Clarence Valley Council

Glenreagh Flood Study
(Extension of Orara Flood Study)

September 2013

Table of contents

Table index

Figure index

Appendices

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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.

Clarence Valley Council (CVC) is responsible local land use planning at Glenreagh, located along the lower Orara River. Clarence Valley Council has prepared this flood investigation for Glenreagh in accordance with the NSW Government's "Floodplain Development Manual: the management of flood liable land", April 2005 (The Manual).

1.2 Study Focus

This study focussed on the village of Glenreagh, located in the Orara River and Bucca Bucca Creek (Bucca Creek) catchments. These 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, Nana Glen and Glenreagh located in the catchment, upstream of Grafton.

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 flood 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. While this event was significant in many respects, anecdotal evidence, through discussions with local residents, note that the 1950 flood was significantly larger than the 2009 event.

In June 2012, Coffs Harbour City Council (CHCC) completed the Orara River Flood Study (GHD, 2012) for the Orara and Bucca Bucca River reaches within the Coffs Harbour Local Government Area (LGA). The current study extends the Orara Flood Study to include the Glenreagh village, which is located within the Clarence Valley Council Local Government Area (LGA).

1.3 Study Objectives

The primary objective of this study was to define the main-stream flood behaviour at Glenreagh 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 collected, compiled and reviewed all available relevant data (including survey, aerial photography and satellite imagery). The study simulated the following design events:

- 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 for the village of Glenreagh by extending existing models developed as part of the Orara River Flood Study (GHD, 2012). The models and results produced in this study will inform a subsequent Floodplain Risk Management Study for Glenreagh, where detailed assessment of flood mitigation options and floodplain risk management measures would be undertaken.

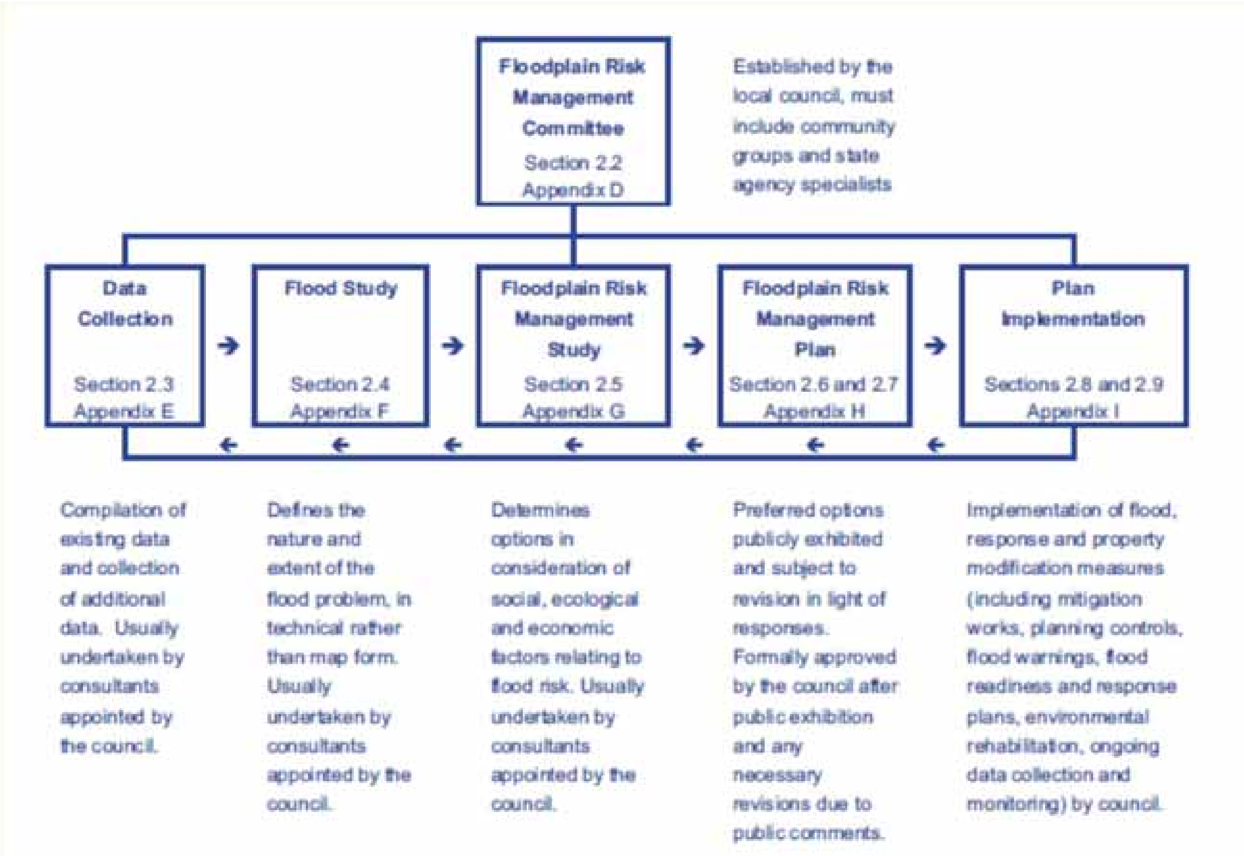


Figure 1-1 Flood Plain Risk Management Process (NSW Government, 2005)

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 at Grafton. 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.

Upstream of Glenreagh the Orara River has a catchment of some 433 km^2. with a length of some 55 km km^2. The catchment area to downstream of the Glenreagh Gauge has some 111 km^2 of additional catchment area entering the Orara River, predominantly from the Tallawudjah Creek catchment between Nana Glen and Glenreagh, to give a total catchment area of 544 km^2.

A number of major tributaries drain into the Orara River Basin, Including:

- 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;
- Kings and Finberg Creek discharging to Bucca Creek upstream of Nana Glen;
- Glenreagh Creek; and
- Tallawudjah creek discharging to Orara River near Glenreagh.

The catchments in the upstream reaches of these creeks are generally steep and heavily forested. Lower reaches are mostly rural in nature. From 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. River slopes vary from 0.2% at Central Bucca to 0.05% at Glenreagh.

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.

Figure 2-1 shows the largest floods on record in the Orara River at Karangi and Glenreagh from the early 1970’s onwards (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 13 m above the creek invert at the gauge. This depth signifies a “Major Flood” classification at the gauge.

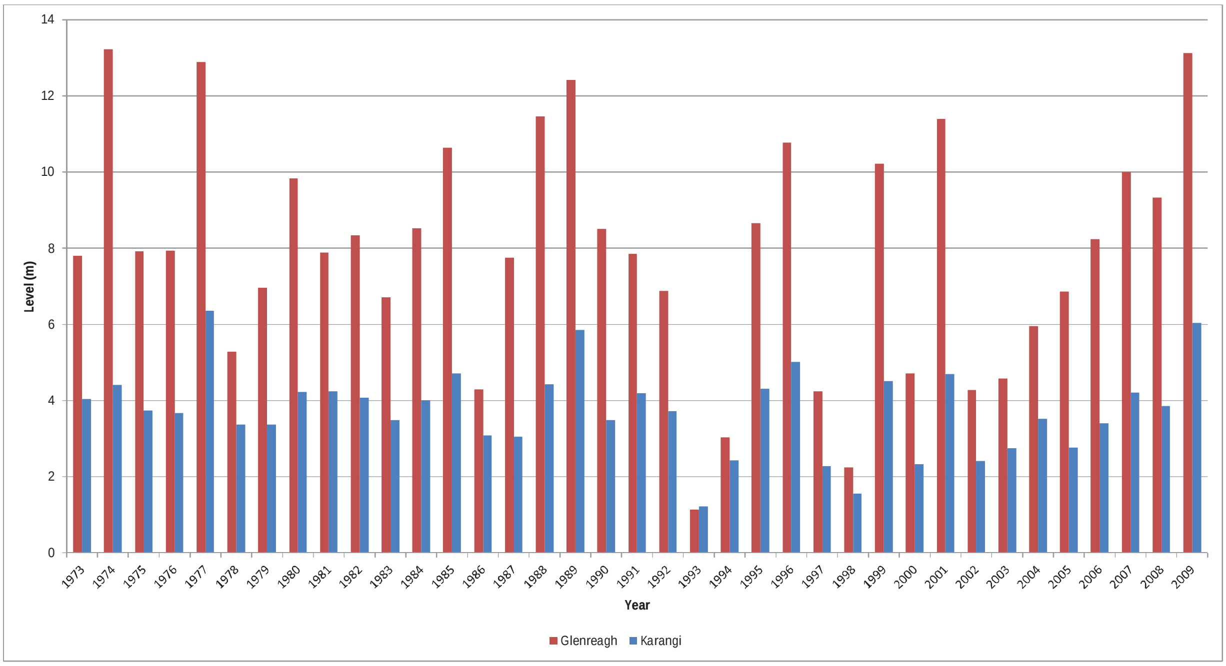


Figure 2-1 Largest Floods in the Orara at Karangi and Glenreagh

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 in Glenreagh 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.

2.2 Previous Studies

The Flood Study for Orara River and Bucca Creek Valleys, June 1991 (CHCC,1991) made mention and included findings of earlier flood assessments, particularly by Coffs Harbour City Council in 1982 and Sinclair Knight in 1984. The study primarily provided information on bridge upgrades. The earlier studies mentioned 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 undertaken. 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 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;
- An extension of the existing hydrological model developed for earlier studies, and determine peak flow rates for the creek system within the study area for the 1% AEP event;
- Hydraulic modelling of the Glenreagh study area, and determination of water surface levels in the creek system for the 1% AEP event. These were limited to linear hydraulic grade line estimations between bridges, thus without hydraulic modelling; 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 River and Tallawudjah creek tributaries. The brief specifically required the need for extensive survey detail as LiDAR survey was not available for this study.

3. Data

3.1 Introduction

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

- Meteorological data, namely rainfall and runoff information;
- Topographic survey data for the compilation of flood models and for the purposes of flood modelling.
- General arrangement drawings and details for the larger structures in the floodplain.

Some of this data had been previously compiled for the Orara River Flood Study (GHD, 2012) and is provided as a précis in this report:

- Concurrent rainfall and runoff data for significant flood events that was available 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; and
- Runoff gauge data, including gauge history and rating curves, to determine hydrographs of flood events.

3.2 River Data

3.2.1 Runoff Gauges

Three river gauges are located along the Orara River (Appendix B and Table 3-1). These gauges were suitable for calibration Orara River Flood Study (GHD, 2012), 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. 2.5 km upstream Of Glenreagh
204068	Orara River At Orange Grove	Orara	14/08/1995 – Present	Orara River Approx. 33 km upstream Of Glenreagh and approx. 4 km upstream of Karangi Dam
204025	Orara River At Karangi	Orara	31/10/1925 – Present	Orara River Approx. 30 km upstream of Glenreagh, 6.8km upstream of Coramba and 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 Karangi Gauge (204025) and at the Glenreagh Gauge (204026). While reviewing these gauges, the following was noted:

- The Glenreagh Gauge rating curve is reliant upon gauging data to a gauge depth 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 depth of 7.5 m. These two points were found to be in good agreement. These gauged depths measured flows when the discharge is confined to the river channel, and flows have not emerged onto the floodplain (approximately 11.5m to 12m gauge depth). Beyond these gaugings, the rating curve relies on extrapolation up to a gauge depth of approximately 14 m; and
- The Karangi Gauge is reliant upon gauging data to a gauge depth 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 depth of approximately 6.8 m and the curve generally shows a “S” shape without confirmation through further gaugings.

Thus beyond the gauge depth 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, referring to Figure 3-1 a number of further concerns exist, which bring into question the accuracy of the data once flow has emerged onto the floodplain:

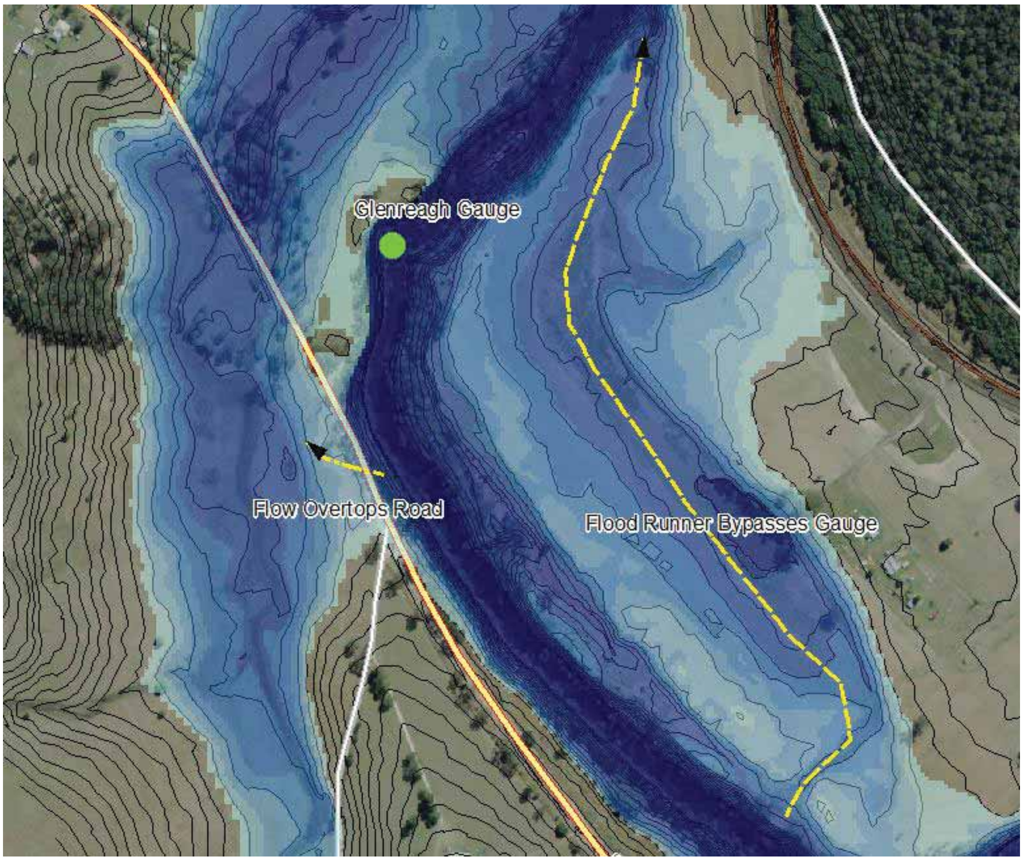


Figure 3-1 Flow distribution near Glenreagh Gauge

- The top of bank level near the gauge occurs at approximately 11.5m to12 m flow depth above the creek invert (as measured off a river cross-section) near the location of the gauge. At this depth flow would emerge onto a very wide flood plain, with a number of complex conveyance paths and flow distributions. Furthermore, 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);
- At the onset and beyond of the emergence of flow onto the floodplain, discharges can bypass the location of the gauge via a flood runner on the eastern floodplain and/or via overflow over Orara Way upstream of the gauge to a left bank tributary, which confluences with the Orara River downstream of the gauge; and
- 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.

Notwithstanding these concerns, the Pinneena flood frequency analysis nominates a 1% AEP flood peak estimate of between 671 m^3/s and 2080 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 depth 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 a gauge depth of approximately 13.5 m. Thus, the 1% AEP estimate of flood peak at the Glenreagh gauge based on the Pinneena flow record flood frequency analysis is 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 depth of 13.1 m, if the Flood Frequency Analysis estimate were to be accepted, this event would have been a 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 by NSW Office of Water:

> *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. These matters must be borne in mind, when evaluating the calibration (Section 5.3.4).

3.2.3 Calibration Event Data

The runoff gauge data in Table 3-1 was interrogated to abstract significant events for calibration 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 Depth (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 have been 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 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:

- The occurrence of significant rainfall events (see Figure 3-2 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 3-4 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 3-2 Typical 1-Day Rainfall Totals at Aurania

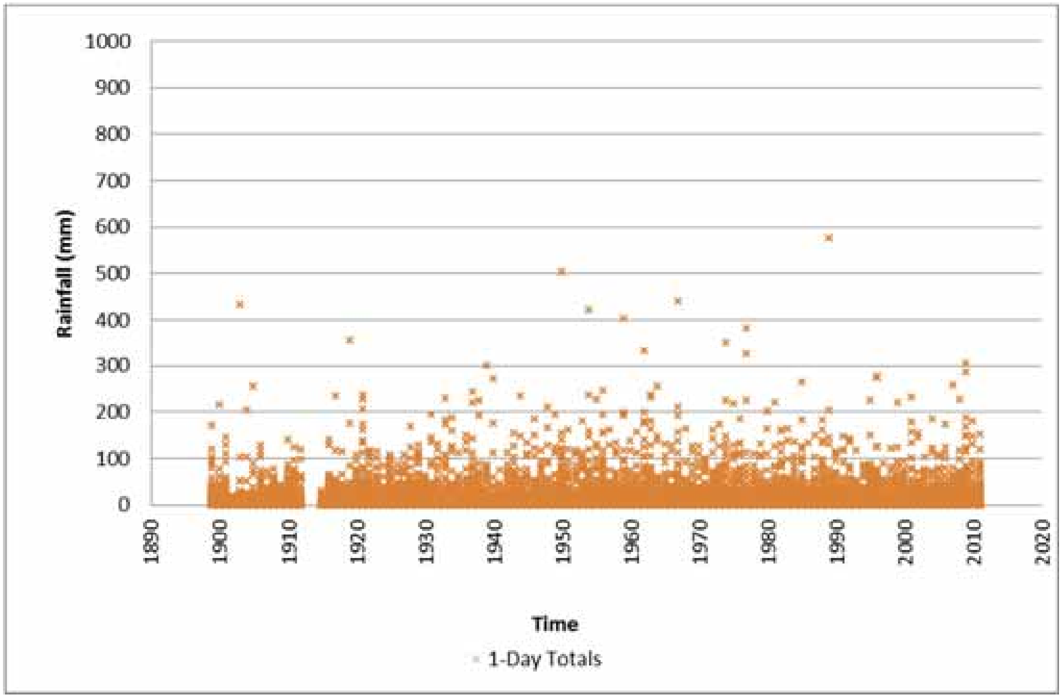


Figure 3-3 Typical 3-Day Rainfall Totals at Aurania

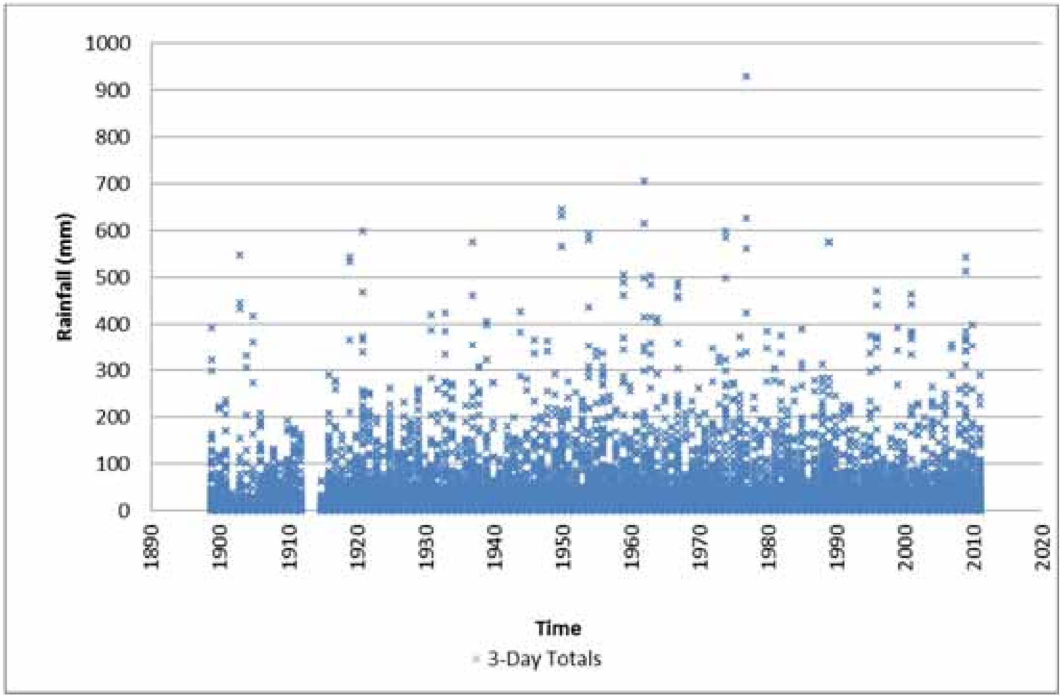
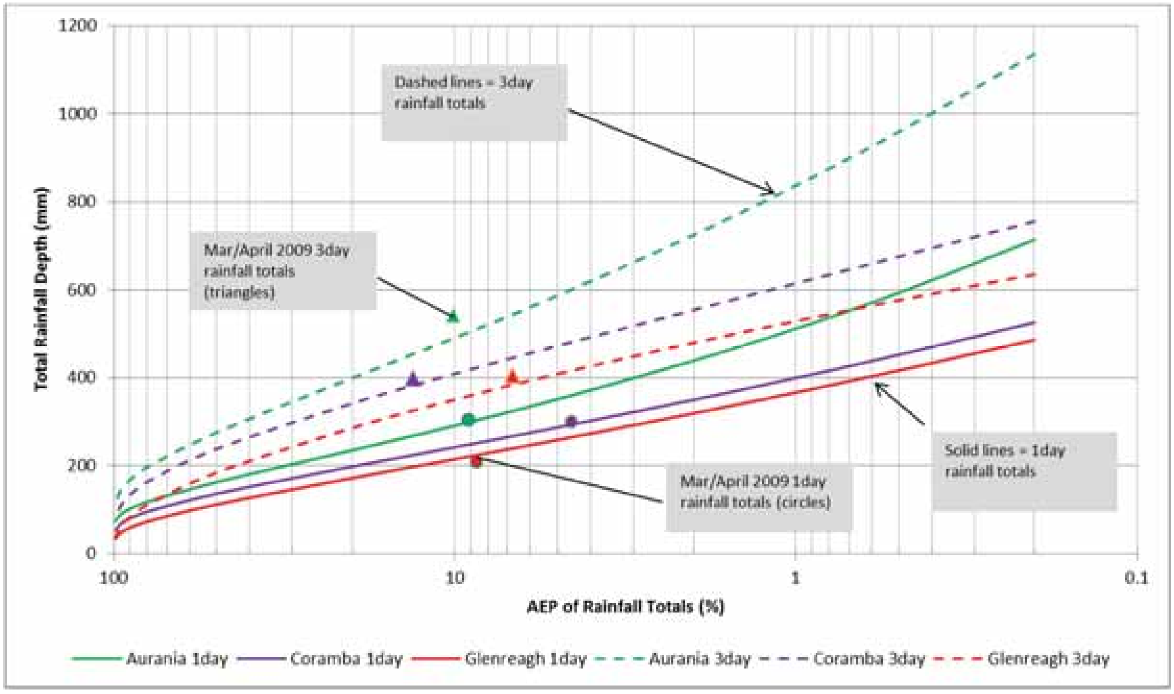


Figure 3-4 Frequency Analysis of 1 and 3-Day-Total Rainfall Totals at Aurania, Coramba and Glenreagh Gauges



3.3.3 Observed Flood Heights (Flood Markers)

A field survey of March/April 2009 flood levels has been undertaken by Clarence Valley Council. This information was provided as a file of flood markers. Four measured flood levels were well placed around Glenreagh, to inform the current study. The flood markers ranged from debris marks in trees, to flood marks observed on walls and structures. 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 Assessment

ID	Easting	Northing	Surveyed Flood Level (mAHD)	Name and Contact Details	Rating (1=high, 2=medium, 3=low)	Comment
1	0498681	6676748	61.521	Property 2601 Orara Way–	1	Flood mark 1.8m above bottom beam of shed (approx. 2m over Ground Level).
2	0498534	6673668	64.67	Near Glenreagh Gauging Station	3	Flood Mark on tree 1.6m above ground level, local topographic grade changes could influence model at this location together with complex flow distributions, see Section 3.2.2.
3	0498435	6675406	63.269	2639 Sherwood Creek Road, Glenreagh	1	Flood mark on stonework of house, 80mm above concrete slab
4	049861	667374	66.221	Automatic Gauging Station, Glenreagh	2	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. Flood level information likely good up to point where flow emerges onto floodplain. Local flood distribution likely to influence flood levels beyond this flood level, see Section 3.2.2.

