BELLINGEN SHIRE COUNCIL

DORRIGO FLOOD STUDY

FINAL REPORT

December 2007

BELLINGEN
SHIRE COUNCIL

Department of Environment & Climate Change NSW

Australian Government
Department of Transport and Regional Services

BELLINGEN SHIRE COUNCIL

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ACKNOWLEDGEMENTS

This study has been undertaken by Paterson Consultants under the auspices of the Bellingen Shire's Floodplain Risk Management Committee.

The Committee comprises representatives from:

- Elected representatives, Bellingen Shire Council;
- Council officers, Bellingen Shire Council;
- Nominated officers of State Emergency Services, Department of Natural Resources;
- Nominated community representatives.

The study has been funded by Federal Government, State Government and Bellingen Shire Council on a 1:1:1 contribution basis from each body.

FOREWORD

The New South Wales Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas as well as ensuring that new development is compatible with the flood hazard and that it does not create additional flooding problems in other areas.

Under the policy, the management of flood-prone land remains the responsibility of local government. The State Government provides specialist technical advice and financial subsidies for studies and capital works to assist councils in the discharge of their floodplain management responsibilities.

The flood policy provides for technical and financial support by the government through the following four sequential stages:

* Stage 1 - Flood study:

  Determines the nature and extent of the flood problem.

* Stage 2 - Floodplain Risk Management Study:

  Evaluates management options for the floodplain in respect of both existing and proposed development.

* Stage 3 - Floodplain Risk Management Plan:

  Involves formal adoption by council of a plan of management for the floodplain.

* Stage 4 - Implementation of the plan:

  Involves construction of flood mitigation works to protect existing development and includes use of local environmental plans to ensure new development is compatible with the flood hazard.

The Dorrigo Flood Study constitutes part of the first stage of the management process for the Bielsdown River through Dorrigo and an unnamed tributary to the Bielsdown River, through Dorrigo. The unnamed tributary falls within a "greenfields" area likely for future development activity. The Dorrigo Flood Study has been prepared for Bellingen Shire Council to determine an appropriate floodplain risk management strategy.

SUMMARY

The Dorrigo Flood Study has been undertaken to provide flood information for establishment of a floodplain risk management plan for Dorrigo. The end use of this study will most likely be for the setting of development controls and addressing flood access issues.

The study area covers:

- the Bielsdown River from the Dorrigo Golf Course to Dangar Falls;
- an un-named tributary, which runs along the eastern side of the developed area of Dorrigo and joins the Bielsdown River some 800 metres upstream of Dangar Falls.

The study approach adopted involves:

- collection and assessment of flood data from government resources and resident interviews;
- definition of waterway areas along the Bielsdown River and the un-named tributary by ground survey;
- establishment and calibration of an hydrologic model and a riverine hydraulic model to predict design flood levels for the 0.5, 1, 2, 5, 10 and 20% AEP floods and the Probable Maximum Flood (PMF);
- presentation of design flood information as:
  - flood profiles for each of the design events;
  - tabulated values for each of the flood contours;
  - flood contours over cadastral maps for three of the seven design floods investigated.

Available data on flooding comprises:

- recorded flood flows;
- recorded rainfalls;
- recorded flood levels.

The nearest (and only relevant) stream gauging station is located on the Bielsdown River at the disused Glenreagh - Dorrigo Railway. The Station, identified as Station 204017, "Bielsdown River at Dorrigo No. 2 and No. 3", has stream flow and flood level records from 1947 to current period.

Initial analysis of the flood records indicated a number of anomalies. Further review indicated that the water level gauges had been moved several times and that the official record did not include any adjustments for the shift in gauges.

The adjusted flood record shows the 1954 event as the largest flood since 1947. The March 2001 flood is ranked sixth largest and appears to be smaller than floods occurring in 1973 and 1974.

Planning for sewerage in Dorrigo commenced in the late 1960's. The "Sewage Compilation Map" for the sewerage scheme notes three 1954 flood levels near the Coramba Road crossing of the Bielsdown River and near the sewage treatment plant.

The Bureau of Meteorology has records from 40 daily read rainfall stations in or near the study catchment. Only 13 stations are currently operational. The longest period of record is Dorrigo Post Office (1908 to 1997).

Long term pluviometer records (rainfall versus time records) are available at Station 59067, "Dorrigo (Myrtle Street)" for the period 1954 to 1998. After 1998, pluviometer records are available (in a raw data format) for the ALERT flood warning system.

Floods, suitable for calibration of hydrological models, having both flood hydrographs and rainfall pluviometer records available are:

- January 1974;
- July 1973;
- March 2001;
- July 1985;
- May 1977; and
- April 1989.

The two highest recorded floods (1950 and 1954) have hydrographs recorded but no pluviometer records.

Resident interviews were also conducted after issuing of 81 questionnaires. Twelve questionnaires were returned, but these did not indicate reliable flood marks. Direct resident interview enabled identification and survey of 6 flood marks for the 2001 flood and one mark for both the 1950 and 1954 floods.

Investigation of the local newspaper (the Don Dorrigo Gazette) yielded only general flood information and no flood marks that could be accurately identified.

Ground survey was undertaken to identify waterway cross-sections. Twelve sections were surveyed on the Bielsdown River and six cross-sections on the un-named tributary (Refer Figure 4).

The catchment area of the Bielsdown River at Station 204017 is 72.8 sq kilometres, as compared to 29.9 sq kilometres for the Bielsdown River at Dorrigo. The catchment of the un-named tributary at its confluence with the Bielsdown River is 1.3 sq kilometres.

An hydrology model was established to predict flood flows through Dorrigo. In this case, the RORB program was used. A riverine hydraulic model is required to predict flood levels from flood flows (as predicted by the RORB model).

A RORB model was established for the Bielsdown River to Station 204017 "Bielsdown River @ Dorrigo No. 2 and No. 3". The RORB model was calibrated and verified against the 1973, 1974, 1977, 1989 and

2001 floods. The model was also tested against the 1985 flood, however, a low coefficient of runoff was required to achieve a suitable match between recorded and modelled discharges. This result could be caused from errors in rainfall, distribution of rainfall or high losses in this event.

A flood frequency analysis was completed for Station 204017, "Bielsdown River @ Dorrigo No. 2 and No. 3" for the available records (1947 to present). The station's discharge records had to be manipulated to account for the differing rating curves for the Bielsdown No. 2 and Bielsdown No. 3 sites.

Frequency analysis gives the 1% AEP flood peak discharge at Station 204017 at 1032 cu m/sec. However, the historical data, when plotted, indicates a 1% AEP flood peak discharge of 794 cu m/sec.

Common Australian practice relies on use of "design rainfall" to produce "design floods" of the same return period. Application of design 1% AEP rainfall with the calibrated RORB model produces a peak discharge of 1224 cu m/sec, considerably above the historically recorded floods and the frequency analysis of the recorded floods.

The anomaly between the design rainfall approach (eg RORB) and the historical flood frequency could be caused by a variety of factors such as:

- differences in rainfall over the catchment;
- storm movements over the catchment;
- rainfall losses in the catchment;
- the short time of concentration of the catchment.

The anomaly was addressed and a number of alternative approaches examined to enable resolution. The adopted approach involves application of no areal reduction over the catchment. This decision considered the following points:

- the end use of the flood study is land use controls;

- Bellingen Shire Council base their land use controls on the design 1% AEP event with consideration of larger events;

- Whilst the design 1% AEP floods are of the correct order, the size of the more frequent floods (eg the 20% AEP design event) are likely to be over-estimated.

The above approach produced peak flood discharges of 455 cu. m/sec and 1,247 cu. m/sec at Dorrigo and Station 204017 respectively for the 1% AEP event.

Design flood flows along the un-named tributary were derived using a separate hydrology model, "DRAINS". The design peak flood discharge for the 1% AEP event for the un-named tributary is 34.8 cu. m/sec. Thus, the un-named tributary contributes about 8% of the flow at Dorrigo. However, the steepness of the catchment means that runoff from the un-named tributary will arrive at the confluence with the Bielsdown River considerably before the runoff from the catchment upstream of Dorrigo.

PMF flood discharges were derived using PMP rainfalls and the hydrological model. PMP rainfall was derived using the Bureau of Meteorology GSDM procedure. The PMF discharges for the Bielsdown River at Dorrigo and the un-named tributary at its confluence with the Bielsdown are 1,667 cu. m/sec and 142 cu. m/sec respectively.

Hydrodynamic models were established for the Bielsdown River and the un-named tributary using MIKE-11 and HEC-RAS respectively.

The HEC-RAS model was run in steady state mode only.

The MIKE-11 model was tested against the 1954 flood (with five flood marks available) and the 2001 flood (with six flood marks available).

