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Department of Environment & Climate Change NSW

Byron Shire Council

Tallow Creek Floodplain Risk Management Study and Plan

FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

- FINAL
- 16 July 2009

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Executive Summary

The Tallow Creek Floodplain Risk Management Study and Plan has been developed by Sinclair Knight Merz to assist Byron Shire Council and landholders within the catchment in managing the flood risks in the Tallow Creek catchment. The development of this floodplain risk management study and plan has been facilitated through a Community Project Committee and been completed in compliance with the NSW Floodplain Development Manual: the management of flood liable land (2005). This working group has included local residents, as well as representatives from Byron Shire Council, NSW Department of Environment and Climate Change, National Parks and Wildlife, State Emergency Services (SES) and NSW Marine Parks Authority.

The flooding risks in the catchment were determined by computer flood modelling, combined with anecdotal catchment flooding information. This allowed for the understanding of the flooding mechanisms and flood behaviour and hence enabled the determination of the likely flood damage cost in the catchment. In addition to the identification of the existing flood risks in the catchment, it was necessary to identify potential future flood risks in the catchment to ensure the ongoing applicability of the proposed plan.

A flood damage assessment was undertaken to determine the scope of damages in existing conditions and to assess the merits of flood mitigation options in reducing those damages. The annual average damage in the Tallow Creek catchment was calculated as approximately $30,000. This low cost indicates that extensive structural works in the catchment are not warranted. This result implies that floodplain risk management in the Tallow Creek catchment should primarily focus on future planning controls within the catchment.

An assessment of the Tallow Lake opening on flood hydraulics was also carried out due to its potential to increase flooding on local properties. It concluded that the flooding in the lower reaches of Tallow Creek is largely dictated by the mouth sandbar level, but this influence does not extend upstream of Broken Head Road. A sand bar management strategy has been developed to mimic the natural process of storm events breaching the sand bar while maintaining the sand bar level such that a storm event will breach the mouth prior to the flooding of properties adjacent to Tallow Lake. This strategy has been developed through consultation with the Community Committee.

Byron Shire Council will be responsible for the monitoring of water levels of Tallow Creek. Any proposed changes to the sand bar level is subject to the approval of relevant government agencies and in accordance with the Interim Management Plan (7.3.3.1).

Environmental impacts to flora and fauna, cultural heritage and statutory approvals will also need to be considered for work around the lake. The manual opening of the Tallow mouth, such that a forced breach is triggered, is not a desirable option and will not be considered unless under emergency circumstances.

The results of flood modelling were used to identify existing areas of high flood risk in the Tallow Creek catchment. It is proposed that classification of high flood hazard areas be adopted in the land use zoning of the Local Environment Plan to preclude these areas from future development. Flood planning levels (FPLs) are to be defined for the Tallow Creek catchment, based on the 1 in 100 year ARI flood level including climate change impacts plus 500mm freeboard. The extent of inundation determined from the flood planning level defined the flood liable land which initiates development approval requirements via the development control plan.

Under both the existing and proposed amended planning controls, filling of land within the FPL is allowable for a development at the discretion of Council, provided that the filling will not adversely affect other land in the vicinity. A fill exclusion zone in South Tallow Creek has been identified. Due to the high sensitivity of flood levels in this area to filling combined with existing identified flood prone properties. A further zone has been identified around Baywood Chase Lake, on the Western side of Broken Head Road.

Flood impacts on future development were also considered in the flood hazard assessment. This assessment led to conclusions that catchment flooding is not greatly susceptible to increased flooding resulting from future development. However, it is recommended that future development utilise on-site detention to restrict peak discharges from site to pre-development rates. The purpose of this control measure is to ensure that flood peak runoff rates do not increase with future development of the catchment

An assessment of the existing stormwater infrastructure in the Tallow Creek catchment identified two sites, Broken Head Road crossing of South Tallow Creek and Coogera Circuit detention basin, where existing drainage infrastructure is exacerbating flooding impacts. The upgrade of this stormwater infrastructure is recommended. The estimated construction and engineering cost to undertake both the Broken Head Road crossing upgrade and Coogera Circuit Basin overflow is $760,000 plus GST (at time of study). This estimate has been prepared for preliminary budget purposes only and to assist with the feasibility of this option.

The proposed floodplain risk management plan has been developed to address existing areas identified as having unacceptable levels of flood risk, as well as to address potential causes of exacerbated flooding in the future. The proposed mitigation strategy adopts the aspects of planning controls, stormwater system upgrades; and sandbar management. The action plan for the proposed mitigation strategies is provided below.

▪ **Table Ex-1 Action Plan for Tallow Creek Catchment**

Task	Action	Responsibility	Costs	Timing
1. Planning Controls	a. New Byron Local Environment Plan to more robustly protect existing development from increased flooding impacts resulting from future development and update to be in line with NSW Floodplain Development Manual (2005)	▪ Byron Shire Council	▪ STAFF	▪ 2010
	b. Commence undertaking to rezone the land identified as high flood hazard for the 1 in 100 year ARI flood to preclude these areas from future development	▪ Byron Shire Council	▪ STAFF	▪ 2010
	c. Adopt FPLs as part of the DCP 2002 as the extent of flood prone land in the Tallow Creek catchment that consider climate change conditions (Scenario 4)	▪ Byron Shire Council	▪ STAFF	▪ 2010
	d. Implementation of design measures and evacuation plans to minimise impacts on future planned community uses as identified in the DCP No. 9	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
	e. Adopt prescribed areas of fill exclusion.	▪ Byron Shire Council	▪ STAFF	▪ Jan 09
	f. Ensure future developments within the catchment utilise on-site stormwater detention measures to maintain pre-development peak runoff characteristics.	▪ Byron Shire Council	▪ STAFF	▪ Nov 08
	g. Adopt new version of the hydraulic model to allow for assessment of all proposed development	▪ Byron Shire Council	▪ STAFF	▪ Nov 08
	h. Prepare a section contribution plan for all civil works in this plan.	▪ Byron Shire Council	▪ $20k	▪ Jan 09
	i. Update 149 certificates and any lots with additional controls over them, including add 1495 certificates for lots effected by PMF and not within the FPL.	▪ Byron Shire Council	▪ STAFF	▪ Jan 09

Task	Action	Responsibility	Costs	Timing
2. Emergency Response Planning	a. Establish relationship between flood return period, sand bar levels and flooding conditions in Tallow Lake to assist in SES flood evacuation planning	▪ Byron Shire Council	▪ $10k	▪ Oct 09
	b. Support SES in inclusion of Suffolk Park in Flood Response Plan	▪ SES	▪ nil	▪ Oct 09
	c. Install flood gauge at Broken Head Road culvert showing example flood levels	▪ Byron Shire Council	▪ $500	▪ Oct 09
	d. Install lake level and rainfall monitoring station on Tallow Lake and connect to Council's flood warning system	▪ Byron Shire Council	▪ $25k	▪ Oct 09
3. Stormwater System Upgrades	a. Upgrade Broken Head Road Crossing of South Tallow Creek	▪ Byron Shire Council	▪ $355k	▪ Dec 09
	b. Upgrade Coogera Circuit Detention	▪ Byron Shire Council	▪ $380k	▪ Dec 09
	c. Raise footpath at Tallow Lake footbridge to ensure trafficable up to a lake level of 2.5mAHD.	▪ Byron Shire Council	▪ $20k	▪ Dec 09
	d. Develop and implement asset management and maintenance plan	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
4. Sandbar Management	a. Implement interim management plan through water level and quality monitoring	▪ Byron Shire Council	▪ STAFF	▪ Dec 08
	b. Develop data collection program for variables such as sand bar and lake stored level, to support development of long-term management plan.	▪ Byron Shire Council	▪ Refer to 7.3.4	▪ Ongoing
	c. Inspect the sand bar and record its level every year prior to the onset of the rainfall season	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
	d. Monitor the level of the opening during the rainfall season and undertake maintenance earthworks to restore the level as per the accepted Interim Sandbar Management Strategy.	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
5. GIS/IT	a. Update Council Geographic Information Systems (GIS) to include outputs of this plan and	▪ Byron Shire Council	▪ STAFF	▪ July 09

Task	Action	Responsibility	Costs	Timing
	update any lots with additional controls over them. b. Ensure authority uses the GIS layers to prepare property reports. c. Add adopted document to Council's website, plus additional A1 pdf of FPL.			

Glossary of Terms

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance of a peak flood discharge of 500m^3/s or larger occurring in any one year.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining through the main stream, as well as tributaries to the stream, to a particular site. It always relates to an area above a specific location.
Flood	Relatively high stream flow which 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 Liable Land	is synonymous with flood prone land (ie) land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL.
	Are the combinations of flood levels and

Flood Planning Levels (FPLs)	freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods.
Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
mAHD	Metres to Australian Height Datum (AHD). The vertical reference for height measurements in Australia, with 0mAHD roughly reflecting mean sea level.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.

1. Objectives

A Floodplain Risk Management Plan describes how particular areas of flood prone land are to be used and managed to achieve defined objectives (NSW Floodplain Development Manual, 2005). The intention of a floodplain risk management strategy is to ensure the suitable and sustainable use and development of land within the catchment. The principles of floodplain risk management are;

- Reduction of the social and financial costs resulting from the risks of occupying the floodplain;
- Increasing the sustainable social, economic and ecological benefits of using the floodplain; and
- Improving or maintaining the diversity and well being of native riverine and floodplain ecosystems which depend on regular floodplain inundation.

The strategy allows for management of the catchment in a controlled manner so that the risk of flooding is maintained within accepted levels, thereby reducing the exposure of the community to the impacts of flooding.

A floodplain risk management strategy can recommend the following:

- Measures for the mitigation of an existing flood risk;
- Planning controls for the control of potential future flood risks.