3.3.4 Summary of Meteorological Data

From the above discussion 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, particularly beyond emergence onto the floodplain at Glenreagh;
- 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 between a 4.5% and 13.2% AEP rainfall event, particularly in the lower parts of the catchment.

3.3.5 Topographic Survey

Clarence Valley Council does not possess LIDAR data for the Glenreagh area. Thus aerial photogrammetry and survey was conducted in order to develop a Digital Terrain Model (DTM) model to describe the topography and floodplains of the Orara River around Glenreagh and Tallawudjah creek tributary in the vicinity of Glenreagh.

The accuracy of this data was nominated as:

- 66% of points within 0.3m; and
- 98% of points within 0.5m.

Given that no other data existed and in the context of the rural nature of the current flood study, this level of accuracy was deemed acceptable, in discussion with Council.

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;
- Informing relevant local community groups; and
- 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 requirements) 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, Survey and Community Meetings

A public notice was placed in the local newspapers. In addition a project information sheet and survey was forwarded to the residents in the Glenreagh area (Appendix C). A total of 34 survey responses were received, from residents spanning the entire catchment area.

In response to the survey, the project team was contacted by a number of members in the community, and were provided specific information regarding flooding in Glenreagh at their properties. The community also kindly provided photographs of flooding at Glenreagh. Key issues raised in the survey were:

- A large number of the residents had experienced flooding at Glenreagh, first hand ;
- Flood levels tend to rise and recede after a few days, with water ponding in areas on the ground for a few weeks. 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 mentioned the 2009 floods and these have been etched in memories of the community. One resident mentioned the 1950 floods and noted that these were significantly more severe than the 2009 event;
- A number of residents noted elevated levels of anxiety during rainfall events. Some residents noted that flood waters had impacted their access to dwellings;
- 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 paddocks 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 Glenreagh School of Arts Hall on the 11/12/2012. The meeting was advertised in the local newspaper and at key locations in Glenreagh. Attendance at the meeting was good with 27 members of the community attending. 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, possibly 3.5m higher than the 2009 event. During this event much infrastructure was damaged, including a washout of the railway embankment at Nana Glen;
- A discussion about the frequency of flooding in the Orara River and that flood waters generally rise rapidly and dissipate over 1 to 2 days. In addition, the observation that flash flooding has become more prevalent;
- A discussion on flood insurance and whether the study was going to influence insurance premiums;
- Questions relating to potential backwater effects from the Clarence River. However flood levels in Glenreagh are a considerable distance from the Clarence confluence and approximately 40m higher, and thus no influence would occur;
- Questions and a discussion relating to the calculation of flood damages;
- As question relating to the contribution of groundwater and property runoffs to the flooding in the Orara, which was explained by the use of antecedent rainfall assumptions in the modelling;

- The noting of a number of anecdotal comments related to emergency responses during flood events. The particularly related to possible conflicting/confusing communications from various agencies; and
- Community members were shown the simulated 2009 and 1% AEP flood extent mapping, and confirmed that this flood coverage representation was similar to what was remembered to have occurred during these events.

5. Hydrologic Model Configuration and Calibration (RORB)

5.1 General

The Orara River Flood Study (GHD, 2012) hydrology 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.

For the current study this RORB model was extended for catchments downstream of the Glenreagh runoff gauge (including the Tallawudjah catchment), requiring a recalibration of the RORB model.

5.2 Configuration

Compilation of the Extended RORB model included:

- Catchment delineation, in accordance with the RORB procedures, with addition of 90 additional sub-catchments;
- Catchment parameter determination, namely sub-catchment area reach lengths and slopes;
- Event rainfall 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).

Since the critical duration at Glenreagh was determined to be the 48hr storm, the RORB model was simulated for these durations. 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 Extended RORB model was calibrated by varying model parameters to achieve a “good” fit comparing simulated hydrographs to measured hydrographs reported at the Glenreagh gauge. The kc parameter is the main means of adjusting the 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, 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 Extended RORB model, possible regional estimates of kc parameters are tabulated below.

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

Method	kc Estimate
Eastern NSW (Kleemola) (Eqn 3.20, ARR (Book V) $Kc = 1.22\ A^{0.46}$	22.12
Australia Wide – Dyer (1994) data (Pearse et al, 2002) $Kc = 1.14\ D_{av}$	40.04
Australia Wide – Yu (1989) data (Pearse et al, 2002) $Kc = 0.96\ D_{av}$	33.71
RORB Default – Eqn 2.5 (RORB Manual) $kc= 2.2A^{0.5}\ (Qp/2)^{0.8-m}$	51.32

5.3.3 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 5-2 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-2 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 5-1 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 51.32 and an m value of 0.8, as shown below in Figure 5-2. Initial and continuing loss parameters at the Aurania gauge were 10mm and 2.55mm/hr. Table 5-3 provides key calibration statistics. From the figure and table the following is noted

- Flood peak approximation is considered good to within 2.1%;
- Average agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within 2.2%.

Figure 5-1 February 2001 Aurania Rainfall Pattern

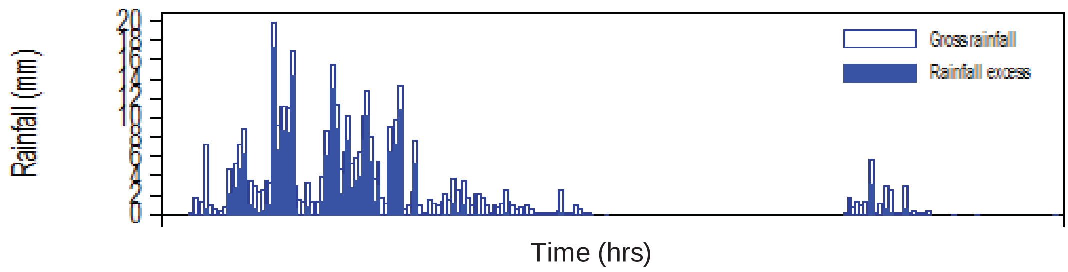
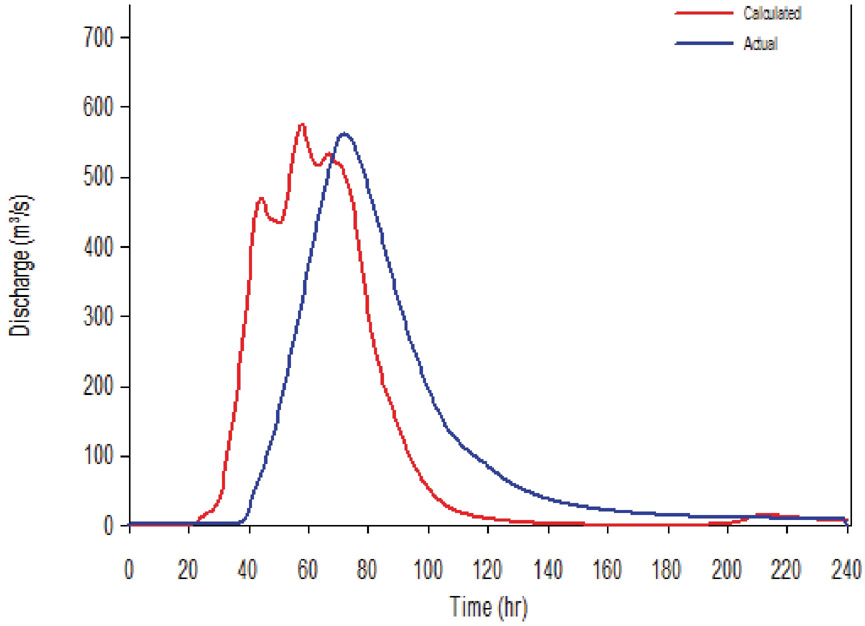


Table 5-3February 2001 Storm Calibration Statistics

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 5-2 February 2001 Rainfall Event and Calibrated hydrograph at Glenreagh (Gauge 204906)



5.3.4 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 5-4 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-4 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 5-3 below shows the rainfall pattern applied to the catchment, as derived from the Coffs Harbour Gauge, since the Aurania Gauge was not operation.

In consideration of the discussion in Section 3.3.3, on the accuracy of gaugings at the depth of this particular event, the best fit calibration achieved for this event was using the RORB default kc parameter of 51.32 and an m value of 0.8, as shown below in Figure 5-4. Initial and continuing loss parameters were 10mm and 5mm/hr respectively.

Table 5-5 provides key calibration statistics. From the figure and table the following is noted:

- Flood peak approximation is considered reasonable to within 9.3%, and the calculated flood peak is conservative;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -9.0%.

Figure 5-3 March/April 2009 Coffs Harbour Rainfall Pattern

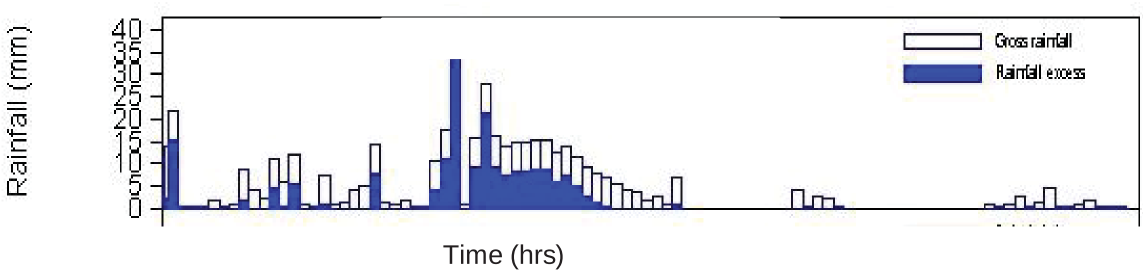
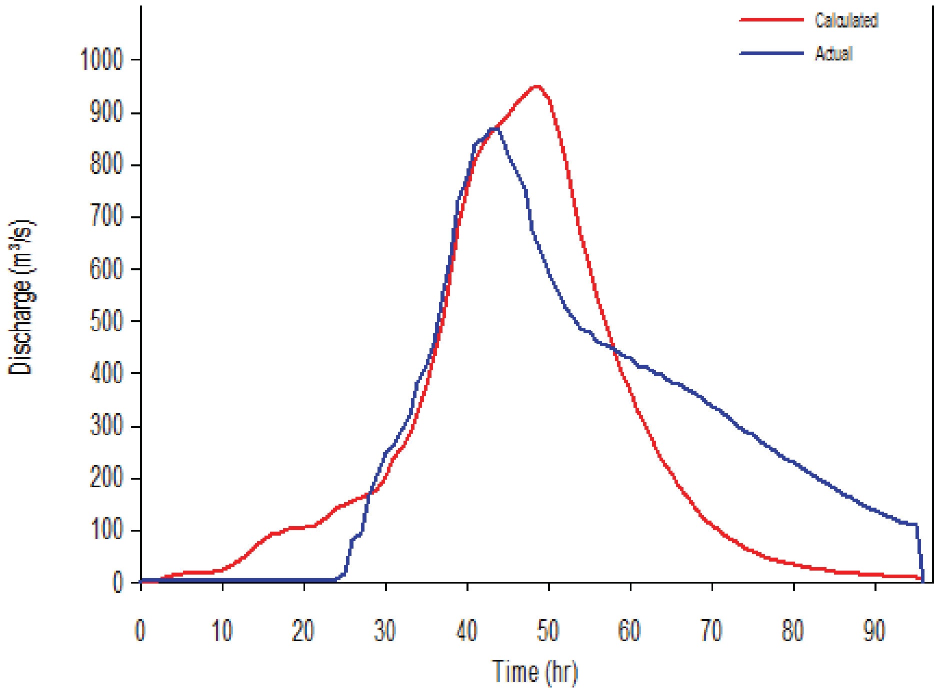


Table 5-5 March/April 2009 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	868.6	949.7	+9.3%
Storm Volume (m^3)	0.98E+08	0.89E+08	-14.0%
Lag (time to peak) (hr)	43	49	-9.0%

Figure 5-4 March/April 2009 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 51.37 and an m value of 0.8, as shown below in Figure 5-6. Initial and continuing loss parameters were 0mm and 5.45mm/hr. Table 5-7 provides key calibration statistics. From the figure and table the following is noted:

- Approximation is considered reasonable to within 10.4%, and the calculated flood peak is conservative;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -9.8%.

Figure 5-5   February 2009 Aurania Rainfall Pattern

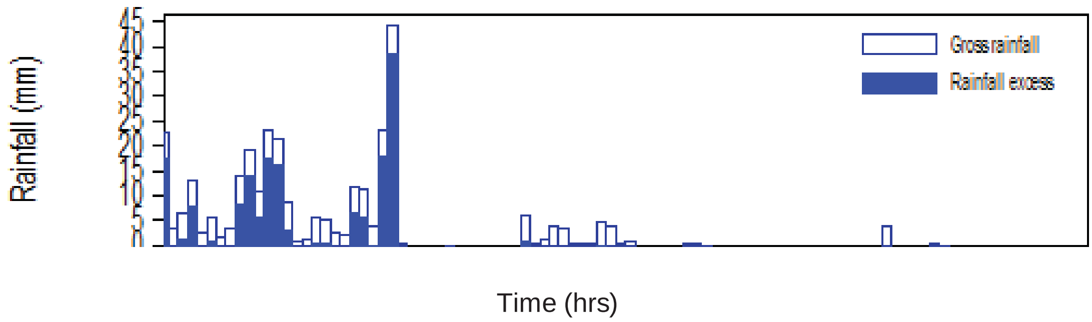
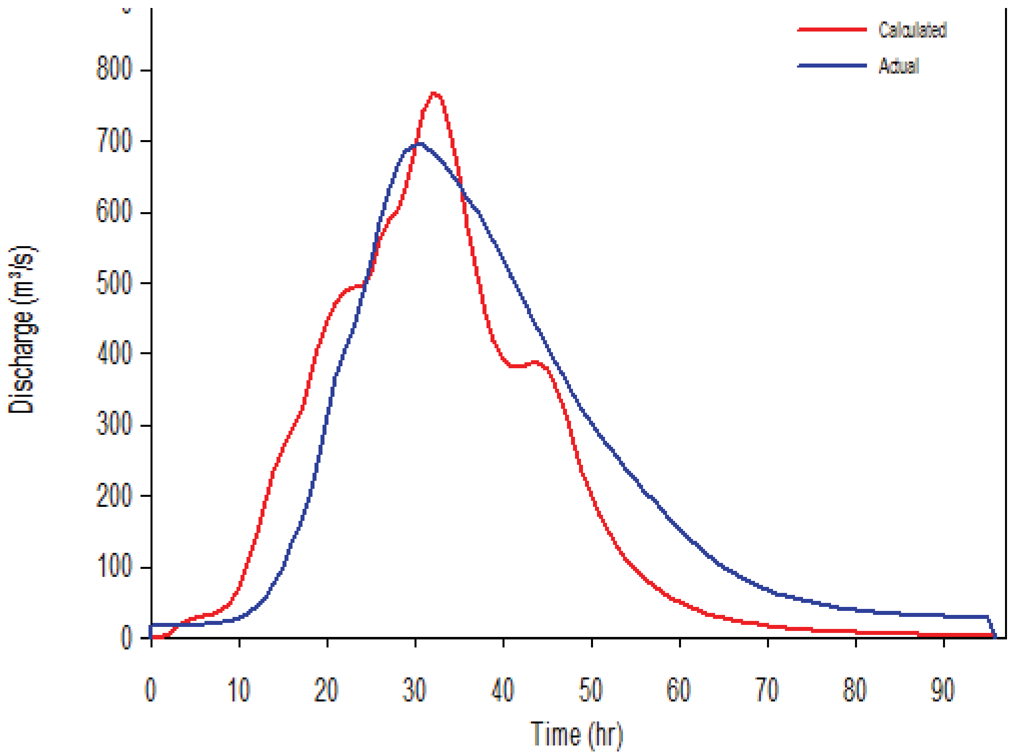


Table 5-7 February 2009 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	695.4	767.5	+10.4%
Storm Volume (m^3)	0.77E+08	0.70E+08	-9.8%
Lag (time to peak) (hr)	30	32	+6.7%

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



5.3.6 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 5-8 were recorded at daily rainfall gauges throughout the Orara catchment.

Table 5-8 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 5-7 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 51.32 and an m value of 0.8, as shown below in Figure 5-8. Initial and continuing loss parameters were 0mm and 17.98mm/hr.

Table 5-9 provides key calibration statistics. From the figure and table the following is noted:

- Approximation is considered reasonable to within 15.4%, and the calculated flood peak is conservative;
- Reasonable agreement in hydrograph shape and timing; and
- Reasonable approximation of the flood volume to within -15.3%.

Figure 5-7 March 1974 Aurania Rainfall Pattern

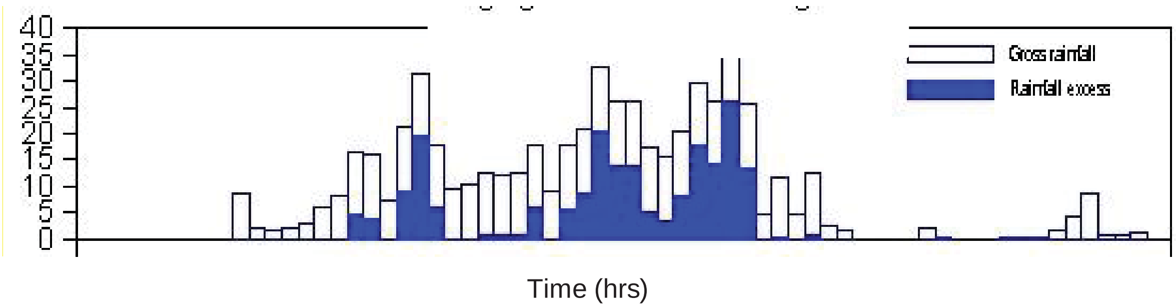
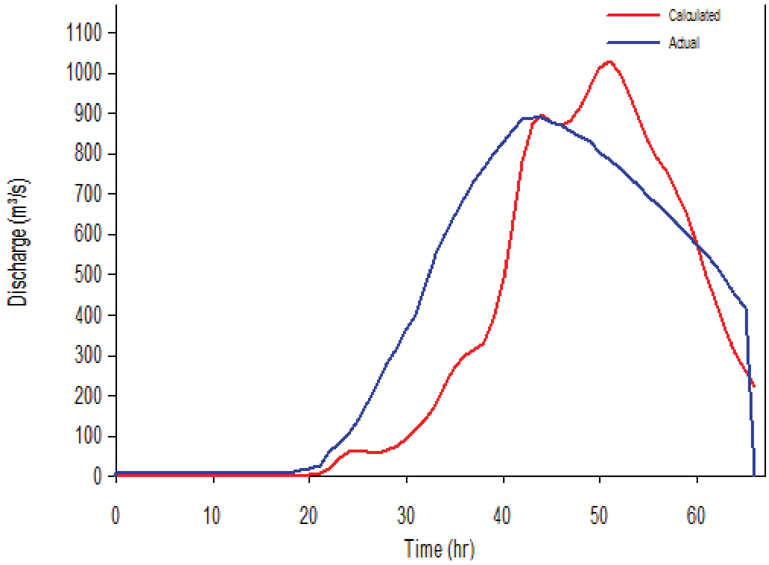


Table 5-9 March 1974 Storm Calibration Statistics

Item	Observed	Simulated	Difference
Storm Peak (m^3/s)	891.0	1028.6	+15.4%
Storm Volume (m^3)	0.95E+08	0.80E+08	-15.3%
Lag (time to peak) (hr)	43.0	51	+18.6%

Figure 5-8 March 1974 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.

Calibrations of the March and February 2009 events, Feb 2001 event and March 1974 event using the RORB default kc value of 51.32 for the Extended RORB model yield similar degrees of accuracy when compared to the RORB model calibration used in the Orara Flood Study (GHD, 2012).

On this basis, it was decided to accept the default RORB kc parameter for the new model, and assess further optimisation as a sensitivity assessment. The findings of this sensitivity assessment have been provided in Section 7.4 of this report.

6. Hydraulic Model Configuration and Calibration (TUFLOW)

6.1 General

The flood conveyance through Glenreagh 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 Clarence Valley 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 relatively small in comparison to the Orara River Flood Study (GHD, 2012) and in consideration of the extensive simulation time (2days per simulation) a stand-alone model was configured for Glenreagh. The TUFLOW model compilation configured the key parameters as described in Table 6-1, using the following methodology:

- Aerial Survey and photogrammetry 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. 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, given that the creek invert width is generally 20m to 40m (3-5 cells);
- All bridges within the floodplain were configured using the terrestrial survey data where available. These were configured within the 2D model grid;
- Culverts and other smaller drainage structures were configured within the 2D Model Grid using 1D connections through the topography where necessary;
- On the basis that a similar calibration was achieved for all the events in Section 0 for the Extended RORB model, the hydrograph outputs from the RORB simulations were used to configure boundary inflow conditions to the Glenreagh TUFLOW model. The downstream boundary conditions was configured as a discharge rating table based on creek invert from topographic survey, at a location some distance downstream of the study area;

- The flood hydrograph output from the Extended RORB model were configured as inflows for all sub-catchments draining to the Glenreagh model; 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 –2D domain

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 – 0.18, with the majority being around 0.1 to 0.18
Manning's "n" – floodplain areas	0.06 – 0.25, with the majority being around 0.08 to 0.18

6.2.1 Significant Structures in the Floodplain

Referring to Appendix F, a number of significant structures are located in the Orara River and Tallawudjah Creek floodplains. A total of four structures were configured in the TUFLOW model. Details of each structure were provided by Council, with exception of the railway bridge. For this bridge, the deck level was determined from the survey data of the rail embankment. Other bridge parameters were approximated from photographic records of the structure. Key bridge parameters included bridge/culvert waterway openings, piers dimensions, bridge deck, soffit and overflow levels.

