Final Report for

ORARA RIVER FLOOD STUDY

June 2012

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The Sydney Morning Herald (NSW : 1842 - 1954), Thursday 13 July 1950, page 1

Families See Homes Washed Away By Flooded River

The flooded Orara River has washed away two homes and damaged several others at Glenreagh, about 20 miles from Grafton.

Eight families have been evacuated and are staying with friends.

Mr. C. R. Elks, a dairy farmer, who supplies the township with milk, lost most of his herd and also his home.

He and his wife had to be rescued by boat from their home.

Water forced them into the ceiling and before they could be rescued parts of the galvanised roof had to be ripped off.

Mr. Elks is supplying the town with milk by buying it from a farmer who usually sells his milk for butter.

Mr. Joe Chapman, his wife and three children saw their house washed away down the Orara River.

The approaches to the road bridge at Glenreagh have been washed away and will take some time to repair. The bridge itself is still intact.

The railway bridge to Dorrigo is undermined and it is estimated that about 900 tons of bricks will be needed to build it up.

(Other Flood News, p. 5)

National Library of Australia

The Sydney Morning Herald (NSW : 1842 - 1954), Thursday 11 February 1937, page 9

FLOODS IN ORARA.

RIVER HIGHEST FOR YEARS.

GRAFTON, Wednesday.

Another terrific downpour occurred at Upper Orara, near Grafton. Eight inches of rain fell between 8.30 a.m. and 4 p.m. At 4 p.m. the Orara River was the highest for many years. All bridges and roads were under water, and the district was completely isolated. No cars could get through, and there was no mail delivery. Children were dismissed from Upper Orara School at midday to enable them to get to their homes. All low-lying land was under several feet of water and all creeks become swiftly-running rivers. Heavy falls were also reported from other centres, including Coramba (406 points), Glenreagh (300), Nana Glen (250). The Clarence district enjoyed a good general fall, ranging from 40 points to over an inch. The falls were opportune, as farme.s in parts of the district had been carting water for their own use.

National Library of Australia http://nla.gov.au/nla.news-article17311562

1. Introduction

1.1 NSW Flood Prone Land Policy

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.

Through the Office of Environment and Heritage (OEH) the Department of Planning (DoP) and the State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding and land use planning matters. The Floodplain Development Manual (NSW Government, 2005) is provided to assist Councils to meet their obligations through the preparation of floodplain risk management plans. Figure 1-1 from the Manual documents the process for plan preparation, implementation and review.

Coffs Harbour City Council (CHCC) is responsible for local land use planning in the Orara River and Bucca Bucca Creek catchments, up to and including the village of Nana Glen. Coffs Harbour City Council has prepared a flood investigation for the study area in accordance with the NSW Government's "Floodplain Development Manual: the management of flood liable land", April 2005 (The Manual).

1.2 Key Issue

The Orara River and Bucca Bucca Creek (Bucca Creek) catchments lie to the west of Coffs Harbour forming part of the Clarence River catchment, the two water courses rise in the south and flow generally in a north westerly direction. The catchments are primarily rural, with villages of Karangi, Coramba and Nana Glen located in the catchment.

Floodwaters in both catchments have been known to rise quickly and isolate communities and properties. While flood peaks can recede equally quickly, properties at times can remain isolated for several days. Many houses can be inundated in flood events necessitating evacuations. Rainfall and river gauging data in the catchment is limited, however significant events have been recorded on gauges at Karangi and Glenreagh. In March/April 2009, the second highest flood level recorded since the start of the Glenreagh Gauge (1972) was recorded in the Orara Valley.

1.3 Study Objectives

The primary objective of this study was to define the main-stream flood behaviour under historical conditions and design flood behaviour under existing and future climate conditions in the study area. The study produced information on flood levels, depths, velocities, flows, hydraulic categories, and provisional hazard categories for a full range of design and historical flood events.

To achieve this objective the study would collect, compile and review all available relevant data (including survey, aerial photography and satellite imagery). The design events comprised the:

- 20% AEP (5-year ARI);
- 5% AEP (20-year ARI);
- 1% AEP (100-year ARI);

- 0.2% AEP (500-year ARI); and
- Probable Maximum Flood (PMF).

Hydrologic and hydraulic modelling was undertaken to satisfy the study objectives. The models and results produced in this study can form the basis for a subsequent floodplain risk management studies by CHCC, where detailed assessment of flood mitigation options and floodplain risk management measures could be undertaken.

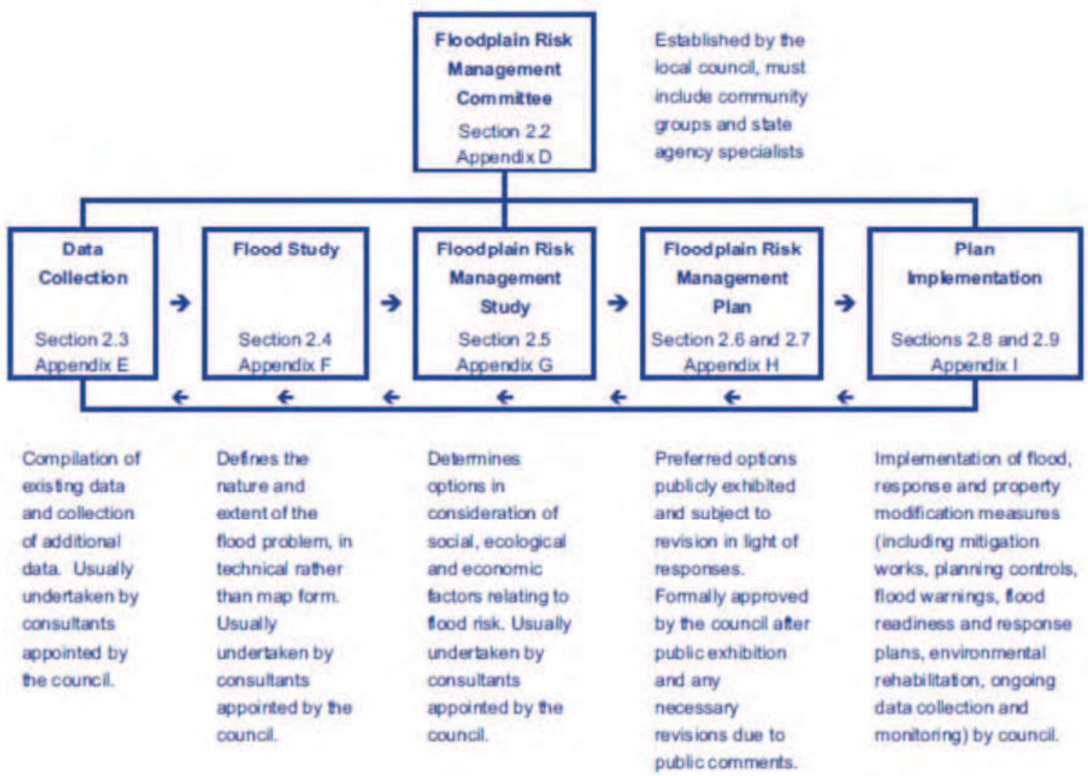


Figure 1-1 Flood Plain Risk Management Process (NSW Government, 2005)

2. Background

2.1 Catchment Description

The Orara River and Bucca Bucca Creek (Bucca Creek) catchments are located to the west of Coffs Harbour on the NSW Mid North Coast (Appendix A). Both creeks drain to the Clarence River. The creeks rise in the south and flow generally in a north westerly direction, through the villages of Karangi, Coramba, Nana Glen and Glenreagh. The main road, Orara Way, is located along the left bank of the Orara River and the Grafton to Coffs Harbour railway line, along the right bank.

The catchment defining the creeks is bounded to the west by Bushmans Range some 2 – 3 km east of Ulong and Lowanna and to the east by Big Boambee, Red Hill and the Coastal Range, approximately 3km west of the Coffs Harbour coastline. The catchment area to Glenreagh is some 433 km^2, and the Orara River has a length of some 66 km. Upstream of Nana Glen the Orara River has a catchment of some 251.2 km^2, while Bucca Creek drains some 115.2 km^2. The Orara River and Bucca Creek confluence downstream of the village of Nana Glen, and receive inflows from a number of significant tributaries, as follows:

- Urumbillum River, Mirum Creek and Fridays Creek, discharging to the Orara River in Upper Orara;
- Wongiwomble Creek discharging to the Orara River near Karangi;
- Nana and Coldwater Creek discharging to the Orara River near Nana Glen; and
- Kings and Finberg Creek discharging to Bucca Creek upstream of Nana Glen.

The catchments in the upstream reaches of these creeks are generally steep and heavily forested. Lower reaches are mostly rural in nature. Downstream of Aurania the Orara River generally has a deep well defined channel with a wide floodplain. River slopes vary from 0.4% between Upper Orara to 0.1% downstream of Nana Glen. Bucca Creek has a smaller channel than the Orara River. River slopes vary from 0.2% at Central Bucca to 0.05% at Nana Glen.

Historically, a number of significant floods have occurred in the Orara Valley. It is understood, from community input that one of the largest floods in the valley occurred on 24 June 1950, when 502 mm was recorded at the Aurania rainfall gauge in a single day and 916 mm fell from 18 to 25 June.

The 10 largest floods on record (noting that the record did not capture runoff data in 1950) at Karangi in order of decreasing magnitude are 1990, 1997, 1973, 2002, 1986, 2000, 1989, 1971, 1996, and 1982. (Pinneena, v 9.3). In March/April 2009, five significant events were recorded at the Glenreagh runoff gauge, all exceeding or close to the “Moderate Flood” classification. Of these the March/April 2009 event provided the highest peak, with a flood depth of some 13m above the creek invert at the gauge. This depth signifies a “Major Flood” classification.

Floodwaters in both catchments have been known to rise quickly and isolate communities and properties. While flood peaks can recede equally quickly, properties at times can remain isolated for several days. Many houses can be inundated in flood events necessitating evacuations. The nature of flooding varies considerably from in-stream flood ways to areas where the floodwaters bypass bends in the river and where floodwaters backup into the lower reaches of tributary creeks. Rainfall and river gauging data in the catchment is limited, however significant events have been recorded on gauges at Karangi and Glenreagh. In 1991, a preliminary assessment of flooding in the two valleys was undertaken (CHCC, 1991).

2.2 Previous Studies

The Flood Study for Orara River and Bucca Creek Valleys, June 1991 (CHCC,1991) is one of the more recent flood studies undertaken for the Orara catchment. This study made mention, and included findings of earlier assessments, particularly by Coffs Harbour City Council in 1982 and Sinclair Knight in 1984 which provided information on bridge upgrades. These earlier studies could not be located for the current study, however were referenced throughout the 1991 study.

The June 1991 study was a preliminary investigation to provide a reasonable assessment of the land within the study area adjacent to the main river system which might be liable to inundation in the 1% AEP flood event. Only limited survey and preliminary hydrologic and hydraulic analysis was required. The theoretical analysis was to be supplemented with readily available data held by various authorities, previous flood studies, interviews with local residents, field survey data and an examination of aerial photographs. The study brief prepared by Council outlined the following tasks:

- Undertake a survey to determine if there is any local knowledge of significant flooding in the creek systems draining the Study Area which might be used in the flood study;
- Examination and collation of existing data available from Council's records in relation to historical and estimated flood levels at locations within the study area;
- Determination of peak flow rates for the creek system within the study area for the 1% AEP event;
- Determination of water surface levels in the creek system for the 1% AEP event; and
- Assess the areas of land likely to be inundated during the 1% AEP event, with the areas of expected inundation shown on a 1:25 000 map of the study area.

The assessment was to be based on experience and professional judgement and was to be based on a collation of historical data and reports on flooding in the area. It was to be limited primarily to flooding from the Orara, Urumbilum and Bucca Creek systems. The brief specifically excluded the need for extensive survey detail or rigorous hydraulic and hydrological analyses.

3. Data

3.1 Introduction

For the purposes of undertaking the flood study, and to calibrate models, the following key data was sourced:

- Concurrent rainfall and runoff data for significant flood events that was able to be used for calibration of the hydrological model parameters;
- Pluviographic rainfall data at 6 minute intervals to provide information on historic storm temporal patterns;
- Daily rainfall data to provide spatial distribution of rainfall events;
- Runoff gauge data, including gauge history and rating curves, to determine hydrographs of flood events; and
- Topographic survey data for the compilation of flood models and for the purposes of flood modelling.

3.2 River Data

3.2.1 Runoff Gauges

Three river gauges are located along the Orara River (Refer to Appendix B and Table 3-1). These gauges were suitable for calibration, as they:

- Are located at appropriate positions along the river channels for the purposes of the study;
- Had captured significant flood events;
- Had reasonable gauging data and rating tables to provide information on reported hydrographs during flood events. It is important to note, that while operational dates may span a number of years, for some of the gauges earlier measurements were only captured as daily totals; and
- Had data periods that were concurrent with pluviographic rainfall data in the catchment.