A floodplain risk management strategy is developed from the findings of a floodplain risk management study conducted for the catchment. In a floodplain risk management study existing and future flood risks in the catchment are identified, quantified and assessed against the risk mitigation options.

The Tallow Creek Floodplain Risk Management Strategy has been developed to assist Byron Shire Council and landholders within the catchment in managing the flood risks in the Tallow Creek catchment. The context of this report, and the actions arising from this document in the context of the floodplain risk management process is illustrated in Figure 1-1 and summarised in Table 1-1.

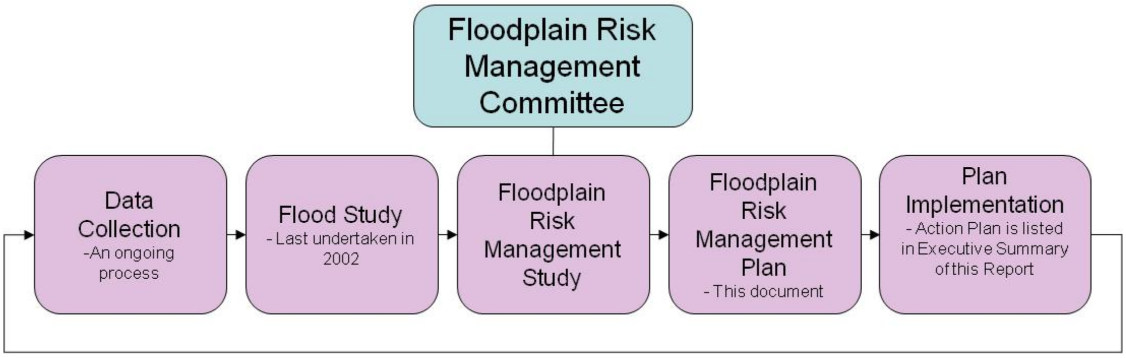


Figure 1-1 The Floodplain Risk Management Process

Table 1-1 The Stages of Floodplain Risk Management

1	Flood Study	Determines the nature and extent of the flood problem and flood risks.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for a floodplain.
4	Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of Development Control Plans and Local Environmental Plans to ensure new development is compatible with the flood hazard.

2. Introduction

Sinclair Knight Merz was commissioned by Byron Shire Council in April 2003 to develop a Floodplain Risk Management Strategy for the Tallow Creek catchment.

The development of the floodplain risk management strategy has been facilitated through a Community Working Group. This working group has included local residents, as well as representatives from Byron Shire Council, NSW Department of Environment and Climate Change (DECC), National Parks and Wildlife, State Emergency Service (SES) and NSW Marine Parks Authority.

The study has used flood modelling information from a preceding investigation commissioned by Byron Shire Council. This information was used to assess the general flooding characteristics of the catchment, calculate specific estimates of flood damages, and to identify areas of high flood hazard.

A review of Council's existing planning provisions in relation to floodplain risk management was also undertaken to identify potential areas for improvement. This included assessment of the existing Byron Local Environment Plan and Development Control Plan.

The Tallow Creek Floodplain Risk Management Study was developed using the NSW Floodplain Development Manual (2005) as the basis for the investigation methodology. The investigations conducted, findings and proposed floodplain risk management strategy are presented under the following section headings;

- Managing Flood Risks;
- Flood Hazard Assessment;
- Principal Flood Risks in the Tallow Creek Catchment;
- Proposed Floodplain Risk Management Strategy; and
- Summary and Conclusion.

3. Background

3.1. Catchment Description

Tallow Creek is situated on the southern outskirts of Byron Bay in northern NSW. The Tallow Creek catchment stretches from the escarpment to the West to the Pacific Ocean on the east, and includes the suburb of Suffolk Park, and the estates of Byron Hills and Baywood Chase. The extent of the Tallow Creek catchment is shown in Figure 3-1. The catchment covers approximately 450 hectares and consists of a steep to undulating upper catchment which drains via three creeks (North, Middle and South Tallow Creek). The lower catchment is characteristic of ancient dune systems, with drainage lines running parallel to the coastline. The three creeks of the Tallow catchment drain to Tallow Lake, which drains to the ocean at Tallow Beach. Broken Head Road roughly delineates the lower and upper catchments of Tallow Creek.

A significant feature of the lower Tallow Creek catchment is the Arakwal National Park managed by the NSW National Parks and Wildlife Service (NPWS), which includes the Tallow Creek mouth. The Tallow Creek mouth has intermittently closed over recent years, with opening of the mouth occurring both by mechanical and natural means.

3.2. Catchment History

Much of the urban development of Suffolk Park is reasonably recent, yet the village has it origins in the 1920's. The Suffolk family originally owned a majority of the land covered by what is now Suffolk Park and the design for the beachside area was originally surveyed 1922, the street names for this area came from many local Byron Bay identities at the time.

The subdivision was originally un-successful as the area was rarely visited, it was not until the 1950's that development began to occur as part of a general growth of the northern NSW coastline. In 1970 Suffolk Park was formally named as place under the Geographic Names Act 1966 and development began to increase.

In 1978 parts of the land which were to become Byron Hills were sub divided into smaller parcels and in 1989 the first major subdivision was completed on the western side of Broken Head Road, named Byron Hills. The Park Hotel was also built in 1989.

In 1993 the second major sub division on the western side of Broken Head Road began and was named Baywood Chase.

During 1999, 2001 and 2003 further subdivisions occurred in the beach side area.

In 2002 the Byron Bay and Suffolk Park Settlement Strategy was adopted by Council and in 2004 further subdivision occurred on the western side of Broken Head road this was named the Forest Glades subdivision. This subdivision created the Beech drive detention basin which is located opposite the BP service Station.

The catchment is now fairly well developed, however, further subdivision is likely to occur is some areas, but this is not likely to be of the sort of scale of Byron Hills or Baywood Chase.

Suffolk Park has a fairly heavily developed urban catchment, which did not have a master plan drainage system, therefore, further subdivision needs be completed carefully to ensure minimal effect on flooding.

Figure 3-1:Tallow Creek Flood Risk Management Study - Study Area

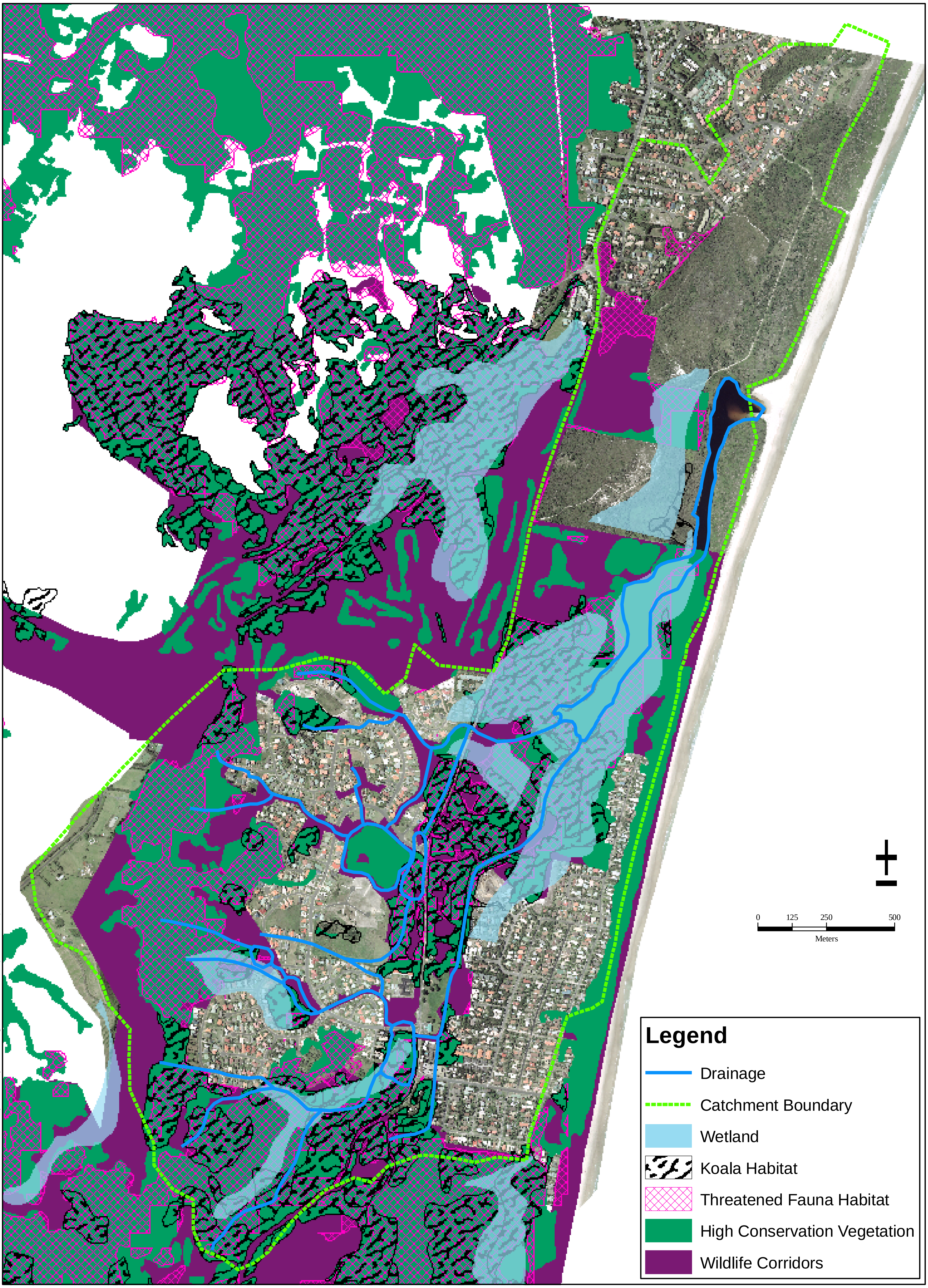
Tallow Creek Catchment

3.3. Existing Environment

Tallow Lake is a brown brackish freshwater lagoon surrounded by a catchment of cleared and drained Melaleuca swamp. The catchment to Tallow Lake is largely developed, comprising predominantly residential development. As a result the water quality is variable. In the past water quality has been affected by discharges from the South Byron Sewerage Treatment plant which ceased operations in late 2005.