6.3 Validation against Observed Flood Markers

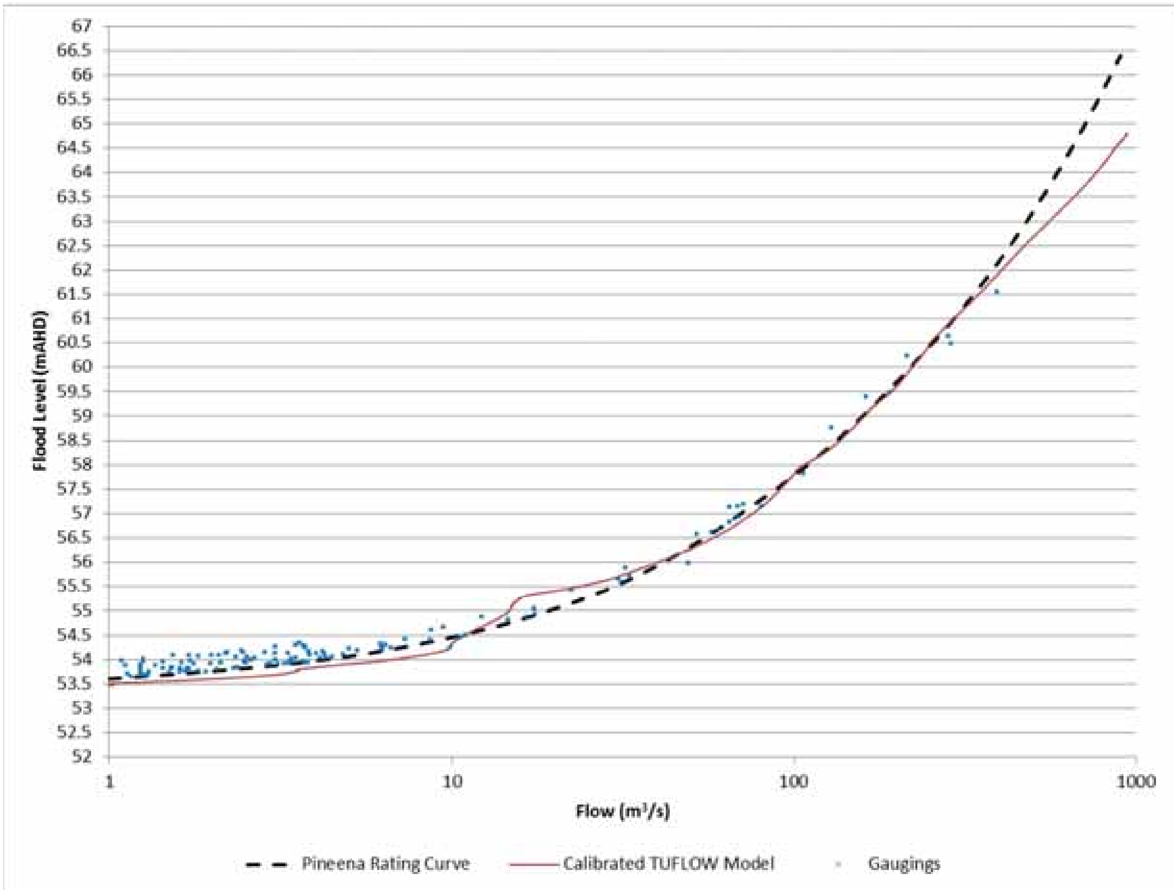
The March/April 2009 flood event was simulated in TUFLOW to calibrate the hydraulic model. The simulated flood levels were reviewed and model parameters adjusted in order to replicate as best as possible the recorded peak water levels as provided by the flood markers (see Section 3.3.3).

Figure F1a in Appendix E shows the comparison on a flood map of the March/April 2009 event. From the appendix it is noted that across the Glenreagh study area along the Orara River and Tallawudjah Creek catchments, the comparisons of observed and simulated flood levels are considered acceptable, particularly where flood markers have been assessed as being more reliable in Section 3.3.3.

As noted in Section 3.3.3, once flows emerge onto the floodplain at the Glenreagh Gauging station, local flow distribution effects are likely to result in lower confidence when comparing flood levels. However, while flows are contained within the river channel, Figure 6-1 below shows that good agreement between observed and simulated flood levels is achieved at the gauge.

Thus the validation of the TUFLOW model was considered acceptable.

Figure 6-1 Elevation-Discharge Relationship for Glenreagh Gauge



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 51.32 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 events.

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 were assessed within the catchment 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 monthly and highest daily rainfall between Aurania and Glenreagh of some 40%, thus showing 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

Month	Rainfall Station									
	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	220	**24**	32.7
2	170	**36**	26.2
3	140	**48**	22.7
4	117.5	**72**	18.7
5	100	**96**	15.8
6	91.7	**120**	13.3
12	52.9		

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 5790 m^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 RORB model was simulated for a number of events, 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	Glenreagh Gauge Flood Peak m³/s	Tallawudjah Creek Flood Peak m³/s	Glenreagh at Confluencewith Tallawudjah Creek m³/s
20% (48hr)	**1000**	**200**	**1115**
10% (48hr)	**1270**	**255**	**1435**
5% (48hr)	**1655**	**330**	**1850**
2% (48hr)	**2125**	**400**	**2405**
1% (48hr)	**2515**	**475**	**2890**
0.2%	**3735**	**692.5**	**4330**
PMF (12 critical duration)	**4974**	**1222**	**5790**

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 2650 m^3/s at the location of the Glenreagh flow gauging station, which compares favourably to the RORB estimate at the confluence in Table 7-5 (2890 m^3/s).

7.3 Flood Behaviour

7.3.1 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; and
- A series of maps showing provisional flood hazard generally in accordance with the NSW Floodplain Development Manual.

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 Tallawudjah Creek channels, and spill onto the floodplain. While some properties to the north of Glenreagh, in the vicinity of the confluence of Tallawudjah Creek and the Orara River would be expected to be at risk , the majority of Glenreagh would largely be unaffected by flood waters. A number of bridges and roads are expected to be inundated in the study area;

- In a 1% AEP event, widespread flooding is noted. Flood waters are expected to inundate large areas of the floodplain on the Orara River, Tallawudjah Creek and associated tributaries. Flood waters are expected to inundate properties north of Connell Street, Glenreagh and in the vicinity of the Tallawudjah Creek Road intersection. Flooding is also expected along Kookaburra Drive and Lorikeet Place in the vicinity of the railway line to the east of Glenreagh;
- A large number of rural properties are expected to be isolated by flood waters across all catchments; and
- In a PMF flood levels are expected to be approximately 3 to 4 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 in the flood plains. However in creeks which are steep and confined, flood velocities greater than 2m/s could be expected. For example the areas upstream of the Glenreagh Gauge and downstream of the Glenreagh Bridge have narrow creek channels and elevated flood velocities would be expected in these locations;
- 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; and
- 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 Tallawudjah Creek 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.

7.3.2 Inundation of Key Bridge and Culvert Structures

An assessment has been made of which bridges and structures likely to be inundated in the 20%, 5% and 1% AEP events. The results are tabulated below, which shows inundation of many of the key trafficable structures, leading to isolation of the Glenreagh community.

Table 7-6 Bridge Inundation Assessment

Locartion	20% Flood event AEP	5% Flood event AEP	1% Flood event AEP
Orara Way near Lurcocks Road	Inundated by approximately 3m	Inundated by approximately 5.8m	Inundated by approximately 8m
Orara Way near Shipmans Road	Not inundated	Inundated by approximate 0.5m at the bridge approaches	Inundated by approximate 2m at the bridge approaches
Glenreagh Bridge	Inundated by up to 2m on the eastern approach road to the bridge	Inundated by up to 3.8m on the eastern approach road to the bridge	Inundated by up to 5.6m on the eastern approach road to the bridge
Tallawudjah Creek Bridge	Inundated by approximate 0.3m at the bridge approaches	Inundated by approximate 2m at the bridge approaches	Inundated by approximate 3.9m at the bridge approaches
Orara Way north of Tallawudjah Creek Bridge	Inundated by approximately 3m	Inundated by approximately 1m to 1.5m	Inundated by approximately 3.5m

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; and
- Future Climate impacts on rainfall and flood levels.

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 5 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 lower reaches of the Orara River, flood level increases of in the order of 100mm can be expected; and
- Downstream of the Confluence of Tullawudjah Creek and Orara River, flood level increases in the order of 250 mm can 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 Glenreagh.

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 downstream of Glenreagh)

Flood event AEP	Default Value	Sensitivity Value
20%	1115 (48hr)	1233 (48hr)
10%	1422 (48hr)	1568 (48hr)
5%	1860 (48hr)	2006 (48hr)
2%	2393 (48hr)	2495 (48hr)
1%	2840 (48hr)	2977 (48hr)

7.4.3 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.2, showing that:

- Increases in roughness as defined in the table below could lead to increases of up to 0.5 to 0.7m, 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 slightly 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 – 0.20, with the majority being around 0.20	0.06 – 0.22
Manning's "n" – floodplain areas	0.06 – 0.18, with the majority being around 0.18	0.08 – 0.20

7.4.4 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.3, showing that:

- Increases in flood level of approximately 50mm, 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
- 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.

7.4.5 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 15 – 57% 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, around Glenreagh;
- 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 2 to 2.5m could be expected, again, particularly in the lower reaches of the Orara River and Tullawudjah Creek, around Glenreagh.

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%	1115 (48hr)	1280 (48hr)	1455 (48hr)	1650 (48hr)
10%	1420 (48hr)	1675 (48hr)	1910 (48hr)	2150 (48hr)
5%	1860 (48hr)	2230 (48hr)	2510 (48hr)	2795 (48hr)
2%	2395 (48hr)	2915 (48hr)	3295 (48hr)	3665 (48hr)
1%	2840 (48hr)	3615 (48hr)	4035 (48hr)	4450 (48hr)

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 544 km^2, and the Orara River has a length of some 55 km;
- 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;
- Clarence Valley Council (CVC) is responsible local land use planning at Glenreagh, located along the lower Orara River. Clarence Valley Council has prepared this flood investigation for Glenreagh 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 at Glenreagh. 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 community, relevant government agencies and local community groups 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 for a number of days. 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. 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 events;

- The flood conveyance at Glenreagh was calculated using the TUFLOW hydraulic model. The model extent for the purposes of flood mapping was defined in collaboration with Clarence Valley Council and the Office of Environment and Heritage. Since the area to be modelled is significant a stand-alone model was compiled, 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 Tallawudjah 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 and associated tributaries. Flood waters are expected to inundate properties to the north of Glenreagh in the vicinity of the Tallawudjah Creek confluence 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 3 to 4 m deeper than the 1% AEP event across the catchment. This would result in significant and widespread flooding;
- Hazard categories are provisional because they do not reflect the effects of other factors that influence hazard. 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; 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 and future climate impacts on rainfall and flood levels. The impact of each assessment has been provided as a series of flood difference map.

9. References

- NSW DECC 2005, NSW Government, Floodplain Development Manual, Management of Flood Liable Land 2005;
- NSW DECC 2007, Practical Consideration of Climate Change, NSW Department of Environment & Climate Change;
- AR&R 2001, Australian Rainfall and Runoff, 2001;
- CHCC 1991, Flood Study for the Orara River and Bucca Valley Creek, Bruce Fidge and Associates, June 1991
- GHD 2012, Orara River Flood Study, Coffs Harbour City Council 2012
- RORB 6 User Manual, Monash University Department Of Civil Engineering In Conjunction With Sinclair Knight Merz Pty. Ltd. And The Support Of Melbourne Water Corporation, Rorb Version 6 Runoff Routing Program User Manual;
- BMT WBM 2010, TUFLOW User Manual
- BOM 2003, Bureau of Meteorology Australia Generalised Tropical Storm Method – Revised Version, November 2003;
- MHL 2009, New South Wales Coffs Harbour and Bellinger Rivers Regions 2009 Flood Summary, Report MHL 1913, April 2009;
- OEH 2007, Department of Environment and Climate Change, Flood Risk Management Guideline, Residential Flood Damages;
- CHCC 2001, Coffs Creek Flood Study, Coffs Harbour City Council, May 2001;

10. 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

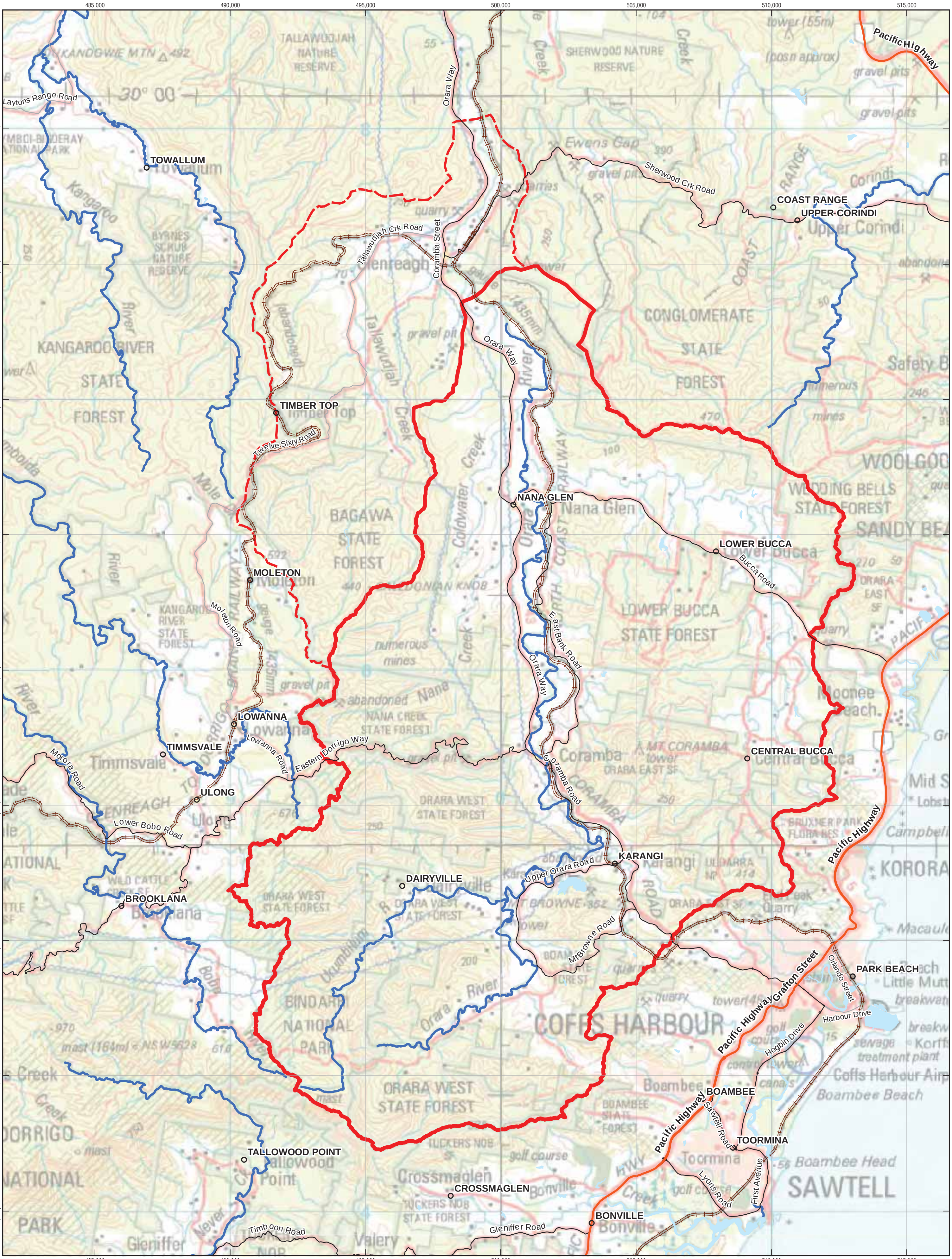
Stage–damage curve - A relationship between different water depths and the predicted flood damage at that depth.

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.

Appendices

Appendix A Location Maps



1:125,000 (at A3)

0 600 1,200 2,400 3,600 4,800

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Legend

- Highways
- Major Roads
- Secondary Roads
- Waterways (lines)
- Original RORB Model
- Glenreagh RORB Extension

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Locality Map
Study Area

Figure A.1

G:\22\16342\GIS\Maps\Working\Maps For Report\Figure-A.1.mxd

230 Harbour Drive Coffs Harbour NSW 2450 Australia T 61 2 6650 5600 F 61 2 6650 5601 E cfsmail@ghd.com.au W www.ghd.com.au

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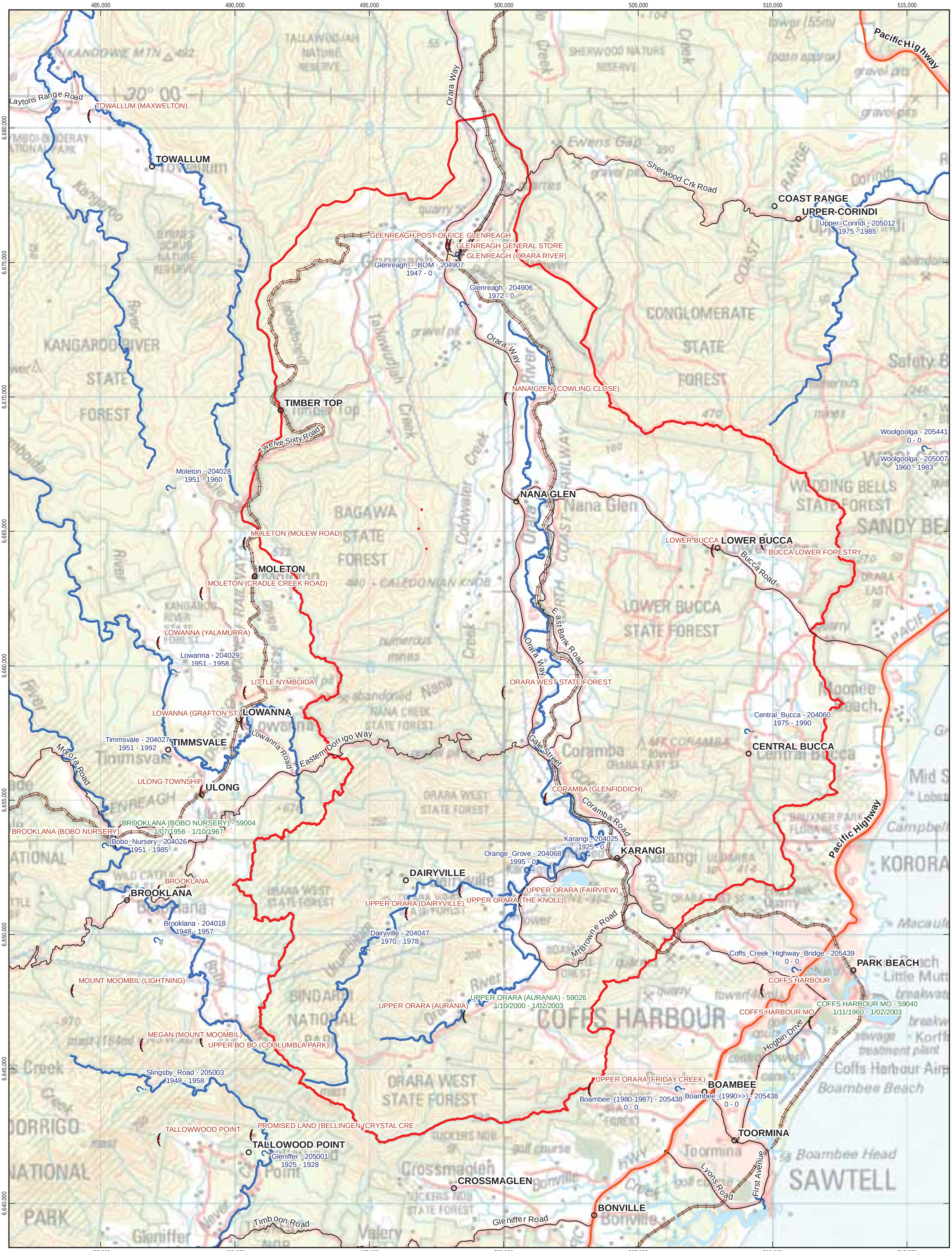
Data source: Clarence Valley Council Created by: SLDouglas

Appendix B Data



1:125,000 (at A3)

0 600 1,200 2,400 3,600 4,800

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Legend

- Highways
- Major Roads
- Secondary Roads
- Pluvio Rainfall
- Runoff
- Daily Rainfall
- Waterways (lines)
- Model Extents

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Orara River Gauging Information

Figure B1

G:\22\16342\GIS\Maps\Working\Maps For Report\Figure-B.1.mxd

230 Harbour Drive Coffs Harbour NSW 2450 Australia **T** 61 2 6650 5600 **F** 61 2 6650 5601 **E** cfsmail@ghd.com.au **W** www.ghd.com.au

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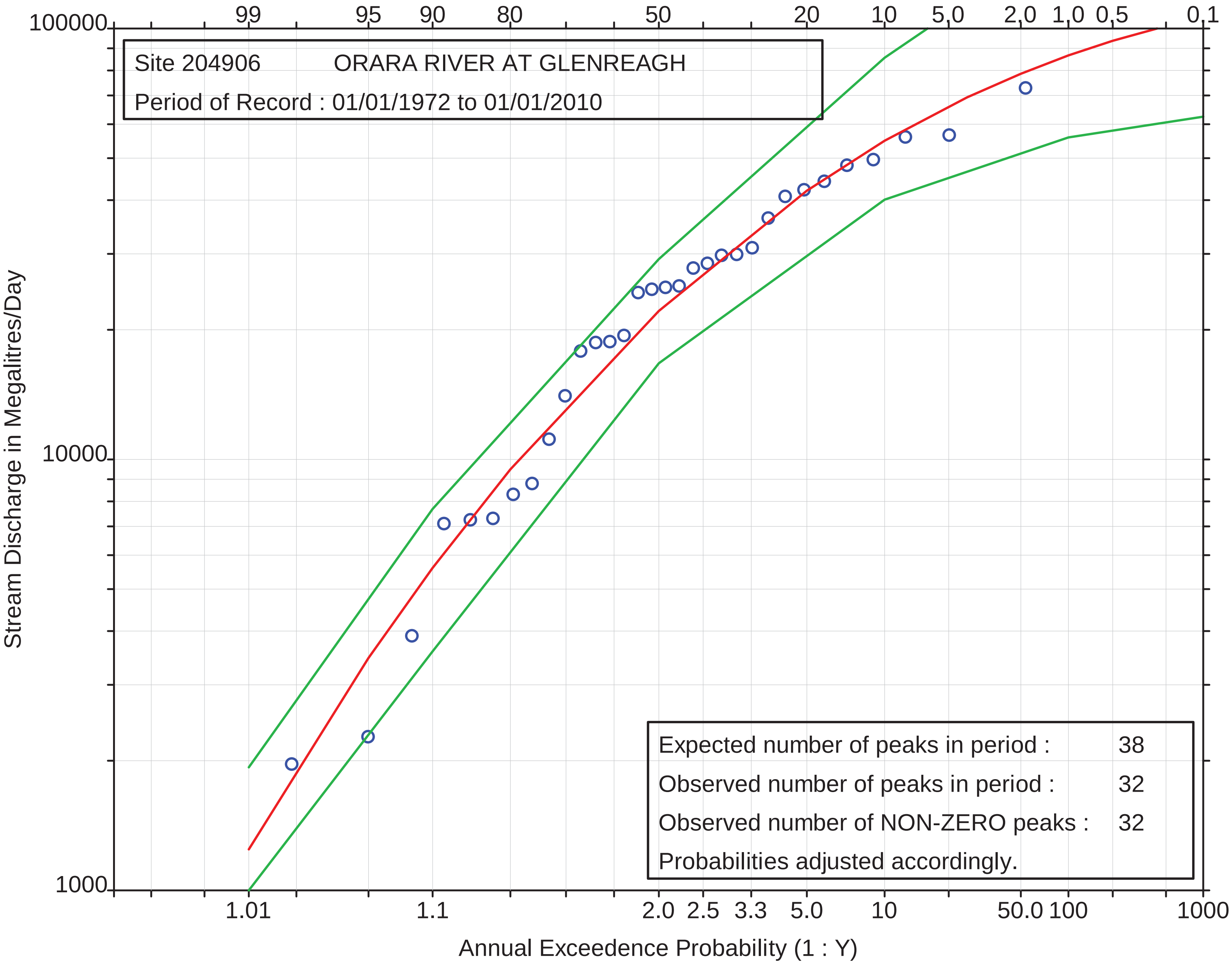
Data source: Clarence Valley Council Created by: SLDouglas

NSW Office of Water

Log-Pearson Type III Analysis. (Annual Series)



Flow	Probability (1/Y)	AEP (1 : Y)
1244	0.990	1.01
5603	0.900	1.11
22090	0.500	2
25325	0.429	2.33
42078	0.200	5
54840	0.100	10
69245	0.040	25
78568	0.020	50
86663	0.010	100
93729	0.005	200
106975	0.001	1000

Statistics of the Logs of Flows.