Table 3-1 Runoff Gauge Data

Gauge Number	Gauge Name	River	Operational Dates	Comments
204906	Orara River At Glenreagh	Orara	15/11/1972 – Present	Orara River Approx. 2 km Upstream Of Glenreagh
204068	Orara River At Orange Grove	Orara	14/08/1995 – Present	11.12km upstream of Coramba, Approx. 4 km upstream of Karangi Dam
204025	Orara River At Karangi	Orara	31/10/1925 – Present	6.83km upstream of Coramba, Approx. 250m downstream of Karangi Dam

3.2.2 Flood Frequency Assessment

Flood frequency analysis was undertaken using the data provided by the Pinneena (Version 9.3) software, for the Orara River at the Karangi Gauge (204025) and at the Glenreagh Gauge (204026). Appendix B provides background data with respect to the gaugings and the rating curves for these gauges, which was used to convert the measured flood levels to flood discharges. Referring to the two figures, the following is noted:

- The Glenreagh Gauge rating curve is reliant upon gauging data to a gauge level of approximately 8.5 m, which was a single point measured on 14/03/1974. Prior to this gauging, two measurements were taken on 14/03/1974 and 08/03/1995 with a gauge level of 7.5 m. These two points were found to be in good agreement. Beyond these stages, the rating curve relies on extrapolation up to a gauge level of approximately 14 m; and
- The Karangi Gauge is reliant upon gauging data to a gauge level of approximately 3.5 m, which was a single point measured on 24/04/1988. Beyond these stages, the rating curve relies on extrapolation up to a gauge level of approximately 6.8 m and the curve generally shows a “S” shape without confirmation through gaugings.

Thus beyond the gauge level of 7.5 m at Glenreagh and 3.5 m for Karangi, the reported flood flows in Pinneena need to be treated with circumspection. In the case of the Glenreagh station, a further concern is that the top of bank level near the gauge occurs at approximately 12 m flow depth above the creek invert (as measured off a river cross-section) near the location of the gauge, at which point flow would emerge onto a very wide flood plain. Thus for a small increment in flood stage, a significant increase in flow would be expected. These issues are well known and noted in previous flood studies (CHCC, 1991).

While the emergence onto the floodplain is likely taken into consideration when the rating curve was extrapolated, a further concern is that the gauge is located near a meander in the creek and the floodplain moves from the left bank to the right bank shortly downstream, with an increased influence of the railway embankment. These local influences could play a role as soon as the flow discharges onto the floodplain.

Notwithstanding these concerns, the Pinneena flood frequency analysis is provided in Appendix B which nominates a 1% AEP flood peak estimate of between 2080 m^3/s and 671 m^3/s at the Glenreagh Gauging Station based on the a reasonably short period of data since 1972. The median is determined by the flood frequency analysis as approximately 1000 m^3/s, at a gauge level of approximately 13.7 m, when flow has emerged onto the floodplain and within the area of circumspection of the rating curve. In fact 13.7 m is beyond the extrapolation of the rating curve, which ends at gauge level of approximately 13.5 m.

The 1% AEP estimate of flood peak at the Glenreagh gauge based on the Pinneena flow record flood frequency analysis is thus likely to be reasonably uncertain, evidenced by the large variance between the nominated estimates. On the basis that the March/April 2009 event measured a gauge level of 13.1 m, if the Flood Frequency Analysis estimate were to be accepted, this event would have been less frequent large event (say 5% to 1% AEP). However given the issues discussed above in relation to the Flood Frequency Analysis, it could be that the March/April 2009 event was a more frequent large event (say around a 10% AEP event).

As further background to the March/April 2009 event, the following Glenreagh Gauging Station remarks were made:

01/04/2009 04:00 REMARK April 2009 flood event. Site decommissioned for upgrade. Flood peak not recorded. Hydrograph estimated as follows; Manual staff gauge read 31.3.2009 0915hr 2.16 m Manual staff gauge read 31.3.2009 1105hr 4.39 m Thereafter gauges approx. due to local flooding Peak by debris 13.1 m (Good mark on 12-13 gauge post) . Local residents advised peak at approx. 4am 1.4.09. 12-13 gauge levelled 2.4.09. STABLE. Refer level book Lockeridge 16, page 6. Recession picked up at 8.01 m by temporary installation. Shape of hydrograph formed with reference to 204025 hydrograph.

Thus this measurement and hydrograph shape recorded during the event at the Glenreagh Gauging Station would also need to be treated with circumspection.

3.2.3 Calibration Event Data

The flow gaugings in Table 3-1 were interrogated to abstract significant events for calibration. These were events where concurrent pluviographic rainfall data was available in the catchment. Events that were considered appropriate for calibration are listed in Table 3-2 below.

Table 3-2 Calibration Event Data (at Glenreagh)

Event	Date	Flood Peak Date	Flood Peak Level (m)	Pinneena Reported Flow (m^3/s)
March 1974	1974.03.10	18/05/1977 10:36 pm	12.89	844
February 2001	2001.02.02	02/02/2001 8:30 am	10.65	564
February 2009	2009.02.16	17/02/2009 2:45 pm	11.78	695
March/April 2009	2009.04.01	01/04/2009 3:54 am	13.12	869

3.3 Rainfall Data

3.3.1 Data Availability

A number of rainfall gauges (Refer to Appendix B) are located within the Orara River catchment, which include Bureau of Meteorology (BOM) gauges tabulated below and gauges operated by Manly Hydraulic Laboratory (MHL, 2009). While the daily rainfall data gauges are numerous, there are only a few pluviograph gauges in the catchment that provide temporal information on historic storms. These include the Aurania Gauge within the Orara Valley, a number of MHL gauges around Coffs Harbour and the BOM gauge at the Coffs Harbour Airport. The MHL gauges are located in close proximity to, and east of the steeply rising topographic relief along the Coffs Coast. Here orographic effects are shown to have a significant effect on rainfall (CHCC, 2001). These effects were confirmed through preliminary assessment of the gauges during for the March/April 2009 event. The daily rainfall gauges are useful to determine any spatial distributions of rainfall that may have occurred during a significant storm event. The pluviographic rainfall station 059026 (Aurania) was primarily used to provide temporal patterns for the purposes of calibration, as it:

- Is located within the catchment;
- Had the longest period of record, coincidental with the runoff gauge data; and

- Provided 6 minute rainfall data for a number of significant storm events;

Where possible, calibration was undertaken using the Aurania pluviographic rainfall temporal pattern to represent rainfall patterns in sub-catchments draining to the Orara River. During the March/April 2009 event, where the Aurania data was incomplete, the Coffs Harbour rainfall gauge (59040) was used to supplement temporal information. Rainfall depths in each sub-catchment were derived from daily rainfall gauges in order to simulate the spatial distribution of rainfall throughout the catchment.

Table 3-3 A selection of available Rainfall Data from BOM

Gauge Number	Type	Operational Dates	Comments
059009 – Coramba (Glenfiddich)	Daily	1891 – Present	Confirmation of rainfall distribution with Aurania Gauge
059042 – Glenreagh PO	Daily	1953 – Present	Confirmation of rainfall distribution with Aurania Gauge
059006 – Lower Bucca	Daily	1901 – Present	Confirmation of rainfall distribution with Aurania Gauge
059095 – Upper Orara (Dairyville)	Daily	1899 – Present	Confirmation of rainfall distribution with Aurania Gauge
059026 – Upper Orara (Aurania)	Pluvio and Daily	1970 – Present	Calibration with Orara River
59040 – Coffs Harbour	Pluvio	1960 – Present	Calibration with Orara River (March/April 2009 Event)

3.3.2 Daily Rainfall Frequency Assessment

To obtain a better estimate of the AEP of the March/April 2009 event , given the relatively short runoff gauge data at the Karangi and Glenreagh river gauging stations, daily rainfall records were interrogated. Analysis was undertaken for the Aurania, Coramba and Glenreagh rainfall stations, collating both 1 day and 3 day consecutive total rainfall depths. The three gauges, which are expected to be a good representation of rainfall throughout the Orara catchment, showed similar trends, namely:

- That the occurrence of significant rainfall events (see Figure 3-1 as a typical example) in the order of magnitude of the March/April 2009 event is common prior to 1972 (which marks the start of the runoff gauge data at Glenreagh). It is thus conceivable that the AEP of the March/April 2009 rainfall event could be a more frequent occurrence; and
- Comparing the results of the rainfall frequency assessment in Figure 3-3 below, the measured 1-day and 3-day rainfall totals at three rainfall gauges during the March/April 2009 event, would equate to between a 4.5% and 13.2% AEP rainfall event. In terms of ARI this would be between a 1 in 7.6 and 1 in 22-year ARI event.

Of the above rainfall gauges, the only operational gauge during the June 1950 event was the Aurania gauge, which measured a 1-day rainfall total of 502.9 mm and 3-day rainfall total of 643.1 mm. This would approximately equate to between a 1% and 2.5% AEP rainfall event. For this June 1950 event, 250 mm fell in the 6 days preceding the peak rainfall and 100 mm fell after the peak rainfall. Thus the Orara Valley would have been saturated and it is likely that this event would be closer to a 1% event.

Comparing the Aurania, Coramba and Glenreagh rainfall gauges thus confirms that the March/April 2009 event was likely between a 4.5% and 13.2% AEP rainfall event throughout the Orara Valley.

Figure 3-1 Typical 1-Day Rainfall Totals at Aurania

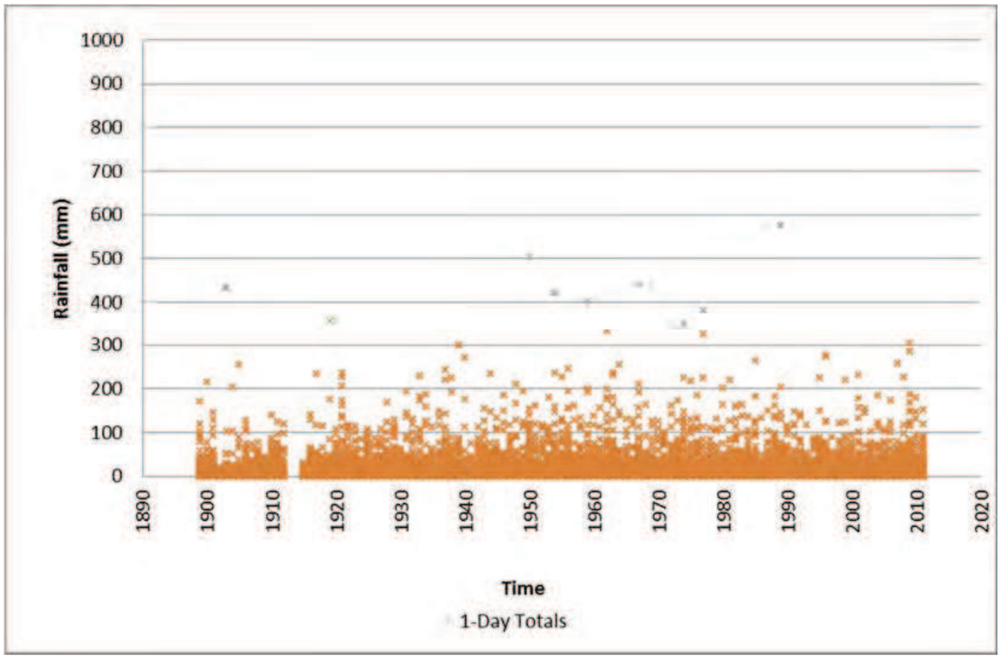


Figure 3-2 Typical 3-Day Rainfall Totals at Aurania

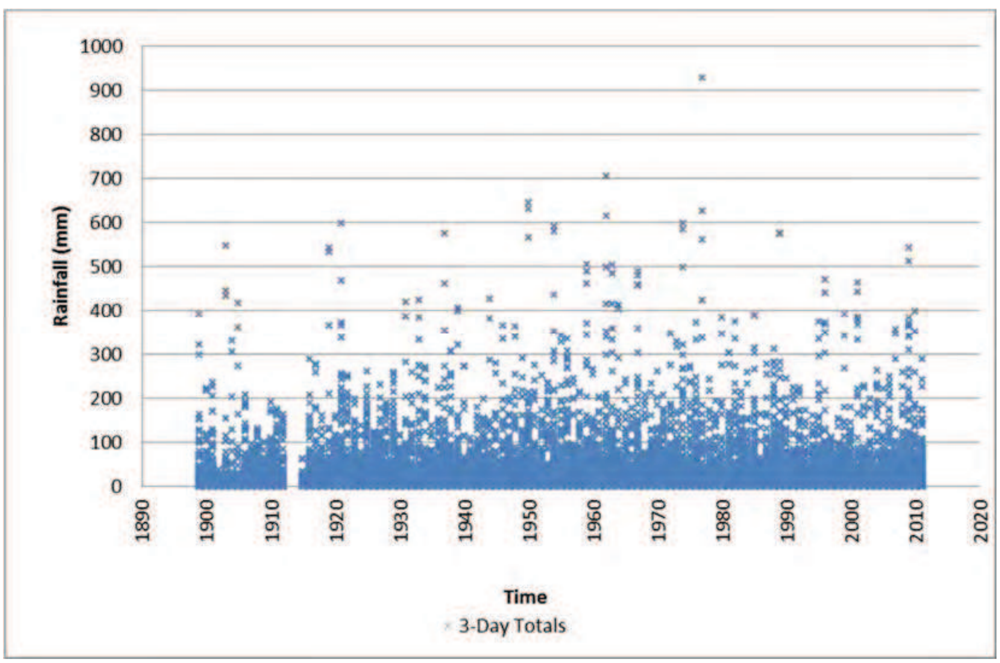
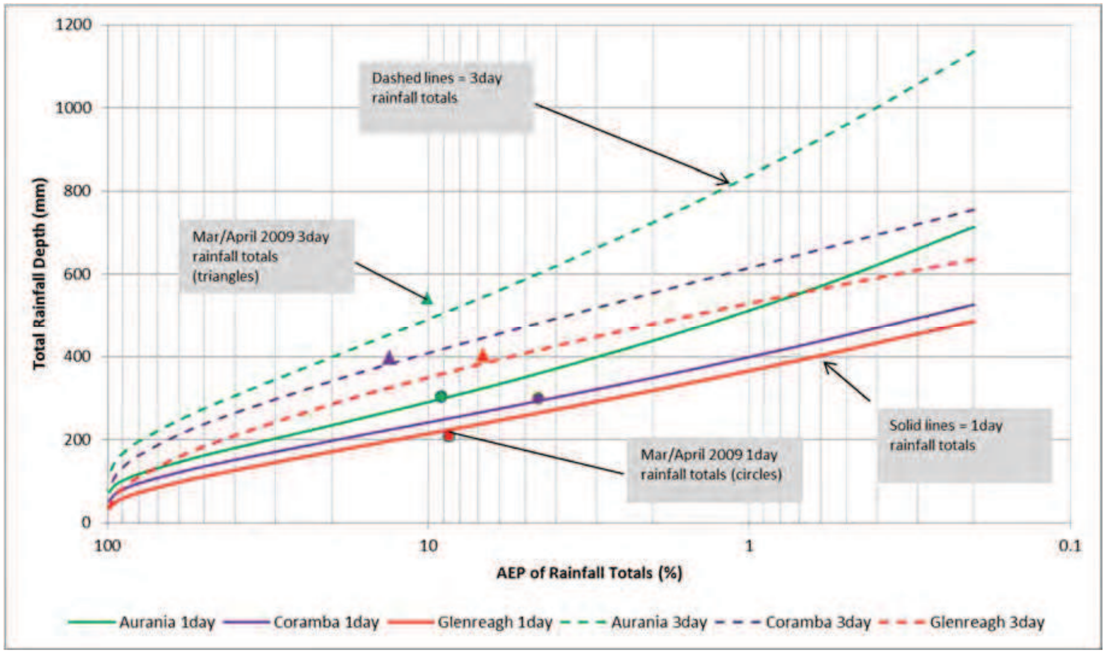


