

## 12 HYDROLOGICAL MODELLING

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### 12.1 Hydrologic Modelling Software

The XP-RAFTS computer model was used to perform the rainfall-runoff modelling for the Bega and Brogo Rivers Flood Study. This type of model produces a time series of flows (a hydrograph) from rainfall information. The resulting hydrographs are input into the hydraulic model for modelling of flow distribution, flood levels, depths and velocities.

The XP-RAFTS software package separates overland flow routing from channel routing. Factors affecting overland flow calculations include the subarea's area, roughness, impervious ratios, and slope. Stream channel routing can be computed either with the time delayed, Muskingum, or Muskingum-Cunge method.

Some of XP-RAFTS features are:

- Design storms, durations 5 minutes to 72 hours, ARI 1 to 100 years.
- Probable Maximum Precipitation using GSDM (Generalised Short Duration Method) by Bureau of Meteorology
- Probable Maximum Precipitation using GSAM (Generalised Southeast Australia Method) by Bureau of Meteorology
- Probable Maximum Precipitation using GTSMR (Generalised Tropical Storm Method Revised), Bureau of Meteorology
- An automatic storm generator for running multiple design storms simultaneously, including events from 1 to 100 year ARI in conjunction with multiple storm durations.
- An automatic storm generator for running multiple design storms simultaneously, including short and long duration PMP events with multiple storm durations.
- Ability to model historic storms with or without a spatial distribution
- Ability to model design storms with variable temporal patterns not standard to AR&R87
- Fully Windows based with input and output graphics
- Templates for rainfall temporal patterns
- Ability to incorporate detention/retention basins with low flow outlets, spillways and rating curves
- Background images
- Nodes representing sub-catchments can be incorporated using the Graphical User Interface
- Links representing channels can be incorporated using the Graphical User Interface
- Node and Link properties can be imported and exported from spread sheets
- Variable units to suit the size of the catchment as either small or large (e.g. ha, km<sup>2</sup>)
- Additional features such as OSD and WSUD
- Options for rainfall losses as Initial/Continuing Loss, Initial/Proportional Loss, or water balancing with the ARBM approach
- Incorporating gauged hydrographs for comparison with output files
- Diversion links
- Various channel routing techniques

XP-RAFTS has been shown to work well on catchments ranging in size from smaller urban to large rural catchments.

### 12.2 Catchment Delineation

The modelling area was divided into sub-catchments based on the available topographic information sourced from one second SRTM data (Shuttle Radar Topography Mission) acquired by NASA in February 2000 and sourced from Geoscience Australia.