With respect to the 2001 flood, the calculated flood levels are within 0.5 metres of recorded levels with the exception of one point, considered an outlier. The outlier has been discarded as it is above upstream flood levels that were defined by photographs taken near the peak of the flood.

The fit between the recorded and calculated flood levels is considered adequate, given the recorded levels have been derived from resident interviews.

To achieve a fit between the recorded and calculated flood levels for the 1954 flood, it was found that the estimated flood hydrographs had to be increased such that sufficient flood volume was available to match recorded flood levels.

Three flood marks are available for the 1954 flood near the Coramba Road bridge. However, use of an estimated flood hydrograph to match flood levels upstream of the Waterfall Way and reasonable Mannings `n' values did not enable a fit against the recorded levels. Given the recorded flood levels match the 2001 flood profile, it was concluded that a datum error exists in these three flood marks.

The model calibration was viewed as adequate given the nature of the flood marks available. There are no flood marks along the un-named tributary and thus, the friction (Mannings `n') values have been set essentially on the basis of the consultant's experience.

Design flood profiles have been derived using the design rainfall from Australian Rainfall and Runoff, the calibrated RORB model and the hydraulic models.

Design flood profiles plus tabulated values for flood level, peak discharge and flow velocities have been derived for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP floods plus the PMP event.

The design flood water level surfaces have been overlaid on the cadastral plan for Dorrigo and flood contours and flood hazard diagrams produced for the design 5% AEP, design 1% AEP and PMF flood events.

1. INTRODUCTION

This report presents the results of the Dorrigo Flood Study.

Bellingen Shire Council, through its local land use and management activities in the Dorrigo area is following the Floodplain Management Process, as outlined in the Foreword and promoted by the NSW Government.

The locality of the study area (Dorrigo) is illustrated in a state wide context and within the context of the Bielsdown River on Figure 1.

Figure 2 presents an aerial mosaic of the Dorrigo township with the street layout and study area.

Specifically, the Flood Study covers:

- the Bielsdown River and its floodplain from the golf course at Dorrigo downstream to Dangar Falls;

- an unnamed tributary, which runs along the eastern boundary of the developed area of Dorrigo and whose confluence with the Bielsdown River is some 800 metres upstream of Dangar Falls. The total river length covered by this Flood Study is some 4 kilometres.

The study approach is detailed in Chapter 2, while the subsequent chapters detail:

- available background information;
- data collection;
- hydrological investigations;
- riverine investigations;
- design flood data;
- conclusions.

2. STUDY APPROACH

The end use of the Dorrigo Flood Study is likely to be:

- setting of floor levels through the Floodplain Management Risk Plan and development controls;
- setting of site specific development controls;
- addressing issues of flood immunity of local access roads.

A reconnaissance survey of the site and the available data suggests that sufficient hydrological data and recorded flood levels will be available to establish and calibrate an hydrological model of the catchment (to estimate flood flows) and to establish a riverine model to define flood levels and flood hazard for a variety of design flood events.

Thus, an appropriate study approach, consistent with the above uses and the constraints outlined in Chapter 1, Introduction, was identified as:

- collection of local flood information by resident interview;
- collection of recent flood records held by government sources;
- collection of ground survey to identify river waterway areas;
- use of the hydrology model for the Bielsdown River to define flood flows;
- development of a riverine hydraulic model for the Bielsdown River (through the study area) and the unnamed tributary, to define the design flood profiles;
- preparation of design flood profiles for the five design events, namely, 0.5% AEP, 1% AEP, 2% AEP and 5% AEP floods plus the Probable Maximum Flood (PMF);
- presentation of PMF, 1% AEP and 5% AEP flood contours on a cadastral base.

It should be noted that the flood records held by government sources can be organised to provide a flood frequency analysis at the measurement site and thus provide a check of historical records against the hydrology and hydraulic models.

3. AVAILABLE DATA

3.1 Overview

The principal data required for a flood study comprises:

- recorded flood levels;
- recorded flood flows;
- rainfalls;
- topographic data information.

Historical rainfall data is available through the Bureau of Meteorology, comprising:

- daily read rain gauges;

- continuous rainfall versus time recorders (Pluviometers which either store the data on site or transfer the data to a central point using radio technology ("ALERT").

Historical flood data is available through:

- previous studies and documents;
- river gauges;
- resident interviews.

Design rainfall information (that is rainfall-intensity-duration data for various return period storms) is commonly derived from Australian Rainfall and Runoff (Ref. 1). This practice has been followed in this study

3.2 Previous Studies, Documents

There are a limited number of historical documents that have been examined, principally for recorded data on:

- rainfall information;
- flood level information;
- flood flow estimation; and
- general flood information.

The documents examined comprise:

- published reports from government agencies;
- published reports from Bellingen Shire Council; and
- Roads and Traffic Authority bridge replacement drawings.

In the review, it was presumed that the published information can be treated as "reliable" and further background work into the published data has not been undertaken.
The most important documents are outlined below.

"PINNEENA, Version 8", Department of Infrastructure, Planning and Natural Resources, 2004 (Ref. 2)

DIPNR has published available New South Wales flows records on CD through a series of editions of PINNEENA.

It should be noted that PINNEENA generally contains the digitally recorded information. There is additional historical flood level information held on the original gauge reader cards that does not appear in PINNEENA.

The only DWR gauging station of relevance to the current study is Station 204017, "Bielsdown at Dorrigo No. 2 & No. 3". The station is located at the disused Glenreagh - Dorrigo railway bridge, downstream of Dangar Falls.

PINEENA indicates the station as operational from 1947 to current date. Water level records available are:

- 1947 to mid 1971: monthly summaries only plus some peak level information (1950, 1954)
- 1971 to current: continuous records

Station 204017 is useful in calibration and verification of any hydrological models. It is however, of little use for tailwater controls for any hydraulic models as it is located downstream of the major channel drop at Dangar Falls.

The records quoted in PINNEENA should be used with caution. The site history is as follows:

- 1947 to 1956: Daily read gauge heights at "Dorrigo No. 2" site;
- 1955 to 1976: Gauge heights measured at "Dorrigo No. 3" site;
- 1976 to current date: Gauge heights measured by gas bubble system at "Dorrigo No. 2" site.

Unfortunately, in the computation of rating tables at the site, published in PINNEENA, the gauge heights at the time of flow gaugings have been used irrespective if the gauge heights were for the No. 2 or No. 3 site. There is significant difference between the gauge heights for the No. 2 and No. 3 sites and combination of the gauge heights causes major discrepancies.

For this study, two separate rating tables have been produced for Dorrigo No. 2 and Dorrigo No. 3 stations respectively. The rating curves adopted appear in Appendix B.

The use of separate rating tables, such that the rating table is appropriate to the date of the flood occurrence, produces a ranking of floods from largest to smallest that is different from that derived from PINNEENA.

Combination of the flood records from PINNEENA and actual water level reading cards held by Department of Natural Resources, has identified the twelve largest floods at Station 204017 "Bielsdown @ Dorrigo" as listed in Table 1 below.

Table 1

Significant Historical Floods
(Station 204017, "Bielsdown River @ Dorrigo")

Flood Year	Peak Flow (cu. m/sec)	Rank
1954	700	1
1950	520	2
1974	470	3
1965	465	4
1973	450	5
2001	435	6
1962	375	7
1985	370	8
1964	345	9
1967	345	10
1976	335	11
1972	250	12

The full ranking of the historical floods appears in Appendix C.

"Dorrigo Sewerage Compilation", Public Works Department, 1968

It appears Dorrigo's sewerage system was constructed under the County Towns Water Supply and Sewerage Program in the early 1970's. The compilation map shows:

- a topographic map (with two foot contours) for Dorrigo plus bench marks to Standard Datum;

- three "observed" flood levels for the 1954 flood near the Vine Street crossing of the Bielsdown River (Coramba Road).

Table 2 below lists the original data and the conversion of flood level data to Australian Height Datum. Figure 4 shows the location of the levels.

Table 2

Historical Flood Levels - PWD Sewage Compilation (1954 flood)

Point	Recorded Flood Level		Location (MGA)	
	ft. Std dtm	m AHD	Easting	Northing
A	2317.0	704.97	472519.9	6644471.2
B	2326.5	707.86	472355.8	6644541.6
C	2327.5	708.17	472326.0	6644578.9

"Inundation Map, Dorrigo", Water Resources Commission, 1980

The map shows the area of Dorrigo inundated from the Bielsdown River during the February 1954 flood. The notes on the map indicate that the flood extents were based on observed flood levels.

The Water Resources Commission calculation file (WRC file No. 1563240 - "Dorrigo Flood Inundation Map") contains three flood marks, additional to those shown on the PWD survey compilation map. The points are listed in Table 3 below.