Figure 3-3 Frequency Analysis of 1 and 3-Day-Total Rainfall Totals at Aurania, Coramba and Glenreagh Gauges



3.3.3 Observed Flood Heights (Flood Markers)

A field survey of March/April 2009 flood levels has been undertaken by Coffs Harbour City Council. This information was provided as a GIS file of flood markers. In total 36 measured flood levels were provided throughout the Orara and Bucca Bucca catchments. The flood markers ranged from debris marks on edges of the flood plain to levels observed on walls and fence posts. For each flood marker, observations sheets were provided that nominated key markers details. The observation sheets were assessed as part of the current study and given a rating, as to whether the flood markers were considered to be high, medium or low accuracy. The findings of this assessment together with details of the flood markers are provided in Table 3-4.

The information provided by the flood markers is extremely useful for the purposes of calibrating the flood model. To this end, the flood model was simulated for the March/April 2009 event, and the modelled flood levels compared to each flood marker, in Section 6.3.

Table 3-4 Observed Flood Markers

ID	Easting	Northing	Surveyed Flood Level (mAHD)	Name and Contact Details	Rating (1=high, 2=medium, 3=low)	Comment
1	509110.125	6657389	111.38	Not available	1	*tall structure/landmark visible on flood plain*
3	509534.1563	6662875.5	88.13	McCrae's Bridge, Bucca Road	3	*level to underside of headstock at bridge, local hydraulic effects likely to occur*
4	508580	6666298	82.40	McClellands Road	1	*tall structure/ landmark visible on floodplain*
5	501735.9688	6666907.5	74.06	Nana Glenn Show Ground	1	*visible high water mark on structure*
6	501833.8125	6667110	74.55	Morrows Road	2	*large walled structure/landmark on side of floodplain, potential for local influences to occur*
7	501837.375	6667121	74.37	Morrows Road	2	*large walled structure/landmark on side of floodplain, potential for local influence to occur, discrepancy with FL6 (10m away) unlikely to occur*
8	501251.2188	6668707.5	73.19	271 Morrows Road	1	*visible high water mark on structure*
9	501069.1875	6669415	72.60	355 Morrows Road	1	*debris pile and surveyed flood level at ground level on edge of flood plain*
10	504643.2188	6666955	77.51	Number 40 Hallgarths Road, Strainer Post	2	*strainer post on property corner, flood level likely observed from nearby residence*
11	504403.9688	6666882	76.73	Number 40 Hallgarths Road, Tree Stump	2	*large structure/landmark in floodplain, likely observed from residence*
12	501198.2188	6663768	78.20	927 East Bank Rd - Garry Dew (02) 66543211	2	*no debris, floodmark located at ground level on edge of floodplain, likely observed by residents*
13	501634.5313	6663987	78.24	927 East Bank Rd - Garry Dew (02) 66543211	2	*strainer post on property fence, peak unliklely to be observed during flood, flood marker noted*
14	500200.625	6650783	119.62	Upper Orara Public School - Julie Lustard 6653 8255	1	*visible high water mark on door, likely to be accurate*
16	500928.7813	6648925.5	127.08	55-59 North Island Loop Road - Mrs Ide	2	*strainer post on property corner, flood level likely observed from nearby residence*
17	501091.1563	6652679	112.01	Watkin Road	2	*debris mark on star picket fence, flood level unlikely to be observed*

ID	Easting	Northing	Surveyed Flood Level (mAHD)	Name and Contact Details	Rating (1=high, 2=medium, 3=low)	Comment
18	504468.4688	6652961	104.67	Pwer Pole #56348, Upper Orara Road, Karangi	1	*in town, debris pile/high water mark on fence, likely observed by residents during event*
19	501759.7188	6654824.5	92.21	86A Hartleys Road - Kevin Hartley 0417 660173	1	*visible high water mark on structure*
20	501658.25	6659178	88.79	Coramba Rec Reserve - Michael Duck 0419 685664	1	*visible high water mark on structure*
22	501719.0313	6670787.5	70.66	Timber Mill - Alan Biggin (02) 66543261	1	*visible high water mark on structure*
23	510011	6661143	93.13	"Rothglen", Wears Road	2	*debris on fence line, unlikely observed during event*
24	501764.4375	6666639	74.00	Morrows Road	1	*debris and high water mark visible on bridge structure*
25	501117.6875	6666568	75.30	Nana Glenn Sports Ground	1	*visible high water mark on structure*
26	500961.7188	6663444	79.80	927 East Bank Rd - Garry Dew (02) 66543211	2	*debris mark on strainer post on river bank, unlikely to be observed during event*
27	500870.4063	6649628	127.70	700 Upper Orara road - Phil Doyle (02) 66538352	2	*observed flood level, likely observed by nearby residents during event*
28	498377.3438	6647031	147.81	North Island Loop Road, Upper Orara - Len Wood (02) 66538116	2	*level likely observed by nearby residents, debris mark at base of stake*
29	501777.4063	6656348	95.61	Coramba Timbers	1	*visible high water mark on structure*
30	501565.25	6656618.5	94.33	8 Martin Street	1	*water mark observed over floorboards*
31	506397.6563	6667338.5	79.23	"Horsing Around", Randalls Roads	2	*flood mark on fence, road was cut off, likely observed by local residents*
32	509127.5313	6657698	109.95	"Sunnyside Park", No. 111 Central Bucca Road	1	*water mark confirmed by residents*
35	500960.327	6652405.735	112.40	Orange Grove Gauge	1	*Orange grove gauge, real-time recorded data*
36	503045.777	6652955.937	104.90	Karangi Gauge	1	*Karangi gauge, real-time recorded data*

3.3.4 Summary on Data

From the above the following is summarised:

- The rating curves at the Glenreagh and Karangi flow gauges stations needs to be treated with circumspection when using this data for larger events;
- The 1% AEP estimate of flood peak at the Glenreagh gauge based on the Pinneena flow record flood frequency analysis is thus likely to be reasonably uncertain, evidenced by the large variance between the 95% and 5% nominated estimates; and
- While the March/April 2009 event was a large event, a number of rainfall events of similar magnitude have occurred historically. On the basis of a rainfall frequency assessment the March/April 2009 event was approximately between a 5% and 10% AEP rainfall event, in-terms of 24hr and 72hr rainfall. Thus it is conceivable that the March/April 2009 event could be in the order of a 10% AEP event, particularly in the lower parts of the catchment.

3.4 Topographic Survey

As part of the study, survey data was compiled as follows:

- Digital Terrain Model (DTM) data to describe the topography and floodplains of the Orara River through the Coffs Harbour City Council local Government area; and
- Terrestrial survey of key features such as bridges and particular areas where the LIDAR data was limited.

Coffs Harbour City Council does not possess LIDAR data for the Glenreagh area, since this is located beyond the limits of the Coffs Harbour City Council Local Government Area. Thus the limit of available LIDAR data intersects the Orara River approximately 4km upstream of the Glenreagh River Gauge. Further topographic data was surveyed as part of this study, which included cross-sections of the Orara River and floodplain, from the extent of the available LIDAR data, to the Glenreagh Gauge. In addition, in selected areas where the LIDAR data was limited, additional topographic survey was carried out.

4. Community Consultation

4.1 Overview

The primary objectives of the flood study consultation activities were as follows:

- Informing the relevant government agencies (for example Office of Environment and Heritage, State Emergency Services) that the study is being undertaken, outlining its objectives and inviting agencies to provide any relevant data they may hold and / or advise of any particular issues of concern;
- Similarly informing relevant local community groups; and
- Similarly informing the general public.

4.2 Floodplain Risk Management Committee

The purpose of the Floodplain Risk Management Committee is to:

- Act as both a focus and forum for the discussion of technical, social, economic, environmental and cultural issues and for the distillation of possibly differing viewpoints on these issues into a management plan; and
- Ensure that all stakeholders (often with competing desires) are equally represented. As such, the composition and roles of committee members are matters of key importance.

The Floodplain Risk Management Committee does not have any formal powers. Rather, it has an advisory role, but an important one. The principal objective of the committee is to assist the Council in the development and implementation of a management plan for the area(s) under its jurisdiction.

4.3 Consultation Activities

4.3.1 Project Notification, Newsletter and Survey

A public notice was placed in the local newspapers. In addition a project information sheet and survey was forwarded to the residents in the Coffs Harbour and Clarence Valley local government areas (Appendix C) and an ABC Radio interview with the GHD Project Manager was broadcast. A total of 206 survey responses were received, from residents spanning the entire catchment area. Key issues raised in the survey were:

- A large number of the residents had experienced flooding in the Orara Valley, first hand ;
- Flood levels tend to rise and recede very rapidly, often within the space of a day. Isolation of residents and inundation of paddocks is common. While floodwaters can recede rapidly, isolation could last for a number of days in some areas of the floodplain;
- Many residents often mentioned the 2009 floods and these have been etched in memories of the community. A number of residents noted elevated levels of anxiety during rainfall events. Some residents noted that flood waters had impacted their dwellings and flowed through the house;
- A number of residents noted the possession of photographs, and had knowledge of flood levels. Many of these referred to debris marks on fences, in paddocks and indicated areas of inundation on their properties. These types of flood markers would generally be noted as lower accuracy;

- A number of residents noted damages associated with flooding to dwellings and boundary fences. In addition loss of personal effects such as tools and other equipment;
- Preparation for flooding includes regular observation of river levels and lifting of belongings. In addition, listening to advice on local radio stations and from the SES. Personal belongings, vehicles and other equipment is moved to higher ground;
- A number of residents noted local stormwater problems and nuisance flooding after heavy localised rainfall; and
- Residents noted issues with regards to fallen trees and debris blocking structures and the river channel. In addition erosion of the creek channel and landscape was noted in a number of responses together with road damage and land slips.

4.3.2 Community Meeting

A community meeting was held at the Coramba Community Hall on the 30/04/2012. The meeting was advertised in the local newspaper and at key locations in the Orara Valley, including Karangi, Coramba and Nana Glen. Attendance at the meeting was low with only two members of the community attending, in contrast to the 206 written responses provided. It is possible that the community considered their written input sufficient and saw no need to attend a meeting. Notwithstanding, a presentation of the study (Appendix C) was provided and the community members engaged in much discussion. Key comments made, included amongst others:

- That the 1950 flood was the most significant event in the Orara Valley. During this event much infrastructure was damaged, including a washout of the railway embankment at Nana Glen;
- That the March/April 2009 event was significant however, not nearly as large as the 1950 event;
- That flood waters generally rise rapidly and dissipate over 1 to 2 days; and
- That the rainfall in the upper catchment is higher than the lower catchment and that a rainfall distribution could be expected across the catchment.

The community members were shown the 1% AEP flood extent, and confirmed that this flood coverage representation was similar to what was remembered to have occurred during the 1950 flood.

5. Hydrologic Model Configuration and Calibration (RORB)

5.1 General

The hydrology for the Orara flood study was developed using the RORB hydrological model. The model was setup as an end of catchment model, producing flood hydrographs for the Orara and Bucca Bucca Rivers upstream of the Glenreagh runoff gauge.