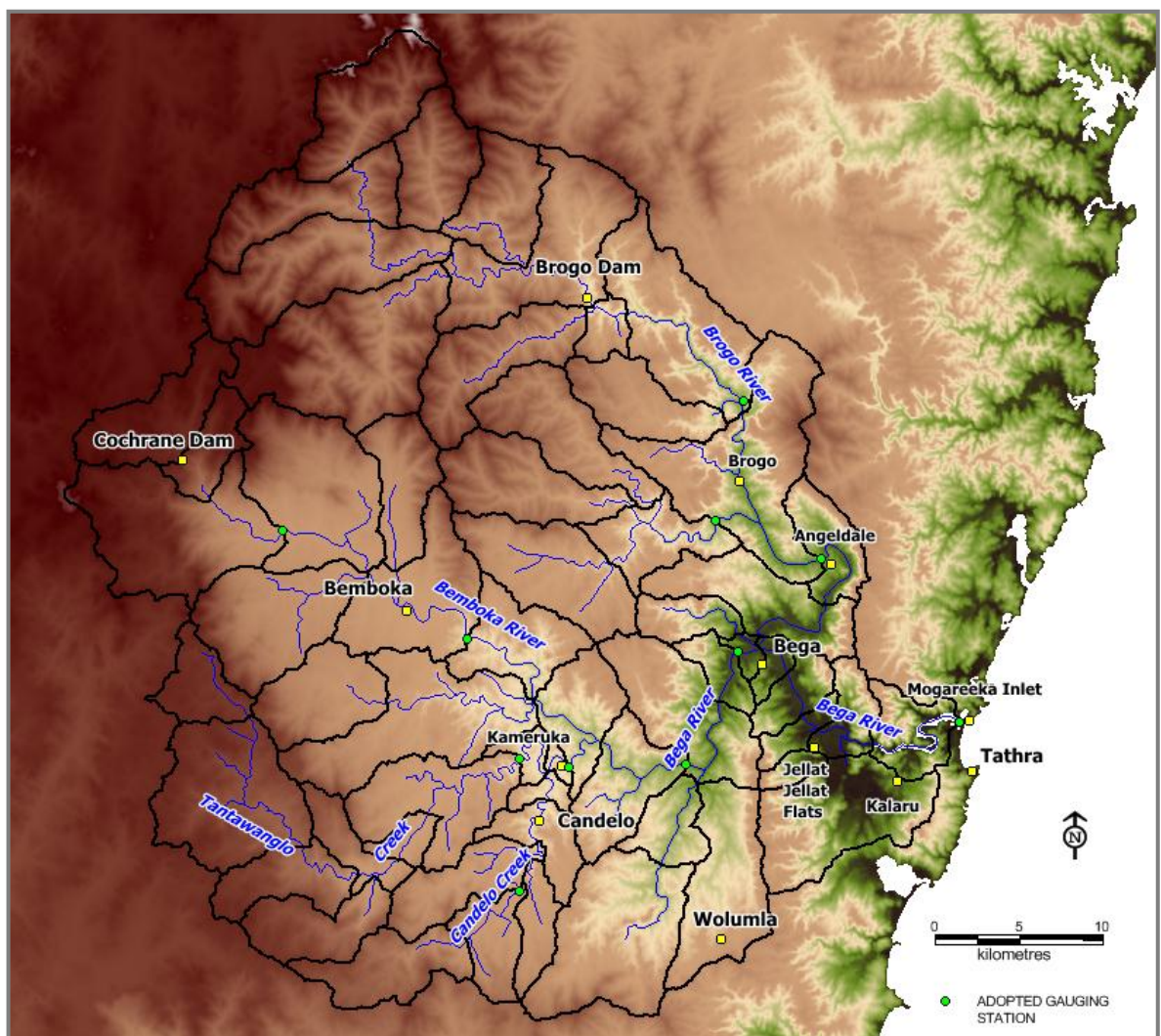
The location of boundary conditions for the hydraulic model was also considered when establishing the locations of sub-catchments. That is, sub-catchments were located where hydrographs were required as

input data for the hydraulic model and at locations where streamflow gauging stations were situated. The total catchment area to the downstream end of Candelo village is approximately 110 km<sup>2</sup> and to the Bega township 1810km<sup>2</sup>.

The delineation of the entire catchment to sub-areas was carried out by utilising the specialised terrain analysis and hydrologic algorithms in the CatchmentSIM software. This software package provides sub-catchment delineation by accurate identification of overland flowpaths. In areas near the catchment outlet the CatchmentSIM results needed to be refined and manually adjusted in GIS due to the mild slopes. A total of 59 subareas were created in the final catchment delineation. The catchment delineation focused on providing a relatively even spread of the sub-areas while at the same time providing outlets at the various gauging station sites for potential calibration/validation. The delineation also required sufficient detail near the towns of Bega and Candelo where hydrograph inputs were required by the hydraulic model.

The catchment delineation is shown in Figure 12.1.

**Figure 12.1: Catchment Delineation**



## 12.3 XP-RAFTS Model Setup

### 12.3.1 Rainfall Losses

The amount of rainfall that produces runoff is of a critical influence in the size and characteristics of a flood. The amount of rain which does not become runoff is termed “loss” (Hill et al, 1998), while the rainfall that does become runoff is termed “rainfall excess”.

Rainfall losses are mainly due to the following processes:

- Interception by vegetation
- Infiltration into the soil
- Depression storage
- Evapotranspiration

The most commonly employed model for simulating the losses that occur during a flood event is the initial loss-continuing loss model (IL-CL). The initial loss represents the larger volume of water lost to processes mentioned above at the initial stages of the storm. The continuing loss represents an average loss over time after the capacity from the initial loss is taken up. The IL-CL method is useful since more complex loss models of soil stores often don't produce better reliability. The IL-CL model approach was employed for this study.

For most pervious surfaces such as grass, water infiltrates initially at a higher level with less infiltration over time. The initial loss can represent the higher infiltration rate early in the flood event while the continuing loss usually represents a lower infiltration rate later in the storm.

Both initial loss and continuing losses can vary during a flood event. It is noted that a study by Walsh et al, (Oct 1998) adopted design temporal patterns from AR&R87. The study fitted the flood peaks to flood frequency analyses by setting the continuing loss at 2.5mm/hr and adjusting the initial losses to fit the flood peaks. AR&R (Institutions of Engineers Australia 1997, Book 2, Table 3.2) recommended median design loss rates for NSW (for regions with mean annual rainfall >300mm) of 10–35mm for initial losses and 2.5mm/hr for continuing loss rates. However, these values are not always representative of real historic storm events and losses can vary significantly due to a number of factors.