Table 3

Historical Flood Levels - WRC Inundation Map

Point	Flood Year	Recorded Flood Level		Location (MGA)	
		ft. Std dtm	m AHD	Easting	Northing
D	1954	2362.0	718.68	471979.2	6643626.2
E	1971	2364.1	719.32	471694.8	6643375.7
F	1954	2370.0	721.12	471530.9	6643068.9

"Design Drawings, Bridge Over Bielsdown River", RTA

The drawings represent the current concrete bridge over the Bielsdown River at Dorrigo for Main Road 76 (Waterfall Way). The current bridge, constructed in 2001, replaced an existing timber bridge that was constructed in 1938.

The bridge drawing quotes an "observed High Flood Level" as RL 719.0 m. It is presumed the datum is AHD, given the construction date.

"Floods of February and March 2001, Bellinger and Kalang Rivers", Bellingen Shire Council, 2003

The report concentrates on the Bellinger and Kalang Rivers. The report quotes rainfall for Dorrigo and Point Lookout. However, the data has been sourced from the Bureau of Meteorology and is thus not the original record.

3.3 Water Level and Rainfall Gauges

Water level and rainfall gauges are installed by a variety of government organisations and are reflective of the operation interest of the organisations. The organisations involved are:

- Bureau of Meteorology (BOM) - flood warning;
- Public Works Department (PWD) - flooding in tidal areas;
- Department of Water Resources (DWR) - flooding in non-tidal areas.

It is noted that PWD and DWR were combined into the Department of Land and Water Conservation (DLWC), which, in turn, has been transferred to the Department of Infrastructure, Planning and Natural Resources and recently created as the Department of Natural Resources.

There are no river level gauges within the study area that can be used for this investigation of flood levels.

There are 40 daily rainfall stations in or near the study catchment. The location of the daily rainfall stations is shown on Figure 3, while Appendix D lists the station numbers, names, date of commencement and closure, and their geographical position.

It should be noted that:

- only 13 of the total are currently operational;

- the daily rainfall station with the longest record is Dorrigo Post Office (1908 to 1997);

- with the exception of Dorrigo, there are no daily rainfall stations within the catchment;

- the southern side of the catchment is the top of the escarpment that falls to the Bellinger River. Orographic effects on rainfall can be expected due to the steep nature of the topography.

The only long term pluviometer in the catchment is located at Station 59067 Dorrigo (Myrtle Street). The instrument is listed by the Bureau of Meteorology as operational between 1954 and 1998. It should be noted that, although a pluviometer may be registered as "operational", this does not imply that full records will be available over the "operational" period.

The Bureau of Meteorology also maintains a pluviometer at Dorrigo as part of its ALERT system for flood warning. The instrument was installed circa 1997.

For the purposes of this study, the complete daily records were collected for 18 stations as:

- Deer Vale
- Dorrigo Post Office
- Megan
- Thora Post Office
- Meldrum
- Bostobrick
- Tallowood Point
- Dorrigo (Myrtle Street)
- Tyringham
- Promised Land
- Dorrigo Police Station
- Orama
- Leigh
- Mount Moombil
- Thora
- Bellingen
- North Dorrigo
- Dorrigo (Old Coramba Road)

Short periods of record were obtained from the Dorrigo pluviograph covering the periods of major floods recorded at the DNR gauging station "Station 204017, Bielsdown @ Dorrigo No. 2 and No. 3".

Table 4 below presents a ranked list of floods that might be used for calibration of the hydrology model to be used.

Table 4

Significant Historical Floods vs Available Records

Flood Date	Rank	Peak Flow [1]	
		(ML/d)	(cu m/sec)
February 1954	1	60,480	700
June 1950	2	44,928	520
January 1974	3	40,608	470
July 1973	5	38,880	450
March 2001	6	37,584	435
July 1985	8	31,968	370
April 1989	15	18,144	210
May 1977	16	16,848	195

Notes: 1. Peak Flow at Station 204017, "Bielsdown @ Dorrigo"

It will be noted that:

- pluviograph data is not available for the two largest floods;
- data is available for medium sized floods with peak discharges in the range of 370 to 470 cu. m/sec;
- data is also available for smaller floods with peak discharges around 200 cu. m/sec;
- the above data gives a suitable range for calibration of an hydrological model.
- in selecting the floods for calibration and verification, a range of floods have been selected, rather than every flood. For this reason, the floods recorded in 1972, 1975 and 1976 have not been used for calibration.

3.4 Resident Interviews

Resident interviews were undertaken to identify appropriate flood information for ground survey to establish flood marks. The interviews were directed to:

- individuals identified by the Floodplain Management Risk Committee as likely to be able to provide reliable and detailed information;
- distribution of questionnaires; and
- "cold" calling on residents along the Bielsdown River.

Bellingen Shire Council distributed 81 questionnaires to property owners through the study area. The recipients of the questionnaires were property owners adjoining the Bielsdown River through the study area, identified via Council's GIS system. A copy of the questionnaire appears in Appendix A.

Twelve completed or partly completed questionnaires were received. Analysis of the questionnaires did not identify likely flood levels that were sufficiently unambiguous to be used for flood modelling.

The response to the questionnaires is not unexpected, given that:

- Bellingen Council has been using the WRC map of the 1954 flood extents for development control;
- there is very little development within the 1954 flood extent area;
- given development is generally flood free (in the largest recorded flood), the residents have little direct exposure to flooding.

The direct contact with residents yielded 7 points, from which flood levels could be deduced. The deduced flood levels appear in Table 5 below.

Table 5

Historical Flood Levels - Resident Interviews

Point	Flood Year	Recorded Flood Level (m AHD)	Location (MGA)	
			Easting	Northing
G	2001	717.82	472153.26	6643684.38
H	2001	717.35	471998.42	6643559.60
I	2001	716.84	472039.07	6643517.30
J	2001	717.25	471718.17	6643376.89
K	1950	718.78	471688.65	6643355.78
L	2001	717.90	471660.03	6643229.18
M	2001	718.71	471715.55	6643025.91

The locations of the identified flood marks are shown on Figure 4.

The resident interviews conducted question the rarity of the flood level quoted for 1971 flood at Point E (see Table 3) in the WRC Flood Compilation. The historical record at Station 204017 shows the 1971 flood as a small event and not within the top fifteen flood ranks. Re-survey of the property (at its corner of Bean and Cyprus Streets) for this study, suggests the 1950 flood level was in the order of RL 718.8 to RL 718.9 m AHD at this location. The statutory declaration by the owner over the period 1946 to 1966 was obtained and noted that the house was raised in 1963. Hence, it is probable that the flood level quoted for Point E represents floor level after the house was raised. Accordingly, by the reported 1971 flood level at Point E has been treated with considerable scepticism.

3.5 Local Newspapers

Dorrigo has a local newspaper (the Don Dorrigo Gazette), which has been published since 1910.

Past copies of the newspaper were obtained, covering periods around floods recorded in:

- June 1950
- February 1954
- March 1974
- May 1977
- July 1985
- April 1989
- March 2001

Although the newspaper has general coverage on flooding on the above dates, no references were found that could be reliably be used to obtain "recorded" flood levels.

3.6 Waterway Cross-sections

The study approach involves use of a one-dimensional hydraulic model to identify flood levels. Such models rely on estimates of waterway areas at regular intervals.

There are no waterway cross-section surveys available for the Bielsdown River or the un-named tributary. Whilst the PWD Sewerage Compilation Plan provides contours at 10 foot intervals with apparently 2 foot contour interpolation, this Plan does not provide sufficient detail on the creek channels and no detail along the un-named tributary.

Waterway cross-section survey using ground survey techniques was commissioned and comprised:

-	Bielsdown River:	13 sections
-	Un-named tributary:	6 sections

The location of the sections is shown on Figure 4. All surveyed points have been located to MGA grid and AHD vertical datum. Concurrent with the cross-section survey, bridge opening details for the Waterfall Way crossing and Coramba Road crossing were collected. Flood levels identified by resident interview were also converted to MGA grid and AHD.

4. HYDROLOGICAL INVESTIGATIONS

4.1 Overview

The study catchment area is shown on Figure 5. The catchment areas of relevance are:

- Bielsdown River at Dorrigo:	29.9 sq kilometres
- Bielsdown River at Station 204017 "Bielsdown @ Dorrigo No. 2 and No. 3:	72.8 sq kilometres

Station 204017 "Bielsdown River @ Dorrigo No. 2 and No. 3" is a particularly useful station, despite the differences in catchment area to Dorrigo, given:

- the study area is located within the catchment of this station;
- the catchment has similar topographical characteristics to the Bielsdown River at Dorrigo;
- there is a relatively long period of records available, which includes the highest recorded flood.