RORB is a general runoff and stream flow routing program used to calculate flood hydrographs from rainfall and other channel inputs. It subtracts losses from rainfall to produce rainfall-excess and routes this through catchment storage to produce runoff hydrographs at any location. It can also be used to design retarding basins and to route floods through channel networks.

The program requires a data file to describe the particular features of the stream network being modelled and is run interactively. It can be used both for the calculation of design hydrographs and for model calibration by fitting to rainfall and runoff data of recorded events.

The model is aerially distributed, nonlinear, and applicable to both urban and rural catchments. It makes provision for temporal and areal variation of rainfall and losses and can model flows at any number of gauging stations. In addition to normal channel storage, specific modelling can be provided for retarding basins, storage reservoirs, lakes or large flood plain storages. Base flow and other channel inflow and outflow processes, both concentrated and distributed, can be modelled. (RORB 6 User Manual).

5.2 Configuration

Compilation of the RORB model included:

- Catchment delineation, in accordance with the RORB procedures. For the Orara model a total of 658 subcatchments were delineated;
- Catchment parameter determination, namely subcatchment area reach lengths and slopes;
- Event rainfall and concurrent flow data compilation, for calibration; and
- Design rainfall determination for generating design storm rainfall events, for the 0.5%,1%, 2%, 10% and 20% AEP events together with the Probable Maximum Flood (PMF).

The RORB model was simulated for a range of durations ranging up to 72 hours. For each event the critical duration was reported, being the duration at which the peak flood flow occurs. Lag times were based on average slopes and flow velocities, ranging between 1 m/s and 2 m/s depending on slope. Percentage of impervious areas, used in the hydrology model, was 5% to represent the rural nature of the catchment. Catchment maps and sub-catchment delineation are provided in Appendix D.

5.3 Calibration

5.3.1 General

The RORB model was calibrated by variation of model parameters to obtain a good fit of the calculated to the measured hydrograph. The parameter kc is the main means of achieving a fit. The parameter, kc, can be decreased to increase the hydrograph peaks and decrease the lag time. Conversely, increasing kc does the opposite. In addition to kc, varying the initial loss is also an important means of achieving a fit. A further means is by altering the 'm' parameter (a measure of the catchment's non linearity) however use of this parameter for calibration is less common.

5.3.2 Regional kc Parameter

A number of regional estimates for the determination of kc are available throughout the literature and in the Australian Rainfall and Runoff (AR&R 2001). A number of these are offered within the RORB model for use in calibration. For the Orara RORB model, possible regional estimates of kc parameters are tabulated below.

Table 5-1 Possible Orara RORB model Regional kc Parameter Estimates

Method	kc Estimate
Eastern NSW (Kleemola) (Eqn 3.20, ARR (Book V) $Kc = 1.22\ A^{0.46}$	19.92
Australia Wide – Dyer (1994) data (Pearse et al, 2002) $Kc = 1.14\ D_{av}$	35.67
Australia Wide – Yu (1989) data (Pearse et al, 2002) $Kc = 0.96\ D_{av}$	30.04
RORB Default – Eqn 2.5 (RORB Manual) $kc= 2.2A^{0.5}\ (Qp/2)^{0.8-m}$	45.79

5.3.3 Calibration – March/April 2009 Storm (30/03/2009)

This event started with rainfall on 30/03/2009 which lasted for 5 days. The Aurania pluviographic rainfall gauge was not operational during this event. To source other pluviographic information, the MHL gauges around Coffs Harbour were investigated. However, as discussed in Section 3.3.1, these gauges are located in close proximity to, and east of the steeply rising topographic relief along the Coffs Coast. Here orographic effects are shown to have a significant effect on rainfall (CHCC, 2001).

Since no other pluviographic rainfall data was available, the rainfall temporal distribution recorded at the Coffs Harbour pluviographic gauge (059040) was applied. This data was sourced directly from the Bureau of Meteorology. During this event the rainfall totals shown below in Table 5-2 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-2 March/April 2009 Event Rainfall Distribution

Date	Daily Rainfall Totals (mm)					
	Nana Glen	Lower Bucca	Coramba	Dairyville	Aurania	Glenreagh
30/03/2009	2.6	4	5.7	31	21.8	0
31/03/2009	62	80	79.2	likely missing data	186	68
1/04/2009	274	266.8	283.4	likely missing data	304.6	210
2/04/2009	45	14.8	34.4	29	51	34
3/04/2009	17	18.2	20.2	likely missing data	8.4	10
TOTAL	416	401.6	434.8	78.6	550	332

Preceding the storm the antecedent conditions within the catchment were rather wet, Figure 5-1 below shows the rainfall pattern applied to the catchment, as derived from the Coffs Harbour Gauge, since the Aurania Gauge was not operation. The best fit calibration achieved for this event was using the RORB default kc parameter of 45.79 and an m value of 0.8, as shown below in Figure 5-2. Initial and continuing loss parameters were 5mm and 6.7mm/hr respectively. Table 5-3 provides key calibration statistics. From the figure and table the following is noted:

- Flood peak approximation is considered reasonable to within 14.4%, and the calculated flood peak is conservative;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -15.7%.

Figure 5-1 March/April 2009 Coffs Harbour Rainfall Pattern

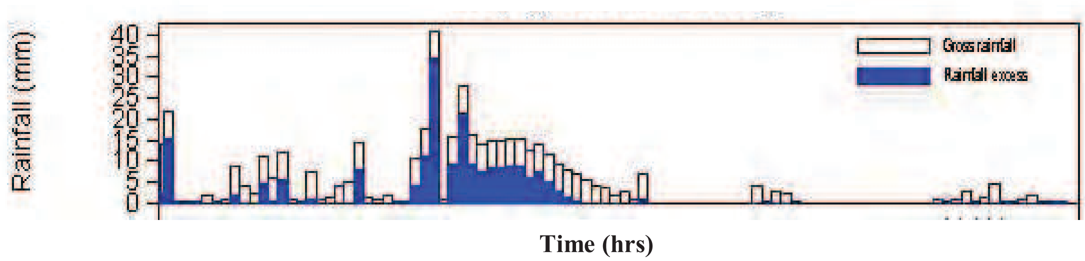
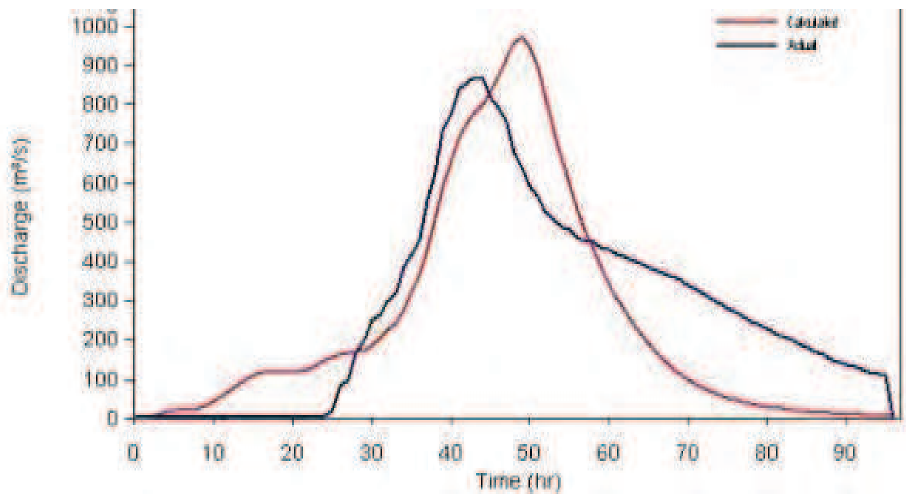


Table 5-3 March/April 2009 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	868.6	994.0	+14.4%
Storm Volume (m^3)	0.98E+08	0.83E+08	-15.7%
Lag (time to peak) (hr)	43	49	+14.0%

Figure 5-2 March/April 2009 Rainfall Event and Calibrated hydrograph at Glenreagh (Gauge 204906)



5.3.4 Calibration – March 1974 Storm (10/03/1974)

This event started with rainfall on 09/03/1974 which lasted for 5 days. The peak rainfall intensity recorded at the Aurania Gauge (059026) was 74.6mm/hr in 6 minutes (at 5:30 am on 10 March 1974). During this event the Aurania station recorded a total rainfall of 786.19mm. During the same period the rainfall totals shown below in Table 5-4 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-4 March 1974 Event Rainfall Distribution

Date	Daily Rainfall Totals (mm)				
	Glenreagh	Lower Bucca	Aurania	Dairyville	Coramba
10/03/1974	106.6	165.4	146.4	142	89
11/03/1974	265.9	388.2	349.6	327.6	337.5
12/03/1974	87	114.6	101.6	89.4	100
13/03/1974	68.2	100.1	133	145.2	109
14/03/1974	48.6	60	86.6	41.8	51.4
TOTAL	576.3	828.3	817.2	746	686.9

Preceding the storm the antecedent conditions within the catchment were rather wet, Figure 5-3 below shows the rainfall pattern applied to the catchment. The best fit calibration achieved for this event was using the RORB default kc parameter of 45.79 and an m value of 0.8, as shown below in Figure 5-4. Initial and continuing loss parameters were 0mm and 12.1mm/hr. Table 5-5 provides key calibration statistics. From the figure and table the following is noted:

- Approximation is considered reasonable to within 13.7%, and the calculated flood peak is conservative;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -13.1%.

Figure 5-3 March 1974 Aurania Rainfall Pattern

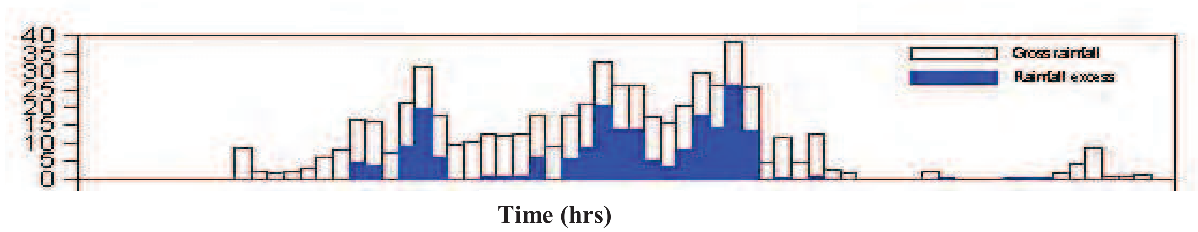
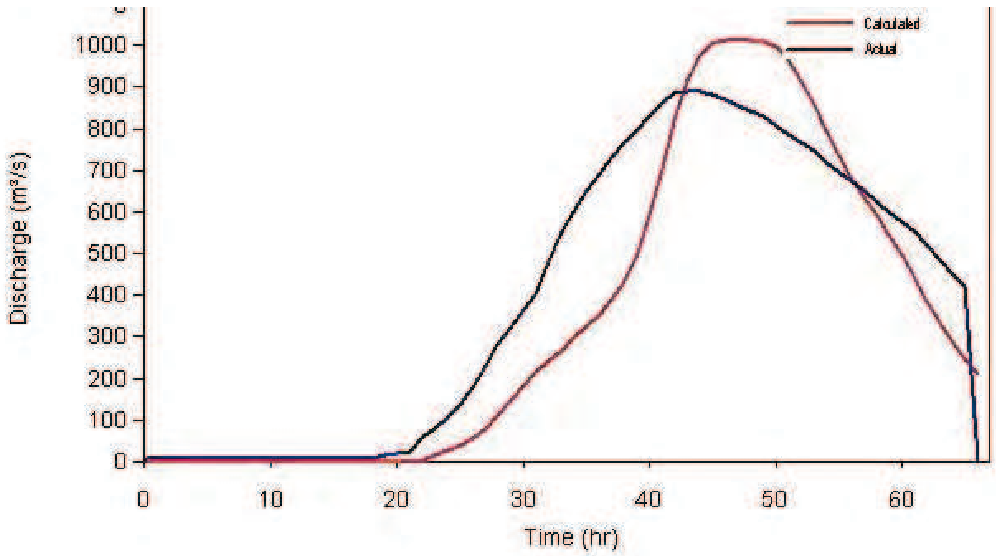


Table 5-5 March 1974 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	891.0	1013.2	+13.7%
Storm Volume (m^3)	0.95E+08	0.82E+08	-13.1%
Lag (time to peak) (hr)	43.0	48	+11.6%

Figure 5-4 March 1974 Rainfall Event and Calibrated hydrograph at Glenreagh (Gauge 204906)



5.3.5 Calibration – February 2009 Storm (13/02/2009)

This event started with rainfall on 13/02/2009 which lasted for 6 days. The Aurania pluviographic rainfall gauge was not operational during this event. Since this was one of the larger historical events in the region, the rainfall temporal distribution recorded at the Coffs Harbour Pluviographic Gauge (059040) was applied. During this event the rainfall totals shown below in Table 5-6 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-6 February 2009 Event Rainfall Distribution

Date	Daily Rainfall Totals (mm)				
	Nana Glen	Lower Bucca	Coramba	Dairyville	Aurania
13/02/2009	23.6	67.4	62.2	60.8	50
14/02/2009	30.2	14.6	31.9	42.6	69.2
15/02/2009	38	57.8	60.8	65.4	28.8
16/02/2009	6	19.2	10.8	20	286.2
17/02/2009	257	167.8	299.6	180.6	54.2
18/02/2009	19	86.4	16.9	20.2	0.8
TOTAL	373.8	413.2	482.2	389.6	489.2

Preceding the storm the antecedent conditions within the catchment were rather wet, Figure 5-5 below shows the rainfall pattern applied to the catchment. The best fit calibration achieved for this event was using the RORB default kc parameter of 45.79 and an m value of 0.8, as shown below in Figure 5-6.