AR&R recommends adjusting both loss parameters with the best combination of losses being judged primarily by examination of the patterns and timing of rainfall and runoff, i.e. continuing loss can be varied. In real conditions, infiltration rates for example, can vary from site to site indicating that setting a constant continuing loss is not always appropriate, therefore a calibration by inspection of the entire hydrograph including volume, timing of the peak, and peak discharge, can warrant varying of the losses used.

A study by Cooperative Research Centre for Catchment Hydrology by Hill et al studied rainfall losses against the AR&R Table 3.2 values of 10-35mm initial loss, 2.5mm/hr continuing loss. Losses were calculated for 1059 bursts of rainfall over 22 catchments and resulted in initial losses varying from 5-70mm, and continuing losses varying from about 0-13.5mm/hr, based on 90% confidence limits (Hill et al, 1998).

Losses derived as part of the current study also varied significantly with the calibration of the March 1983 event, for example, producing losses that significantly varied from the median 2.5mm/hr CL from AR&R Table 3.2.

The application of losses to design events are later further tested by plotting the results from the hydrologic model on the flood frequency curves applicable to the study.

### 12.3.2 Storage Factors

Storage affects the catchment response and lag times of rainfall to runoff within a catchment. Several hydrologic factors are considered to impact on the transport and behaviour of a flood. These factors impact on the flood by attenuating the hydrograph, reducing the peak discharge and lagging the flows over time.

Equations and relationships have been developed and used by Water Resource Engineers in several programs. The general Laurenson equation is used in runoff routing programs such as XP-RRAFTS, WBNM, and RORB as shown below.

The storage-discharge relationship is presented in the form

$$S = K Q$$

Where the representative discharge is the outflow  $Q$  and  $K = BQ^n$ . Thus

$$S = B Q^{n+1}$$

Several programs use various values for the value  $n$ . By default XP-RRAFTS applies a value of  $n = -0.285$ , hence  $m$  (or  $n+1$ ) = 0.715, which corresponds to a non-linear storage routing methodology.

The value of  $B$  also varies by the different modelling software. XP-RRAFTS uses the following regression equation derived by Aitken (1975). Factors impacting on catchment storage based on work by Aitken include area, imperviousness, slope, and roughness. This is combined into the derived equation for  $B$ ,

$$B_{ave} = 0.285 A^{0.52} (1+U)^{1.97} S_c^{-0.50}$$

where:

- $A$  is the area of each subarea ( $\text{km}^2$ )
- $U$  is the fraction of the subarea urbanised, which is based on a relationship against the percentage imperviousness (%)
- $S_c$  is the main drainage slope of the subarea (%)

In addition to the above equation a further calibration parameter is used to modify the above equation based on the adopted "PERN" or Manning's roughness coefficient. If further modification of the storage is required then an additional catchment wide multiplier is available ( $B_x$ ) that adjusts all subarea storage within the catchment.