With reference to Figure 5, the study area essentially contains two riverine sections, namely:

- the Bielsdown River through Dorrigo;
- an un-named tributary to the Bielsdown, which is located immediately east of Dorrigo and which joins the Bielsdown downstream of Dorrigo.

The process envisaged for this study involves use of a riverine model to predict flood levels through the site. Inputs to the riverine model are flood flow hydrographs, derived from hydrological analysis.

For the Bielsdown River at Dorrigo, the data is available to develop a hydrological model of the catchment to the downstream gauging station, Station 204017 "Bielsdown @ Dorrigo No. 2 and No. 3" and to extract design flow hydrographs from this model for Dorrigo itself.

A number of hydrological investigations are required as input for the riverine investigation of flooding and as checks of the results of the riverine investigations.

For the un-named tributary, the difference in catchment size suggests a small scale model for this tributary in isolation is appropriate.

For the Bielsdown River, the required investigations can be categorised as:

- development of a rainfall-runoff-routing model to enable the development of predicted flood inflows to the riverine system;

- development of appropriate "design" rainfall volumes and rainfall temporal patterns so that "design" hydrographs resulting from the "design rainfall" can be derived;

- flood frequency analysis of historically recorded flood events to enable extrapolation to rarer or "design" events and as a cross-check against the results of the hydrological model.

The above three aspects are addressed below.

It should be noted that the assumption that "design rainfall of a particular frequency (return period) will create a flood of the same frequency", is implicit in the above approach. Such an assumption is reasonable in the coastal areas of New South Wales, but becomes questionable in the western areas of the state.

4.2 Hydrology Model - Bielsdown River

Current Australian practice for estimation of flood hydrographs for catchments of similar size to the Bielsdown River involves rainfall runoff-routing models. "Australian Rainfall and Runoff" (Reference 1) identifies suitable models as RORB, WBNM and RAFTS. Other models that could be used involve unit hydrograph techniques or time-area diagrams.

In this instance, RORB has been chosen, principally because:

- all three suggested models are quite similar;
- RORB has been used for the longest period historically;
- the consultant's experience with use of this model.

The RORB model layout is shown on Figure 6. The model comprises of 30 sub-areas and 38 notional storages (representing individual river reaches).

Review of the available rainfall and flow data (see Table 4) suggests that appropriate floods for model calibration/verification are 1973, 1974, 1985, 1989 and 2001.

The principal parameters within the RORB model are:

- catchment storage parameter:	k_c
- non-linearity parameter:	m

Given that the Dorrigo area is a high rainfall area, the rainfall loss model adopted was an Initial Loss and Coefficient of Runoff type model.

The non-linearity parameter was set at the normal value of 0.8.

The catchment storage was initially set at 8.8 (based on Kleemola Equation 9.20, Reference 1).

Testing against the 1973, 1985, 1989 and 2001 floods showed better results were obtained with a k_c value of 9.5.

A comparison of modelled and recorded values for the floods tested appears in Table 6 below, while Figures 7, 8 and 9 illustrate the comparison.

Table 6

Comparison of Modelled and Recorded Floods

Flood	Peak Discharge (cu m/sec)		Coefficient of Runoff	Calibration Verification
	Recorded	Modelled		
1973	440	426	1.0	Verify
1974	470	464	1.0	Calibrate
1977	225	261	0.90	Calibrate
1985	352	316	0.42	Verify
1989	239	240	0.82	Verify
2001	405	354	1.0	Verify

4.3 Flood Frequency Analysis

The object of flood frequency analysis can be viewed as:

- estimation of the recurrence interval of particular sized floods;
- estimate of the recurrence interval for a particular historical flood;
- extrapolate flood behaviour beyond the historical record or interpolate within the historical record period.

The preferred methods of flood frequency analysis in Australia (see Australian Rainfall and Runoff - Reference 1) involve:

- use of peak flood discharges as frequency plots of peak flood height often exhibits discontinuities which affect the analysis;

- use of Log Pearson III as the preferred frequency distribution.

The process generally undertaken for the Bielsdown River at Station 204017, "Bielsdown River @ Dorrigo" was thus:

- conversion of flood heights from a gauge reading to flood discharge using the appropriate height versus discharge table (a rating table), derived from the adopted rating curves in Appendix B;

- assembly of an annual series of flood discharges;
- ranking the flood heights from largest to smallest;
- assigning a frequency plot position to the historical events using the Cunnane formula (Reference 1, Equation 10.5);
- fitting a probability distribution to the plotted data.

The plotted flood frequency appears on Figure 11.

It should be noted that:

- the peak discharges for various frequencies, as derived from Log Pearson III distribution, are given in Table 7 below;
- the actual historical floods plot below the Log Pearson III distribution (with a 1% AEP peak discharge of about 800 cu. m/sec);
- in fitting the Log Pearson III distribution, the complete annual series is used and thus the historical data plots lower than the distribution for rare floods and above the distribution for more frequent flood events.
- the historical events plot between the derived flood discharges and the 95% confidence limit;
- the maximum gauging at Station 204017 No. 3 site (1958 to 1976 inclusive) was 306 cu. m/sec and thus this gauging was exceeded by floods in 1962, 1964, 1965, 1967, 1973, 1974 and 1976 (7 floods). Similarly, the maximum gauging at Station 204017 No. 2 site (1947 to 1957 and 1977 to current day) of 316 cu. m/sec was exceeded by floods in 1950, 1954, 1985 and 2001 (4 floods). Thus, the flood frequency results do rely on a considerable extrapolation of the rating curves above the maximum gauging.

Table 7

Peak Flood Discharges - "Bielsdown @ Dorrigo No. 2 and No. 3"

Frequency		**Discharge (cu m/sec)**	
AEP (percent)	**ARI (yrs)**	**Log Pearson Distribution**	**Fit by Eye**
0.5	200	1330	
1.0	100	1032	794
2.0	50	784	680

Frequency		**Discharge (cu m/sec)**	
AEP (percent)	**ARI (yrs)**	**Log Pearson Distribution**	**Fit by Eye**
5.0	20	518	485
10.0	10	359	371
20.0	5	230	277

The plot of actual discharge versus probability shows a distinct inflection at about the 20% AEP flood level. Above the 20% AEP flood, the recorded floods fit a relatively good straight line. This enables discharges estimates "by line of fit", as tabled in Table 7 above.

4.4 Initial Analysis - Design Hydrographs - Bielsdown River

Australian Rainfall and Runoff (Reference 1) provides "design" rainfalls and temporal patterns that can be utilised by the RORB model to produce "design" flood hydrographs. The design rainfall intensity frequency duration data for Dorrigo appears in Appendix E.

Temporal patterns with durations between 3 hours and 18 hours have been run for the design 1% AEP rainfall for the Bielsdown RORB model (as outlined earlier). The results appear in Table 8 below.

Table 8

Initial Analysis of Peak Flow - Bielsdown River

AEP (percent)	**Duration (hrs)**	**Peak Flow - Bielsdown River (cu m/sec)**	
		Dorrigo	**Station 204017**
1	3	277	763
1	4.5	332	895
1	6	455	1224
1	9	438	1224
1	12	444	1164
1	18	425	1132
10	6	209	587

Table 8 indicates the "critical duration (that is, the storm duration that produces the highest discharge) as 6 hours at both Dorrigo and Station 204017, "Bielsdown @ Dorrigo No. 2 and No. 3". It is anticipated that the "critical" duration at Dorrigo will be between 6 and 9 hours due to the flood storage available in the Bielsdown River, immediately upstream of the Waterfall Way, which is not explicitly included in the RORB model.

4.5 Refinement of Design Hydrographs

The initial design hydrographs, developed in the previous section, were checked against the Rational Method (Reference 1, Chapter 5) and the historical flood data from Station 204017, downstream of the study site.

Design peak flows for the Bielsdown at Dorrigo and Station 204017, "Bielsdown @ Dorrigo No. 2 and No. 3" appear in Table 9 below.

With respect to Table 9, it should be noted that:

- the Rational Method estimates peak flows only and does not estimate the flood hydrograph;
- the statistical interpretation of the Rational Method is essentially a link between the design rainfalls and flows predicted by flood frequency analysis.

Table 9

Comparison of Peak 1% AEP Flows

Analysis Method	Peak Flows	
	Dorrigo	**Bielsdown @ Dorrigo No. 2 and No. 3**
RORB (Section 4.4)	455	1,247
Flood Frequency (Section 4.3): - Fit by Eye (Actual Floods)	N/A	794
- LPIII Distribution	N/A	1,032
Rational Method (As per Chapter 5, Ref 30)	404	872

Review of Table 9 and Figure 11 shows:

- the RORB estimates are significantly larger than the historical floods;
- the RORB estimates are significantly larger than the frequency distribution of the historical data.