Initial and continuing loss parameters were 0mm and 4.3mm/hr. Table 5-7 provides key calibration statistics. From the figure and table the following is noted:

- Approximation is considered reasonable to within 8.8%, and the calculated flood peak is conservative. The calibration is marginally better than achieved for the March/April 2009 event;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -9.9%.

Figure 5-5 February 2009 Aurania Rainfall Pattern

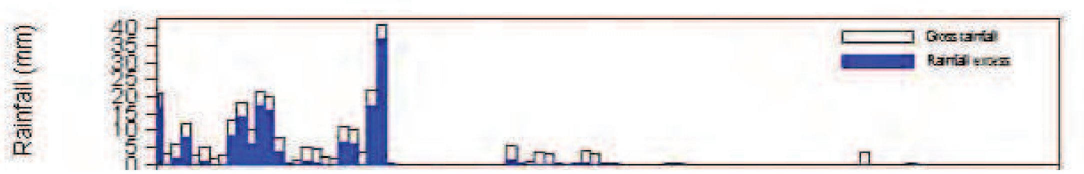
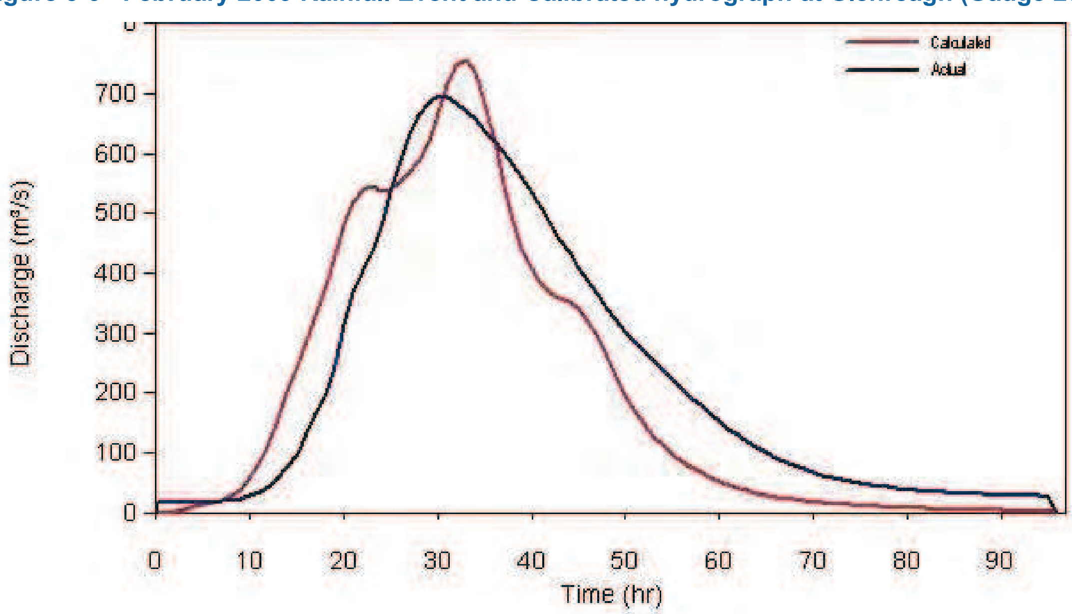


Table 5-7 February 2009 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	695.4	756.5	+8.8%
Storm Volume (m^3)	0.77E+08	0.70E+08	-9.9%
Lag (time to peak) (hr)	30	33	+10.0%

Figure 5-6 February 2009 Rainfall Event and Calibrated hydrograph at Glenreagh (Gauge 204906)



5.3.6 Calibration – February 2001 Storm (02/02/2001)

This event started with rainfall on 31/01/2001 which lasted for 5 days. The peak rainfall intensity recorded at the Aurania Gauge (059026) was 46.5mm/hr in 6 minutes (at 11:48 pm on 1 February 2001). During this event the Aurania station recorded a total rainfall of 375.4mm. During the same period, the rainfall totals shown below in Table 5-8 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-8 February 2001 Event Rainfall Distribution

Date	Daily Rainfall Totals (mm)				
	Nana Glen	Lower Bucca	Coramba	Dairyville	Aurania
31/01/2001	24	38	42.1	58	23
1/02/2001	101	118	167.8	215.8	155.2
2/02/2001	168	107	189.8	103	176.3
3/02/2001	45.6	10	44.2	54.8	36.6
4/02/2001	11.8	6.2	10.6	16.4	8.6
TOTAL	350.4	279.2	454.5	448	399.7

Preceding the storm the antecedent conditions within the catchment were rather wet. Figure 5-7 below shows the rainfall pattern applied to the catchment. The best fit calibration achieved for this event was using the RORB default kc parameter of 45.79 and an m value of 0.8, as shown below in Figure 5-8. Initial and continuing loss parameters at the Aurania gauge were 7.5mm and 2.47mm/hr. Table 5-9 provides key calibration statistics. From the figure and table the following is noted

- Flood peak approximation is considered good to within 0.7%;
- Average agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within 2%.

Figure 5-7 February 2001 Aurania Rainfall Pattern

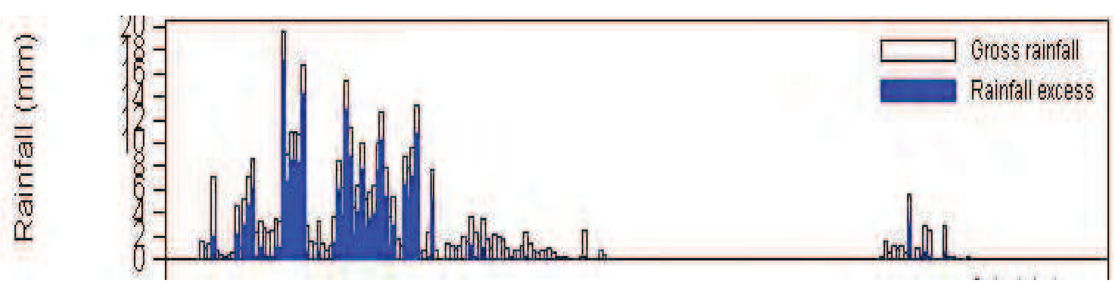
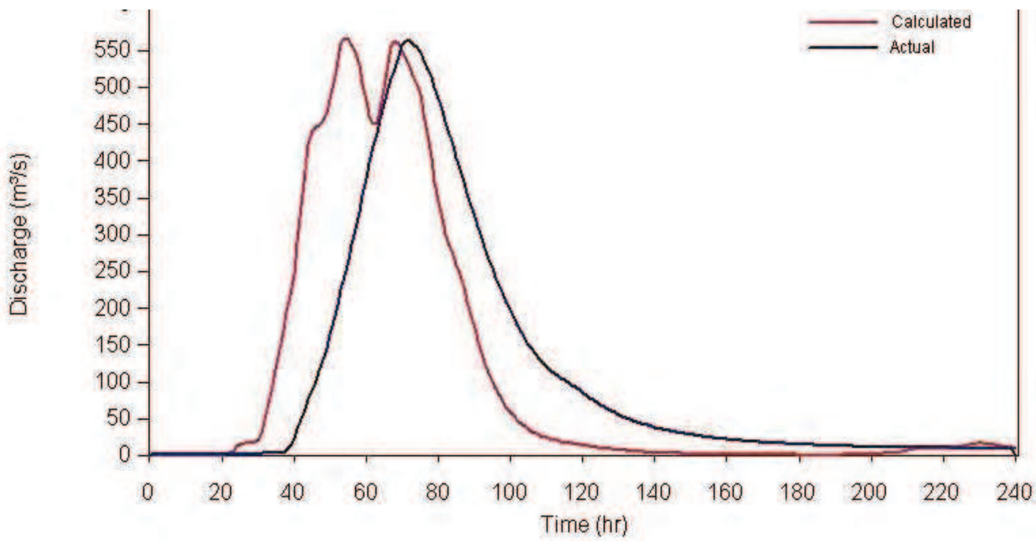


Table 5-9 February 2001 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	563.4	567.2	+0.7%
Storm Volume (m^3)	0.93E+08	0.91E+08	-1.6%
Lag (time to peak) (hr)	71	54	-23.9%

Figure 5-8 February 2001 Rainfall Event and Calibrated hydrograph at Glenreagh (Gauge 204906)



5.3.7 Summary

The RORB manual (RORB Manual, Section 7.3) stresses that users need to be realistic in expectations of accuracy for calibrations, nominate that accuracies in the order of ±15% could be expected in the underlying flow data used for calibrations.

Additional RORB simulations showed that slightly better agreement could be achieved with a kc value of 60. In general this achieved a difference in flood peak and flood volume of approximately 5%, thus a 5% improvement in statistics. While a kc of 60 is higher than the default RORB parameter used (kc 45.79), given the matters raised in Section 3.2 on gauging and rating curve accuracies, it was not deemed appropriate to further optimise the calibration. It was decided to accept the default RORB kc parameter, and assess further optimisation as a sensitivity assessment. The findings of this sensitivity assessment have been provided in Section 7.4.6 of this report.

6. Hydraulic Model Configuration and Calibration (TUFLOW)

6.1 General

The flood conveyance through Orara was calculated using the TUFLOW hydraulic model.

TUFLOW is a computer program for simulating depth-averaged, two and one-dimensional free-surface flows such as occurs from floods and tides. TUFLOW was originally developed for modelling two-dimensional (2D) flows, and stands for Two-dimensional Unsteady FLOW. However, it incorporates the full functionality of the ESTRY 1D network or quasi-2D modelling system based on the full one-dimensional (1D) free-surface St Venant flow equations (see below). The 2D solution algorithm is based on Stelling 1984, and is documented in Syme 1991. It solves the full two-dimensional, depth averaged, momentum and continuity equations for free-surface flow. The scheme includes the viscosity or sub-grid-scale turbulence term that other mainstream software omit. The initial development was carried out as a joint research and development project between WBM Oceanics Australia and The University of Queensland in 1990. The project successfully developed a 2D/1D dynamically linked modelling system (Syme 1991). Latter improvements from 1998 to today focus on hydraulic structures, flood modelling, advanced 2D/1D linking and using GIS for data management (Syme 2001a, Syme 2001b). TUFLOW has also been the subject of extensive testing and validation by WBM Pty Ltd and others (Barton 2001, Huxley, 2004).

TUFLOW is specifically orientated towards establishing flow and inundation patterns in coastal waters, estuaries, rivers, floodplains and urban areas where the flow behaviour is essentially 2D in nature and cannot or would be awkward to represent using a 1D model. A powerful feature of TUFLOW is its ability to dynamically link to 1D networks using the hydrodynamic solutions of ESTRY, ISIS and XP-SWMM. The user sets up a model as a combination of 1D network domains linked to 2D domains, ie. The 2D and 1D domains are linked to form one overall model. (BMT WBM 2010)

6.2 Configuration

The model extent for the purposes of flood mapping was defined in collaboration with Coffs Harbour City Council. The final model extent was adjusted slightly to provide model stability and negate the effects of boundary conditions, as shown in Appendix E.

Since the area to be modelled is significant a “herringbone” approach was used within the model, to strike a balance between model output and simulation efficiency. This comprised a model configuration simulating in 1D for the creek reaches within the rural areas and a 2D/1D setup for the village areas. In addition, areas of complex flow distribution were simulated in 2D. The TUFLOW model compilation configured the key parameters as described in Table 6-1, using the following methodology:

- LIDAR data for the local area was imported into a digital terrain-modelling program (12D) and triangulated to represent the ground surface as a DTM;
- A TUFLOW grid was generated with a cell size of 8 m by 8m for the village areas. Each point in the grid was given an elevation based on its location in the DTM. The grid size was chosen because this is a compromise between the accuracy of the DTM data, simulation run time, model stability, and the accuracy of the results. This cell size also would also generally capture the in bank topography in the

two 2D areas, given that the creek width is generally greater than 8m. In some areas where LIDAR data was lacking, additional survey was captured;

- TUFLOW 1D cross-sections were generated for the entire creek network to simulate the creek channel in the 1D domain. These cross-sections were obtained from the LIDAR data, which required careful assessment and in some cases adjustment to compensate for lack of channel invert data. Similar adjustment were made by interpolating in areas of heavy vegetation;
- All bridges within the floodplain were configured using the terrestrial survey data. These were configured within the 1D and/or 2D model grid;
- The flood hydrographs output by the RORB model were configured as inflows for all sub catchments draining to the Orara River. Downstream boundary conditions were configured as a flow stage relationship at the Glenreagh flow gauging station, as shown in Figure 6-1; and
- Based on aerial photography and site inspections, hydraulic roughness coefficients were estimated, digitised in the 2D domain areas and input to the model. The table below lists general roughness assumptions made.