Mean	4.283
Standard Deviation	0.399
Skewness Coefficient	-0.929

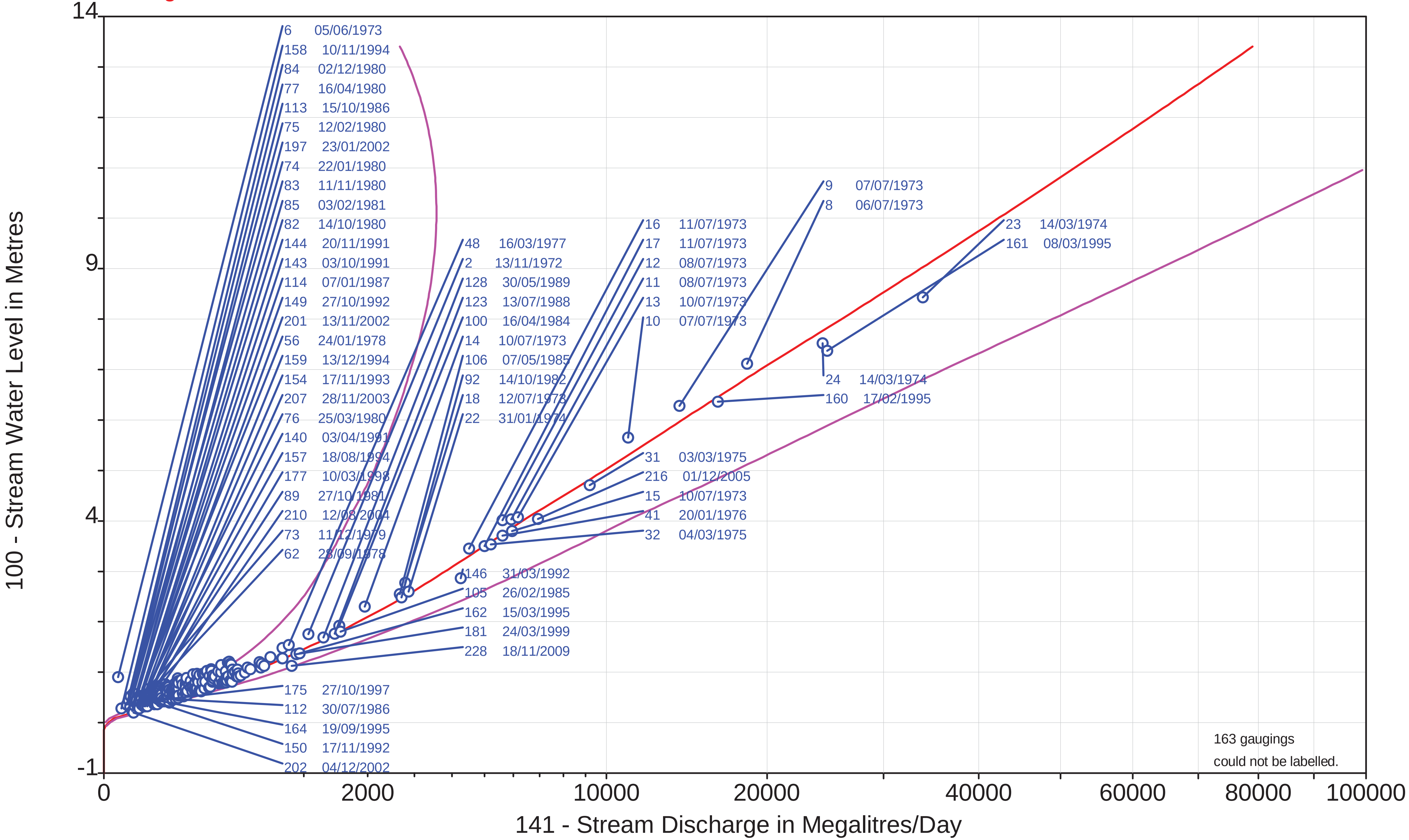
NSW Office of Water PINNEENA 9.3

HYGPLOT V128 Output 10/02/2012

204906 ORARA RIVER AT GLENREAGH

Gaugings from 18/10/1972 to 18/11/2009

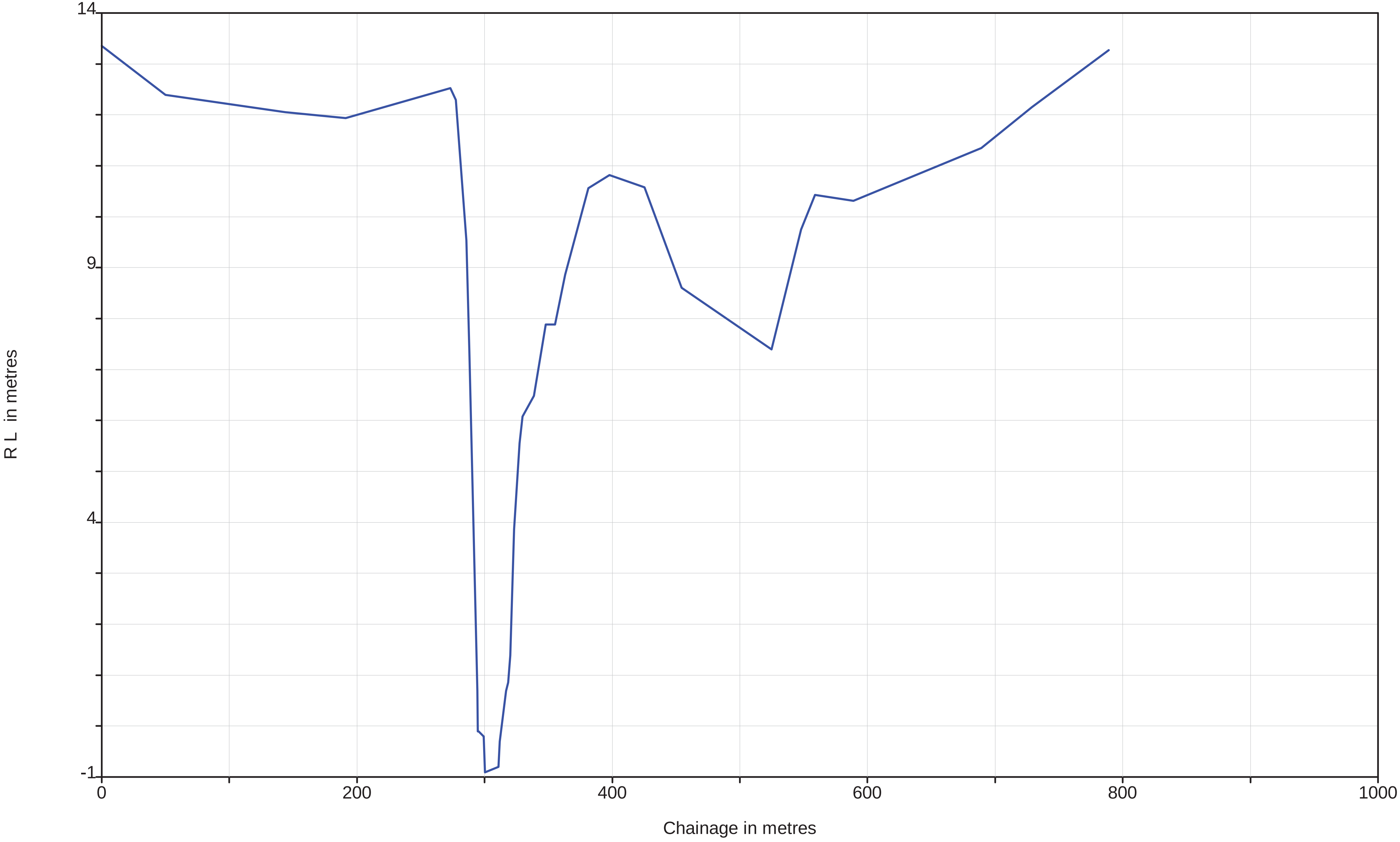
Rating Table 231.00 21/08/2007 to Present



NSW Office of Water PINNEENA 9.3

Cross Section Plots

Site	SectID	Date	Type	Section	Run	Name
204906	990001	17/12/1998	At gauges	1	1	ORARA RIVER AT GLENREAGH



Appendix C Community Consultation


Glenreagh Flood Study

Community Meeting
10/12/2012

Glenreagh Flood Study

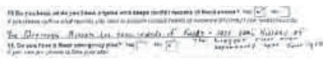
Flood History

@ Karangi 1990, 1997, 1973, 2002, 1986, 2000, 1989,1971, 1996, and 1982

Glenreagh Flood Study

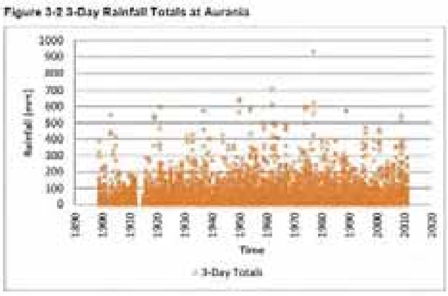
Glenreagh Flood Study

Flood History

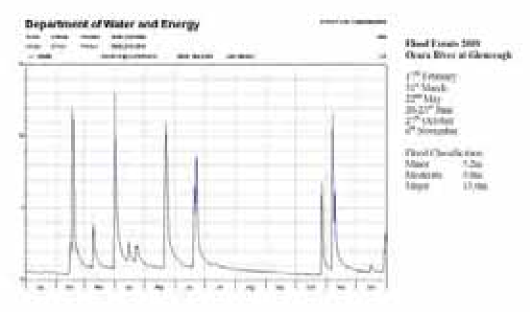


Families See Homes Washed Away By Flooded River

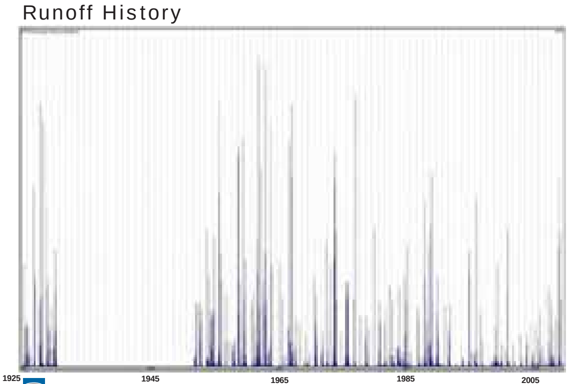
Rainfall History



2009 Flood Event

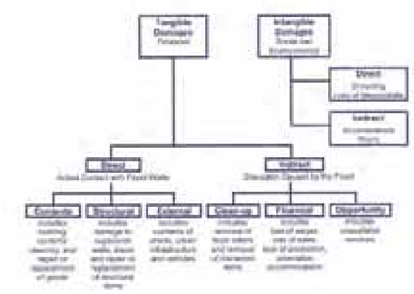


Runoff History



2009 Flood Event

Flood Damage



Floodplain Development Manual

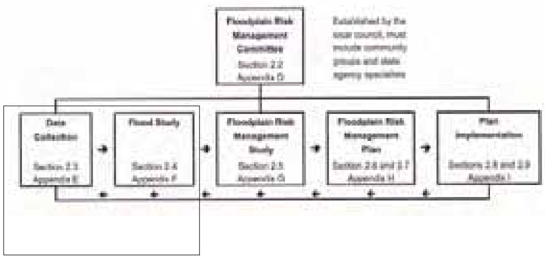
the management of flood liable land

- Reduce the social and financial
- Increase the sustainable benefits of using the floodplain
- Improve or maintain floodplain

PROVIDES A PROCESS !!

..how does one manage Flood Liable Land?

Floodplain Risk Management Process

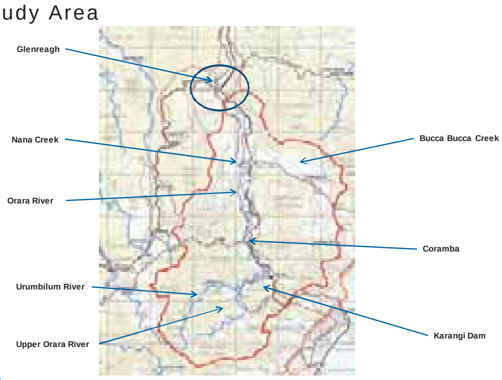


Flood Study - Key Tasks

1. Obtain Survey
2. Community Input
3. Flood Model
   - Calculate Flood Peaks & Flood Flows
   - Calculate Flood Levels
4. Provide Flood Mapping

Rainfall and Runoff Data

Study Area



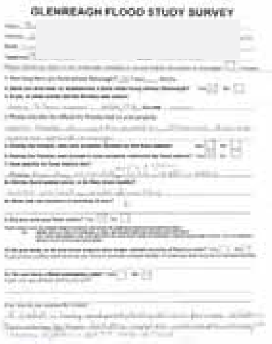
Survey

- Photogrammetry to DTM
- Structures/Bridges

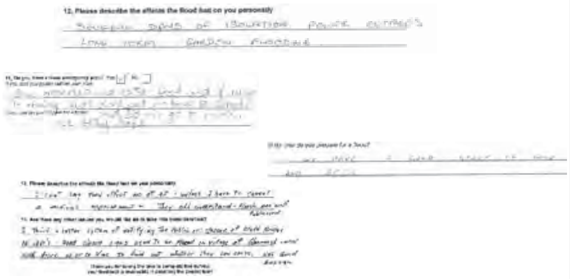
Community Involvement

- Media Release
- Newsletter & Survey

Survey Returns
- Over 24



Community comments...



Community comments...

Flood Modelling

Rain +

Flood Flow

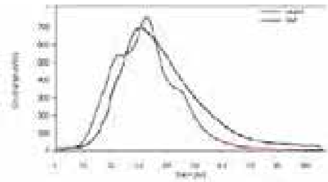
Flood Level

+ survey

Flood Flow?

Flood Peaks & Hydrographs

Step A2
- Calibrate Rainfall / Runoff Model



Flood Peaks & Hydrographs

Step A1
- Compile Rainfall / Runoff model (RORB)

Flood Peaks & Hydrographs

Step A3
- Calculate Flood Flows & Flood Peaks

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Flood Levels?

Flood Levels & Maps

Step B2

- Calibrate Flood Level Model
  - Compare to measured flood levels (2009)
  - Repeat until acceptable

Flood Levels & Maps

STEP B1

- Compile Flood Level Model
  - Input Creeks and Floodplain
  - Input Flows

(TUFLOW)

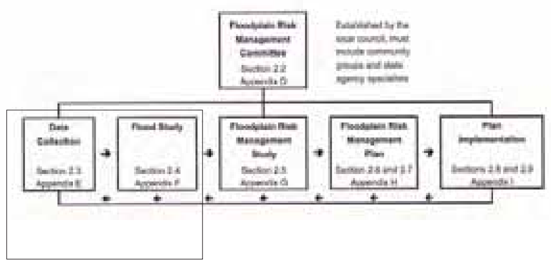
Flood Levels & Maps

Step B3

- Calculate Flood Levels
- Produce Flood Mapping
  - 20% AEP (5-year ARI);
  - 5% AEP (20-year ARI);
  - 1% AEP (100-year ARI);
  - 0.2% AEP (500-year ARI); Probable Maximum Flood (PMF).

The End

Floodplain Risk Management Process



Current Study

..where to from here?

Floodplain Management Options

Floodplain Management Options

Property Modification

- Land Use Planning.
- House raising or Flood Proofing of Buildings.
- Voluntary Purchase of High Hazard Properties

Response Modification

- Flood Warning Systems and Evacuation Plans.
- Flood Insurance and Recovery.
- Public Flood Awareness Scheme

Flood Modification

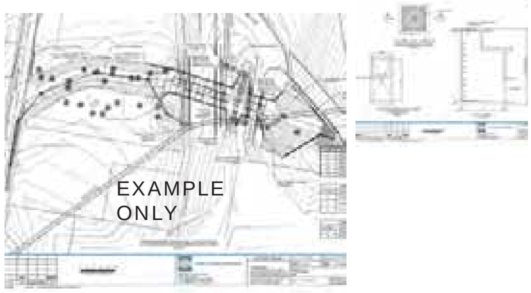
- Flood Mitigating Dams or Detention Basins.
- Levees.

Assessment of Options

Category	Issues
Social	• The capacity of the option to reduce flood hazards and personal safety risks to the community, • How the option will influence property values; • The capacity of the option to promote community growth; and • The level of disruption to the community, either through implementing the option or through the resulting floodplain behaviour.
Economic and Financial	• The capital costs associated with implementing the option; • The ongoing or maintenance costs of the option; and • The costs or savings of flood damage after the option is implemented.
Environmental	• Change to ecology, habitats, riparian vegetation, and the "natural state" of the river; • Pollution; • Energy and resources required to implement the option; and • Energy and resources required for maintaining and decommissioning the option.

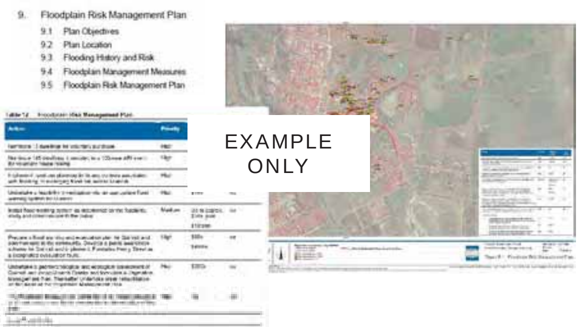
GHD

Design



GHD

Floodplain Risk Management Plan



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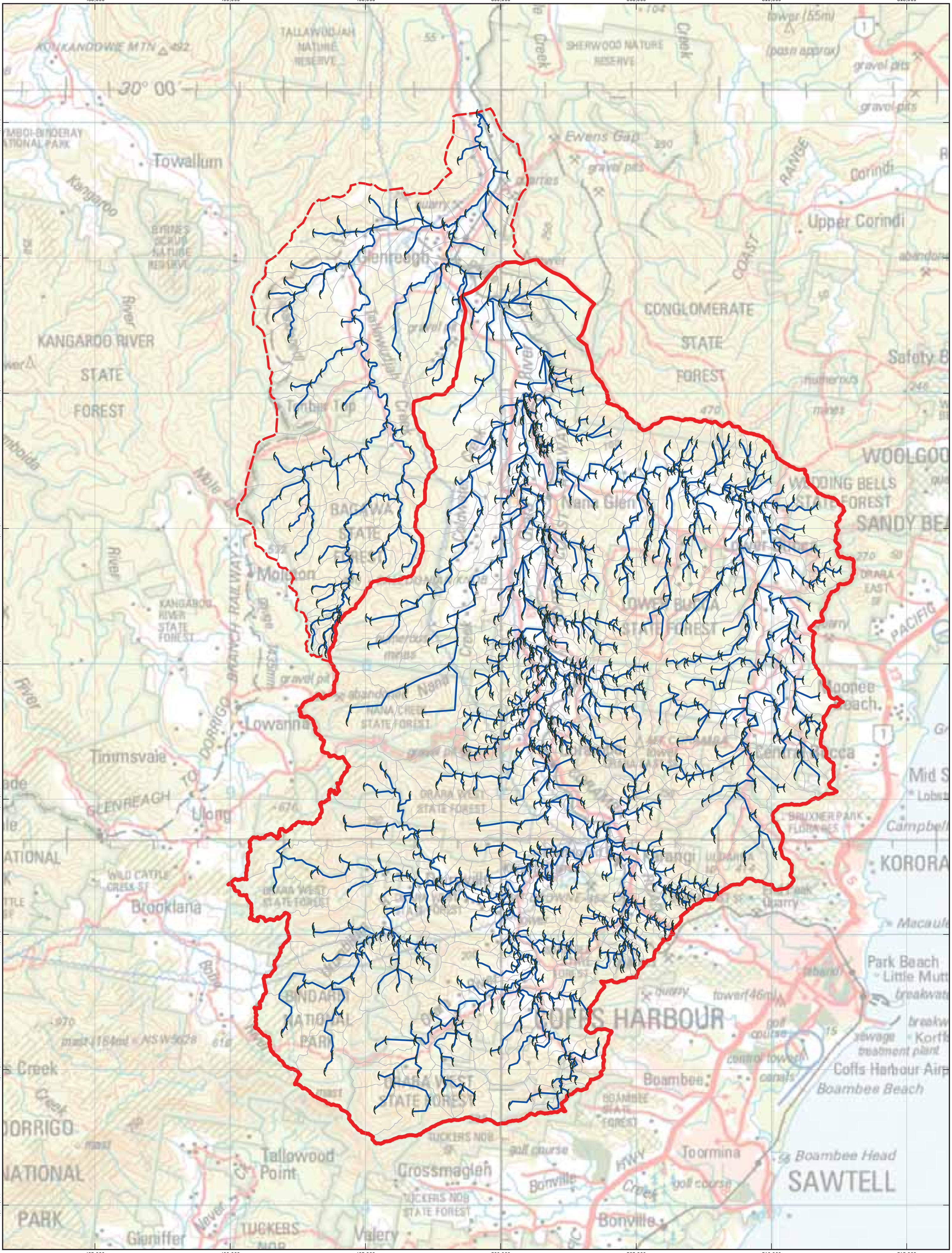
Appendix D Hydrological Data



1:125,000 (at A3)

0 600 1,200 2,400 3,600 4,800

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Legend

Original RORB Model

Glenreagh RORB Extension

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Orara River Catchment RORB Nodes and Reaches