The differences between the various flow estimates given in Table 9 were unexpected and warranted further examination.

It is clear that the 1954 flood is the largest flood over the past 60 years. It may well be the largest flood since European settlement. If a flood ranking were produced, the 1954 flood would rank as the largest and thus, by the Cunnane plotting formula, would plot as having a return period of about 100 years. Hence, the 1954 flood would be larger than a 2% AEP event.

Re-analysis of the Dorrigo pluviometer (Station 590067 - Myrtle Street) by the Bureau of Meteorology has shown the rainfall intensity frequency duration data from ARR and used in this study is correct.

Examination of the rainfall intensity frequency durations at Dorrigo for a 1% AEP storm of 6 hour duration shows that the confidence limits for ± 5% represents the mean rainfalls multiplied by factors of 1.54 and 0.65. This range of design rainfalls would produce 1% AEP flood discharges between approximately 810 and 1900 cu. m/sec. The flood frequency data suggests a design discharge for the 1% AEP event as approaching the lower of these two approximate values.

Chapter 3 "Available Data" of this report lists 13 recorded flood levels derived from previous studies and resident interviews.

The recorded flood levels relate to:

- 1950 flood (1 level)
- 1954 flood (5 levels)
- 1971 flood (1 level)
- 2001 flood (6 levels)

The above flood levels are viewed with caution, given the flood marks were derived some time after the flood and most appear to be based as "flood marks on the ground", which can be of limited accuracy.

With respect to the flood levels above, the 1971 flood level could be mistaken for the 1974 flood, given that the 1971 flood is ranked twentieth at Station 204017as opposed to the 1974 flood ranked third and the 1977 flood ranked eighteenth in magnitude (Refer Appendix C). Further, the flood level is considered dubious, being higher than the 1950 and 1954 floods.

The anomaly between the design flood hydrographs as predicted by application of design flood rainfall to the RORB model and historical flood frequency analysis at Station 204017 has been addressed by application of no areal reduction to the design rainfalls in the RORB model.

The approach was taken, mindful of a number of factors:

- the adopted design rainfalls are within the ± 5% confidence limits of the analysis of the pluviometer records at Dorrigo;

- the design one percent AEP flood will exceed the recorded flood levels in Dorrigo for the 1950, 1954, 1974 and 2001 floods;

- the design peak flood discharges exceed the historical flood discharges on a frequency basis; and

- the differences in topography for the two contributing catchments to Station 204017 (Bielsdown River and Rocky Creek), and their proximity to the escarpment, could create significant rainfall variations across the catchments.

- the approach, while satisfactory for the design 1% AEP event, is likely to over-estimate the more frequent events. For example, the approach will indicate the 2001 flood as less than a 20% AEP flood, however, local enquiries suggest that the 2001 flood was rarer than this exceedence probability.

The approach above is considered reasonable, given that the end use of this study will be for land use planning and development controls within and beside the flood liable area. Bellingen Shire Council's land use controls implicitly use the design 1% AEP flood level as the "bench mark" with consideration of floods larger than this event. Thus, the over-estimation of the more frequent floods is not viewed with the same concern as the assessment of the 1% AEP flood event.

The peak flood discharge at Dorrigo required to match the recorded flood levels for the 1954 flood was 370 cu. m/sec. This value was reached by trial using the hydrodynamic model of the Bielsdown River (MIKE-11, as discussed in Chapter 5). Inflow hydrographs were derived using the recorded stage hydrographs at Station 204017 with peak discharges of 260, 330, 340, 370, 380 and 400 cu. m/sec. The recorded stage hydrograph at Station 204017 rises and falls sharply and thus is not reflected by the rise and fall of the hydrographs created from RORB using the ARR design rainfall temporal patterns.

Application of the above constraints results in a zero areal reduction factor being applied to the design rainfall. The resultant peak discharges are listed in Table 10 below. Figure 12 displays the comparison between the historical flood frequency at Stn 204017 versus the design flows.

Table 10

Adopted Peak Flows - Bielsdown River

Return Period		Areal Reduction Factor	Peak Flow (cu. m/sec)	
ARI (years)	AEP (percent)		At Dorrigo	At Stn 204017
500	0.2	1.0	522	1,425
100	1	1.0	455	1,247
50	2	1.0	391	1,075
20	5	1.0	312	861
10	10	1.0	255	709
5	20	1.0	212	595

Figure 13 shows the design flood hydrographs for the PMF, 1% AEP and 5% AEP floods for the Bielsdown River at Dorrigo, and the 1% AEP and 5% AEP events for the Bielsdown River at Station 204017.

4.6 Flood Inflows - Un-named Tributary

The un-named tributary joins the Bielsdown River some 600 metres downstream of the Coramba Road (an extension of Vine Street).

The catchments at the confluence of the Bielsdown River and the tributary are:

- Bielsdown River:	32.2 sq kilometres
- Un-named Tributary:	1.27 sq kilometres

The catchment of the un-named tributary is characterised by its steepness and the steepness of the areas contributing to the tributary.

There are no flow measurements available within this watercourse. The resident interviews did not indicate any recorded flood levels along this tributary nor were they expected to do so, given the isolation of the tributary from any development.

Given the disparity in the catchment sizes and the difference between the un-named tributary and the sub-catchment areas used in the RORB model, incorporation of a finer definition of the un-named tributary into the Bielsdown River was seen as unwise.

There are a number of models that could be used for the un-named tributary to provide flow estimates along the un-named tributary. These are:

- RORB
- WBNM
- DRAINS

The catchment of the tributary has only limited urban development and is thus principally rural.

Both RORB and WBNM are essentially rural models, although WBNM has the facility to separate runoff from pervious and impervious areas (an advantage in dealing with urban development areas).

DRAINS is mainly a pipe drainage network model, however, it does include a module to incorporate the time of travel of runoff. DRAINS was selected principally because incorporation of the time of travel was seen as likely to produce a better estimate of flow hydrographs as opposed to RORB and WBNM, which rely on model parameters based on larger catchments and whose parameters are essentially linked to catchment area only.

The sub-catchment layout for the DRAINS model of the un-named tributary appears as Figure 14.

Testing of the DRAINS model with a variety of duration storms (as per Australian Rainfall and Runoff) indicates the 4.5 hour storm as "critical", as illustrated by Table 11 below.

Table 11

Peak Outflows - Un-named Tributary
(design 1% AEP flood)

Storm Duration	Peak Discharge (cu. m/sec)
15 mins	15.5
30 mins	23.1
45 mins	26.4
60 mins	27.6
90 mins	33.7
2 hours	33.0
3 hours	28.9
4.5 hours	34.8
6 hours	31.7

It should be noted that, although the "critical" storm is 4.5 hours, the time to peak for flood flow with all storms is about 90 minutes and this time to peak is relatively constant throughout the whole model. For comparative purposes, the Rational Method (ARR, Ref. 1, Section 5.4.1) gives an estimated 1% peak discharge for the un-named tributary as 36.2 cu. m/sec.

The design peak flows for a variety of return periods were derived using a storm duration of 4.5 hours, the design rainfalls in Appendix D, and temporal patterns from Australian Rainfall and Runoff, as given in Table 12 below along the various reaches of the un-named tributary.

Table 12

Design Peak Flows - Un-named Tributary

Channel Link [1]		**Peak Flows (cu. m/sec)**						
		Probability (%)						
Upstream Node	**Downstream Node**	**50**	**20**	**10**	**5**	**2**	**1**	**0.5**
A1	A2/A3	1.18	2.9	2.41	3.0	3.5	3.95	4.4
A2/A3	A4/A5	3.8	5.6	6.9	8.5	9.7	11.1	12.4
A4/A5	A6/A7	6.4	9.66	11.7	14.0	16.1	18.3	20.4
A6/A7	A8	8.03	12.3	15.0	18.0	20.7	23.5	26.3
A8	A9/A10	9.45	14.8	18.2	22.1	25.6	29.3	33.0
A9/A10	End	10.9	17.2	21.3	26.0	30.4	34.8	39.1

Note: 1. Refer Figure 14

Comparison of the peak flows for the un-named tributary (in Table 11) and the Bielsdown River at Dorrigo and Station 204017 shows that the un-named tributary represents about 8% of the total flow at Dorrigo, while the differing catchment response times means that the flood peaks from the un-named tributary will arrive at the Bielsdown River before the arrival of water from the upper reaches of the Bielsdown catchment.

4.7 PMF Estimates

The Bureau of Meteorology publishes a variety of methods to estimate Probable Maximum Precipitation (PMP). The catchment size and location of the Bielsdown suggest that the GSDM method "Generalised Short-Duration Method", (Reference 4) is appropriate.