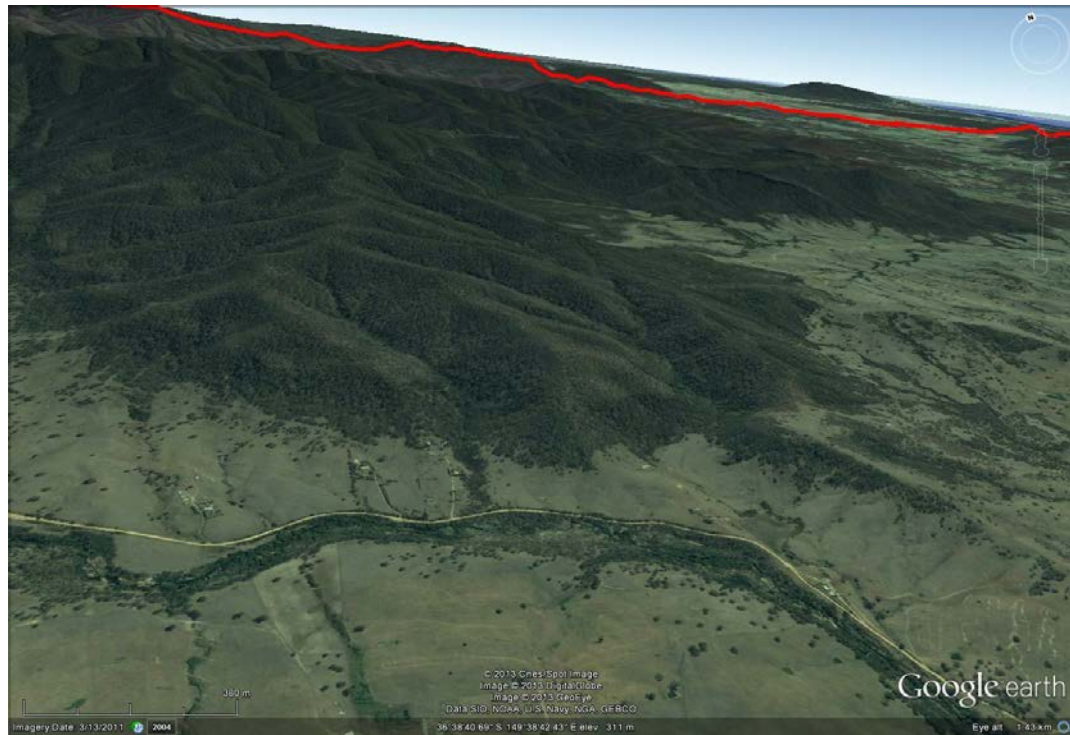
Channel routing can be simulated using three main techniques in XP-RRAFTS. These include the time lags, Muskingum, and Muskingum-Cunge routing. Time lags are usually recommended for catchments that are primarily urbanised, while Muskingum and Muskingum-Cunge methods are often applied to rural catchments that include a reduction in flow peak and lagging effect affecting the transport of a flood along a channel. The Muskingum method was used during the calibration based on a mean velocity of 2m/s. Appropriate results were achieved using this approach. Subsequently the travel time of the hydrographs along the channels were tested by identifying the timing of peak flows at the upstream and downstream end of the channel, and computing the final velocities as a validation. These post calculations consistently produced velocities around 2m/s validating the approach employed.



### 12.3.3 Land Types and Surface Roughness

Two basic land types were identified from the aerial photos. In some areas the land was identified as having been cleared and others were considered to be in a natural condition mainly comprised of forested areas. Figure 12.2a-b shows a snapshot of these two different land types.

**Figure 12.2a: Cleared and Natural Land Types within the catchment (Google Earth, 2013)**



**Figure 12.2b: Cleared and Natural Land Types within the catchment (Google Earth, 2013)**



The hydrologic model incorporated these two land types by applying different Manning's roughness coefficients. The cleared areas were incorporated into the calibrations with roughness coefficients ranging from  $n=0.050$ – $0.060$  while the natural/ forested areas were represented by roughness coefficients ranging from  $n=0.100$ – $0.200$ . These roughnesses were adjusted in the process of model calibration (Refer Table 14.7 below).