Figure D.1

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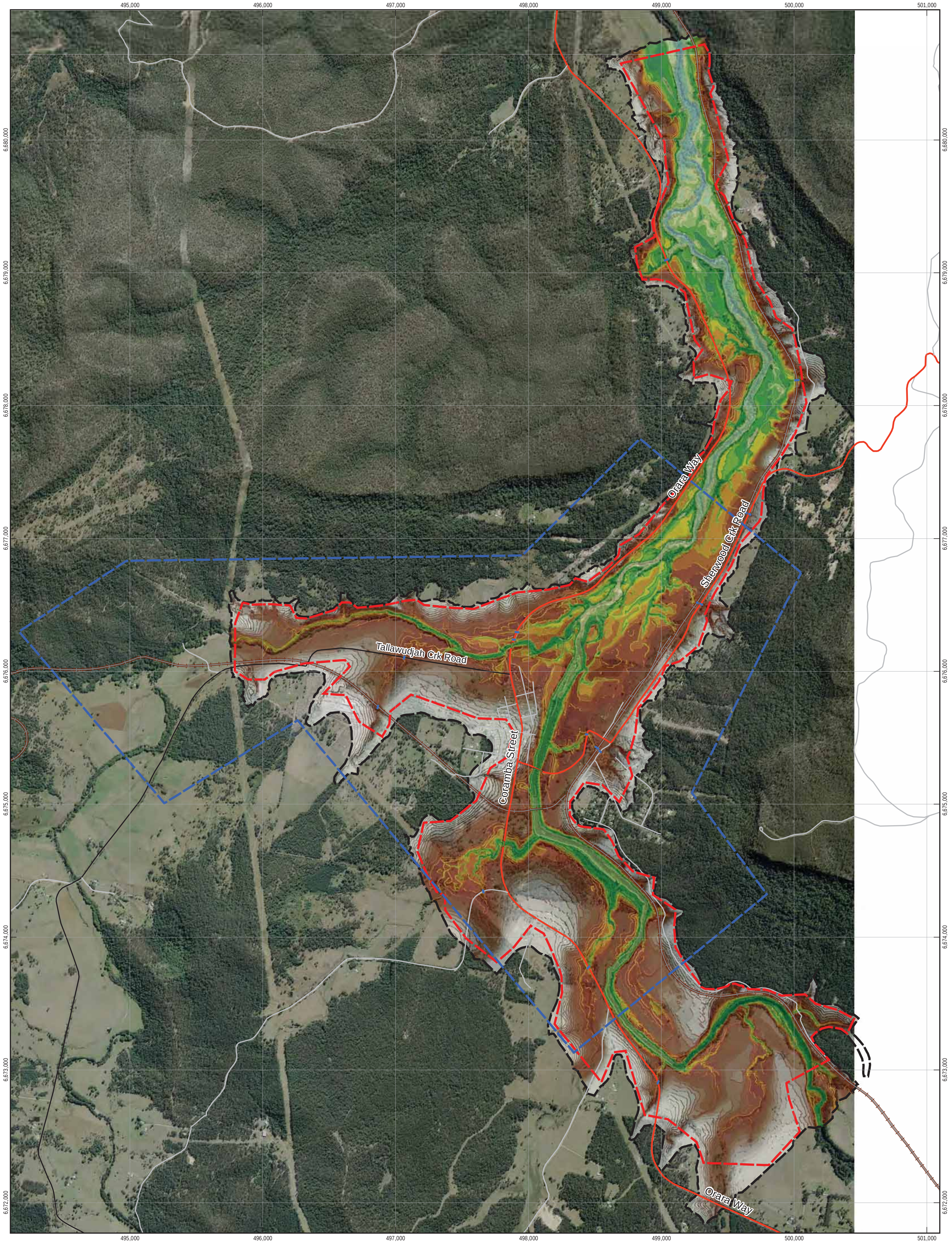
Data source: Clarence Valley Council Created by: SLDouglas

Appendix E Hydraulic Data



1:25,000 (at A3)

0 120 240 480 720 960

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Legend

- Highways
- Major Roads
- Secondary Roads
- Other Roads
- Railways
- Survey Extent
- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

TUFLOW Model Overview
Hydraulic Model Extent

Figure E.1

G:\22\16342\GIS\Maps\Working\Maps For Report\Figure-E.1.mxd

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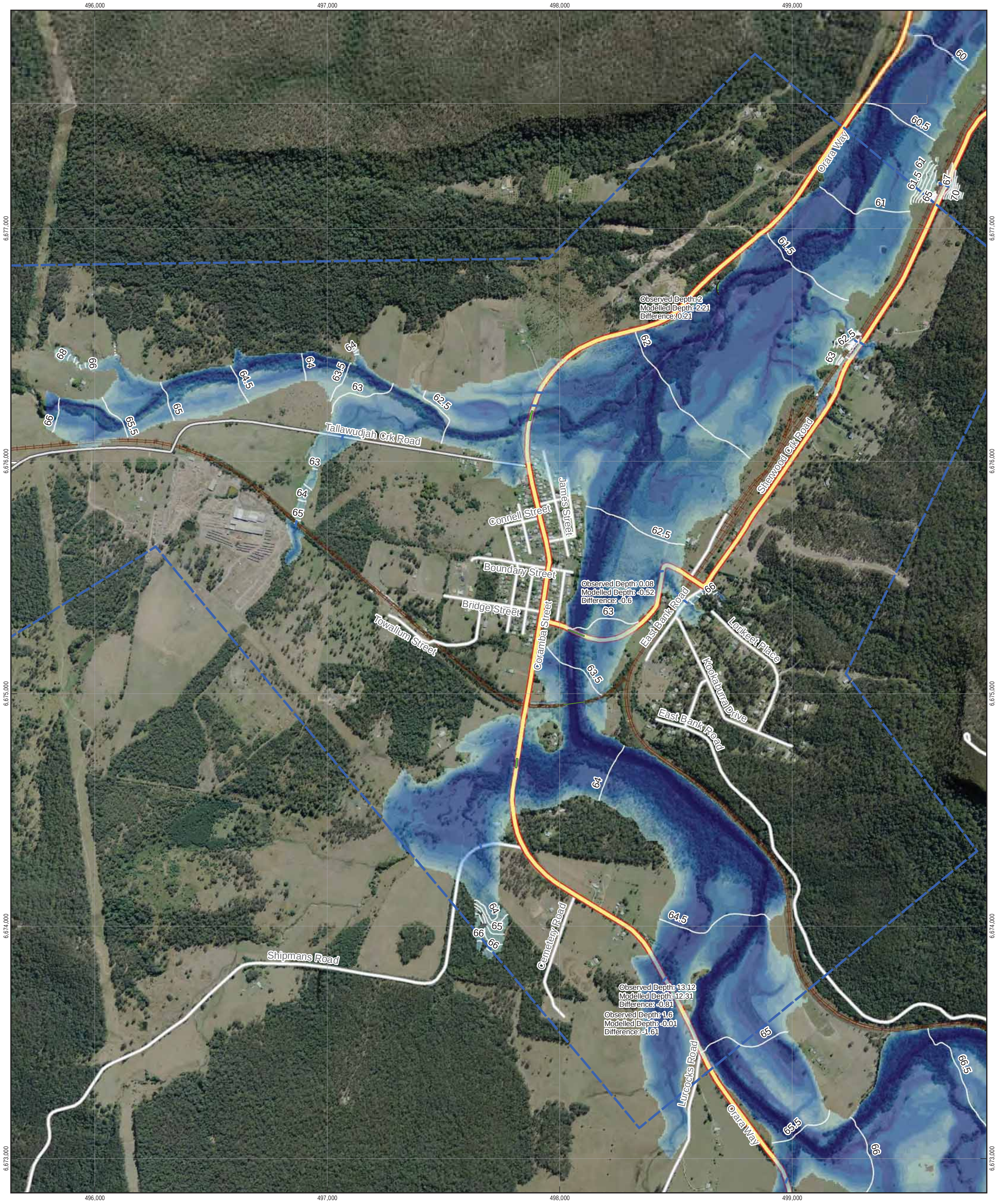
Appendix F Design Flood Results and Mapping



Legend

Flood Extent and Depth (m)

- 0.16 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 20.0

Flood Level Contours (mAHD)

Flood Calibration Markers

- Lower than 1m
- -1.00m - -0.50m
- -0.50m - -0.25m
- -0.25m - 0.25m
- 0.25m - 0.50m
- 0.50m - 1.00m
- Greater than 1m

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Flood Map
2009 Calibration Event

Figure F.1a

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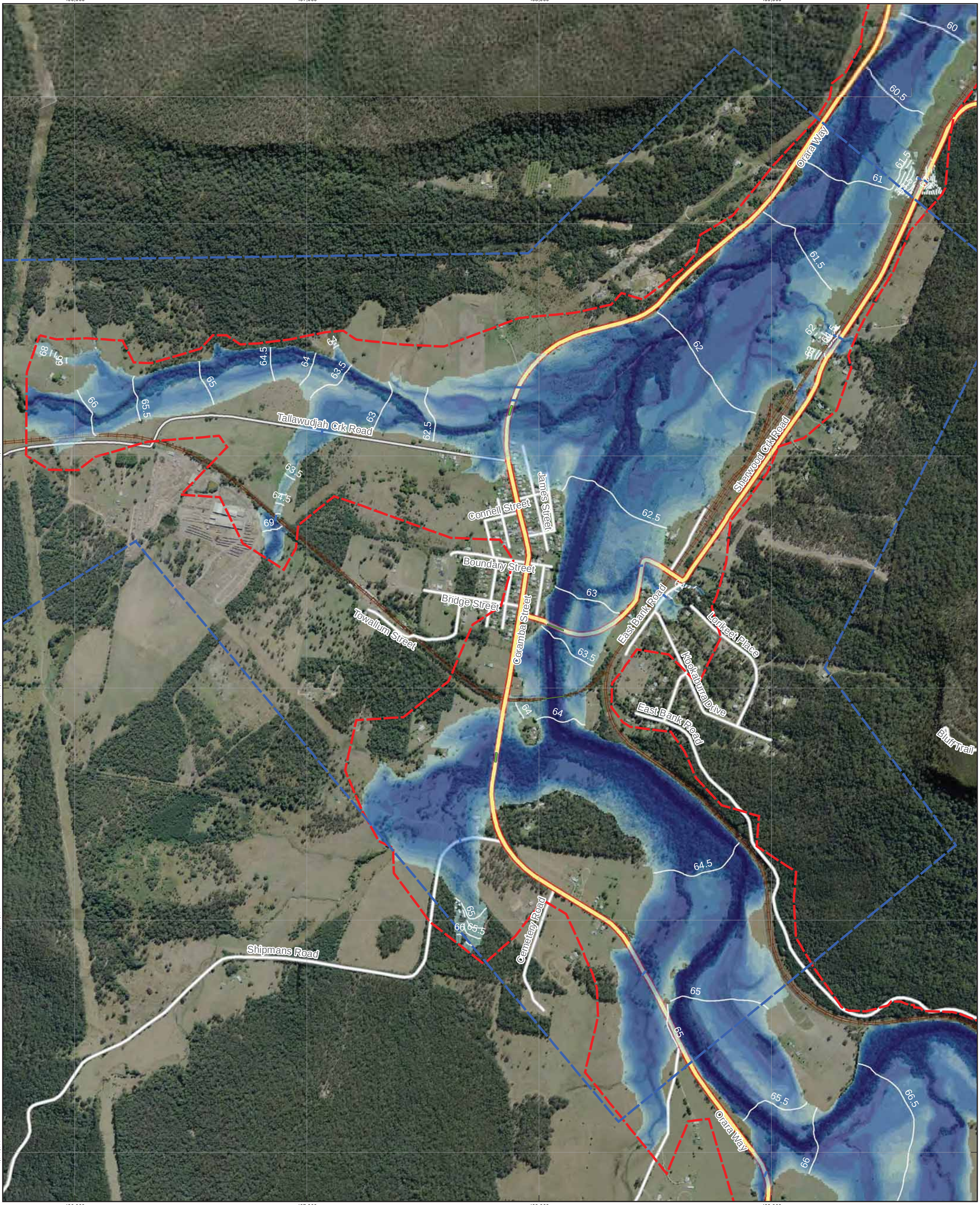
Data source: Clarence Valley Council Created by: SLDouglas



Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Flood Extent and Depth (m)

- 0.16 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 20.0

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2012

Flood Map
20% AEP Flood Event

Figure F.2a

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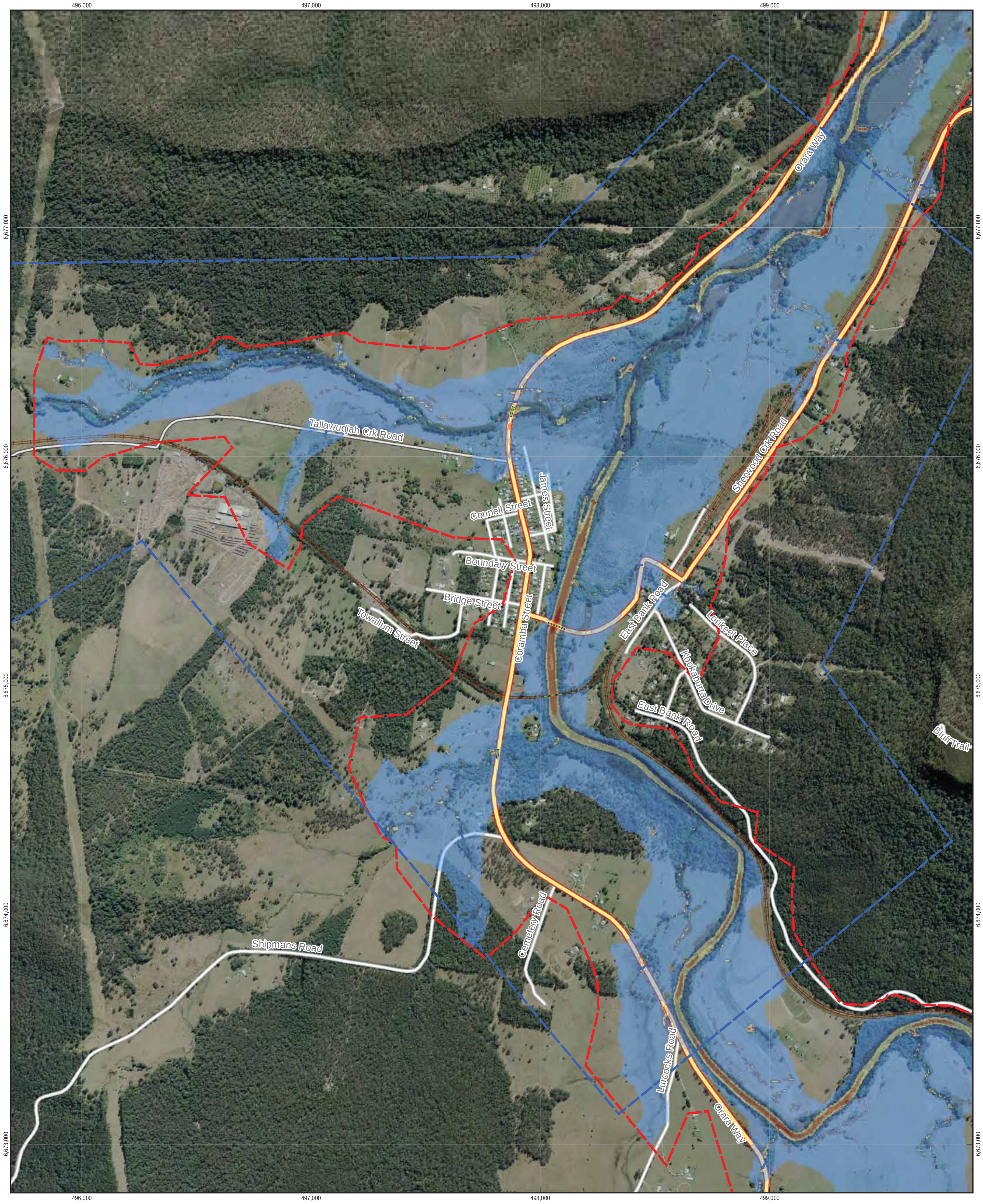
Data source: Clarence Valley Council Created by: SLDouglas



Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Velocity (m/s)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- Greater than 2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Flood Velocity Map
20% AEP Flood Event

Figure F.2b

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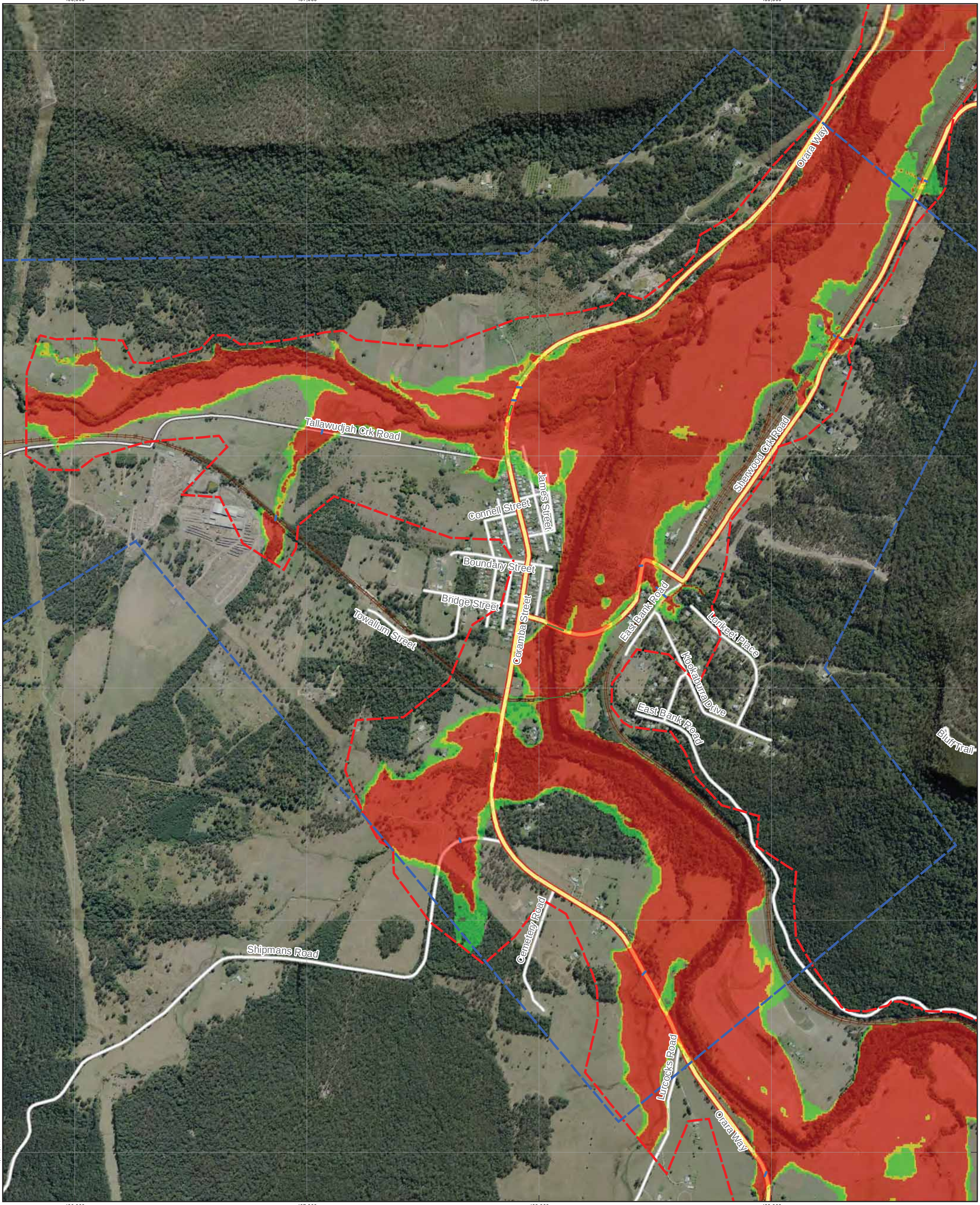

Legend

Study Area

2D TUFLOW Modelled Bridges

1D TUFLOW Modelled Culverts

2D TUFLOW Model Area

Flood Hazard Category

1 - Low Hazard

2 - Intermediate Hazard

3 - High Hazard

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Flood Hazard Map
20% AEP Flood Event

Figure F.2c

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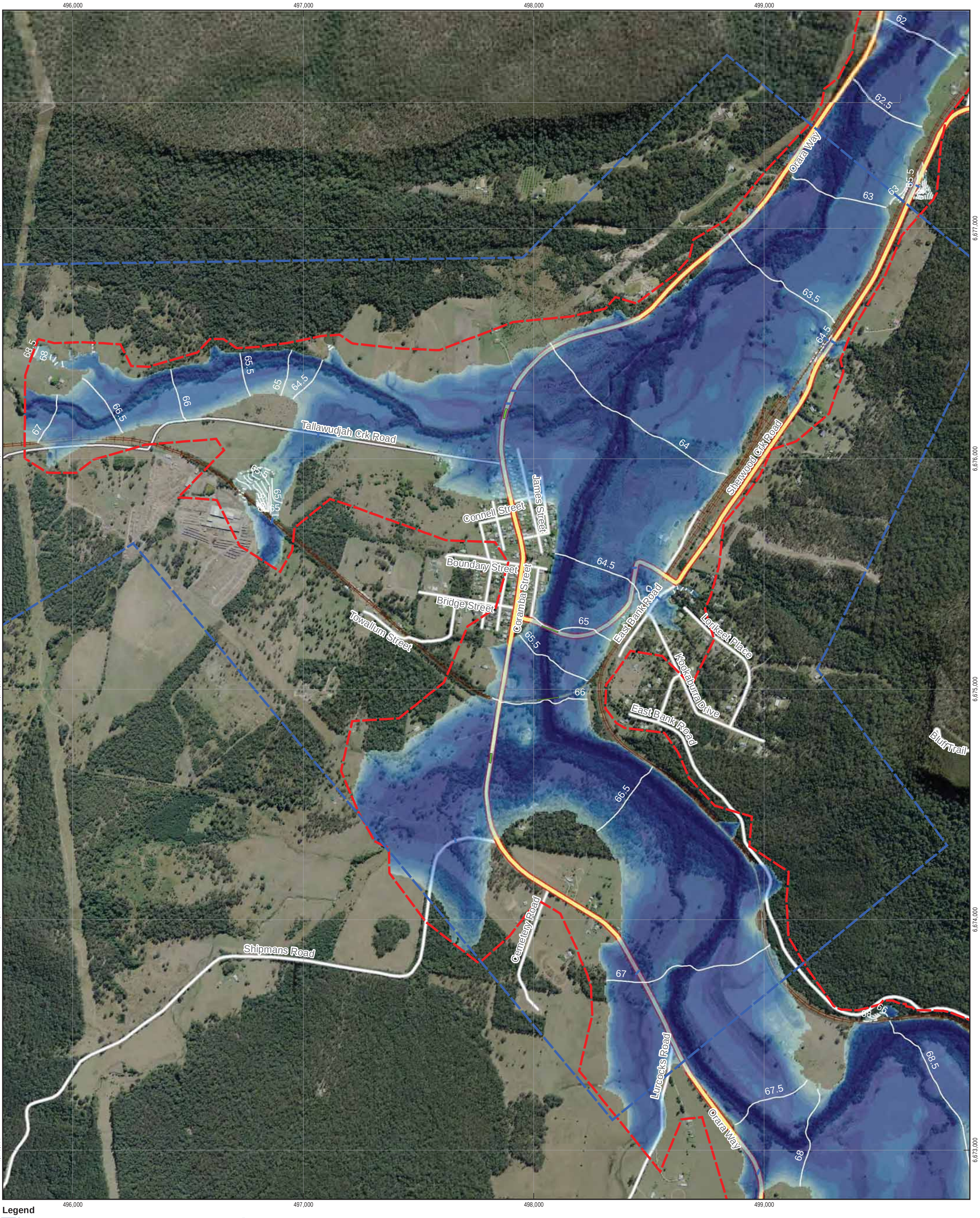

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Flood Extent and Depth (m)

- 0.16 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 20.0

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Flood Map
5% AEP Flood Event