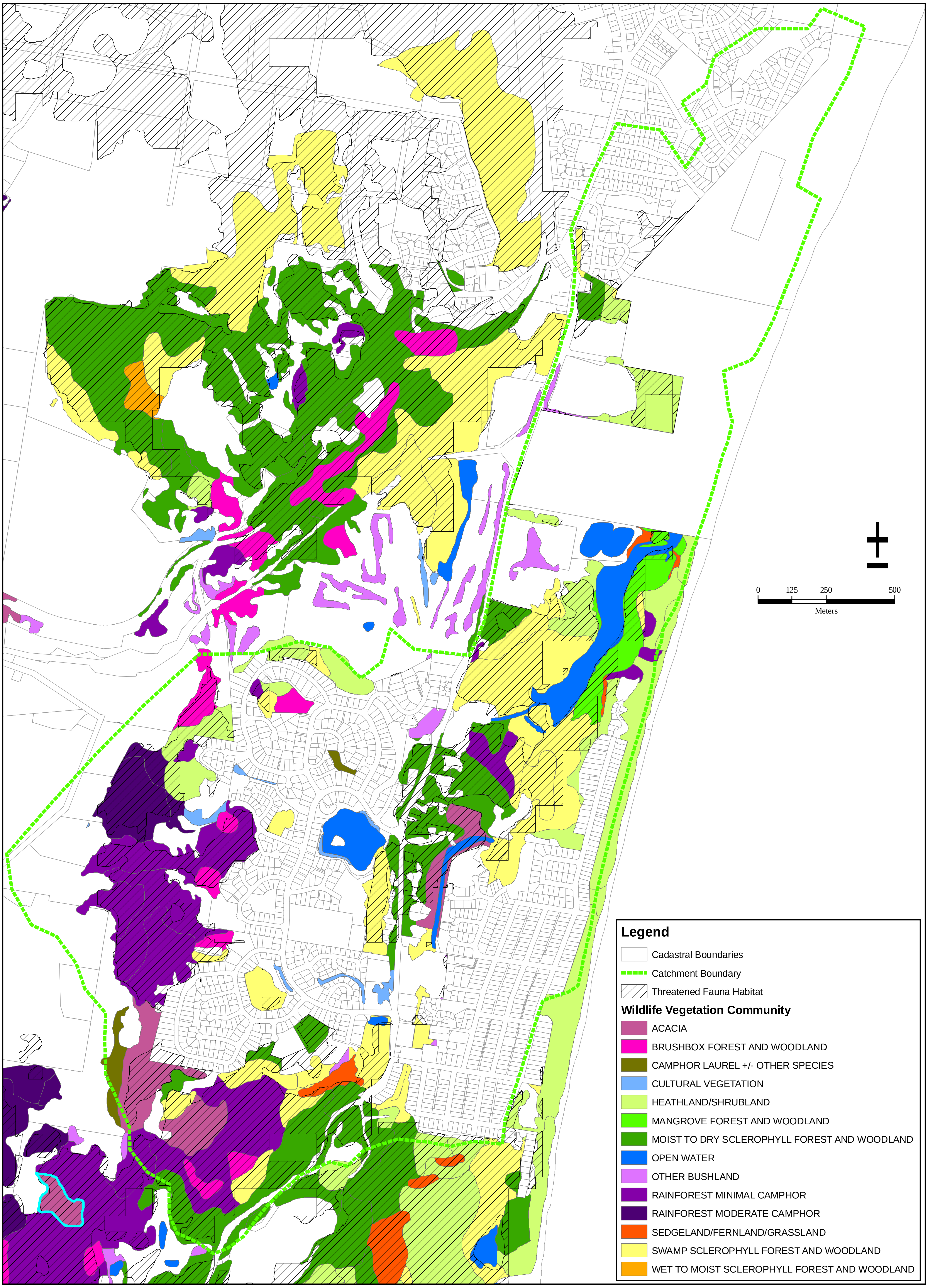
The Byron Shire Councils Flora and Fauna Study identified the catchment as important with extremely high biodiversity. The study also identified individual species that are identified as threatened under the Threatened Species Conservation Act 1995. Figure 3-2 and Figure 3-3 illustrate the locations of threatened species and areas of environmental significance. Appendix A provides a list of threatened flora and fauna identified within the Tallow Creek Catchment.

The biodiversity study also identifies current environmental concerns for the area. The aquatic environment has been impacted by the previous unregulated opening of the creek to the sea. This unregulated opening occurred after prolonged periods of high water levels in Tallow Lake and resulted in immediate release of water from Tallow Lake. The biodiversity study notes that the sudden unregulated release resulted in unfavourable mixing of deoxygenated water from the lake and oxygenated marine water causing fish and bird kills.



Filename: Threatened Species Map Date: Aug 2008 Location: QENV Job: QE08218

Figure 3-2: Tallow Creek Flood Study - Threatened Species Map



Filename: Endangered Species Wildlife Corridors Date: Aug 2008 Location: QENV Job: QE08218

Figure 3-3: Tallow Creek Flood Study - Wildlife Corridors

3.4. Existing Land Use

A review of land uses in the study area was undertaken to assess the nature of impacts potentially caused by flooding. This assessment was based on a site inspection of the study area, the Standing Committee on Agriculture and Resource Management (*SCARM) (2000), Floodplain Management in Australia: best practice principles and guidelines,* and the NSW *Floodplain Development Manual: the management of flood liable land*.

The land use adopted for flood prone land largely defines the resulting flood hazard. Matching of land use to flood hazard minimises the risk and consequences of flooding. The Tallow Creek lake mouth borders the Cape Byron Marine Park, which was declared in November 2002 and the Arakwal National Park. The key land uses in the Tallow Creek study area are shown in Figure 3-4. These include the residential suburb of Suffolk Park and estates of Baywood Chase and Byron Hills, which consist predominantly of detached dwellings. Other land uses include:

- Arakwal National Park;
- Neighbourhood shopping centre (including post office, supermarket, bakery, etc);
- Hotel;
- Motel;
- Holiday accommodation;
- Service station;
- Open space;
- General store;
- Nursing home;
- Byron Bay High School and St Finbarrs Primary School; and
- Decommissioned sewage ponds.

Council is currently in the process of preparing a shire wide LEP, the land zoning presented here may change in the new LEP.