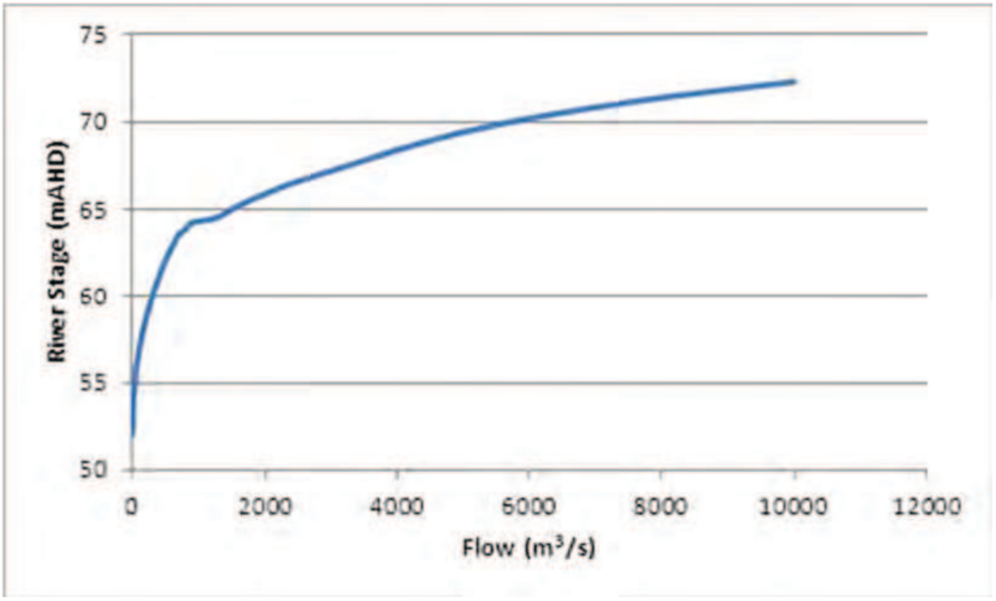
Table 6-1 TUFLOW Modelling Parameters – 1D and 2D domains

Feature	Value
Time step	1 second
Grid size	8m x 8m
Manning's "n" – Hardstand areas	0.02 to 0.05
Manning's "n" – Developed areas (residential, commercial, industrial, farm sheds), houses or blocked out with storage areas (zero conveyance)	0.5
Manning's "n" – creek/river channels depending on vegetation	0.04 – 0.15, with the majority being around 0.1 to 0.12
Manning's "n" – floodplain areas	0.06 – 0.18, with the majority being around 0.08 to 0.15

6.2.1 Downstream Boundary Conditions

Downstream boundary conditions were configured in the TUFLOW model as a stage discharge relationship, at the Glenreagh flow gauge. The floodplain in this area comprises an approximately 12m deep creek channel and a wide floodplain. The railway embankment traverses the floodplain, generally parallel to the creek. This resulted in instabilities in the flood model during larger events. Figure 6-1 shows the adopted elevation – discharge relationship used for the downstream boundary condition.

Figure 6-1 Elevation-Discharge Relationship for Downstream Boundary Condition



6.2.2 Significant Structures in the Floodplain

Referring to Appendix E, a number of significant structures are located in the Orara River and Bucca Bucca Creek floodplain. Approximately 62 bridges were configured in the TUFLOW model and each structure was surveyed, capturing key bridge/culvert parameters. These parameters included bridge/culvert waterway openings, piers dimensions, bridge deck, soffit and overflow levels.

6.3 Validation against Observed Flood Markers

The March/April 2009 flood event was simulated in TUFLOW in order to calibrate the hydraulic model. The simulated flood levels were reviewed and model parameters adjusted in order to replicate as best as possible the recorded peak water levels as provided by the flood markers (see Section 3.3.3).

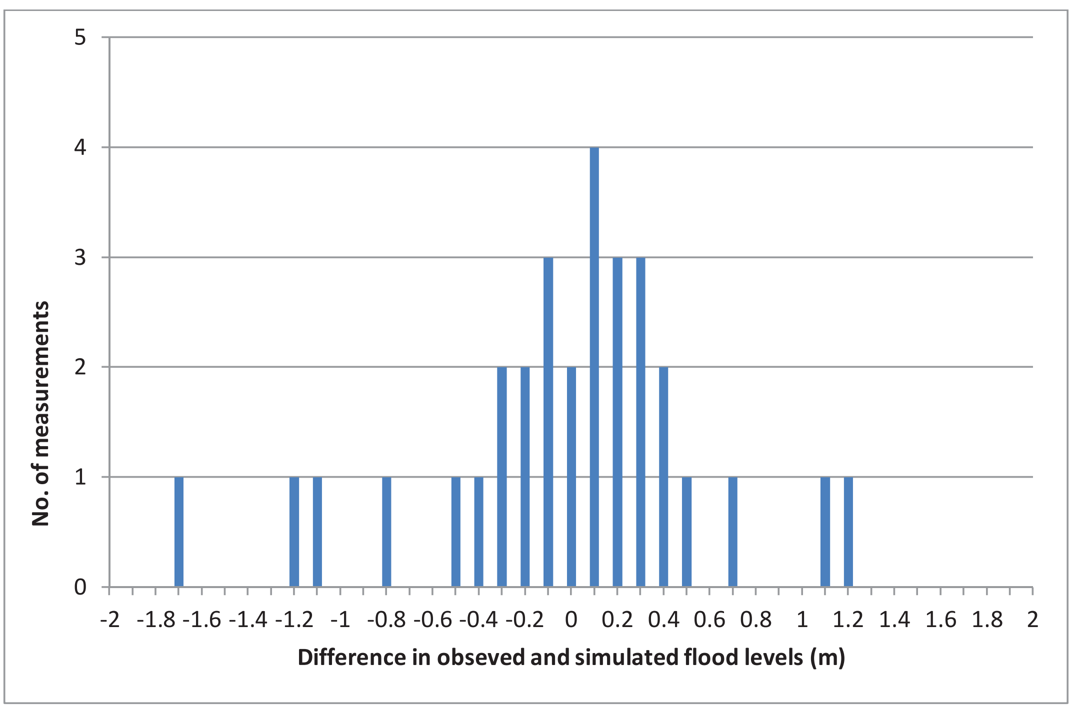
Figure F.1a in Appendix F shows the comparison on a flood map of the March/April 2009 event. The comparisons results have been shown in Figure 6-2 below. From the appendix and the figure below, the following is noted:

- Across the entire Orara River and Bucca Creek catchment, the comparisons of observed and simulated flood levels are considered very good and within approximately 0.3m. In a few cases, the difference is less favourable; however this could be on account of local effects at that particular location. For the flood markers which deviated in excess of 0.5 m on Figure F.1a in Appendix F, the following is noted:
  - Flood Marker 27 was located within an overflow route, off the main channel, and may be substantially affected by local topographic effects;

- Flood Marker 13 deviated by 1.0m to the calibrated water surface. However, the confidence in this survey mark is low (Appendix B) considering the good agreement with flood markers 13 and 26 in the immediate vicinity of this marker;
  - Flood marker 3 was taken within the bridge opening and therefore is expected to be heavily influenced by local conveyance effects;
  - Flood marker 36 was taken from the recorded river level at the Karangi gauge, however the good agreement with observed levels from flood markers 35 and 17 upstream, and flood markers 18 and 19 downstream indicated that this gauge may have experienced local effects; and
  - Flood markers 10 and 11 are lower than the surveyed flood levels. While the confidence in the accuracy of the flood level is only medium, a number of local topographic effects may exist in this location, which could come into effect during lower, more frequent, AEP events. This area could benefit from simulation in a 2D model which would better simulate the local topography, roads and bends in the creek; and
  - Flood marker 23 was a debris line on the top of a fence and this flood marker was estimated to be of medium accuracy. Considering that the upstream flood markers 32 and 1 compare favourably and are of higher accuracy, this flood marker is considered less important.
- Within the 0.3m range, there is an even distribution of flood level differences higher and lower compared to the observed flood markers; and
- The vast majority of simulated levels compare to observed flood levels, to accuracies commensurate with a rural flood study.

The findings of the above assessment were discussed with Council and OEH. After Council and OEH provided agreement with the calibration results, design event simulations were commenced.

Figure 6-2 Comparison of Observed and Simulated Flood Levels



7. Design Flood Behaviour

7.1 Overview

To determine the design flood behaviour, both the RORB and TUFLOW models were simulated, using the parameters derived through the calibrations together with design rainfall in accordance with the Australian Rainfall and Runoff (AR&R 2001). The simulations were undertaken as follows:

- The RORB model was simulated using a kc value 45.79 together with design rainfall and rainfall loss estimates in accordance with the Australian Rainfall and Runoff. Each event was simulated for a range of durations; and
- The results from the RORB model were used as boundary conditions for the TUFLOW model which was simulated for a range of durations.

Further details on the input used for the simulations are provided below.

7.2 Flood Hydrographs

7.2.1 Design Rainfall

Design rainfall events were derived in accordance with the procedures of the Australian Rainfall and Runoff, Region 2 (AR&R 2001). The Intensity Frequency Duration parameters adopted for the Orara catchment are listed in the table below.

Table 7-1 Orara catchment IFD Parameters

Parameter	Value
2yr 1hr (ARI, duration)	42.87
2yr 12hr (ARI, duration)	9.67
2yr 72 hr (ARI, duration)	3.39
50yr 1hr (ARI, duration)	82.66
50yr 12hr (ARI, duration)	19.91
50yr 72 hr (ARI, duration)	7.97
Skew	0.08
F2 Value	4.38
F50 Value	16.55
Zone	A

7.2.2 Rainfall Spatial Distributions

A number of daily rainfall gauges within the catchment were assessed in order to determine the rainfall distribution trends throughout the catchment. Table 7-2 lists the monthly mean and highest daily rainfalls for five rainfall gauges distributed throughout the catchment. The results presented as a mean shows a variation in mean annual and highest daily rainfall between Aurania and Glenreagh of some 40%, thus confirming a significant trend in rainfall across the Orara River and Bucca Bucca Creek valleys. While a small difference exists between the mean daily and mean highest daily rainfall, this was considered insignificant and the mean distribution based on mean daily rainfall was adopted. Thus a non-uniform rainfall distribution was adopted throughout the catchment. This non-uniform rainfall distribution was applied to the rainfall on a sub-catchment by sub-catchment basis in the RORB model.

Table 7-2 Mean Annual Rainfall throughout Catchment

	Rainfall Station									
Month	**Aurania**		**Dairyville**		**Coramba**		**Lower Bucca**		**Glenreagh**	
	Mean	**Highest Daily**	**Mean**	**Highest Daily**	**Mean**	**Highest Daily**	**Mean**	**Highest Daily**	**Mean**	**Highest Daily**
Jan	217.4	440.7	210.6	140	195	412.8	162.3	256	170.6	259.1
Feb	251.6	420.6	248.2	218.6	199.2	421.1	194.7	249.4	180.6	397.8
Mar	282.4	355.6	257.8	327.6	232.8	337.5	204.2	388.2	160.7	265.9
Apr	189.9	331	148.4	236	149.4	283.4	154.1	276.9	124.4	242.6
May	147.3	380.2	117	257.6	121.9	196.9	139.4	320	109.8	197.0
Jun	136.7	502.9	101.4	209.8	129.3	257.1	115.1	215.9	82.6	135.0
Jul	95.4	263.4	81.9	244.4	67.4	187.2	72.7	164.6	59.9	182.9
Aug	80.7	258	43.7	260.4	70.6	252.4	52.3	151.1	51.9	195.0
Sep	71.9	181.6	54.9	98.0	54.6	108.8	54.1	137.2	47.5	193.0
Oct	109.9	180.6	113.4	240.8	102.9	223.2	90.8	174.6	90.7	203.2
Nov	140.4	276.4	156.4	128.2	133.8	176.4	114.6	225.4	104.1	127.0
Dec	161	174.8	162.6	172.4	139.2	167.6	128.8	208.8	130.6	153.4
Mean	157.1	313.8	141.4	211.2	133.0	252.0	123.6	230.7	109.5	212.7
Mean (%)	118%	129%	106%	87%	100%	103%	93%	95%	82%	87%

7.2.3 Probable Maximum Precipitation and Flood (PMP and PMF)

Given the size of catchment and recommended BOM thresholds, the Probable Maximum Precipitation was compiled using the Bureau of Meteorology Australia Generalised Tropical Storm Method – Revised Version (GTSMR – BOM 2003), and the Bureau of Meteorology Australia Generalised Short Duration Method (GSDM – BOM 2003). The PMP rainfall depths derived for a range of durations using this method are tabulated below.

Table 7-3 PMP Rainfall Depths

Duration (hrs)	PMP Rainfall Depth (mm)	Duration (hrs)	PMP Rainfall Depth (mm)
1	300	24	793
2	360	36	953
3	440	48	1103
4	500	72	1370
5	520	96	1536
6	570	120	1618
12	640		

The PMP rainfall depths were simulated in the RORB model to calculate the PMF. A conservative approach was used for the intermediate 12 hour duration, with the 12 hour rainfall depth simulated in RORB using the temporal patterns of both methods and adopting the higher flood peak. Loss factors as discussed in Section 7.2.4 were applied. The PMF flood peak at Glenreagh was calculated to be 5015m^3/s, with a critical duration of 12 hours.

7.2.4 Rainfall Losses

Rainfall losses were adopted in accordance with the Australian Rainfall and Runoff (AR&R 2001) Book 2 and Book 6. These recommend the losses as listed in Table 7-4.

Table 7-4 Rainfall Losses

Event	Initial Loss	Continuing Loss
Up to and including the 1% AEP event	25 mm	2.5 mm/hr
1% event up to the PMF	0 mm	1 mm/hr
PMF	0 mm	1 mm/hr

7.2.5 Design Flood Peaks

The simulation of the RORB model was undertaken for a number of events and a number of durations, up to and including the PMF. For each event design flood hydrographs were input as an upstream boundary condition inflow to the TUFLOW model. The flood peaks determined for each event are summarised below.