Figure F.3a

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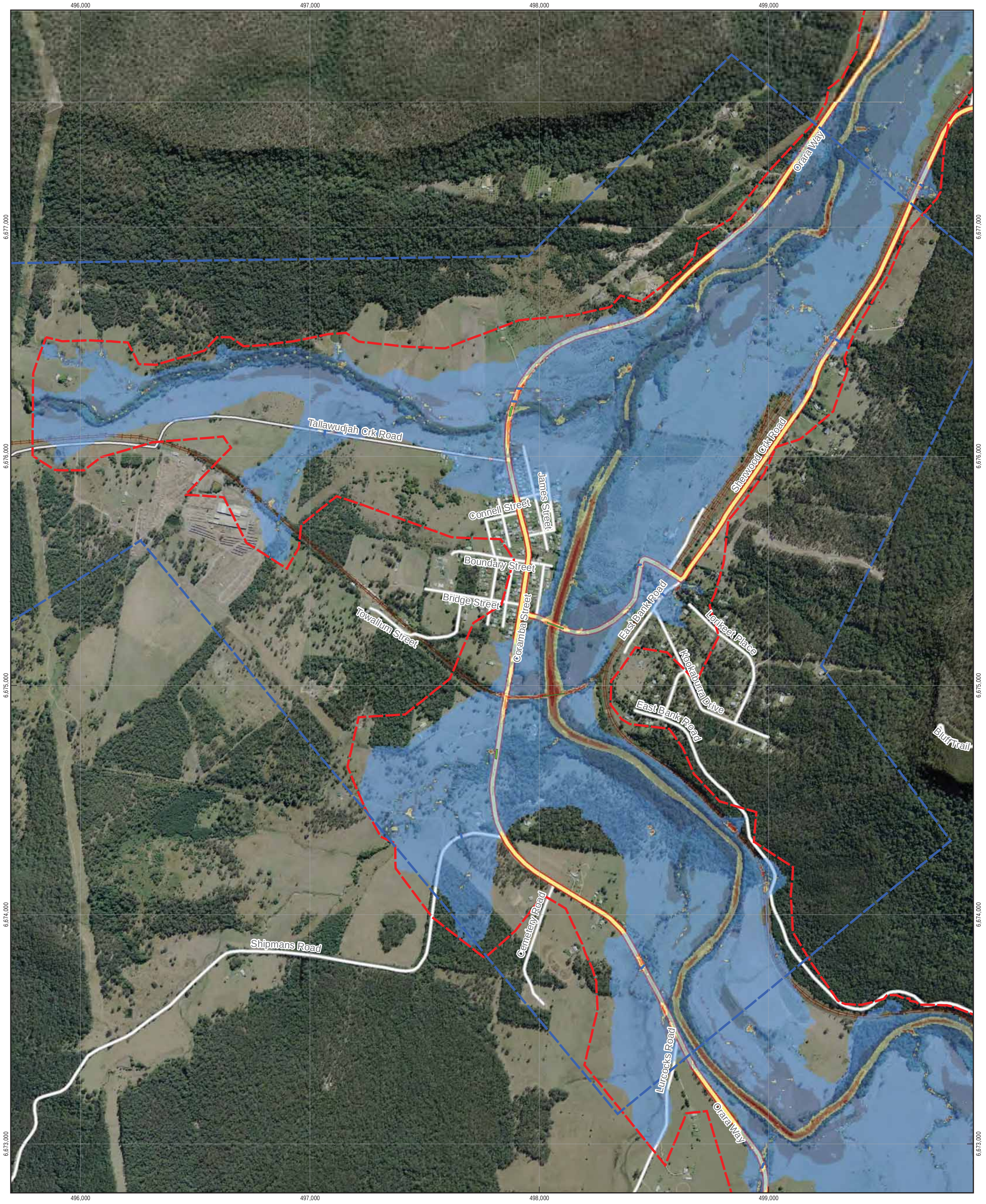
Data source: Clarence Valley Council Created by: SLDouglas



Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Velocity (m/s)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- Greater than 2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Flood Velocity Map
5% AEP Flood Event

Figure F.3b

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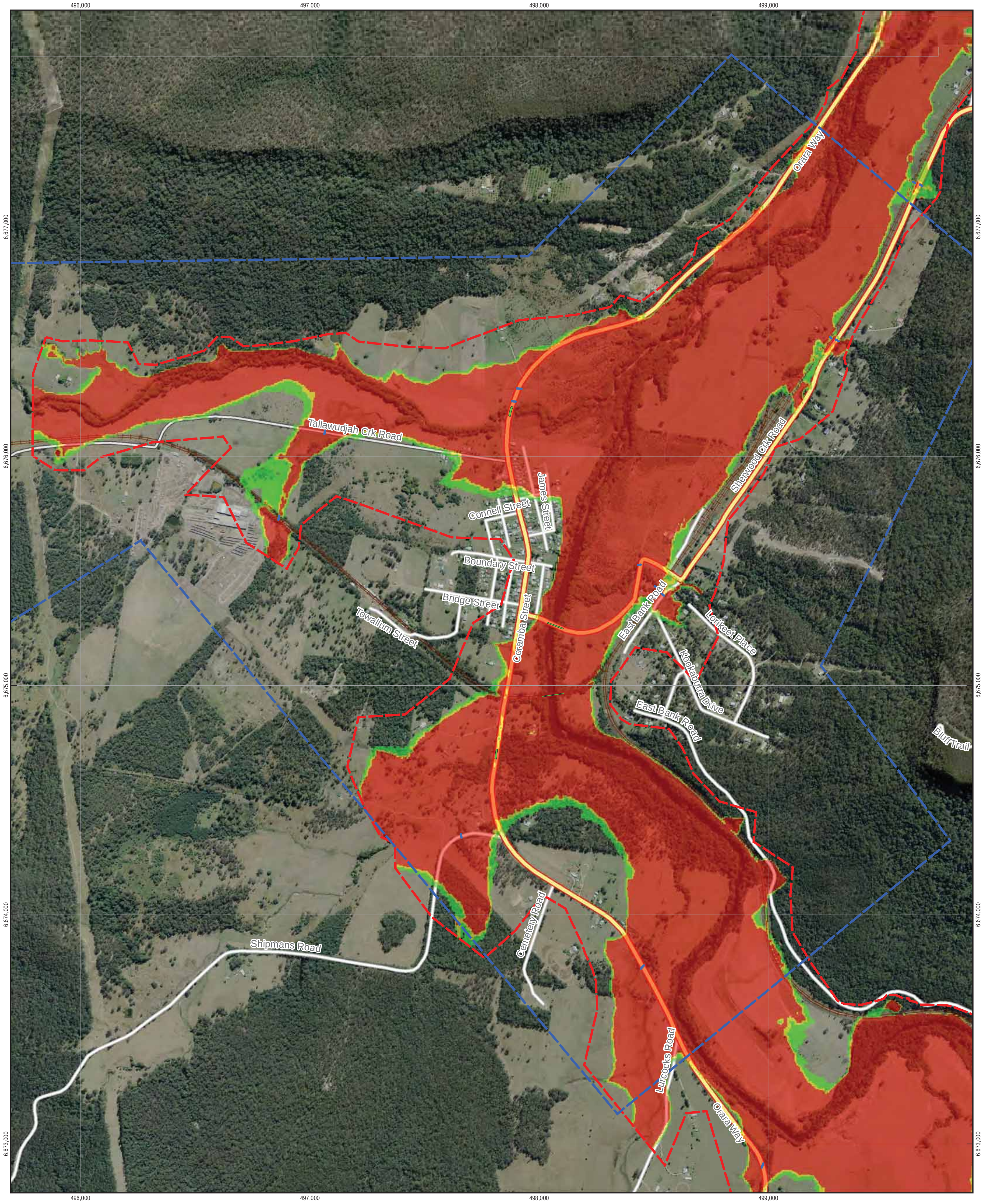
Data source: Clarence Valley Council Created by: SLDouglas



Legend

Study Area

2D TUFLOW Modelled Bridges

1D TUFLOW Modelled Culverts

2D TUFLOW Model Area

Flood Hazard Category

1 - Low Hazard

2 - Intermediate Hazard

3 - High Hazard

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Flood Hazard Map
5% AEP Flood Event

Job Number	22-16342
Revision	A
Date	08 March 2013

Figure F.3c

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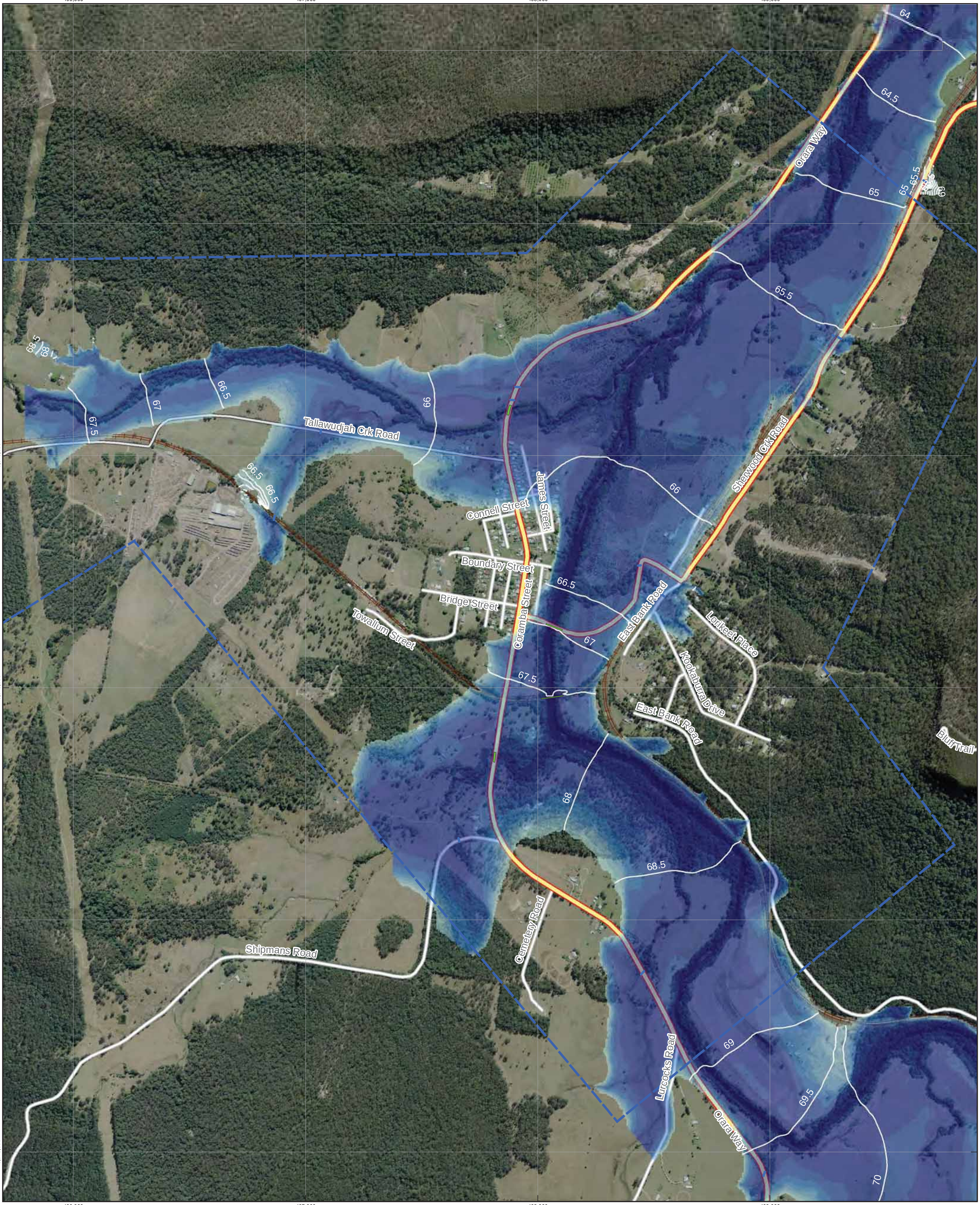

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- Flood Level Contours (mAHD)

Flood Extent and Depth (m)

- 0.16 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 20.0

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Flood Map
1% AEP Flood Event

Figure F.4a

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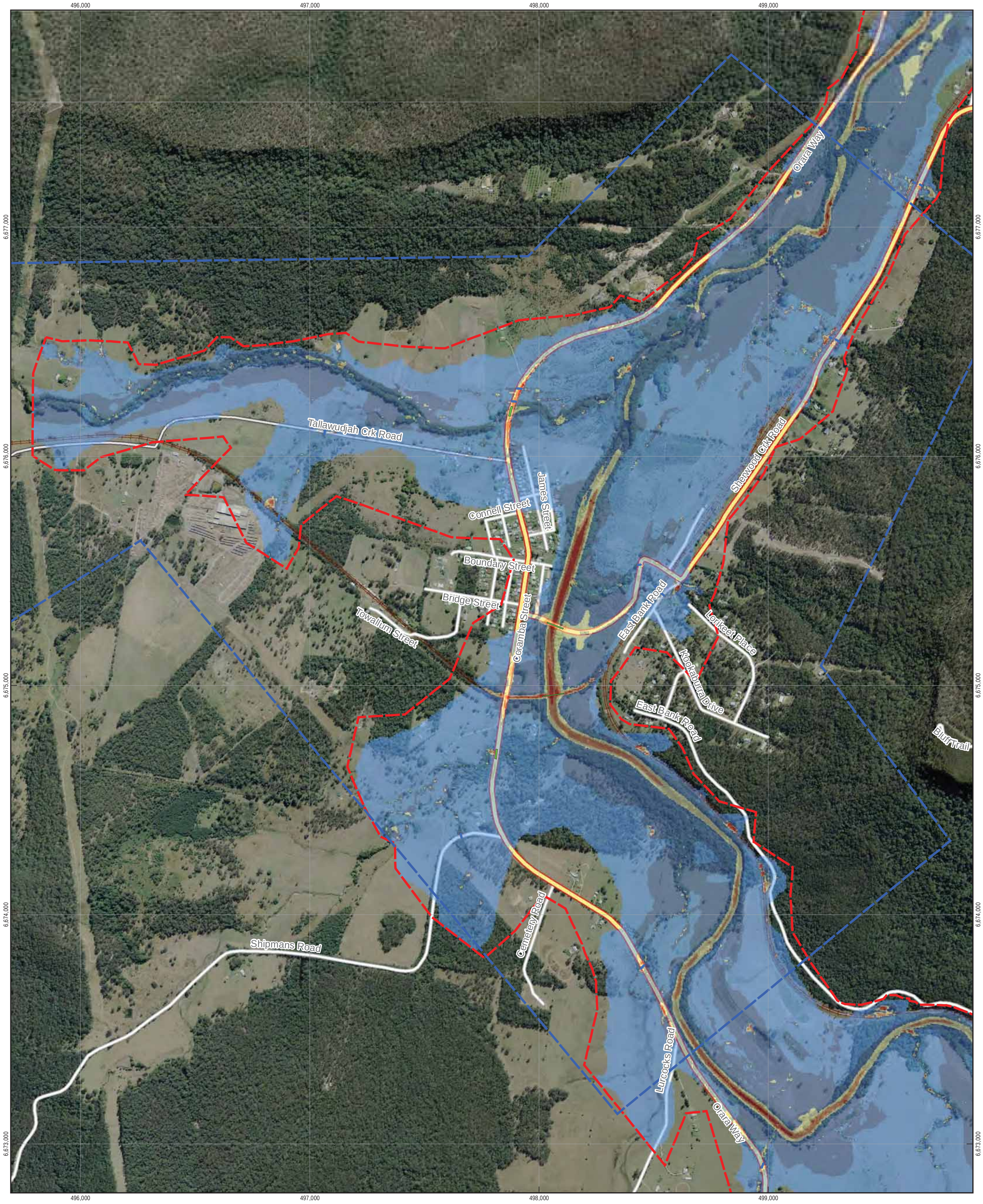

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Velocity (m/s)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- Greater than 2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Flood Velocity Map
1% AEP Flood Event

Figure F.4b

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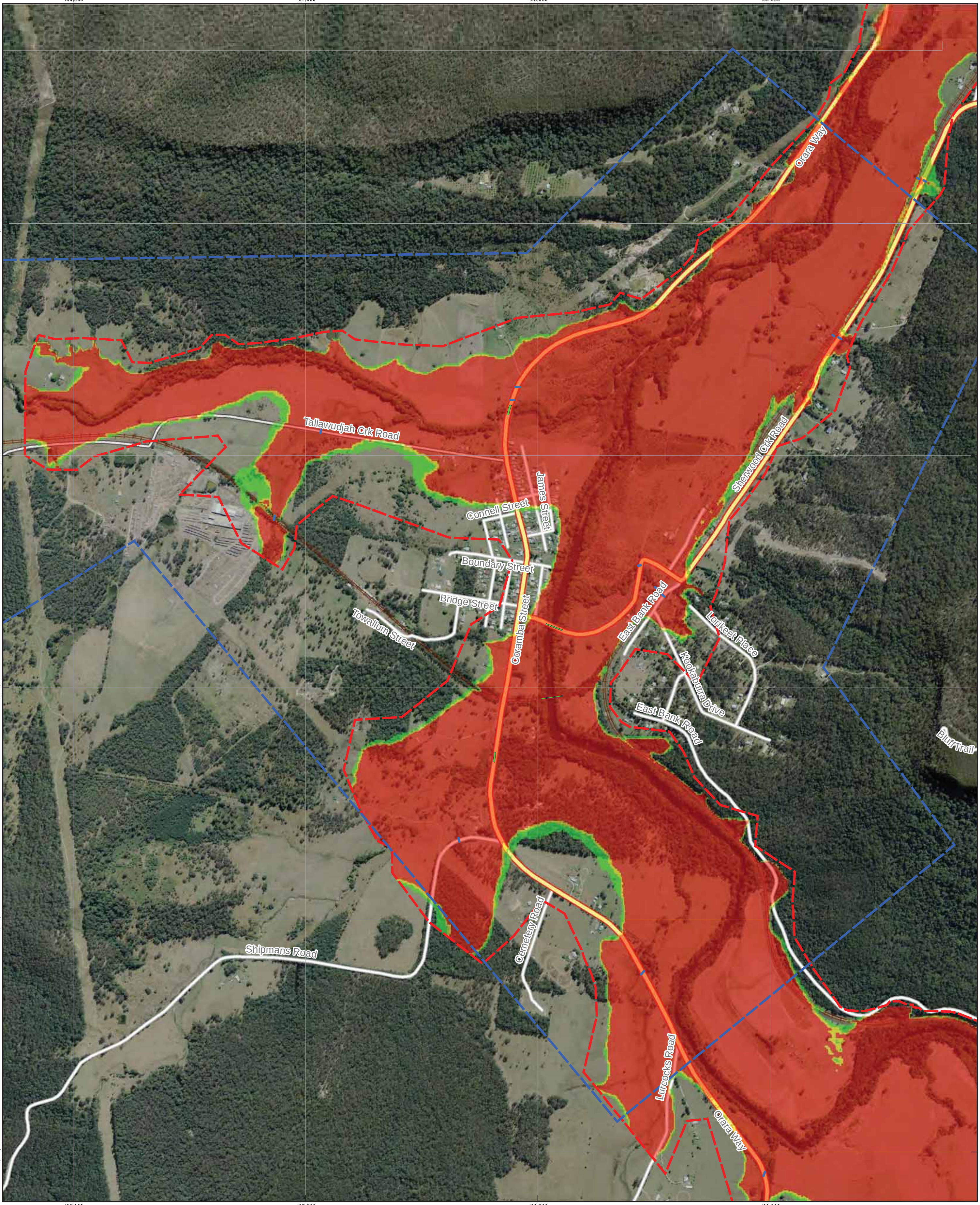

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Hazard Category

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number	22-16342
Revision	A
Date	08 March 2013

Flood Hazard Map
1% AEP Flood Event

Figure F.4c

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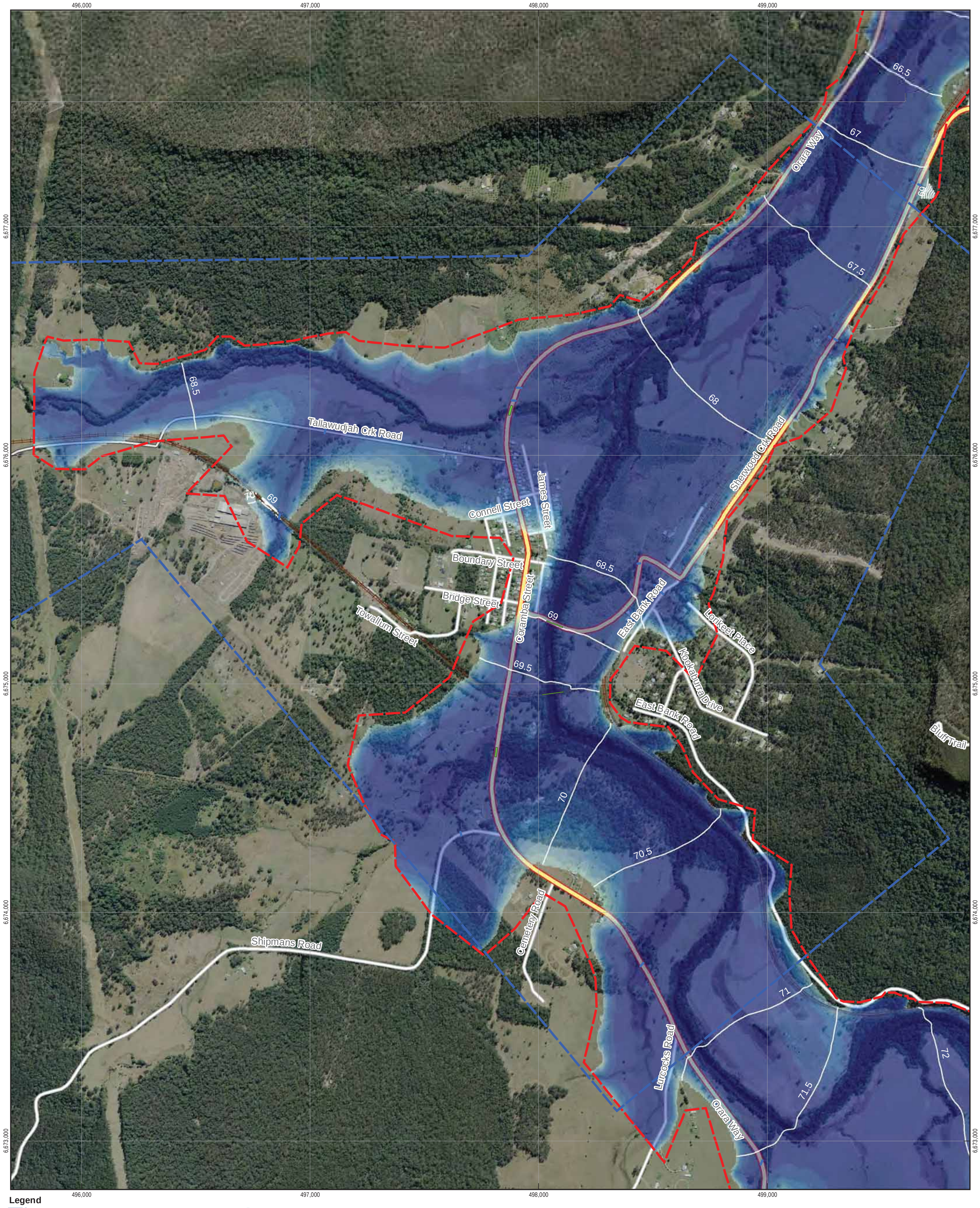