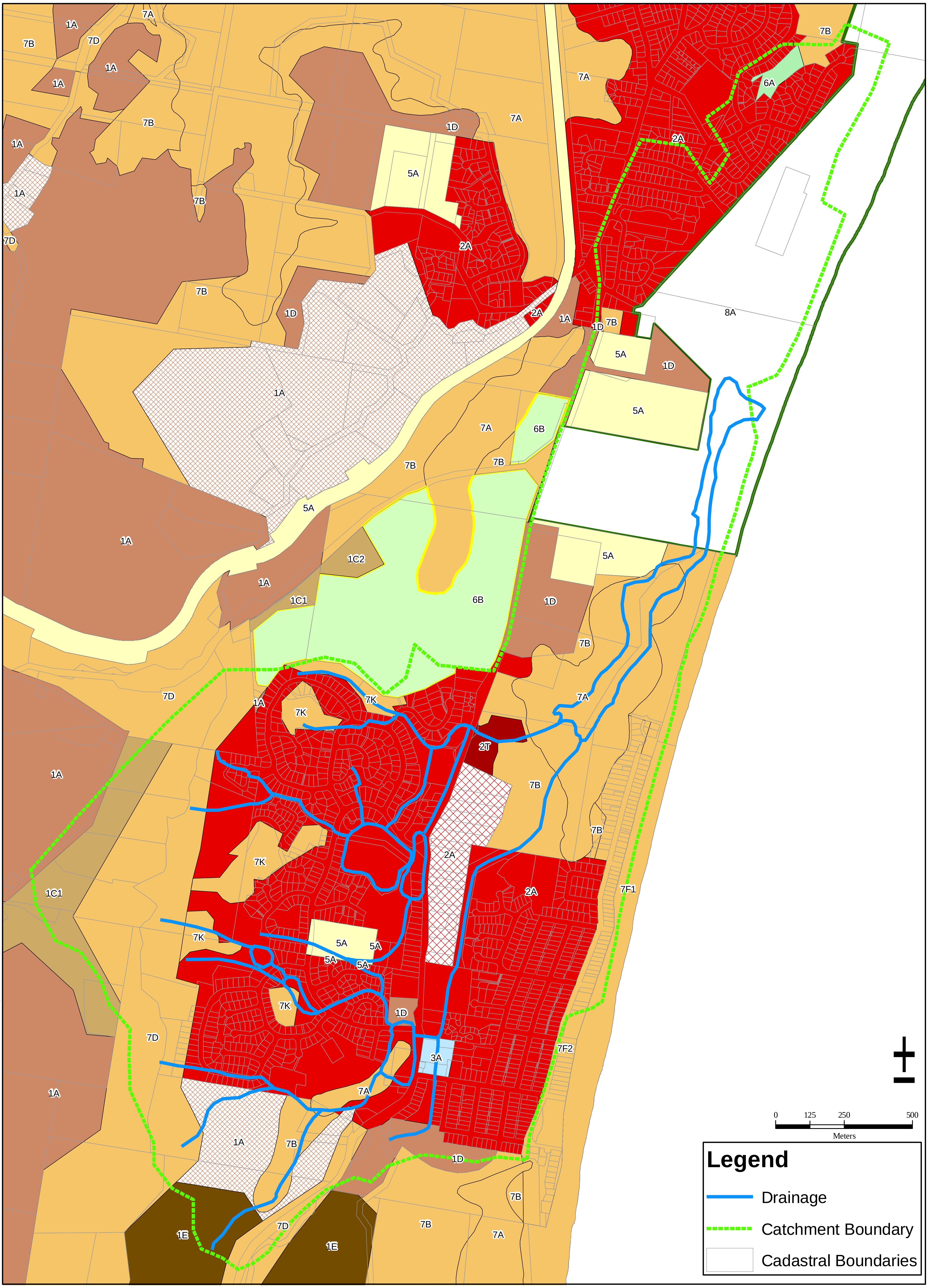
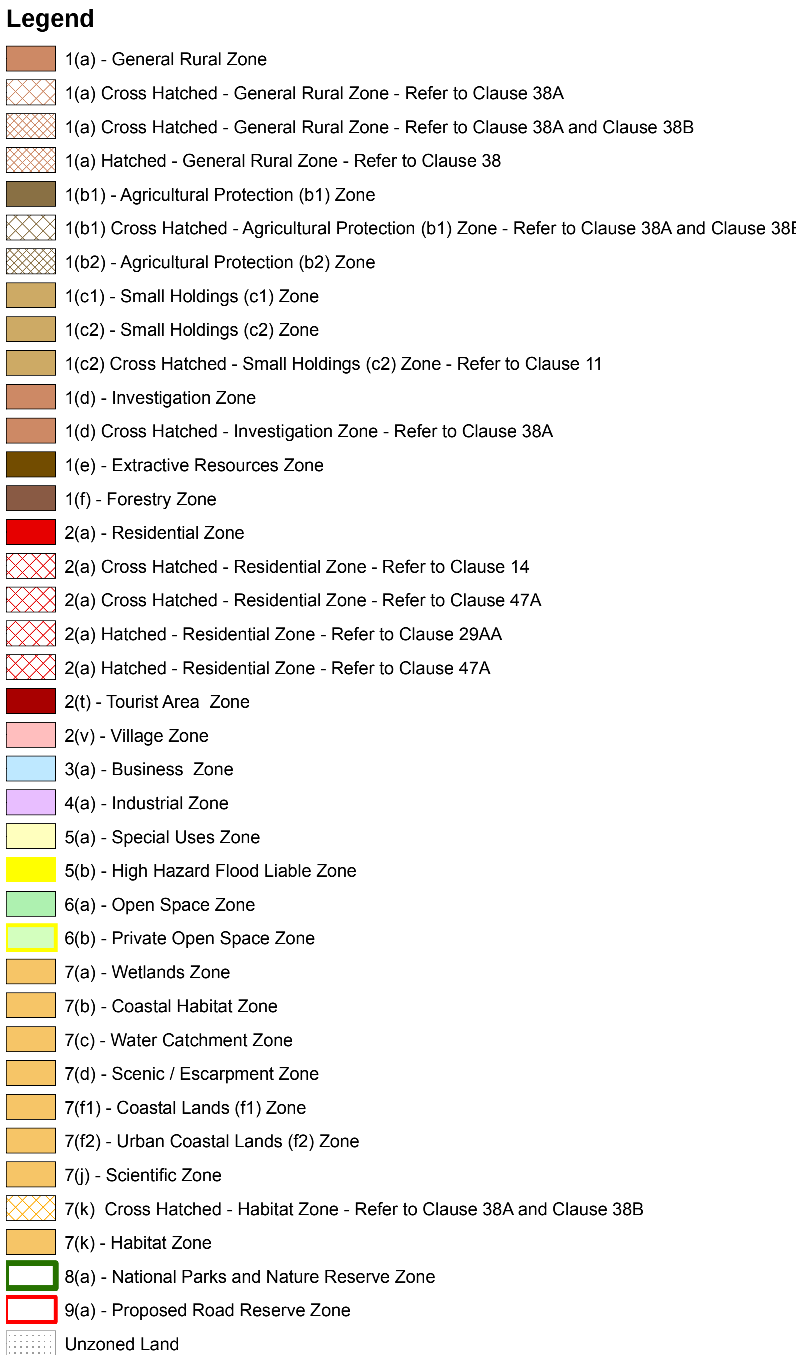


Figure 3-4: Tallow Creek Flood Study - Existing Zoning Map

Filename: Flood Hazard Date: Nov 2003 Location: QENV Job: QE08218



- **Figure 3-5 Land use zoning colour scheme as from Byron LEP (1988)**

3.5. Previous Investigations

A flood study of Tallow Creek was undertaken by Water Studies (2002) – *Tallow Creek Flood Study*. This study was undertaken to establish the behaviour of flooding in the Tallow Creek catchment through the development of computer models and the simulation of design flood events. In this study a RAFTS hydrologic model and TUFLOW hydraulic model were developed for the Tallow Creek catchment. The TUFLOW hydraulic model was subsequently amended as part of this Floodplain Risk Management Strategy to correct the representation of some hydraulic features. The report detailing the modifications to the existing hydraulic model is contained as Appendix F of this report.

The Byron Bay, Suffolk Park and Ewingsdale Local Environmental Study (Byron Shire Council, 2005) has been prepared, addressing environmental aspects of the study area on a broad scale. This report has identified the inputs required for the review of the existing Byron Local Environment Plan, including desired amendments to the plan on aspects of flooding. This strategy has sought to provide this necessary information.

3.6. Current Planning Provisions

An overview of Council's planning controls for the Tallow Creek study area was undertaken to assess how well they address planning requirements for floodplain risk management. Four documents detail the flood management guidelines for Tallow Creek, and these are;

- NSW Floodplain Development Manual (2005);
- Byron Local Environment Plan 1988;
- Byron Development Control Plan (2002); and
- State Environmental Planning Policy 71 – Coastal Protection

These are discussed under in the following sections. Various other statutory planning documents, including the Arakwal National Park Plan of Management (2007) were referenced in the development of this report, however these have not been specifically detailed here.

3.6.1. NSW Floodplain Development Manual 2005

The *Floodplain Development Manual 2005* supports the NSW Government's Flood Prone Land Policy. The manual provides a framework for implementing the policy to ensure that the impact of flooding and flood liability on individual owners and occupiers of flood prone areas is reduced, and to reduce private and public losses resulting from floods.

Council's policy for development on flood liable land outlined in Council's Local Environmental Plan and Development Control Plan are generally consistent with the policies identified in the *Floodplain Development Manual*.

3.6.2. Byron Local Environment Plan

The *Byron Local Environmental Plan 1988* (LEP) is the relevant local planning instrument that established the detailed decision making framework for the planning and control of land uses within the Tallow Creek study area. The LEP is established in accordance with the *Environmental Planning and Assessment Act 1979*. The objectives of the LEP are:

a) to enhance individual and community (social and economic) well-being by following a path of economic development that safeguards the welfare of future generations;
b) to provide for equity within and between generations; and
c) to protect biodiversity, and re-establish and enhance essential ecological processes and life support systems.

Clause 24 of the LEP relates to development on flood liable land. The LEP defines *"flood liable land"* as either that land identified as flood liable within a flood management plan; or land inundated by the 1 in 100 year ARI flood. The LEP states that a person shall not erect a dwelling-house, or any other building, or carry out filling or construction of levees on land that is flood liable, except with the consent of the council.

The LEP further states that the council shall not consent to the erection of a building or the carrying out of a work on flood liable land unless the council is satisfied that:

- the development would not restrict the flow characteristics of flood waters;
- the development would not increase the level of flooding on other land in the vicinity;
- the structural characteristics of any building or work the subject of the application are capable of withstanding flooding; and
- the building is adequately flood proofed; and
- satisfactory arrangements are made for access to the building or work during a flood.

Land Use Zoning

The Byron LEP identifies a number of land use zones within the Tallow Creek study area. These include:

- 1 (d) – Investigation Zone
- 2 (a) – Residential Zone
- 2 (t) – Tourist Area Zone
- 3 (a) – Business Zone
- 5 (a) – Special Uses Zone
- 8 (a) – National Park & Nature Reserve Zone
- 6 (a) – Open Space Zone
- 7 (a) – Wetlands Zone
- 7 (b) – Coastal Habitat Zone
- 7 (f2) – Urban Coastal Lands (f2) Zone
- 7 (k) – Habitat Zone

As shown in Figure 3-6, almost 38% of the catchment is classified as Residential Zone (2a) and approximately 21% of this area (ie 8% of the total catchment) is presently undeveloped.

According to the *Local Environmental Plan 1988 (LEP),* potential future development may be permitted in areas currently classified as Investigation Zones (1d), Tourist Area Zones (2t), Business Zones (3a) or Special Uses Zones (5a). This corresponds to a further 10% of the total catchment area that could be subject to future development.