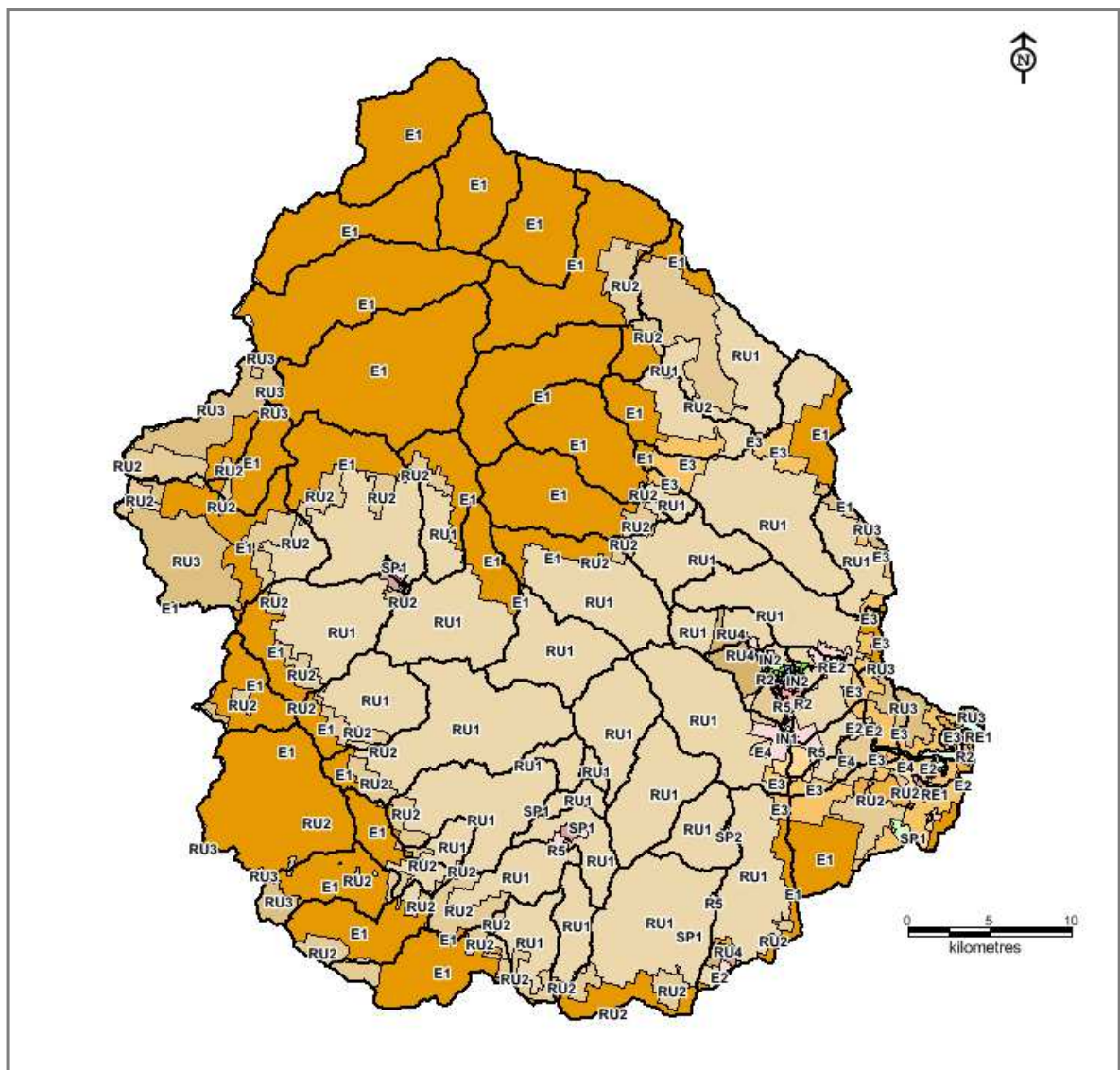
The values derived as part of the calibration are within reasonable limits to documented values with cleared areas similar to scattered brush, and forested areas similar to heavy vegetative cover. This suggests the hydrologic model achieved a good representation of the catchment roughness and storage effects for all flood events.

The calibration did not highlight a need to alter the roughness values for the different flood events. To confirm this, an inspection of Landsat imagery dated 1972 and 1980 indicated that there was no major change to the forested and cleared areas around the catchment.

#### 12.3.4 Land Zoning and Percentage Imperviousness

A map showing the land zonings within the catchment is shown in Figure 12.3 based on the Council's draft LEP 2012. This map was used to compute the percentage imperviousness in each subarea.

**Figure 12.3: Land Zoning within the Catchment**



The breakdown of percentage imperviousness used for each land zoning is presented in Table 12.1. By applying these fractions throughout the catchment it was found that the vast majority of the land surface throughout the catchment is considered to be pervious.

**Table 12.1: Percentage Imperviousness Applied Individual Land Zones**

Land Usage	Percentage Imperviousness
B1 – Neighbourhood Centre	80
B2 – Local Centre	100
B4 – Mixed Use	50
E1 – National Parks and Nature Reserves	0
E2 - Environmental Conservation	0
E3 - Environmental Management	0
E4 - Environmental Living	5
IN1 – General Industrial	70
IN2 – Light Industrial	70
IN4 – Working Waterfront	100
R2 – Low Density Residential	30
R3– Medium Density Residential	40
R5 – Large Lot Residential	20
RE1 – Public Recreation	10
RE2 - Private Recreation	10
RU1 – Primary Production	0
RU2 – Rural Landscape	0
RU3 - Forestry	0
RU4 – Primary Production Small Lots	5
RU5 - Village	40
SP1 – Special Activities	50
SP2 - Infrastructure	70
SP3 - Tourist	50
W1 – Natural Waterways	0
W2 – Recreational Waterways	0
W3 – Working Waterways	0

The surface type is primarily pervious throughout the catchment as observed from aerial photography supplied by Council, and by Landsat images dated 1972 and 1980. These images coarsely highlight the forested and cleared land surfaces with no discernible difference over the catchment area over time. Therefore it is considered that the present day values of imperviousness presented in Table 12.1 are appropriate for use in all four historic flood events used in the calibration. The same imperviousness ratios were applied to the design events as a representation of the hydrology under current land zoning conditions.