The PMP rainfalls for various durations over the Bielsdown River to Dorrigo are tabulated in Table 13 below.

Table 13

PMP Rainfalls - Bielsdown River @ Dorrigo

Storm Duration	Total Rainfall (mm)
1 hour	395
1.5 hours	505
2 hours	680
3 hours	710
4 hours	805
5 hours	875
6 hours	940

Reference 4 also includes design guidelines for the spatial distribution of a PMP storm together with a design temporal pattern (noting that the design temporal pattern differs from those given in Australian Rainfall and Runoff).

The PMP rainfall was converted to a Probable Maximum Flood (PMF) by application of the PMP rainfall (including the spatial pattern and temporal distribution) to the RORB model for the Bielsdown River and the DRAINS model for the un-named tributary catchment. The results appear in Table 14 below.

Table 14

PMF Flow Estimates

Stream	Critical Duration	Peak Flow (cu. m/sec)
Bielsdown @ Dorrigo	3 hours	1,667
Bielsdown @ Stn 204017	3 hours	3,960
Un-named Tributary	90 minutes	142

4.8 Summary of Hydrological Analysis

The previous sections of this Chapter have outlined the investigation of design flood estimation by several methods.

Table 15 contains a summary of the design flows for the 10%, 1% and PMF floods for comparative purposes.

Table 15

Adopted Design Peak Flows

	10% AEP	**1% AEP**	**PMP**
Bielsdown @ Dorrigo	255	455	1,667
Bielsdown @ Stn 204017	709	1,247	3,960
Un-named Tributary	21.3	34.8	142

5. HYDRODYNAMIC INVESTIGATIONS

5.1 Overview

The object of the hydrodynamic models is to convert flood hydrographs to flood levels at particular locations.

The study area comprising of the Bielsdown River and the un-named tributary, is essentially long and linear. The Bielsdown River, downstream of the Waterfall Way, is essentially confined. Similarly, the side slopes of the un-named tributary can be expected to confine flooding to a relatively narrow strip.

On the Bielsdown River, upstream of the Waterfall Way, there is a relatively wide flood storage area.

To date, Bellingen Shire Council has used the flood extents of the 1954 flood to control development along the Bielsdown River. Further, there is very little development pressure to develop within the 1954 flood extents along the Bielsdown River.

In the above situation, a one dimensional hydrodynamic model is appropriate. There are a number of computer systems available to develop the model, for example:

- MIKE-11
- RUBICON
- ISIS
- HEC-RAS
- SOBEK
- ESTRY

In this instance, MIKE-11 has been used, principally on the basis of its relatively wide-spread acceptance and the consultant's familiarity with this program.

In this instance, MIKE-11 has been used to model the Bielsdown River, while HEC-RAS has been used for the un-named tributary. This approach has been taken because:

- MIKE-11 will model the floodplain storage effects upstream of the Waterfall Way; and

- the un-named tributary is considerably steeper than the Bielsdown River and thus has the potential to create numerical instabilities in the MIKE-11 model if the Bielsdown River and the un-named tributary are combined.

5.2 MIKE-11 Model of the Bielsdown River

The MIKE-11 model of the Bielsdown River comprises:

- three channel links, identified as “BIELS_HEAD”, “UPPER_BIELS”, upstream of the Waterfall Way, and “LOWER_BIELS” downstream of Waterfall Way;

- two notional links to represent the bridge at Waterfall Way and Coramba Road;
- waterway areas defined by 15 surveyed cross-sections.

Figure 15 illustrates the model layout, the surveyed cross-sections, and the river distances (chainages) used to identify these cross-sections.

Table 16 below tabulates the surveyed cross-sections, their assigned river branches and the assigned distances ("River distance") along each channel for the cross-sections. Appendix L gives the plot positions of each cross-section to MGA co-ordinates.

Table 16

Localities – Cross-section River Distances

Locality	River Section	River	River Distance (m)
	B1	Biels_Head	57.8
	B1.5	"	1168.0
	B2	"	1646.0
Junction "Biels_Head" with "Upper_Biels"	B2	Biels_Head Upper Biels	1656.0 820.0
	B2	"	826.8
	B3	"	1052.8
	B4	"	1662.2
Junction "Upper Biels" with "Lower Biels"		Upper Biels	1872.4
Waterfall Way	B5	Lower Biels	0.45 (equivalent)
	B5	"	42.4
	B6	"	637.0
	B7	"	811.8
	B9	"	1325.0
	B10	"	1546.0
Coramba Road			1575 (equivalent)
	B11	Lower Biels	2010.6

Locality	River Section	River	River Distance (m)
Un-named Tributary Confluence			2160.0
	B12	Lower Biels	2379.1
	B13	“	2870.2
	UN1	Un-named Trib	0.0
	UN2	Un-named Trib	322.9
	UN3	“	662.4
	UN4	“	926.4
	UN5	“	1281.9
	UN6	“	1667.3
Confluence with “Lower Biels”			1793.4

The boundary conditions for the MIKE-11 model were:

- hydrographs derived from the RORB model for the upstream point on the Bielsdown River and for the un-named tributary;
- a discharge versus level relationship for the most downstream cross-section (BS13) derived assuming "normal" flow conditions.

The steepness of the Bielsdown River and its virtual confinement to a narrow section downstream of the Coramba Road bridge implies that flood levels in Dorrigo will not be sensitive to changes in the downstream tailwater controls.

5.3 MIKE-11 Model Calibration and Verification

The data available for model calibration and verification along the Bielsdown River is scanty. The data comprises:

- 2001 flood:	six flood marks and estimated hydrograph from RORB model; and
- 1954 flood:	five flood marks and flood hydrograph at Stn 204077 downstream.

The friction within the MIKE-11 model, represented by Mannings `n', is listed in Table 17 below.

Table 17

Adopted Mannings `n' Values

River	Link	Mannings `n'
Bielsdown	"BIELS_HEAD" Ch 0.0 to 1656	0.07
Bielsdown	"UPPER_BIELS" Ch 820.0 to 1373	0.07
Bielsdown	"LOWER_BIELS" Ch 0.0 to 637	0.07
Bielsdown	"LOWER_BIELS" Ch 637 to 2900	0.06

March 2001 Flood

Figure 16 shows the flood profile for the March 2001 flood, while Table 18 tabulates the differences between the recorded and modelled flood levels.

Table 18

Comparison of Flood Levels - 2001 Flood

Point [1]	Channel	Chainage	Flood Levels (m AHD)		Difference (m)
			Recorded	Calculated	
M	UPPER_BIELS	1223	718.6	718.27	-0.33
L	UPPER_BIELS	1501	717.9	717.77	-0.13
J	UPPER_BIELS	1662	717.25	717.60	0.35
I	LOWER_BIELS	18.89	716.84	717.33	0.49
H	LOWER_BIELS	18.89	717.35	717.33	-0.02
G	LOWER_BIELS	215.9	717.82	716.91	-0.91

Notes: 1. Refer Figure 4

The fit between the recorded flood levels and modelled levels is considered reasonable. The most accurate recorded flood level is at Point H, where a photograph was taken near the peak of the flood. Similarly, Point G is considered unreliable, being higher than Point H, but downstream.

February 1954 Flood

Whilst a flood hydrograph for the 1954 flood can be deduced at Station 204017 from the gauge readings, there is no available flow measurements at Dorrigo itself.

Initial runs for the 1954 flood were thus based on the recorded hydrograph at Station 204017, factored by the same proportion as indicated by the design flood between Dorrigo and Station 204017. This approach did not produce sufficient flood volume above the Waterfall Way to match the existing flood levels. Thus, the total flood discharges (and consequently flood volumes) were raised such that a reasonable match was obtained between the recorded and modelled levels upstream of Waterfall Way.

Figure 16 shows the flood profile for the 1954 flood and a comparison between recorded and calculated flood levels is given in Table 19.

Table 19

Comparison of Flood Levels - 1954 Flood

Point [1]	Channel	Chainage	Flood Levels (m AHD)		Difference (m)
			Recorded	Calculated	
F	BIELS_HEAD	1583	721.12	720.97	-0.15
K	UPPER_BIELS	1632	718.78	719.34	0.56
D	LOWER_BIELS	53.1	718.60	718.61	0.01
C	LOWER_BIELS	1524	707.17	710.87	2.70
B	LOWER_BIELS	1574	707.86	708.97	1.11
A	LOWER_BIELS	1792	704.97	706.60	1.63

Notes: 1. Refer Figure 4

The adopted peak of 370 cu. m/sec gave a reasonable comparison of modelled level versus recorded level with realistic Mannings `n' values. This value was reached by trial using the hydrodynamic model of the Bielsdown River (MIKE-11, as discussed in Chapter 5) with peak discharges of 260, 330, 340, 370, 380 and 400 cu. m/sec.

