zero, or the number of values specified after "NUMBER=" did not equal the number of values listed, or the volume of water in the dam is greater than the maximum storage value.

? STOREs & GETs do not match in catchment file - aborted

The number of STORE commands in the catchment file did not agree with the number of GET commands.

? Too many rating curves for rating curve location *location* - aborted

More than nine rating curves were listed for one dependent rating curve location in the catchment file.

? Two or more sub-catchments have the same area number *number* - aborted

The area *number* specified was given to more than one sub-catchment.

? Unknown catchment parameter after *number* - aborted

One of the required keywords: "RATING CURVE", "PLUVIOGRAPH", or "GAUGING STATION" was not used after the specified number in the catchment file.

? Unknown dependent rating curve location name - aborted

A dependent rating curve location specified in the rating curve data in the catchment file

? Unknown instruction: [*instruction*] - aborted

The specified instruction could not be used by the program. This error is due to either a typing mistake, or a previously incorrect command caused the program to be looking for a different format type at this point in the file.

? Unknown pluviograph *location* in rainfall file - aborted

This pluviograph location was specified in the rainfall file, but was not listed in the pluviograph information in the catchment file.

13. WARNINGS

The following is a list of the warnings which may occur when running program URBS. The warnings are listed alphabetically.

Warning - bad value for VBF *label* - resetting to zero

The environment variable *label* was not set to a proper number, therefore VBF was set to zero.

Warning - cannot open input file *filename*

An input hydrograph was specified in the catchment file, but the required data file was not found.

Warning - gauging station data for *location* not found

A gauging station was specified in the rainfall file, but was not listed in the gauging station information in the catchment file.

Warning - missing data for input *location*

No input hydrograph data was found for this location.

Warning - no data available for gauge *location*

A gauging station location was specified in the catchment file, but no data was given in the rainfall file, and no data file was found.

Warning - no data available for runoff station *location*

A rainfall-runoff station location was specified in the catchment file, but no data was given in the rainfall file, and no data file was found.

Warning - no pluviograph data for area *number*

No pluviograph was specified for this sub-catchment in the catchment file.

Warning - no pluviograph data for area number *number* (will use d/s area data)

No pluviograph information was specified for this sub-catchment in the rainfall file, therefore the next downstream pluviograph will be applied to this sub-catchment.

Warning - setting VBF value for *label* to zero

The environment variable *label* was not found, therefore VBF was set to zero.

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