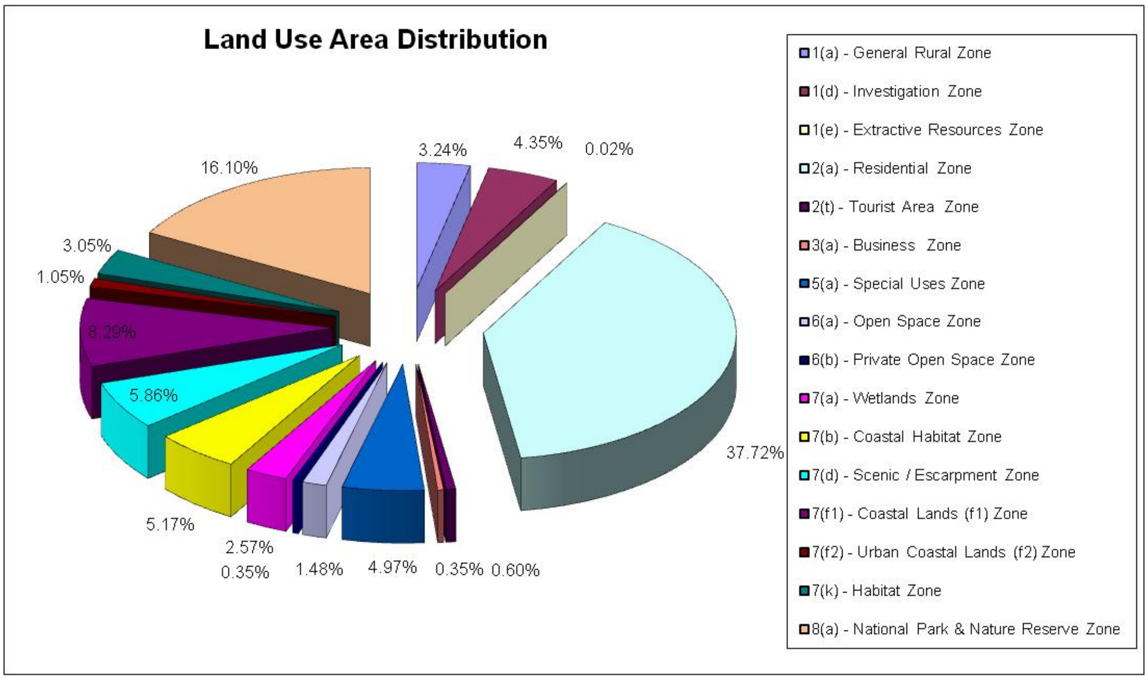


Figure 3-6 Land use area distribution

The LEP specifies land uses for each zone that can be developed *"without development consent"*, *"only with development consent"* or that are *"prohibited"*. The majority of land uses in these zones can only be developed with the consent of the development authority or are otherwise prohibited from being developed.

The Byron LEP also establishes a High Hazard Flood Liable Zone. This zone has not been defined within the study area. The objectives of the zone are to identify land within the high hazard flood storage or floodway area which has little potential for any development and which should be kept free of development liable to be damaged by flood waters and development which is likely to adversely affect the flow of flood waters. A further objective is the proper management of land within the zone which is of environmental significance by prohibiting or controlling development likely to have an adverse effect on the environmental value of that land.

3.6.3. Development Control Plan

The Byron Development Control Plan 2002 (DCP) applies to all land to which the LEP applies. The DCP is established under the Environmental Planning & Assessment Act 1979 and has the primary purpose to provide planning strategies and controls for various types of development permissible in accordance with the LEP. The general objectives of the DCP are:

- To provide development controls and guidelines which will assist in achieving the Aim, Objective and Guiding Principles of Byron Local Environmental Plan 1988.
- To provide development controls and guidelines which are sufficiently flexible to promote innovative and imaginative building and development which relates well to its surroundings, both man-made and natural but sufficiently defined to remove ambiguity.
- To promote and encourage a high quality of design and amenity for all development in the Shire.
- To manage change in a way that ensures an ecologically, socially and economically sustainable urban and rural environment in which the needs and aspirations of the community are recognised.

Flood Liable Lands

Part K of the DCP relates to flood liable lands. The purpose of this Part is to set out the adopted flood levels as referred to in the definition of flood liable land LEP; provide detailed provisions in regard to clause 24 of the LEP; and set out Council's interim flood policy in terms of the NSW *Floodplain Development Manual*.

The objectives of Part K are:

- to reduce the impact of flooding and flood liability on individual owners and occupiers;
- to reduce private and public losses resulting from flooding;
- to ensure that all development and building proposals on flood liable lands are considered by Council, taking into account social, economic and ecological issues, as well as flooding considerations to ensure floodplains are not unnecessarily sterilised and development not unreasonably restricted by virtue of the land being liable to flooding; and
- to provide guidelines for determination of the merits of development on flood liable lands as required by section 79C(a)(iv) of the *Environmental Planning and Assessment Act*.
-

Part K of the DCP identifies development standards for development on flood liable land relating to flood standard and development criteria.

The DCP identifies the 1% Annual Exceedance Probability (AEP) flood plus 500mm as the flood planning level. The 1% AEP flood is the commonly adopted standard for floodplain management for communities across Australia. Council does not have any flood related development controls in regard to flooding for development that would be affected by flood events larger than the 1% AEP flood.

The objective of the development criteria is to ensure that all development and buildings proposed on flood liable lands is considered by Council. Prior to April 2005, in assessing development on flood prone land, Council has adopted the flood hazard categories specified in the *NSW Floodplain Development Manual* which defined flood prone land as the 1 in 100 year ARI flood extent. The April 2005 revision of the NSW Floodplain Development Manual defines flood prone land as the probable maximum flood extent. While the requirements identified in the DCP for development in each of the flood hazard categories was previously consistent with the *Floodplain Development Manual,* this is now inconsistent .

The DCP also requires developers to prepare an adequate flood evacuation/ contingency plan to show that the proposed development does not involve any risk to life, human safety, property or the environment during a flood event.

DCP No. 9 – Suffolk Park

The *DCP No.9 – Suffolk Park* was adopted in May 1996 under the *Environmental Planning and Assessment Act*. The aims of the DCP relevant to this study are to:

- Preserve significant areas of environmentally sensitive habitat and vegetation value and protect these areas from domestic animals by physical barriers or other suitable means;
- Take advantages of the variety of land forms and drainage patterns to provide a range of innovative subdivision designs, housing types and residential development designs to give Suffolk Park its own identity and uniqueness;
- Minimise and control flooding by appropriate drainage controls and works;
- Encourage medium density and cluster residential development in appropriate locations where conventional subdivision may have an adverse affect on the environmental quality of the area;
- Minimise engineering works associated with roadworks, drainage and individual allotment development;
- Control development in such a way that the integrity of the Tallow Creek wetlands system are maintained and not affected by any new development.

The DCP identifies specific controls to provide in the long term a public reserve and access along the entire Tallow Creek. This includes the provision of a 10 m wide reserve as measured from the centre of Tallow Creek for open space and passive recreation, and the need to ensure that new development is not within 5 m of the outer edge of the 10 metre reserved referred to above. Specific controls are also included for drainage to ensure that people and property are protected from flooding erosion and wash aways.

The DCP also identifies sites for future uses such as an interdenominational church, community hall/ meeting place, and pre-school. While these sites are located in low flood hazard areas for the 100 year flood event, design measures and evacuation plans should ensure that the impacts of flooding on these uses, particularly the school, are minimised.

3.6.4. State Environmental Planning Provision 71 – Coastal Protection

The State Environmental Planning Provision (SEPP) 71 – Coastal Protection, defines the areas that are classified as a sensitive coastal location. Included in this are:

(a) land within 100m above mean high water mark of the sea, a bay or an estuary,

(b) a coastal lake,

(c) a declared Ramsar wetland within the meaning of the Environment Protection and Biodiversity Conservation Act 1999 of the Commonwealth,

(d) a declared World Heritage property within the meaning of the Environment Protection and Biodiversity Conservation Act 1999 of the Commonwealth,

(e) land declared as an aquatic reserve under the Fisheries Management Act 1994,

(f) land declared as a marine park under the Marine Parks Act 1997,

(g) land within 100m of any of the following:

(i) the water's edge of a coastal lake,

(ii) land to which paragraph (c), (d), (e) or (f) applies,

(iii) land reserved or dedicated under the National Parks and Wildlife Act 1974.

This defines large areas of the lower reaches of the Tallow Creek catchment as a sensitive coastal location.

3.6.5. Summary

The review of planning controls for the Tallow Creek study area identified the following implications for floodplain management.

- Planning controls relevant to development on flood prone land within the study area are generally consistent with the *NSW Floodplain Development Manual*;
- Areas of high flood risk within the study area are generally confined to drainage channels and lakes within existing zones, including residential zones. Council may wish to consider rezoning these areas to "High Hazard Flood Liable" Zones, to ensure that these areas are not inappropriately developed;
- Impacts of flooding on future planned community uses identified in the DCP No. 9 – Suffolk Park, particularly the school, should be minimised through the implementation of appropriate design measures and evacuation plans.

3.7. Current Flooding Characteristics

The current flooding characteristics in the Tallow Creek catchment vary across the catchment. Flooding from local stormwater runoff and drainage network surcharge is the dominant flooding mechanism along Tallow Creek upstream of Suffolk Park Lake and North Tallow Creek upstream of Broken Head Road. In the lower catchment downstream of Broken Head Road, flooding is dominated by storm tide levels and is also governed by Tallow Lake entrance conditions.

Number of Properties Affected by Flooding

Modelling undertaken for the floodplain management study was used to produce flood inundation extents and flood depths for storm events ranging from the 1 in 5 year ARI storm event up to the probable maximum flood event (PMF), based on current climatic conditions. These flood extents are presented in Appendix B of this report and are discussed in greater detail in Section 5.1. This information was combined with a floor level survey of properties to establish the number of flood prone properties in the Tallow Creek catchment. The number of properties flooded above and below floor level is listed in Table 3-1, based on existing (non climate change) conditions.

- **Table 3-1 Number of flooded properties in the Tallow Creek catchment**

Modelled Flood Event (ARI) Years	Above Floor Affected Properties	Below Floor Affected Properties	Total Flood Affected Properties
5	1	53	54
20	5	71	76
50	9	77	86
100	13	80	93
500	18	96	114
PMF	135	112	247

The majority of properties affected by flooding up to the 1 in 500 year ARI flood incur below floor level flooding (ie flooding of the outside property). For flood events greater than this (ie the PMF), the majority of properties are affected above the floor level.