The difference between the recorded flood levels and the modelled levels near the Coramba Road bridge are significant.

Testing with Mannings `n' values as low as 0.04 near the Coramba Road showed that it was difficult to match the recorded flood levels against the calculated levels. Review of Figure 16 shows the recorded levels are quite similar to the 2001 flood profile, suggesting that there may be a datum error in the three recorded flood levels.

On balance, the model calibration is viewed as adequate, given the limited nature of the available data.

5.4 HEC-RAS Model - Un-named Tributary

The HEC-RAS model along the un-named tributary is a steady state model, in that it uses peak discharges only.

There is no flood data available for this waterway. Further resident interviews were seen as unlikely to produce any worthwhile result, given the land use along the waterway is grazing with no building or prominent features near the waterway for flood marks.

In this situation, the friction values Mannings `n' have been set by the consultant's experience and respected texts (eg Chow, "Open Channel Hydraulics"). The Mannings `n' values are:

- Channel: `n' value = 0.066
- Overbank areas: `n' value = 0.060

Tailwater for the HEC-RAS model has been derived from the Bielsdown River model, assuming co-incidence of flood peaks. This assumption is conservative in that it allows for the worst timing scenario for flows both down the Bielsdown River and down the un-named tributary.

5.5 Design Flood Profiles

Design flood profiles were derived for the 20, 10, 5, 1 and 0.5% AEP floods and the PMF flood for both the Bielsdown River at Dorrigo and the un-named tributary. The profiles were derived using:

- design flood hydrographs for the Bielsdown River;

- design peak flows for the un-named tributary;

- the riverine hydraulic models for the Bielsdown River (MIKE-11) and the un-named tributary (HEC-RAS).

The initial analysis of peak flows down the Bielsdown River indicated a critical storm duration for the design storms between 4.5 and 9 hours (Refer Table 8 of this report). Testing of the 1% event for these storms showed the 6 hour storm as producing the highest flood levels along the Bielsdown River, confirming the adoption of the 6 hour storm as "critical".

Figure 17 illustrates the flood profiles for the Bielsdown River, while Appendices F, G and H present numerical information on flood levels, flood flows and flood velocities.

Similarly, Figure 18, Table 12 and Appendices I and J present the same information for the un-named tributary.

The design flood surfaces for the 5% AEP and PMF floods are shown on Figures 19, 20 and 21 respectively as flood contours (to AHD) over the cadastral information at Dorrigo.

The ground information used to define the flood extents on Figures 19, 20 and 21 have been derived from three sources as follows:

- PWD Dorrigo Sewage Compilation Map (1968);
- Ground contour maps with 2 metre contours held by Bellingen Shire Council for Dorrigo, and supplied by the Department of Lands;
- The cross-section survey undertaken for this study.

The cross-section survey is the most accurate representation of the ground surface over the line of the section, but these have limited widespread coverage.

The contours produced by the photogrammetric means (PWD Sewage Plans and Department of Lands contours) were compared at each surveyed cross-section by overplotting of the sections with the ground information taken off the photogrammetric contours.

The conclusions drawn from the comparison of the three data sources at each cross-section were:

- the PWD Sewage Compilation provided a better representation of natural surface than the Department of Lands contours, excepting in the area near Mahogany Street (south of the Waterfall Way);
- a better representation of natural surface (in areas other than those covered by the PWD Sewage Compilation Plans) was derived applying the Department of Lands contours less one metre.

Accordingly, the flood extents have been defined by:

- assessment of the flood extents at each cross-section;
- interpolation between the cross-sections using either the Sewage Compilation data or the Department of Lands contours as outlined above.

5.6 Sensitivity Analysis

Examination of design flood profiles on Figure 17 shows that the Bielsdown River at Dorrigo can be divided into four particular reaches as follows:

- Reach 2, upstream of the Waterfall Way, which acts essentially as a level pool. This behaviour follows principally from the topography and the road embankment for the Waterfall Way.
- Reach 1, being relatively steep and upstream of Reach 2;

- Reach 3 between the Waterfall Way and the Coramba Road bridge, where the Bielsdown transitions from waterway with a small main channel with a wide floodplain to a narrow confined channel; and

- Reach 4, downstream of the Coramba Road bridge, where the Bielsdown River is confined to a narrow channel. The steep sides of the channel indicate that it is unlikely that there will ever be development pressure in this area.

The principal components of the hydraulic behaviour relate to:

- the topography;
- the design flood discharges;
- the frictional resistance of the channel (as denoted by Mannings `n').

The topography is essentially fixed, while the design flood discharges and Mannings `n' values are quantified through the model calibration and verification process.

The sensitivity of the hydraulic modelling system was tested by running the model with:

- design discharges increased by twenty percent;
- the Mannings `n' values increased by twenty percent.

Appendix K provides the predicted flood levels for the design 1% AEP flood and the two sensitivity tests outlined above.

Table 20 below gives the comparison between the design flood and sensitivity tests at a reference point in each of the four river reaches outlined earlier.

Table 20

Comparison of Flood Levels - Sensitivity Runs

Reach	Reference Point		Design 1% AEP (Adopted)	Design 1% AEP Q * 1.2	Design 1% AEP Mannings `n' * 1.2	Difference in Flood Levels	
	Channel	Chainage				(Q * 1.2 less Adopted 1% AEP)	(Mannings `n' less Adopted 1% AEP)
Reach 1	BIELS_HEAD	830.97	727.26	727.64	727.62	0.38	0.36
Reach 1	BIELS_HEAD	1168.00	725.29	725.65	725.65	0.36	0.36
Reach 2	UPPER-BIELS	1504.94	719.93	720.35	720.16	0.42	0.23
Reach 3	LOWER-BIELS	811.8	716.27	716.63	716.61	0.36	0.34
Reach 4	LOWER-BIELS	2010.5	705.01	705.38	705.33	0.37	0.32

Review of Table 20 shows:

- in Reaches 1, 3 and 4, where channel flow is controlled by friction, that the increases in flood level with increased flows or increased friction are similar.
- in Reaches 1, 3 and 4, the increase in flood level with increased friction is less than that created by increased flows. This result is expected.
- in Reach 2, where the Bielsdown River acts as a level pool, friction is a lesser contributor to flood levels. Thus, the increase in flood levels with increased flows (and consequently increased flood volumes) is larger than the increase in flood levels with the increase in the frictional resistance.

The sensitivity analysis above is provided to assist Bellingen Shire Council Floodplain Risk Management Committee's consideration of an appropriate freeboard for development adjacent to the flood liable land.

The MIKE-11 model for the Bielsdown River indicates a head loss, as the Bielsdown passes the Waterfall Way, of 0.86 m under 1% AEP flow conditions. Given the magnitude of the predicted head loss, the loss value has been reviewed by comparison against other methods. Under 1% AEP flood flow conditions, the soffit of the bridge is submerged and calculation methods rely on a sluice gate type formula with a coefficient of discharge.

MIKE-11 offers a number of ways to estimate head loss past bridges. In the Dorrigo model, the US Federal Highways method (identified as FHWA WSPRO) has been used. The bridge afflux, as calculated by MIKE-11 has been checked by other methods as outlined below.

Bradley (Reference 5), for submerged bridges, adopts a coefficient of discharge of 0.8. The implication of adoption of this value, is that the head loss through the bridge will be less than predicted by MIKE-11.

Chow (Reference 6) presents a constricted opening analysis based on the US Geological Survey publication (Reference 8) which in turn leads to a coefficient of discharge. Application of this method at the Waterfall Way gives a coefficient of discharge of 0.6.

Adopting Chow's coefficient of discharge of 0.6 and the method outlined in the US Geological Survey publication, the head loss through Waterfall Way bridge is 0.96 for 1% AEP flood flow, which is 0.1 m more than that estimated by MIKE-11. This relatively small difference validates that head loss estimated in the MIKE-11 hydraulic modelling.

King and Brater (Reference 7) quote model tests for discharge coefficients for orifices between 0.7 and 0.6. The lower values apply to turbulent flow conditions, as occur in rivers during floods.

Given that Bradley's method (for submerged bridges) is based on model tests, but without sufficient information on those model tests, and the weight of information from the other sources, it was decided to place little weight on Bradley's method and to place more weight on Chow, which essentially reproduces the head loss through the Waterfall Way bridge estimated by MIKE-11.

5.7 Provisional Flood Hazard and Hydraulic Analysis

The NSW Floodplain Development Manual (Reference 3) seeks to identify provisional flood hazard at particular locations using the combination of flood depth and flood velocity as illustrated by Figure 25.