Table 7-5 RORB Design Flood Peaks

Flood event AEP	Coramba Flood Peak m^3/s	Nana Glen Flood Peak m^3/s	Glenreagh Flood Peak m^3/s
20%	665 (36hr)	670 (36hr)	945 (48hr)
10%	800 (36hr)	820 (36hr)	1215 (48hr)
5%	970 (36hr)	1025 (36hr)	1570 (48hr)
2%	1180 (36hr)	1260 (36hr)	2025 (48hr)
1%	1355 (36hr)	1375 (36hr)	2410 (48hr)
0.2%	1530 (12hr)	1640 (12hr)	2995 (36hr)
PMF (12 critical duration)	3580(6hr)	3520 (6hr)	5015 (12hr)

7.2.6 Probabilistic Rational Method

The Probabilistic Rational Method was used to provide an additional estimate of the flood peak for the 1% AEP event. This method is not suitable for catchment sizes of area greater than 250 km^2 and inherently does not necessarily account for catchment effects such as attenuation. However the method gives an indication of the flood peak “order of magnitude”.

Using the Probabilistic Rational Method, the 1% AEP flood peak was estimated as 2650m^3/s at the location of the Glenreagh flow gauging station.

7.2.7 Comparison of 1% and 10% AEP Flood Peak Estimates

The derived flood peak estimates for a range of events using a number of methods has been tabulated below. Since the March/April 2009 event was determined (through the rainfall frequency analysis) to represent approximately the 10% AEP rainfall event, the comparison below shows both the 1% and 10% AEP events.

Referring to the table, it is noted that the Rational Method compares favourably with the calibrated RORB model. The flood frequency analysis based on the runoff data provides a considerable range in peak estimate, however the discussion in Section 3.2.2 provides background on reasons why this estimate needs to be treated with circumspection. Notwithstanding, both the RORB and the Rational Method compare favourably, with the upper envelope of the flood frequency estimate.

The 1991 RORB flood peak estimates are significantly higher than the estimates undertaken using the Rational Method at the time of the 1991 study. In determining the RORB kc, rudimentary calibration was done against flood levels, however the report does not present any calibration against measured events. In addition an earlier version of the regional RORB kc was adopted. It is thus considered that this estimate is overly conservative.

Table 7-6 Comparison of 1% and 10% AEP Flood Peak Estimates

Flood event AEP	Flood Frequency Analysis	Calibrated RORB Model	Probabilistic Rational Method	1991 Study (CHCC 1991)
Glenreagh				
1%	441 to 2302 m^3/s	2410 m^3/s	2650 m^3/s	RORB 3790 m^3/s Rational Method 2980 m^3/s
10%	522 to 947 m^3/s	1215 m^3/s	1370 m^3/s	N/A
Karangi				
1%	333 to 1273 m^3/s	1320 m^3/s	1080 m^3/s	RORB 1790 m^3/s Rational Method 1180 m^3/s
10%	345 to 566 m^3/s	800 m^3/s	560m^3/s	N/A

7.3 Flood Behaviour

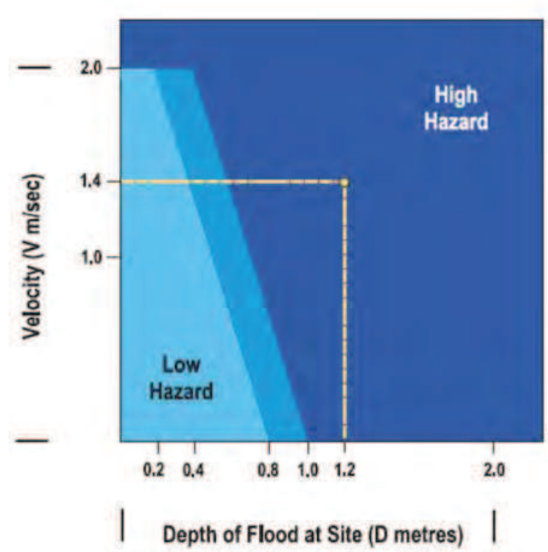
7.3.1 Boundary Conditions

For the upstream boundary conditions to the TUFLOW model, the design flood hydrographs discussed in Section 7.2.5 were input to the model. Downstream boundary conditions were configured in the TUFLOW model as per the existing conditions simulations, namely by using a stage discharge relationship at the location of the Glenreagh flow gauging station.

7.3.2 Flood Map Results

The results of the design flood simulations have generally been provided as maps (Appendix F), as follows:

- A series of flood maps showing flood depth (in blue), overlain by flood level contours;
- A series of maps showing flood velocities on a cell by cell basis for the 2D areas of the model, and annotated as average reach velocities for the 1D areas of the model; and
- A series of maps showing provisional flood hazard generally in accordance with the NSW Floodplain Development Manual, determined by using the maximum velocity and maximum depth during each event (see graphic, after ref NSW DECC 2005).



Referring to the flood maps, the following is noted:

Flood Maps of Depth and Level

- In the 20% and 5% AEP events, flood flows are expected to surcharge the Orara River and Bucca Bucca Creek channels, and spill onto the floodplain. While a few isolated properties would be expected to be at risk, the majority of Nana Glenn, Coramba and Karangi would largely be unaffected by flood waters. A number of bridges are expected to be inundated as listed in Appendix F;
- In a 1% AEP event, widespread flooding is noted. Flood waters are expected to inundate large areas of the floodplain on the Orara River, Bucca Bucca Creek and associated tributaries. Flood waters are expected to inundate properties along Thrower Avenue and in the vicinity of Star Creek Road in Coramba. Flooding is also expected along Weir Street and Morrows Road in Nana Glenn and lower laying properties along Brewers Road;
- A large number of rural properties are expected to be isolated by flood waters across all catchments;
- In a PMF flood levels are expected to be approximately 2 to 3 m deeper than the 1% AEP. This would result in significant and widespread flooding;

Maps of Flood Velocity

- Flood velocities are generally below 2m/s, in the 20% and 5% AEP flood events. However in creeks which are steep and confined, flood velocities greater than 2m/s could be expected. For example the area downstream of Coramba Bridge has a narrow creek channels and elevated flood velocities would be expected in this location;
- In the 1% AEP event, large areas of the floodplain would be expected to have flood velocities below 2 m/s. However flood velocities within many of the creek channels would be expected to be in excess of 2m/s;
- Many of the tributaries, which are generally steep in grade, exhibit flood velocities in excess 2m/s;

Maps of Provisional Flood Hazard

Hazard categories are provisional because they do not reflect the effects of other factors that influence hazard. For example a particular hazard may be reduced if an effective local flood plan is developed and implemented. In general High Hazard could pose possible danger to personal safety, make wading difficult, result in structural damage to buildings and make evacuation by trucks difficult. Low Hazard would permit evacuation by trucks and able-bodied adults would have little difficulty in wading to safety.

- The majority of the Orara River and Bucca Bucca Creeks are designated as being high hazard, due to the excessive flow depths. In the 20% and 5% AEP events, only small areas on the floodplain are designated as low or medium hazard; and
- In a 1% AEP event, almost the entire valley, with exception of a few areas, is considered high hazard. This would mean that a number of access tracks to rural properties and road crossings would be expected to be isolated by high hazard flood waters.

7.3.3 Inundation of Key Bridge and Culvert Structures

An assessment has been made of which key bridges and structures are likely to be inundated in the 20%, 5% and 1% AEP events. The results provided on Figure F,4e in Appendix F shows that a large number of key structures throughout the Orara Valley are at risk of being cut-off, potentially resulting in isolation.

7.4 Sensitivity Analyses

7.4.1 Overview

A number of sensitivity analyses were undertaken to determine the impacts of parameters and assumptions on flood behaviour. This was achieved by making the adjustments to the models and re-simulation of both the RORB and TUFLOW models where appropriate. Since the most important event used in planning in NSW is the 1% AEP event, the assessments were done for this event only. In addition, the assessments have been undertaken by simulating only the 48hr duration event.

The results are presented as difference maps in Appendix G. The items/assumptions assessed in the sensitivity analysis were:

- Sensitivity of rainfall loss parameters on the design flood hydrographs and flood levels;
- Sensitivities of culvert and bridge blockages and loss assumptions;
- Sensitivity of Manning's roughness assumptions on flood levels;
- Future Climate impacts on rainfall and flood levels; and
- Sensitivity of RORB kc parameter.

7.4.2 Sensitivity of Rainfall Loss Parameters

To assess the impacts of rainfall loss parameter assumptions, both the RORB and the TUFLOW models were re-simulated using the amended rainfall losses tabulated below. These generally show a reduction in initial and continuing losses. The impacts on the simulated flood peaks using the RORB model are shown in Table 7-8, generally showing a 3 to 11% increase in the flood peak flow. The impacts on the 1% AEP 48hr duration event flood level is presented in Figure G.1, showing that:

- In the upper reaches of the Orara River and Bucca Bucca Creek, flood level increases of in the order of 50mm can be expected;
- In the middle reaches, flood level increases of 50 to 100 mm could be expected; and
- In the lower reaches, around Nana Glen increases in the order of 100 mm to 300 mm could be expected.

It is thus noted, that reduction in initial and continuing loss assumptions would lead to a slight increase in flood levels, which is more pronounced in the lower reaches of the model, around Nana Glen.

Table 7-7 Rainfall Loss Sensitivity Values

Event	Initial Loss	Continuing Loss	Initial Loss	Continuing Loss
	Default Value		Sensitivity Value	
Up to and including the 1% AEP event	25 mm	2.5 mm/hr	10 mm	2.0 mm/hr
1% event up to the PMF	0 mm	1 mm/hr	10 mm	0.5 mm/hr
PMF	0 mm	1 mm/hr	10 mm	0.5 mm/hr

Table 7-8 Rainfall Loss Sensitivity impacts on Peak Flows (m^3/s at the Glenreagh gauge)

Flood event AEP	Default Value	Sensitivity Value
20%	945 (48hr)	1047 (48hr)
10%	1215(48hr)	1324 (48hr)
5%	1570 (48hr)	1697 (48hr)
2%	2025 (48hr)	2110 (48hr)
1%	2410 (48hr)	2490 (48hr)

7.4.3 Sensitivities of Culvert and Bridge Blockages and Loss Assumptions

To assess the impacts of culvert and bridge blockages, the TUFLOW model was re-simulated using the amended waterway opening assumptions, representing an approximate 50% blockage on bridges throughout the study area. These generally represent the impacts should debris block bridges during flood events, potentially resulting in local increase in upstream flood levels and potential redistribution of flood flows.

The impacts on the 1% AEP 48hr duration event flood level is presented in Figure G.2, showing that:

- Increases in flood level of approximately 100mm, generally upstream of bridges;
- The increases in flood levels would be expected to be more significant for larger bridges on the main-stem of the Orara River and Bucca Bucca Creeks; and
- Increases are more pronounced in situations, where bridges are not overtopped. In cases where bridges are overtopped, the blockages of waterway openings have less of an impact.

7.4.4 Sensitivity to Manning's Roughness Assumptions

To assess the impacts of roughness assumptions, the TUFLOW model was re-simulated using the amended roughness assumptions tabulated below. These generally represent between a 10% and 40%

increase in topography roughness. The impacts on the 1% AEP 48hr duration event flood level is presented in Figure G.3, showing that:

- Increases in roughness as defined in the table below could lead to increases of up to 0.3 to 0.5m, with more pronounced increases likely in the faster flowing creek reaches; and
- Commensurate with the level increases, a number of areas in the flood plain would be expected to increase in extent.

Table 7-9 Roughness Sensitivity Values

Feature	Default Value	Sensitivity Value
Manning's "n" – Hardstand areas	0.02 to 0.05	0.02 to 0.07
Manning's "n" – Developed areas (residential, commercial, industrial, farm sheds), houses or blocked out with storage areas (zero conveyance)	0.5	1.0
Manning's "n" – creek/river channels depending on vegetation	0.04 – 0.15, with the majority being around 0.1 to 0.12	0.06 – 0.18
Manning's "n" – floodplain areas	0.06 – 0.18, with the majority being around 0.08 to 0.15	0.08 – 0.20

7.4.5 Future Climate Impacts on Rainfall

Future climate impacts on rainfall have been assessed generally in accordance with the NSW Government, Department of Environment & Climate Change, Practical Consideration of Climate Change (NSW DECC 2007) guideline. For this assessment the hydrological RORB models was updated to represent future climate rainfall intensities based on the suggestions in the guideline. This recommends simulating 10%, 20% and 30% increases in rainfall intensities. On the basis of this guideline, the estimated future climate rainfall simulated in the RORB model is tabulated below.

The impacts on the simulated flood peaks using the RORB model are shown in Table 7-11, generally showing a 16 – 55% increase in peak flow. The impacts on the 1% AEP 48hr duration event flood level is presented in Figure G.4, 5 and 6, showing that:

- For a 10% increase in rainfall intensity, increases up to 0.5 to a 1m could be expected, particularly in the lower reaches of the Orara River and Bucca Bucca Creek, around Nana Glen;
- In the upper reaches of these creeks the increases are less pronounced, due to the smaller contributing catchment areas; and
- As rainfall intensity increase to an assumed 30% under future climate the abovementioned increases in flood levels are also shown to increase. For a 30% increase in rainfall intensity, increases up to 1 to a 2m could be expected, again, particularly in the lower reaches of the Orara River and Bucca Bucca Creek, around Nana Glen.