Most of the properties affected by flood events include residential uses. For a 1 in 100 year ARI flood event, two non-residential properties are affected above floor level. These are the Park Hotel Motel and BP Service Station, both on Broken Head Road.

The above results are based on the existing catchment condition, and climate conditions that do not reflect potential impacts of climate change. The considerations for climate change are addressed in Section 5 of this report.

3.8. Future Catchment Development

The Tallow Creek catchment and surrounding area has been the subject of recent intensive development, primarily residential and tourism based. Despite this, there remains large areas within the catchment zoned as residential that are as yet undeveloped. The general lifestyle attraction of the region coupled with predicted strong future growth emphasise the need for catchment development control to mitigate future flooding risks.

3.9. Conclusion

The review of land uses in the study area showed:

- Existing land uses are generally appropriate for the relevant flood hazard area;
- While the location of the Pinehaven Nursing Home (located on Broken Head Road) is in the low hazard flood area, this site is subject to minor flooding of the outside property only. Therefore, this is not expected to raise any issues for the evacuation of elderly residents in a flood event; and
- The majority of properties affected by flooding up to the 1 in 500 year ARI flood event result in flooding of the outside property only.

4. Managing Flood Risks

4.1. Principles of Risk Management

Floodplain risk management involves balancing the relative costs and benefits of using the floodplain (NSW Government, 2002). The steps necessary in developing a strategy to manage risks are:

- Identifying the risks, both current and future;
- Quantifying the likelihood of the risk and the consequences of the risk becoming an incident;
- Identifying means to mitigate the risks, through both future planning and modification to the existing system;
- Quantify the risk mitigation options, most commonly by the cost to implement;
- Develop a strategy for the management of the identified risks, balancing the cost of protecting against the risk with the likely costs should the risk not be managed.

These steps have formed the basis for this investigation, discussed in further detail in the following sections.

4.2. Approach Adopted for the Project

The approach adopted for the Tallow Creek Floodplain Risk Management Study is outlined in Figure 4-1. The four steps in this figure are discussed in the following sections.

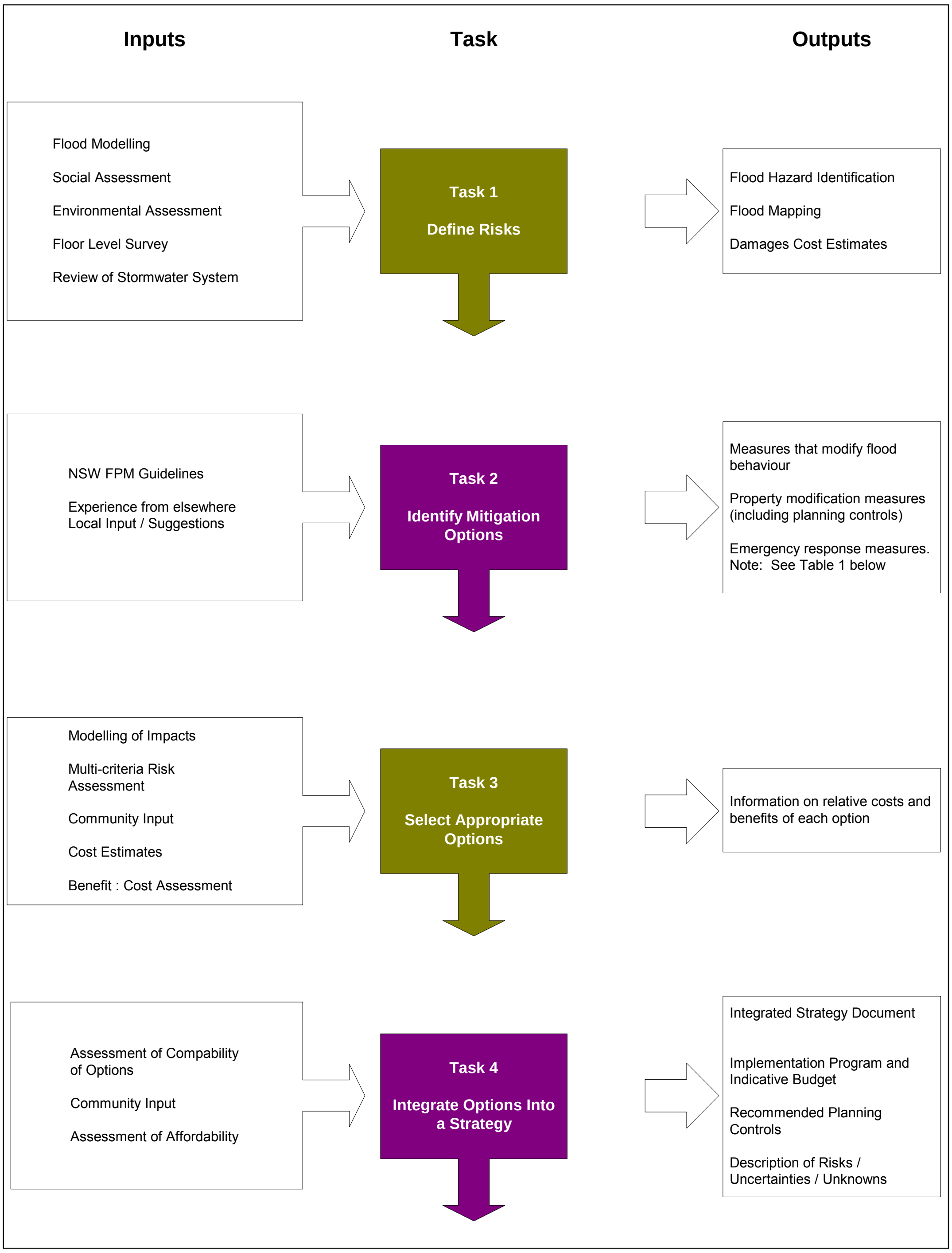


Figure 4-1 Flow diagram of study approach

4.2.1. Define Risks

The flooding risks in the catchment were determined by computer flood modelling, combined with anecdotal catchment flooding information. This allowed for the understanding of the flooding mechanisms and flood behaviour in the catchment. This understanding of the flood behaviour allowed for the determination of the likely flood damage cost in the catchment.

In addition to the identification of the existing flood risks in the catchment, to ensure the ongoing applicability of the proposed strategy it was necessary to identify potential future flood risks in the catchment. Development potential in Byron Shire is very strong, emphasising the need to properly manage future development such that it does not increase the flood risks of the catchment.

4.2.2. Development of Mitigation Options

Flood mitigation options were identified and assessed for their ability to reduce the likely cost of flooding when compared to the existing conditions cost of flooding. This allowed for a cost-benefit analysis to be undertaken.

4.2.3. Strategy Development

The proposed floodplain risk management strategy for the Tallow Creek catchment was formulated based on the investigations into the flood risks of the catchment and the potential mitigation options. Working with the community project committee, key flood risk issues were identified in the catchment. From the input of the community, discussion papers were developed on the following issues, identified as significant flood risk related issues in the catchment:

- Planning and social issues;
- Stormwater drainage and overland flow management;
- Sand bar management; and
- Environmental survey.

Investigations were conducted into each of the above catchment issues, with the findings presented to the project committee for review. Feedback from the community committee was incorporated into the formulation of a draft risk management plan that was placed for public display as part of the community consultation.

4.2.4. Consultation

Community involvement was a strong element in the development of the Tallow Creek Floodplain Risk Management Plan. From the project inception, the project was directed by a Project Committee. Members of the project committee included representatives from National Parks and Wildlife Services, NSW Marine Parks Authority, Byron Shire Council, SES, Department of Environment and Climate Change and local residents.

The proposed catchment management strategy was displayed for community feedback by the public display of information posters. The posters detailed the key elements of the proposed strategy, leading up to a community consultation session where feedback on the proposed strategy was sought from the community. This feedback was incorporated in the proposed floodplain risk management strategy, detailed in this report.

5. Flood Hazard Assessment

5.1. Flood Modelling

Computer modelling was undertaken as part of the Tallow Creek Flood Study (Water Studies, 2002). Computer simulation of design flood events allows for the identification of land likely to be inundated during a flood event, as well as the identification of land with elevated flood hazard (high water velocity or depth). The results of this modelling were used to identify existing areas of high flood risk in the Tallow Creek catchment, as well as dictating the areas where future development should be excluded.

For this, both a hydrologic and hydraulic model were developed of Tallow Creek catchment to allow for the simulation of design flood events. A RAFTS hydrologic model was developed for the catchments, allowing for the estimation of design discharge hydrographs from delineated sub-catchments of the Tallow Creek catchment. The hydrographs were modelled in a TUFLOW two-dimensional hydraulic model of the catchment.

The primary output of this modelling was peak flood depths, velocities and discharges for design flood events with a range of return intervals. The modelled flood return periods were:

- 1 in 5 year ARI;
- 1 in 20 year ARI;
- 1 in 50 year ARI;
- 1 in 100 year ARI; and
- 1 in 500 year ARI.

In addition to these, the probable maximum flood event (PMF) was modelled for the Tallow Creek catchment. The peak flood depth and water level contours for these flood events have been mapped, with the results presented in Appendix B of this report. The flood depth and water level contours for the 1 in 100 year ARI flood event are shown here in Figure 5-1.

The above listed flood return periods were assessed based on the current climate conditions. In addition to this, and subsequent to the Water Studies (2002) investigation, the potential impacts of climate change on flooding behaviour were similarly assessed. This is specifically addressed in the following sub-sections.

The Tallow Creek hydraulic model by Water Studies was technically reviewed by WBM to verify the validity of the modelling as well as check its consistency. Subsequent changes were made in the model where appropriate as required by this review.