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Flood Extent and Depth (m)

- 0.16 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 20.0

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Flood Map
0.2% AEP Flood Event

Job Number	22-16342
Revision	A
Date	08 March 2013

Figure F.5a

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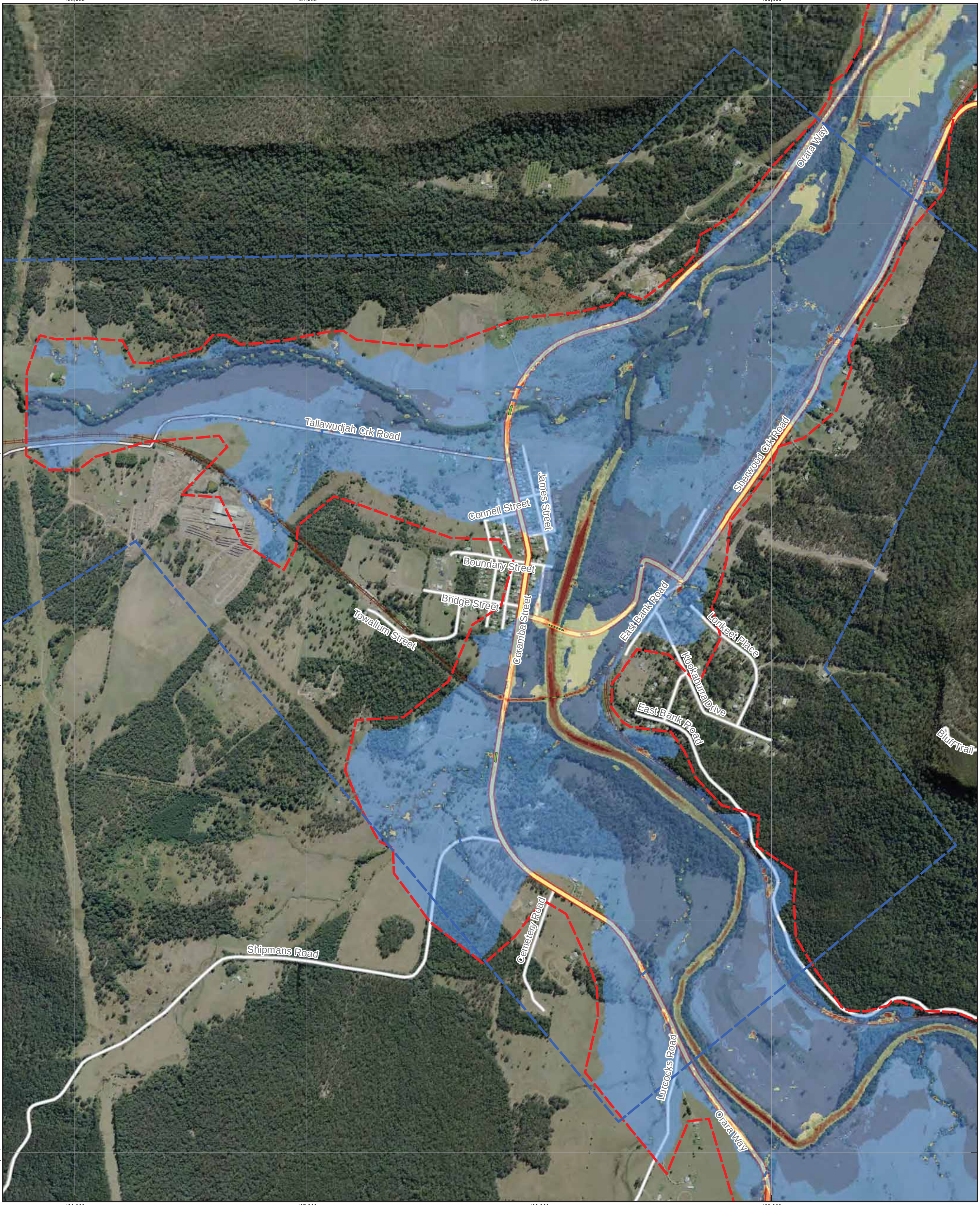

Legend

Study Area
2D TUFLOW Modelled Bridges
1D TUFLOW Modelled Culverts
2D TUFLOW Model Area

Flood Velocity (m/s)

0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
Greater than 2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

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Clarence Valley Council
Glenreagh Flood Study

Flood Velocity Map
0.2% AEP Flood Event

Job Number 22-16342
Revision A
Date 08 March 2013

Figure F.5b

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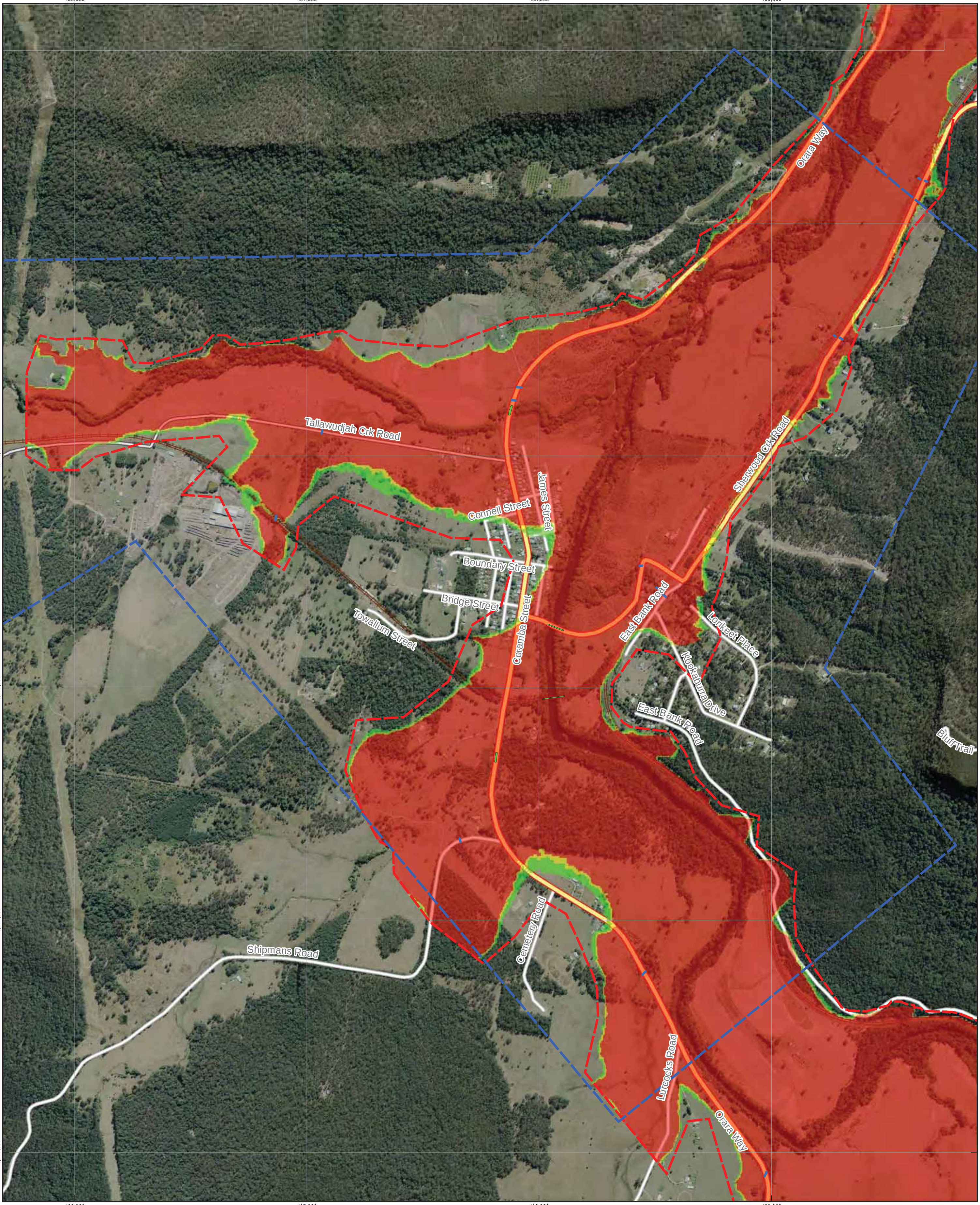

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Hazard Category

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Flood Hazard Map
0.2% AEP Flood Event

Job Number	22-16342
Revision	A
Date	08 March 2013

Figure F.5c

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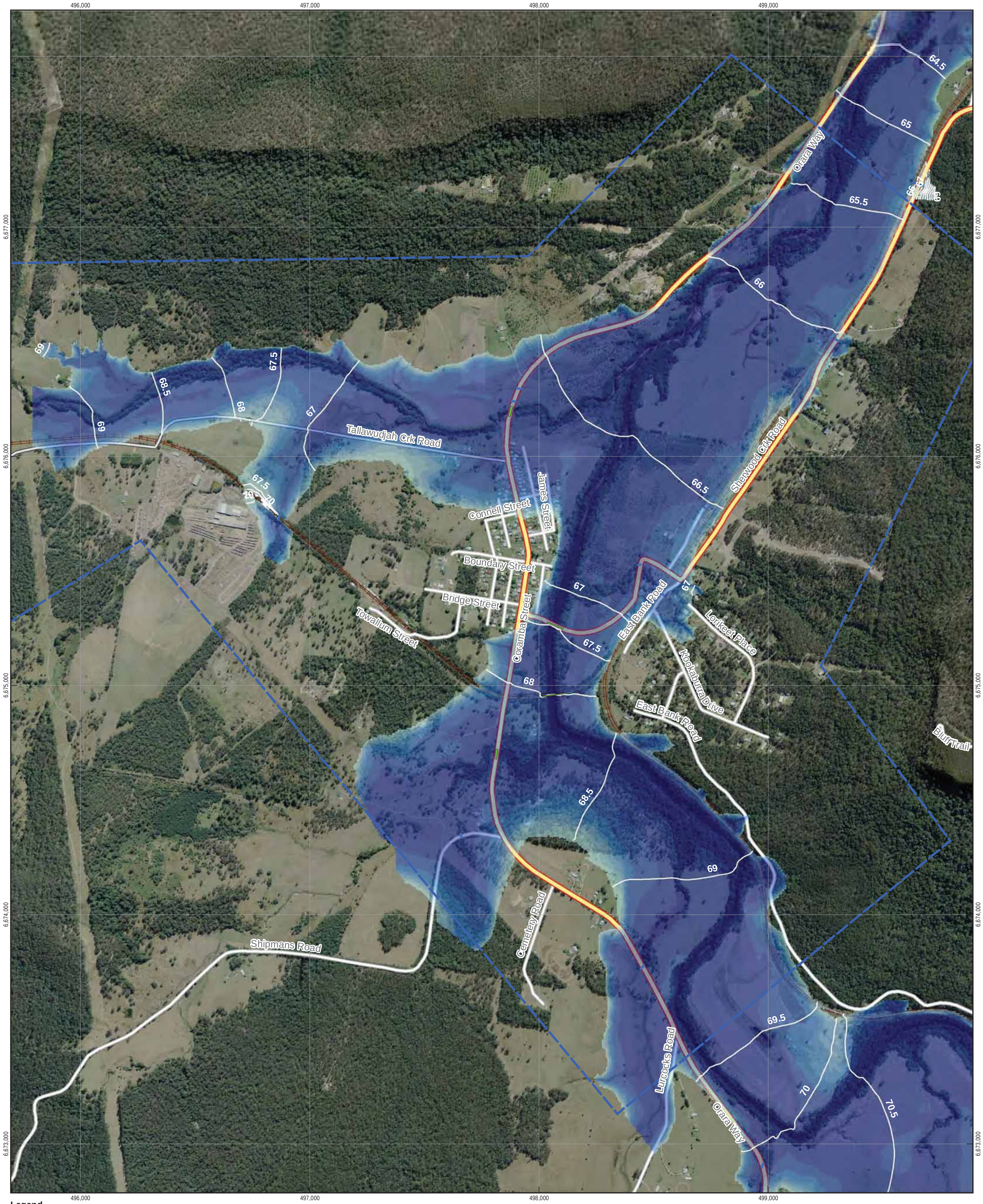

Legend

Study Area
2D TUFLOW Modelled Bridges
1D TUFLOW Modelled Culverts
Flood Level Contours (mAHD)

Flood Extent and Depth (m)

0.16 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 3.0
3.0 - 5.0
5.0 - 10.0
10.0 - 20.0

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Flood Map
PMF Flood Event

Job Number	22-16342
Revision	A
Date	08 March 2013

Figure F.6a

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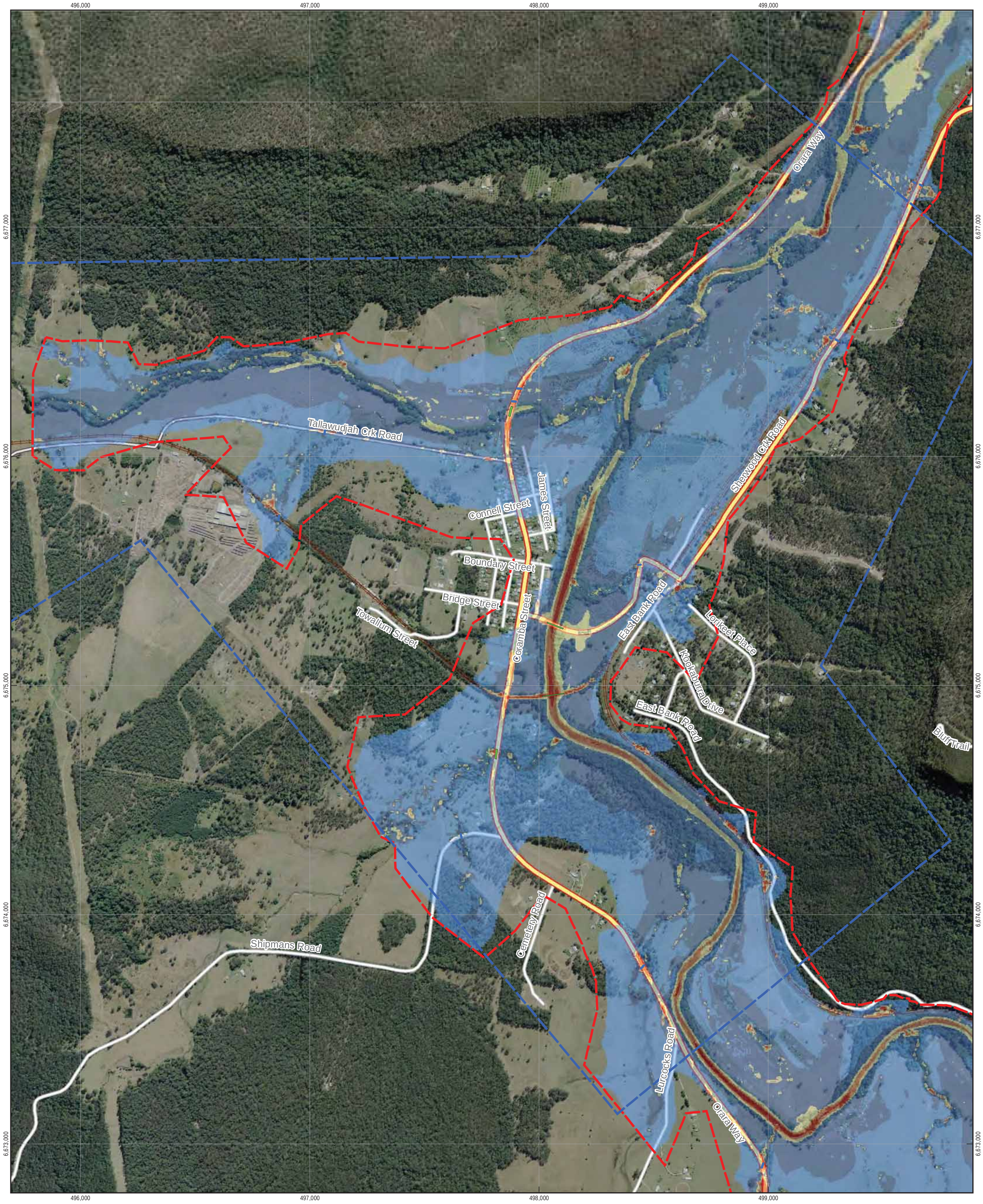

Legend

Study Area

2D TUFLOW Modelled Bridges

1D TUFLOW Modelled Culverts

2D TUFLOW Model Area

Flood Velocity (m/s)

0 - 0.5

0.5 - 1.0

1.0 - 1.5

1.5 - 2.0

Greater than 2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Flood Velocity Map
PMF Flood Event

Figure F.6b

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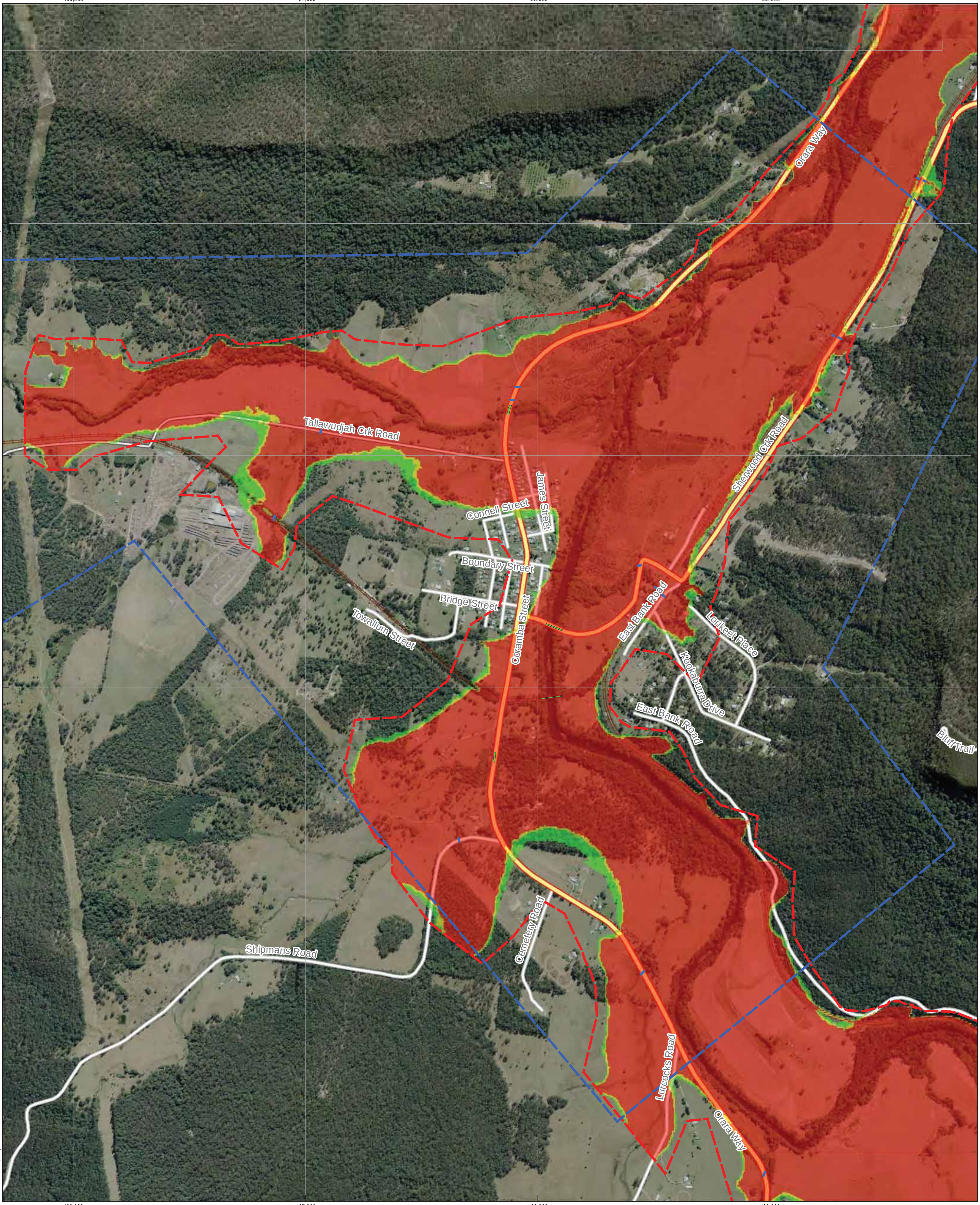

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area

Flood Hazard Category

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

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Glenreagh Flood Study

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Revision A
Date 08 March 2013

Flood Hazard Map
PMF Flood Event

Figure F.6c

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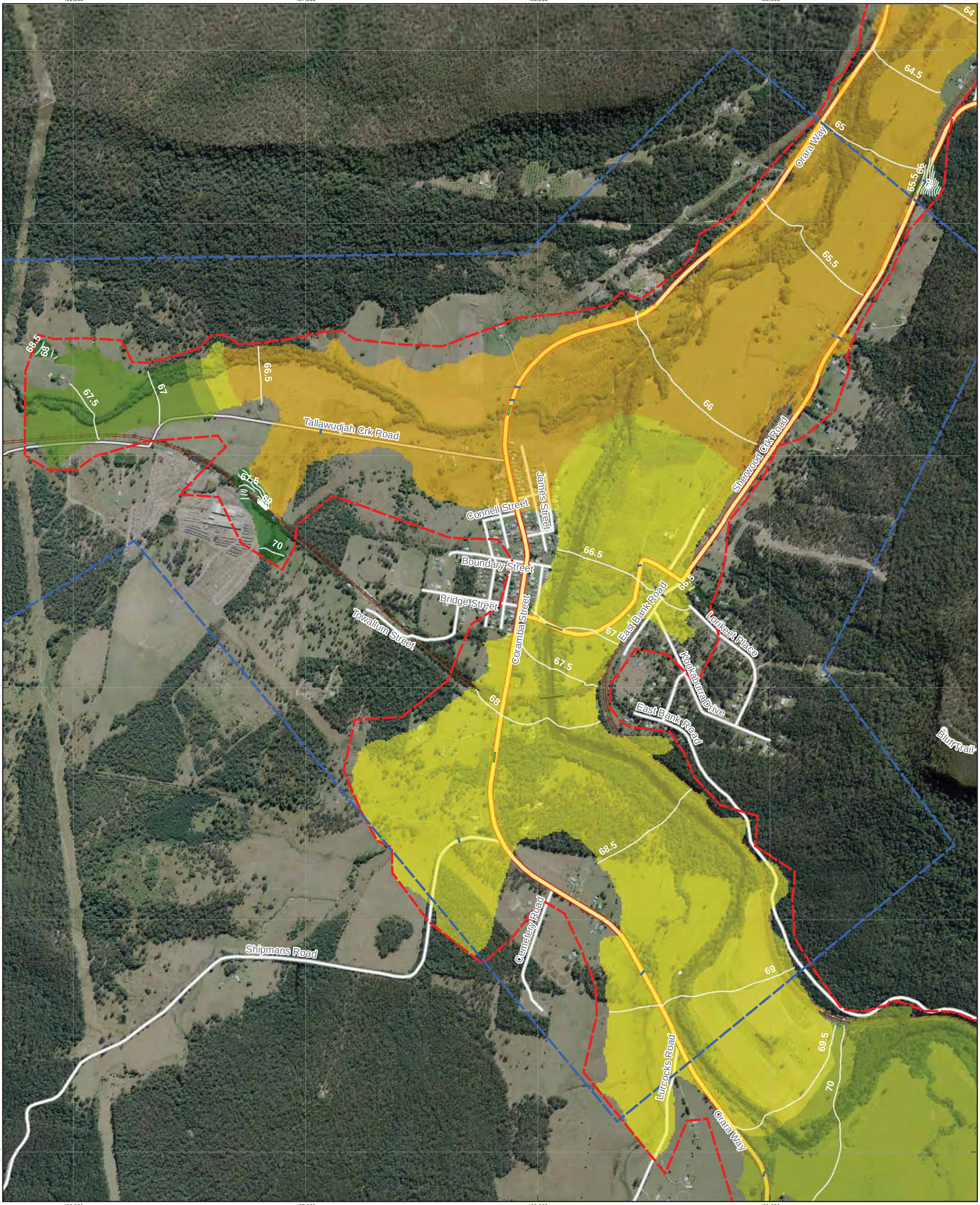
Appendix G Sensitivity Analysis



Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Change in Flood Level (mm)

- 0mm - 50mm
- 50mm - 100mm
- 100mm - 150mm
- 150mm - 200mm
- 200mm - 250mm
- 250mm - 300mm
- >300mm

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Sensitivity Assessment
Loss Sensitivity

Figure G.1

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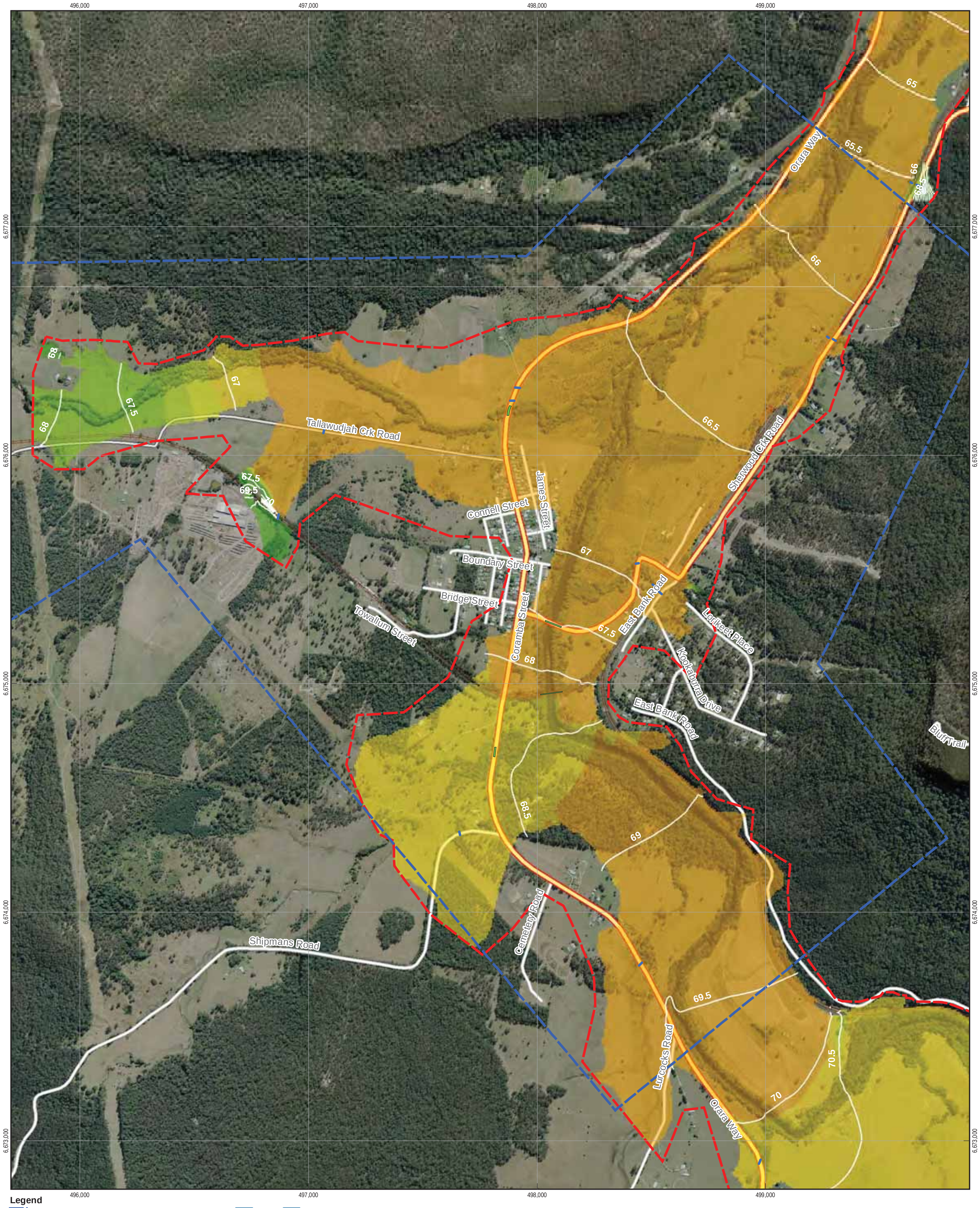

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Change in Flood Level (m)

- 0.0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

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Revision A
Date 08 March 2013

Sensitivity Assessment
Roughness Sensitivity

Figure G.2

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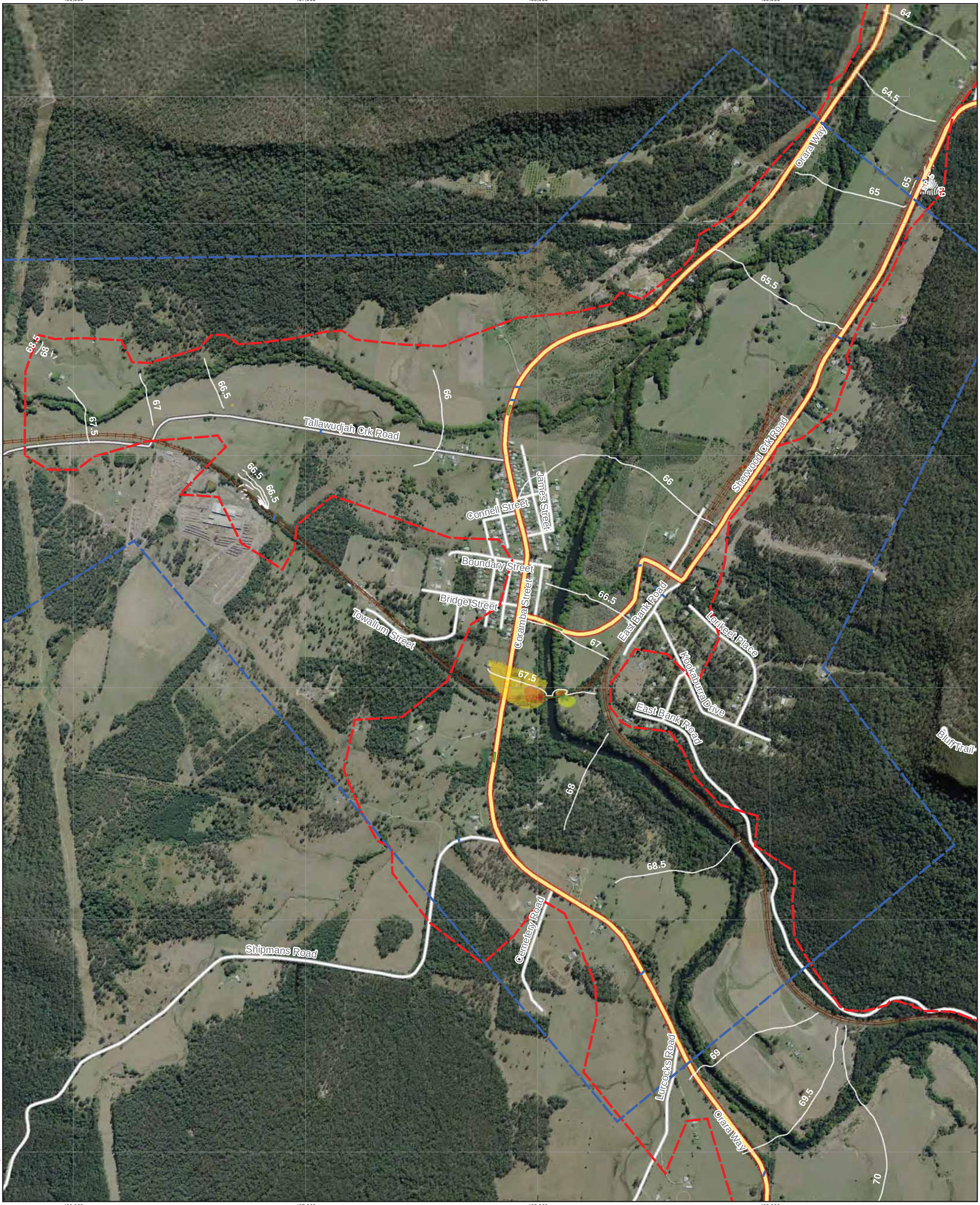

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Change in Flood Level (m)

- <-0.05
- -0.05 - -0.04
- -0.04 - -0.03
- -0.03 - -0.02
- -0.02 - -0.01
- -0.01 - -0.005
- -0.005 - 0.005
- 0.005 - 0.01
- 0.01 - 0.02
- 0.02 - 0.03
- 0.03 - 0.05
- >0.05

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Sensitivity Assessment Blockage Sensitivity

Figure G.3

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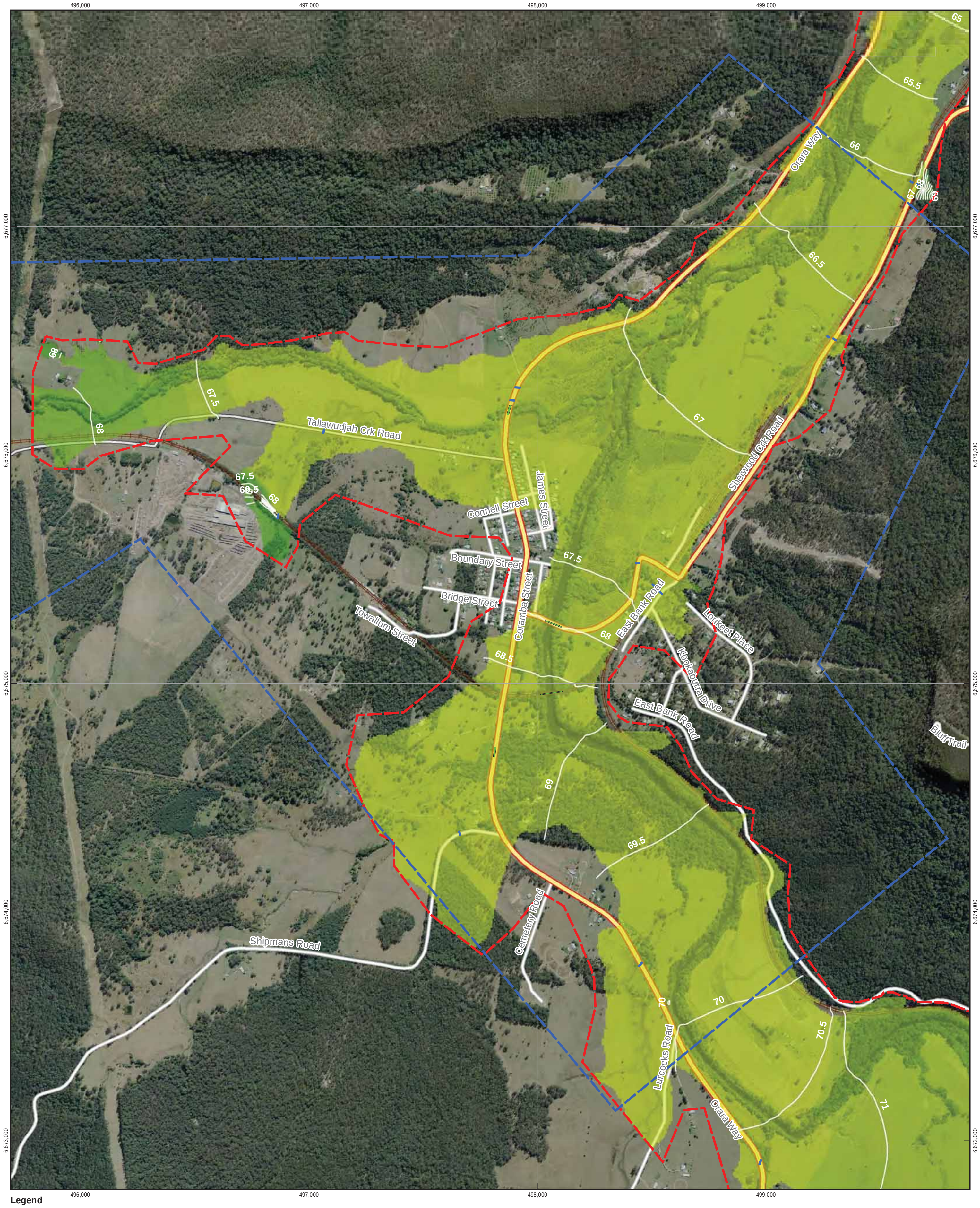

Legend

Study Area
2D TUFLOW Modelled Bridges
1D TUFLOW Modelled Culverts
2D TUFLOW Model Area
Flood Level Contours (mAHD)

Change in Flood Level (m)

0 - 0.2	0.9 - 1	1.9 - 2.2
0.3 - 0.4	1.1 - 1.2	2.3 - 2.4
0.5 - 0.6	1.3 - 1.4	2.5 - 2.6
0.7 - 0.8	1.5 - 1.6	2.7 - 2.8
	1.7 - 1.8	2.9 - 3.2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Sensitivity Assessment 10% Climate Change

Figure G.4

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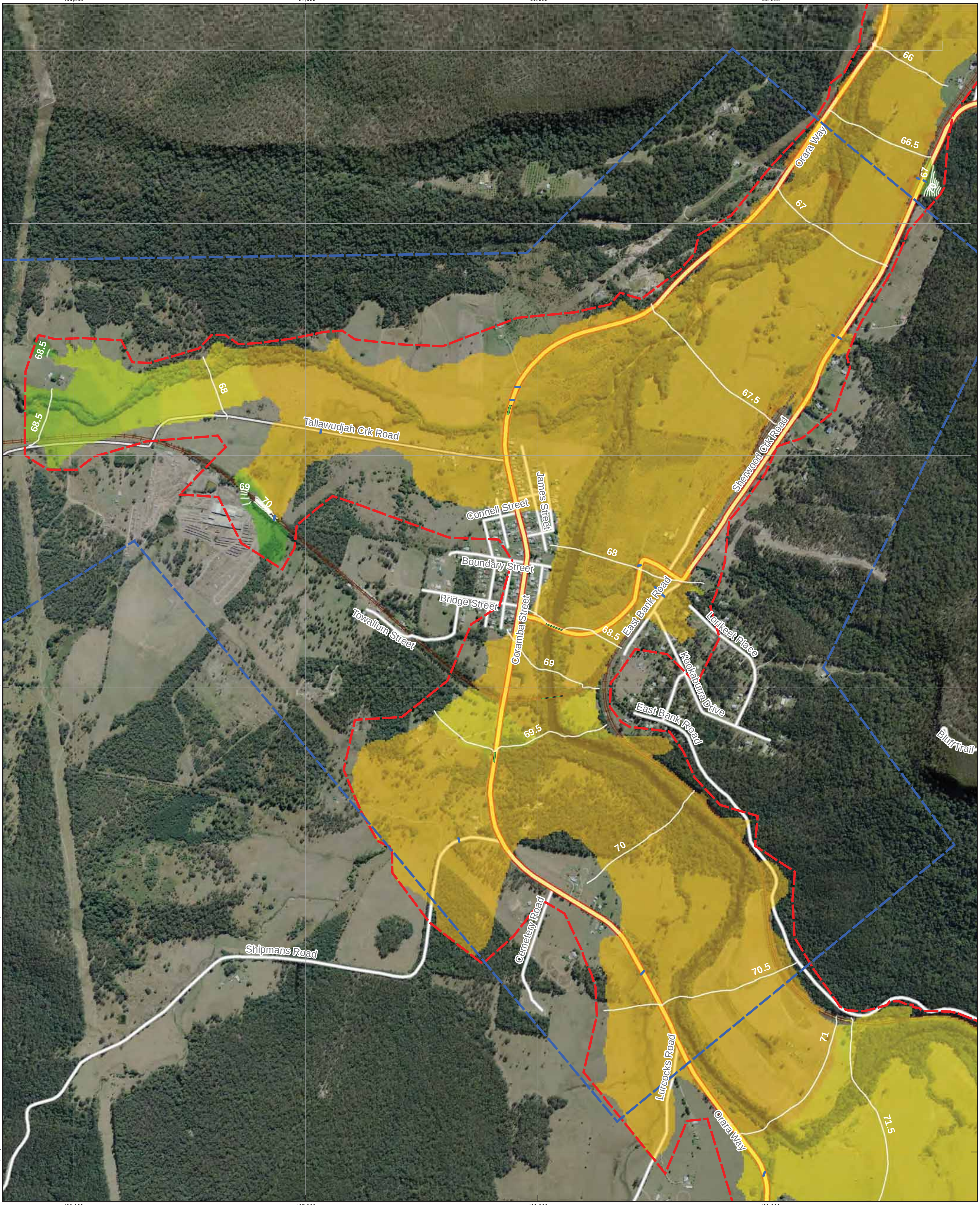

Legend

Study Area

2D TUFLOW Modelled Bridges

1D TUFLOW Modelled Culverts

2D TUFLOW Model Area

Flood Level Contours (mAHD)

Change in Flood Level (m)

0 - 0.2
0.3 - 0.4
0.5 - 0.6
0.7 - 0.8
0.9 - 1
1.1 - 1.2
1.3 - 1.4
1.5 - 1.6
1.7 - 1.8
1.9 - 2.2
2.3 - 2.4
2.5 - 2.6
2.7 - 2.8
2.9 - 3.2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

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GHD

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Sensitivity Assessment 20% Climate Change

Figure G.5

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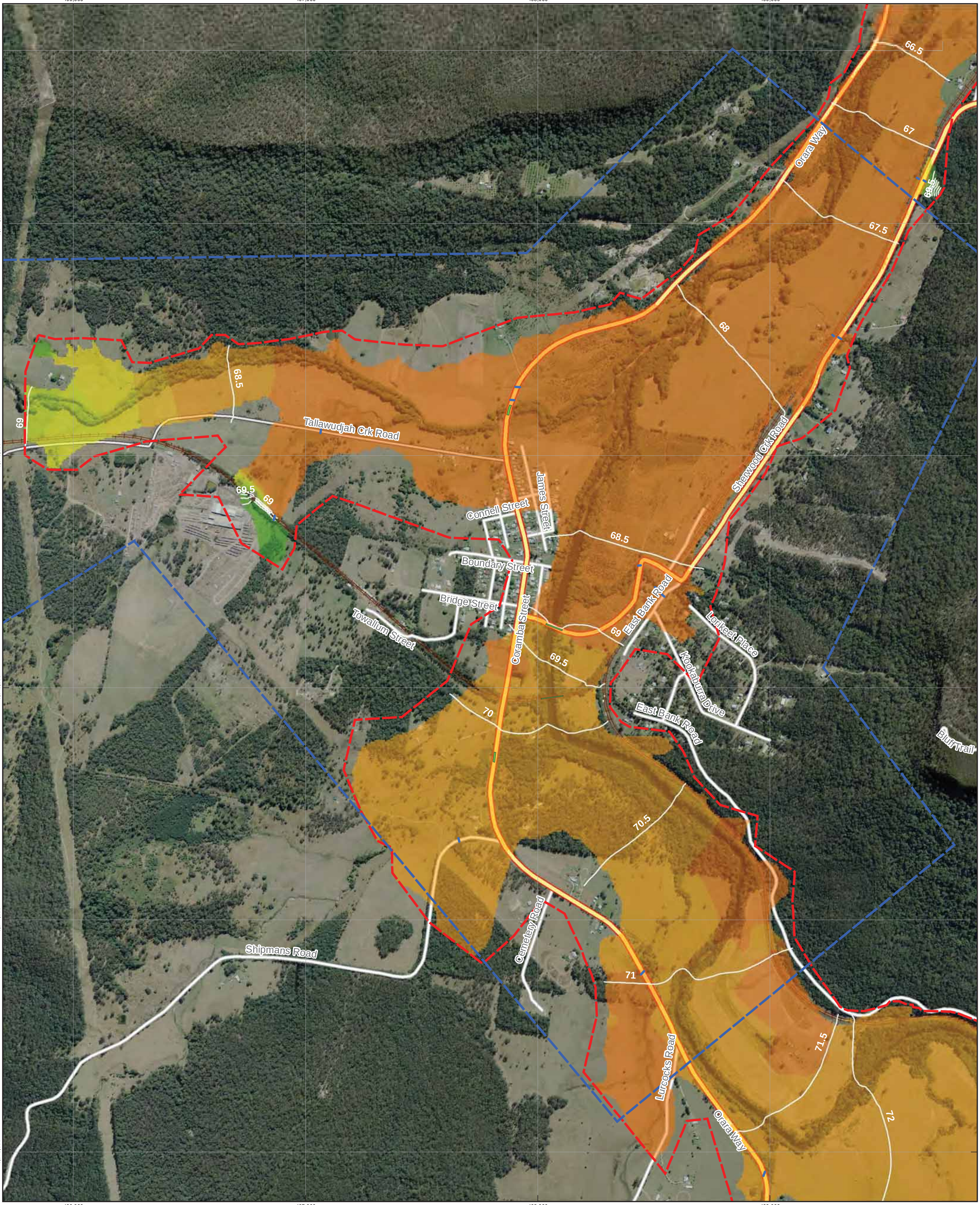

Legend

- Study Area
- 2D TUFLOW Modelled Bridges
- 1D TUFLOW Modelled Culverts
- 2D TUFLOW Model Area
- Flood Level Contours (mAHD)

Change in Flood Level (m)

0 - 0.2, 0.3 - 0.4, 0.5 - 0.6, 0.7 - 0.8, 0.9 - 1, 1.1 - 1.2, 1.3 - 1.4, 1.5 - 1.6, 1.7 - 1.8, 1.9 - 2.2, 2.3 - 2.4, 2.5 - 2.6, 2.7 - 2.8, 2.9 - 3.2

1:15,000 (at A3)

0 70 140 280 420 560

Metres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia
Grid: Map Grid of Australia 1994, Zone 56

Clarence Valley Council
Glenreagh Flood Study

Job Number 22-16342
Revision A
Date 08 March 2013

Sensitivity Assessment 30% Climate Change

Figure G.6

G:\22\16342\GIS\Maps\Working\Maps For Report\Figure-G.6.mxd

230 Harbour Drive Coffs Harbour NSW 2450 Australia T 61 2 6650 5600 F 61 2 6650 5601 E cfsmail@ghd.com.au W www.ghd.com.au

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Data source: Clarence Valley Council Created by: SLDouglas

GHD

230 Harbour Drive
Coffs Harbour NSW 2450
T: (02) 6650 5600   F: (02) 6650 5601   E: cfsmail@ghd.com.au

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Early Draft	S.Douglas/ R. Berg	R. Berg		Early draft not for distribution		28/11/12
Draft	S.Douglas/ R. Berg	R. Berg		R Berg		08/03/13
0	S.Douglas/ R. Berg	R. Berg	[signature]	R Berg	[signature]	20/9/2013

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