Table 7-10 Existing and Future Climate 100-yr Rainfall

Rainfall	Event & Duration	Existing Climate	Future Climate (mm)		
			10%	20%	30%
mm/hr	100 YR 48hr	559.31	666.82	726.91	787.68

Table 7-11 Future Climate 100-yr Rainfall Sensitivity impacts on Flood Peaks

Flood event AEP	Default Value	Sensitivity Value		
		10%	20%	30%
20%	945 (48hr)	1095 (48hr)	1245 (48hr)	1395 (48hr)
10%	1215 (48hr)	1410 (48hr)	1620 (48hr)	1825 (48hr)
5%	1570 (48hr)	1895 (48hr)	2130 (48hr)	2375 (48hr)
2%	2025 (48hr)	2470 (48hr)	2755 (48hr)	3075 (48hr)
1%	2410 (48hr)	3030 (48hr)	3390 (48hr)	3745 (48hr)

7.4.6 Sensitivity of RORB kc Parameter

Following on from the discussions in Section 5.3.7, where it was noted that additional simulations showed a slightly better RORB calibration agreement could be achieved with a kc value of 60, a sensitivity simulation was undertaken with this higher kc value. The impacts on the 1% AEP 48hr duration event flood level is presented in Figure G.7, showing that:

- Flood levels would be expected to decrease by up to approximately 0.1 m, on the main stems and lower reaches of the Orara River and Bucca Bucca Creeks; and
- The lowering of flood levels would reduce in the upper reaches of the tributary creeks, where little or no impact would be expected.

While a kc of 60 is higher than the default RORB parameter used (kc 45.79), given the matters raised in Section 3.2 on gauging and rating curve accuracies and that the impact is only expected to be approximately 100mm, it was not deemed appropriate to further optimise the calibration. It was decided to accept the default RORB kc parameter of 47.59. This would furthermore provide a level of conservatism in the flood mapping.

8. Summary and Conclusions

- The Orara River and Bucca Bucca Creek (Bucca Creek) catchments are located to the west of Coffs Harbour on the NSW Mid North Coast (Appendix A). Both creeks drain to the Clarence River. The creeks rise in the south and flow generally in a north westerly direction, through the villages of Karangi, Coramba, Nana Glen and Glenreagh. The main road, Orara Way, is located along the left bank of the Orara River and the Grafton to Coffs Harbour railway line, along the right bank. The catchment area to Glenreagh is some 433 km^2, and the Orara River has a length of some 66 km. Upstream of Nana Glen the Orara River has a catchment of some 251.2 km^2, while Bucca Creek drains some 115.2 km^2. The Orara River and Bucca Creek confluence downstream of the village of Nana Glen, and receive inflows from a number of significant tributaries;
- Floodwaters in both catchments have been known to rise quickly and isolate communities and properties. While flood peaks can recede equally quickly, properties at times can remain isolated for several days. Many houses can be inundated in flood events necessitating evacuations. Rainfall and river gauging data in the catchment is limited, however significant events have been recorded on gauges at Karangi and Glenreagh. It is understood, from community input that one of the largest floods in the valley occurred on 24 June 1950, when 502 mm was recorded at the Aurania rainfall gauge in a single day and 916 mm fell from 18 to 25 June. In 2009, five significant events were recorded at the Glenreagh runoff gauge, all exceeding or close to the “Moderate Flood” classification. Of these the March/April 2009 event provided the highest peak on record, with a depth of some 13m above the creek invert at the location of the gauge. This depth signifies a “Major Flood” classification;
- Coffs Harbour City Council (CHCC) is responsible for local land use planning in the Upper Orara River and Bucca Bucca Creek catchments, up to and including the village of Nana Glen. CHCC has prepared a flood investigation for the study area in accordance with the NSW Government’s “Floodplain Development Manual: the management of flood liable land”, April 2005 (The Manual);
- The primary objective of this study was to define the main-stream flood behaviour under historical conditions and design flood behaviour under existing and future climate conditions in the study area. The study produced information on flood levels, depths, velocities, flows and provisional hazard categories for a full range of design and historical flood events;
- A number of community consultation activities were undertaken as part of the study. The primary objectives of the flood study consultation activities are to inform the relevant government agencies, local community groups and the general public that the study is being undertaken. The information provided by the community, showed that a large number of the residents had experienced flooding in the catchment first hand, and flood levels rise quickly potentially isolating communities and properties. Preparation for flooding includes regular observation of river levels and lifting of belongings. In addition, listening to advice on local radio stations and from the SES. Many residents mentioned the 2009 floods and these have been etched in memories of the community;
- The hydrology for the flood study was developed using the RORB hydrological model. The model was setup to produce flood hydrographs for the creeks and tributaries draining to the Orara River and Bucca Bucca Creek. The RORB model was calibrated by variation of model parameters to obtain a good fit of the calculated to the measured hydrograph. A number of sensitivity analyses were undertaken on model parameters and the RORB model was simulated for a range of durations ranging up to 72 hours;

- The flood conveyance through the catchment was calculated using the TUFLOW hydraulic model. The model extent for the purposes of flood mapping was defined in collaboration with Coffs Harbour City Council and the Office of Environment and Heritage. Since the area to be modelled is significant a “herringbone” approach was used within the model, to strike a balance between model output and simulation efficiency. The TUFLOW model compilation configured the key parameters including DTM data for the local area, triangulated to represent the ground surface. Bridges within the floodplain were configured using the terrestrial survey data. The March/April 2009 flood event was simulated in TUFLOW in order to calibrate the hydraulic model. The simulated flood levels were reviewed and model parameters adjusted in order to replicate as best as possible the recorded flood markers surveyed during the March/April 2009 event;
- To determine the design flood behaviour, both the RORB and TUFLOW models were simulated, using the parameters derived through the calibrations together with design rainfall in accordance with the Australian Rainfall and Runoff (AR&R 2011);
- In the 20% and 5% AEP events, flood flows are expected to surcharge the Orara River and Bucca Bucca Creek channels, and spill onto the floodplain. In the 1% AEP event, widespread flooding is expected. Flood waters are expected to inundate large areas of the flood plains on the Orara River, Bucca Bucca Creek and associated tributaries. Flood waters are expected to inundate properties in Coramba, Nana Glenn and a number of key roads would be cut-off by flood waters. Many rural properties would be expected to be isolated by flood waters. In a PMF flood levels are expected to be approximately 2 to 3 m deeper than the 1% AEP event across the catchment. This would result in significant and widespread flooding;
- In a 1% AEP event the entire valley, with exception of a few areas, is considered high hazard. This would mean that a number of accesses to rural properties and road crossings would be expected to be isolated by high hazard flood waters; and
- A number of sensitivity analyses were undertaken to determine the impacts of parameters and assumptions on flood behaviour. This was achieved by making the adjustments to the models and re-simulation of both the RORB and TUFLOW models where appropriate. The items/assumptions assessed in the sensitivity analyses were sensitivity of rainfall loss parameters, culvert and bridge blockages and loss, Manning’s roughness assumptions on flood levels, future climate impacts on rainfall and flood levels and sensitivity of RORB kc parameter. The impact of each assessment has been provided as a flood difference map.

9. Glossary

Annual Exceedance Probability (AEP) - AEP (measured as a percentage) is a term used to describe flood size. AEP is the long-term probability between floods of a certain magnitude. For example, a 1% AEP flood is a flood that occurs on average once every 100 years. It is also referred to as the ‘100 year flood’ or 1 in 100 year flood’. The terms 100-year flood, 50-year flood, 20-year flood etc, have been used in this study. See also average recurrence interval (ARI);

> 1e-4% (approx) AEP sometimes referred to as the PMF Event
>
> 0.2% AEP sometimes referred to as the 1 in 500 year ARI Event
>
> 1% AEP sometimes referred to as the 1 in 100 year ARI Event
>
> 2% AEP sometimes referred to as the 1 in 50 year ARI Event
>
> 5% AEP sometimes referred to as the 1 in 20 year ARI Event
>
> 10% AEP sometimes referred to as the 1 in 10 year ARI Event
>
> 20% AEP sometimes referred to as the 1 in 5 year ARI Event

Afflux - The increase in flood level upstream of a constriction of flood flows. A road culvert, a pipe or a narrowing of the stream channel could cause the constriction.

Australian Height Datum (AHD) - A common national plane of level approximately equivalent to the height above sea level. All flood levels; floor levels and ground levels in this study have been provided in meters AHD.

Average annual damage (AAD) - Average annual damage is the average flood damage per year that would occur in a nominated development situation over a long period of time.

Average recurrence interval (ARI) - ARI (measured in years) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100-year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The terms 100-year flood, 50-year flood, 20-year flood etc., have been used in this study. See also annual exceedance probability (AEP).

Catchment - The land draining through the main stream, as well as tributary streams.

Critical Duration – The storm duration at which the peak flood flow and/or flood level occurs

Development Control Plan (DCP) - A DCP is a plan prepared in accordance with Section 72 of the *Environmental Planning and Assessment Act, 1979* that provides detailed guidelines for the assessment of development applications.

Design flood level - A flood with a nominated probability or average recurrence interval, for example the 1% AEP flood is commonly use throughout NSW.

OEH (formerly DECCW, DECC, DNR, DLWC, DIPNR) - Office of Environment and Heritage. Covers a range of conservation and natural resources science and programs, including native vegetation, biodiversity and environmental water recovery to provide an integrated approach to natural resource management. The NSW State Government Office provides funding and support for flood studies.

Discharge - The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving.

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.

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.

Emergency management - A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

EP&A Act - Act Environmental Planning and Assessment Act, 1979

Extreme flood - An estimate of the probable maximum flood (PMF), which is the largest flood likely to occur.

Flood - A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

Flood awareness - An appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response and evacuation procedures.

Flood hazard - The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.

Flood level - The height of the flood described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (e.g. the flood level was 7.8m AHD). Terms also used include flood stage and water level.

Flood liable land - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood prone land. 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 superseded Floodplain Development Manual (NSW Government, 2005).

Flood Planning Levels (FPLs) - The combination of flood levels and freeboards selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies.

Flood Prone Land - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood liable land.

Flood Proofing - A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate damages during a flood.

Flood stage - see flood level.

Flood Study - A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.

Floodplain - The area of land that is subject to inundation by floods up to and including the Probable Maximum Flood event, that is, flood prone land or flood liable land.

Floodplain Risk Management Study – Studies carried out in accordance with the Floodplain Development Manual and assess options for minimising the danger to life and property during floods.

Floodplain Risk Management Plan - The outcome of a Floodplain Management Risk Study.

Floodway - Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways 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 expressed as the height above the design flood level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as 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.

High Flood Hazard - For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.

Hydraulics Term - given to the study of water flow in waterways, in particular, the evaluation of flow parameters such as water level and velocity.

Hydrology Term - given to the study of the rainfall and runoff process; in particular, the evaluation of peak discharges, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).

LGA - Local Government Area, or Council boundary.

Local catchments - Local catchments are river sub-catchments that feed river tributaries, creeks, and watercourses and channelised or piped drainage systems.

Local Environmental Plan (LEP) – A Local Environmental Plan is a plan prepared in accordance with the *Environmental Planning and Assessment Act*, 1979, that defines zones, permissible uses within those zones and specifies development standards and other special matters for consideration with regard to the use or development of land.

Local overland flooding - Local overland flooding is inundation by local runoff within the local catchment.

Local runoff - local runoff from the local catchment is categorised as either major drainage or local drainage in the NSW Floodplain Development Manual, 2005.

Low flood hazard - For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.

Flows or discharges - It is the rate of flow of water measured in terms of volume per unit time.

Merit approach- The principles of the merit approach are embodied in the *Floodplain Development Manual* (NSW Government, 2005) and weigh up social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the State’s rivers and floodplains.

Overland flow path - The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as ‘overland flows’, may or may not re-enter the main channel from which they left — they may be diverted to another watercourse.

Peak discharge - The maximum flow or discharge during a flood.

Present value - In relation to flood damage, is the sum of all future flood damages that can be expected over a fixed period (usually 20 years) expressed as a cost in today’s value.

Probable Maximum Flood (PMF) - The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain.

Reliable access - During a flood, reliable access means the ability for people to safely evacuate an area subject to imminent flooding within effective warning time, having regard to the depth and velocity of floodwaters, the suitability of the evacuation route, and other relevant factors.

REP - Regional Environmental Plan. A plan prepared in accordance with the EPA Act that provides objectives and controls for a region, or part of a region. For example, the Georges River REP.

Risk - Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

RORB/RAFTS - The software programs used to develop a computer model that analyses the hydrology (rainfall–runoff processes) of the catchment and calculates hydrographs and peak discharges. Known as a hydrological model.

Runoff - the amount of rainfall that ends up as flow in a stream, also known as rainfall excess.

SES - State Emergency Service of New South Wales

Stage–damage curve - A relationship between different water depths and the predicted flood damage at that depth.

Velocity - the term used to describe the speed of floodwaters, usually in m/s (metres per second). 10km/h = 2.7m/s.

Water surface profile - A graph showing the height of the flood (flood stage, water level or flood level) at any given location along a watercourse at a particular time.

10. References

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