5.2. Climate Change

Climate change has the potential to alter the flooding characteristics in the Tallow Creek catchment. Two ways that climate change can impact on flooding is through increased ocean levels and through modified frequency and intensity of rainfall events. Both of these potential impacts have been considered in this investigation.

This report considered the impacts of climate change scenarios on the regional flooding behaviour of Tallow Creek and was prepared based on the Practical Consideration of Climate Change: Floodplain Management Guideline (Department of Environment and Climate Change, 2007).

5.2.1. Ocean Level Background

The adopted ocean tail water level is based on consideration of storm tide events concurrent with a rainfall event. The ocean tailwater level adopted in the original hydraulic modelling (Tallow Creek Flood Study, 2002) considered predicted peak tailwater level with an allowance for climate change. This method was consistent with storm tide levels for the northern New South Wales coast. The adopted tailwater condition for the 1 in 100 year ARI flood event was 2.6mAHD. This included a 0.25m allowance for climate change affects on storm tides. Since this investigation, climate change science has progressed significantly which necessitated additional consideration of sea level rise for climate change conditions.

The adopted tailwater conditions from the existing modelling was compared to regional tailwater estimates for design assessment. The following provides a summary of these regional estimates;

- Gold Coast City Council adopted a conservative existing climate ocean tailwater level of 2.05mAHD. This was based on a predicted 100 year ARI ocean tailwater of 1.95mAHD. The sea level rise prediction by 2050 was 18cm which resulted in a climate change ocean tailwater level of 2.23mAHD;
- Ballina Ocean Level Study (Lawson & Treloar, 1994) predicted a 100 year ARI ocean tailwater level of 1.9mAHD. This estimate, while not including a climate change component, is well below the adopted level from the Flood Study of 2.6mAHD;

- Belongil Creek (SMEC 2007) recommended a 100 year ARI ocean tailwater level of 2.65m AHD, incorporating guidance from the Intergovernmental Panel on Climate Change (IPCC). This level is based on the consideration of a 100 year planning period. This report identified an existing climate ocean tailwater level of 2.21mAHD, hence the 2002, Tallow Creek Flood Study adopted level of 2.6mAHD effectively incorporates a climate change allowance of 0.39m.

These estimates were further justified by the Practical Consideration of Climate Change: Floodplain Management Guideline (Department of Environment and Climate Change, 2007), requiring further assessment of adopted storm surge levels. These levels are discussed in Section 5.2.3.

5.2.2. Rainfall Intensity Background

Climate change also has the potential to change the frequency and possibly the intensity of extreme rainfall events. The original Tallow Creek Flood Study (2002) made no consideration for changed rainfall intensity from climate change, as was standard practice at the time of this study.

A climate change scenario intensity-frequency-duration (IFD) rainfall set was developed from CSIRO estimates for rainfall intensity impacts from *The Impact of Climate Change on Extreme Rainfall and Coastal Sea Levels over South-East Queensland (2004).* CSIRO reports including The Impact of Climate Change on Extreme Rainfall and Coastal Sea Levels over South-East Queensland, Part 1: Analysis of Extreme Rainfall and Wind Events in a GCM (2004) and Climate change in New South Wales, Part 2: Projected Changes in Climate Extremes (2004) were consulted to determine suitable percentage increases for rainfall depth caused by climate change. Rainfall depths were expected to increase by 1-2 % by 2030 and by 5% by 2070. The current (2007) rainfall depths and those for 2030 and 2070 can be seen in Table 5-1. These altered rainfall conditions were not modelled using the hydrologic or hydraulic models for the Tallow Creek catchment, as the rainfall intensity represents only one element of the potential change to hydrologic conditions resulting from climate change.

■ **Table 5-1 Intensity-Frequency-Duration (IFD) Rainfall Estimates for Tallow Creek***

Current Design Rainfall Depth			
ARI (Years)	Intensity in mm/hr for duration		
	30min	45min	60min
2	73.18	58.9	50.17
5	90.63	73.29	62.64
20	112.4	91.29	78.28
100	141.36	115.26	99.1
2030 (+2%)			
ARI (Years)	Intensity in mm/hr for duration		
	30min	45min	60min
2	74.6	60.1	51.2
5	92.4	74.8	63.9
20	114.6	93.1	79.8
100	144.2	117.6	101.1
2070 (+5%)			
ARI (Years)	Intensity in mm/hr for duration		
	30min	45min	60min
2	76.8	61.8	52.7
5	95.2	77.0	65.8
20	118.0	95.9	82.2
100	148.4	121.0	104.1

*- note that the critical duration rainfall event varies across the Tallow Creek catchment.

These estimates were further justified by the Practical Consideration of Climate Change: Floodplain Management Guideline (Department of Environment and Climate Change, 2007), requiring further assessment of adopted storm surge levels. These levels are discussed in Section 5.2.3.

5.2.3. Adopted Climate Change Scenarios

Following on from the earlier assessments of potential climate change impacts, climate change assessment was undertaken based on the Practical Consideration of Climate Change: Floodplain Management Guideline (Department of Environment and Climate Change, 2007) and Byron Shire Council policy on allowing for climate change in future flood studies. This reference was the current information source at the time of the report authoring.

Hydrologic and hydraulic modelling was performed to investigate the effect of different climate change scenarios and their impact on flooding behaviour. Assessment of the impact of climate change utilised four different variations of the 100 year ARI flood event. The following table specifies the varying rainfall intensities and tailwater levels that were assessed in each of the climate change scenarios. It is noted that the modelling and subsequent results presented in **Table 5-3** is based on Byron Shine Council estimates which are conservative when compared to the DECC's Practical Consideration of Climate Change.

- **Table 5-2 Climate Change Scenarios**

Scenarios	Initial Tailwater Level (m)	Rainfall Intensity (mm/hr)	Comments
1	2.6	77.86	1:100 year rainfall intensity
2	2.91	85.65	1:100 year rainfall intensity plus 10 percent
3	3.31	93.43	1:100 year rainfall intensity plus 20 percent
4	3.62	109.00	1:100 year rainfall intensity plus 40 percent

This investigation extends on the previous modelling of the Tallow Creek catchment area (2002) to develop hydraulic model results. The following outlines the modelling procedure;

- Hydraulic modelling utilised the Tallow Creek RAFTS hydrologic model, developed in 2002 as part of the Tallow Creek Flood Study (2002), to provide variations in rainfall intensity for the specified initial tailwater conditions;
- Hydraulic modelling also made use of the Tallow Creek hydraulic TUFLOW modelling package, developed in 2002, to determine the variations in the climate change scenarios, specifically differing initial tailwater levels; and
- The impact was assessed using the 90 minute critical duration storm.

Hydraulic modelling identified minor increases in water depth for already flood prone residents in the Suffolk Park, Baywood Chase and Byron Hills locations. Approximately an additional 65 properties are affected by flood inundation in the Scenario 4 condition when compared to the Scenario 1 (existing) condition. The greatest increases occur downstream of Broken Head Road, where impacts of ocean level rise are more pronounced. The following table details the approximate number of properties affected by climate change and their corresponding maximum depths.

- **Table 5-3 Properties inundated in varying climate change scenarios**

Scenarios	Initial Tailwater Level (m)	Number of affected Residents	Maximum Residential Increase in Depth (m)
1	2.60	112	0.0
2	2.91	146	0.24
3	3.31	167	0.39
4	3.62	181	0.52

5.2.4. Discussion of Climate Change Scenarios

The results highlight that the majority of properties of the Suffolk Park and Baywood Chase areas achieve a flood protection in excess of the 100 year ARI climate change flood events. However, noticeable increases in flooded properties are observed in the northern stretches of Suffolk Park driven by the combination of increased ocean level and rainfall intensity. Specifically, the areas west of Kalemajere Drive and north of Korau Place appear to be subject to progressive flood inundation due to the increases in the climate change scenarios. Furthermore, the results indicate that the road system in this area and on Redgum Place in the Baywood Chase location have lower flood immunity than some of the surrounding dwellings. The 100 year ARI flood extent for Scenario 1 is shown in Figure 5-1 and the Scenario 4 flood extent is shown in Figure 5-2.

Local catchment flooding remains consistent upstream of Suffolk Park Lake and along North Tallow Creek upstream of Broken Head Road. This result is consistent with the Tallow Creek Flood Study (2002) which states that the flood levels for local catchment upstream from Suffolk Park Lake and Broken Head Road are independent of the Tallow Lake entrance conditions. Localised flooding is also restricted to portions of the Baywood Chase and Byron Hills locations.

Generally, during the climate change scenarios, flooding of the Tallow Creek catchment area is mostly limited to the Tallow Lake. The flood gradient resulting from the climate change scenarios is relatively flat between the Tallow Creek mouth and the Suffolk Park area due to the high flood conveyance of this reach.

Climate change scenario flood results are presented in Appendix B of this report. Climate change scenarios demonstrate the importance of evacuation strategies for the existing flood prone residents in the Baywood Chase, Suffolk Park and Byron Hills regions.

Overall, although a large number of existing flood prone properties will be adversely affected by increases in rainfall intensity coupled with increasing water levels, no new major flood hazards seem to be incurred due to the climate change scenarios.