The provisional flood hazard categories derived from Figure 25 are "preliminary" and can be modified for local factors such as availability of evacuation routes.

The provisional flood hazard categories for the Bielsdown River at Dorrigo have been derived for the 5% AEP, 1% AEP and PMF events and appear as Figures 22, 23 and 24 respectively.

Figures 22 to 24 were derived by:

- determination of flood hazard at each individual survey point on the surveyed cross-sections (see Figure 4);
- extension of the flood hazard at surveyed points to other areas using the available ground survey from other sources. The particular sources used were:
    - o the Sewage Compilation Map;
    - o 2 metre contours provided by Department of Lands to Bellingen Shire Council.

Both the Sewage Compilation Map and the 2 metre contours were compared to the actual ground survey at the surveyed cross-sections. The Sewage Compilation Map showed a better representation of ground levels and consequently, the Sewage Compilation Map has been used, as the first preference, for extension of the flood hazard mapping.

The NSW Floodplain Development Manual also adopts a definition of floodways as "those areas of the floodplain where a significant discharge occurs during floods".

It adopts a definition for flood storage as "those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood". As a further guide it suggests that flood storage areas are "those areas outside floodways which, if completely filled with solid material, would cause peak flood levels to increase anywhere by more than 0.1 m and/or would cause the peak discharge anywhere downstream to increase by more than 10%."

These definitions are difficult to apply and separate at Dorrigo, where the river system is essentially linear with a single channel and flat floodplain (where floodplain exists). In view of this, a modified approach has been adopted to define the floodways and flood storage at Dorrigo.

Firstly, as it is difficult to separate floodways and flood storage, these areas have been combined and classified as "provisional floodways".

Secondly, the provisional floodways for the 5% AEP and 1% AEP floods were identified by an iterative process where notional floodplain filling was identified, such that the increase in flood levels (after filling) did not exceed 0.1 metres. The filling tested was sited on the right hand side of the Bielsdown River (looking downstream), then modified so that both the left and right hand sides were similarly treated.

The provisional floodways for the 5% and 1% AEP events, using this definition, appear on Figures 26 and 27.

With regard to Figures 26 and 27, it should be noted that:

- filling of the floodplain to the extent shown for the 5% AEP flood would imply a flood level increase in the 1% AEP flood of 0.15 metres, 50 percent higher than the specified limit;

- the floodplain filling tested is located on the eastern side of the Bielsdown River, then distributed about equally between the east and west banks of the Bielsdown (as discussed above). Some filling could occur on the western side of the Bielsdown River, provided it is matched by a retreat from the floodway lines on the eastern side. Such proposals would need to be examined on a case by case basis.

- The survey data base used in this study is not adequate to confidently define the division between “floodway” and “flood storage” through the areas indicated as “floodway” on Figures 26 and 27.

- It would be necessary to obtain additional topographic data and additional floodplain cross-sections to further enhance the hydraulic modelling and refine the delineation of the floodway boundary.

6. CONCLUSIONS

This study, to define flood levels, flood velocity and flood hazard through Dorrigo, follows currently accepted Australian practice, using a rainfall runoff routing model to define flood flows and an hydraulic model to define flood levels and flood behaviour. There is a reasonable number of daily rainfall gauges around the study catchment, but unfortunately, only at Dorrigo within the study catchment.

The nearest flow gauging station to Dorrigo is Station 204017 "Bielsdown River at Dorrigo", located three kilometres downstream of Dorrigo. Adjustment of the flow gauging records for changes in the station's physical location enables a consistent record of floods since 1947 to be created.

A frequency analysis of this data enables flood discharges for various return periods to be completed for Station 204017.

The rainfall runoff model, RORB, was created for the Bielsdown River to Station 204017, which was calibrated against flood events in 1973, 1974, 1977, 1985, 1989 and 2001. Application of design rainfalls derived from Australian Rainfall and Runoff (ARR, Ref. 1) creates design flood flows that are considerably larger than the historical record at Station 204017. However, the hydraulic models indicated that a direct transfer of flows from Station 204017 did not match the historical flood levels at Dorrigo.

Accordingly, a zero areal reduction factor has been applied to design rainfall over the catchment. This approach produces a design 1% AEP flood event similar to the highest recorded flood. The approach will over-estimate more frequent floods, though this is considered acceptable, given that the end use of the flood levels will be by Bellingen Shire Council for setting development controls.

Two hydraulic models were established as:

- the Bielsdown River using MIKE-11 software; and
- the un-named tributary using HEC-RAS software.

There is limited historical flood level data for the 1954 and 2001 floods on the Bielsdown River for model calibration and verification. There is no historical flood level data on the un-named tributary, nor is any information likely to become available because of the isolation of the watercourse from Dorrigo.

The approach adopted is considered adequate, given:

- Bellingen Shire Council's current use of the 1954 flood for planning purposes; and

- the general lack of development pressure in Dorrigo and the ready availability of flood free land in Dorrigo.

The hydrologic and hydraulic models have been used to produce design flood profiles for both the Bielsdown River through Dorrigo and the un-named tributary. The design flood profiles are adequate for assessment of floodplain risk management options and decision making.

Flood surface contours and provisional flood hazard diagrams overlaying the cadastral information have been prepared for the 5% AEP, 1% AEP and PMF flood events.

The installation of a water level recording instrument on the Bielsdown River at Dorrigo itself and two additional pluviometers would enable some of the issues of the discrepancy between the Bielsdown at Dorrigo and Station 204017 to be resolved.

REFERENCES

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GLOSSARY - Terms and Abbreviations

annual exceedance probability (AEP)
the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a peak flood discharge of 500 m^3/s or larger occurring in any one year (see average recurrence interval).

annual flood series
is comprised of the highest instantaneous rate of discharge in each year of record. The highest flow in each year is selected, whether it is a major flood or not, and all other floods are neglected.

Australian Height Datum (AHD)
a common national surface level datum approximately corresponding to mean sea level.

average annual damage (AAD)
depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.

average recurrence interval (ARI)
the long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. This is the inverse of AEP and does not reflect the time elapsed between floods.

Floodplain Management Manual
the management of flood liable land development is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).

disaster plan (DISPLAN)
a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge
the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD)
using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual are related to ESD.

GLOSSARY - Terms and Abbreviations (Cont)

effective warning time
the time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

flash flooding
flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood fringe areas
the remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land
is synonymous with flood prone land (ie land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual (see flood planning area).

flood mitigation standard
the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

floodplain
area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

flood plan (local)
a sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.

flood planning levels (FPLs)
are the combinations of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. The concept of flood planning levels supersedes the "standard flood event" of the 1986 edition of the Floodplain Development Manual.

flood prone land
is land susceptible to flooding by the probable maximum flood (PMF) event. Flood prone land is synonymous with flood liable land.

flood risk
potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types: existing, future and continuing risks. They are described below.

GLOSSARY - Terms and Abbreviations (Cont)

existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

future flood risk: the risk a community may be exposed to as a result of new development on the floodplain.

continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas
those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas
those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

freeboard
a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such and wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change. Freeboard is included in the flood planning level.

hazard
a source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community.

hydraulics
term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph
a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology
term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

GLOSSARY - Terms and Abbreviations (Cont)

local overland flooding
inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam

Manual or Floodplain Development Manual
The New South Wales Government publication "Floodplain Development Manual", 1986

mathematical/computer models
the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

partial flood series
consists of all floods with peak discharges above a selected base value, regardless of the number of such floods occurring each year.

peak discharge
the maximum discharge occurring during a flood event.

probable maximum flood (PMF)
the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.

probable maximum precipitation (PMP)
the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.

probability
a statistical measure of the expected chance of flooding (see annual exceedance probability).

profile
a graph showing the flood stage at any given location along a water surface profile watercourse at a particular time

rating table
a relationship between flood level (as measured by gauge height) and flood flows, usually derived using actual flow measurements

Reduced Level (RL)
a measured height above Australian Height Datum

GLOSSARY - Terms and Abbreviations (Cont)

risk
chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff
the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.

stage
equivalent to "water level". Both are measured with reference to a specified datum.

stage hydrograph
a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

wind fetch
the horizontal distance in the direction of wind over which wind waves are generated.

Organisations

BOM:	Bureau of Meteorology
BSC:	Bellingen Shire Council
DECC:	Department of Environment and Climate Change
DLWC:	Department of Land and Water Conservation
DIPNR:	Department of Infrastructure Planning and Natural Resources
DNR:	Department of Natural Resources
DWR:	Department of Water Resources
MHL:	Manly Hydraulics Laboratory
PWD:	NSW Public Works Department
SES:	State Emergency Service

FIGURES