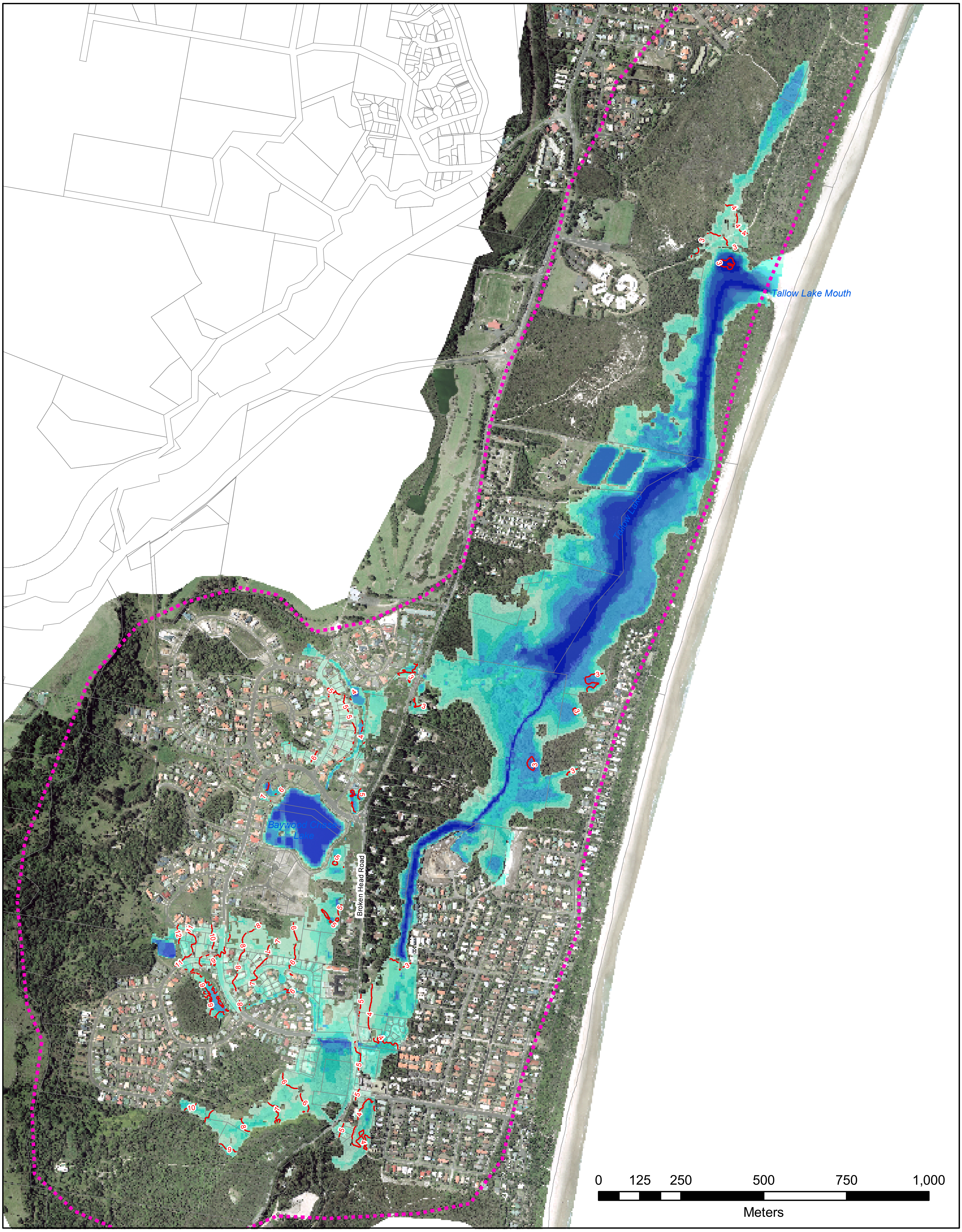


Figure 5-1: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 100 year ARI Flood Extent and Depth

Filename: Inundation_1inx Date: Jan 2006

Legend

Catchment Boundary

Cadastral Boundaries

Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1
0.11 - 0.2
0.21 - 0.4
0.41 - 0.6
0.61 - 0.8
0.81 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 <

N

Byron Shire Council

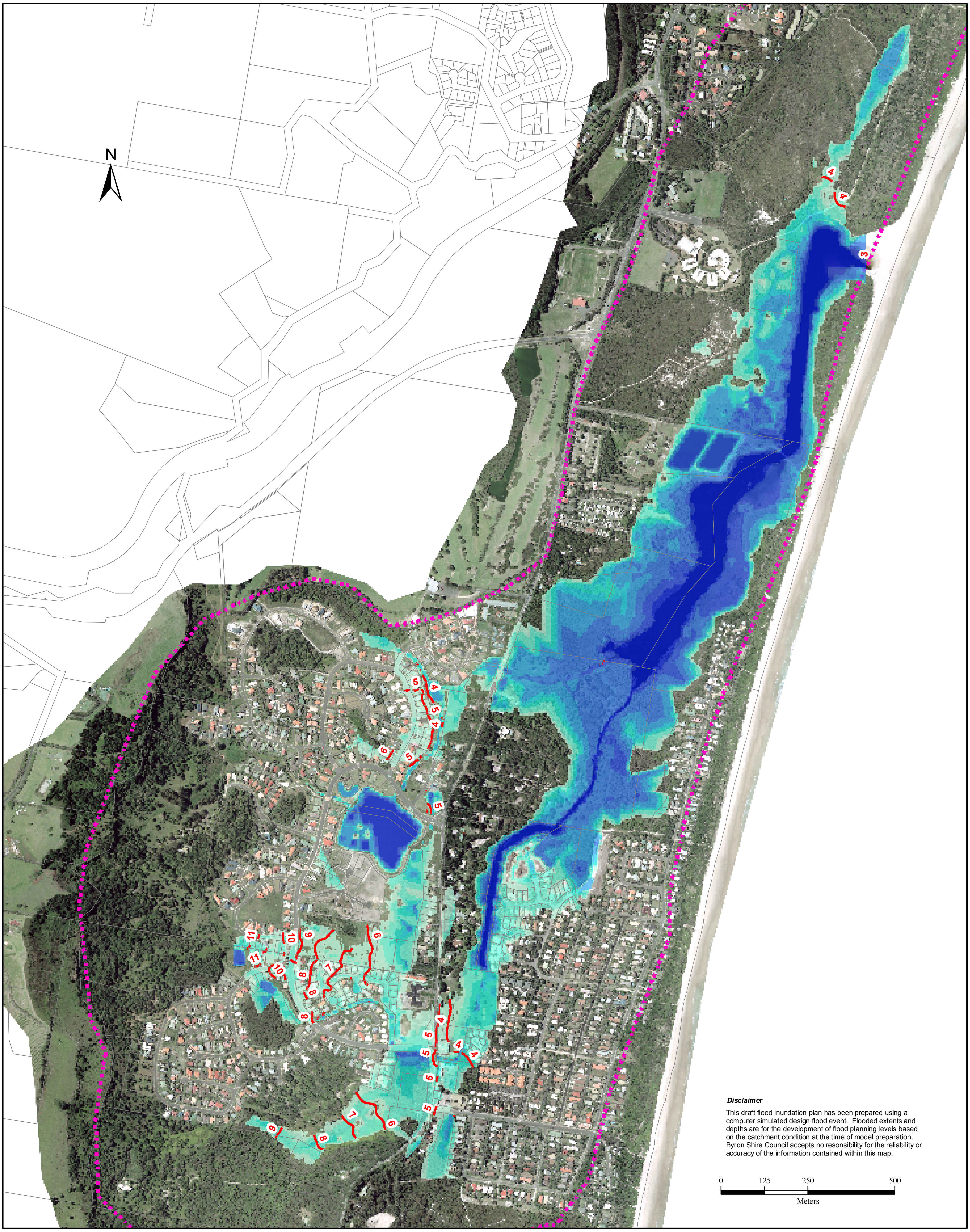


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Figure 5-2: Tallow Creek Climate Change Flood Risk Study - Flood Inundation Map

Maximum Flood Depth (m)

- 0.001 - 0.1 m
- 0.1 - 0.2 m
- 0.2 - 0.4 m
- 0.4 - 0.6 m
- 0.6 - 0.8 m
- 0.8 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2 m
- 2.0 - 2.5 m
- > 2.5 m
- Water Surface Level Contour (m AHD)

100 Year ARI Flood Event Scenario 2
10% Increased Rainfall Intensity
Initial Tailwater Level: 2.91m

Byron Shire Council

5.3. Flood Damage Assessment

A flood damage assessment was undertaken to determine the scope of damages in existing conditions and to assess the merits of flood mitigation options in reducing those damages. The assessment is a key component in the determination of a preferred flood mitigation scheme, directly via estimates of damages and as input into a financial cost-benefit assessment.

The flood damage assessment was undertaken using a model developed in-house by SKM. The model was constructed in a GIS environment using the ArcView GIS software package. The GIS environment provides a visual representation of the assessment. It can show property locations, flood extents and flood affected properties as well as list property data and calculate resulting damages. The methods and damage data used in the model are those of a model called ANUFLOOD (1992) developed by the Centre for Resource and Environmental Studies (CRES) at Australian National University.

The data requirements for the flood damages assessment are significant. The types and sources of data are discussed in the following sections.

5.3.1. Property Data

Fundamental to the assessment is the compilation of a property database for properties potentially affected by flood. The data of interest are predominantly building data. The data were collected by field survey and/or field inspections. For the assessment the following property data were required:

- Property Location

The property location must be defined by ground coordinates and imported into the GIS as a point theme. The property coordinates are used by the model to identify the flood level at each property. Property address (Street No and Street Address) is not compulsory for the damage assessment but it is fundamental for the production of flood affected property listings if required (eg. for emergency services).

- Land Use

The land use for each property is a major factor in determining the expected damage for a given flood depth. Land uses include residential, commercial, industrial, public, open space and recreation. Clearly for a given flood depth damages will differ with land use. The flood damage model considers two land use categories, residential and non-residential. The latter is used to cover a range of non-residential land uses (commercial, public and industrial).

- Property Damage or Value Class

Property value is a fundamental determinant in flood damages. The flood damage model requires each property to be assigned to a damage or value class. The class determines which flood depth versus damage data is used for each property. Class categories differ for residential and commercial properties. For residential properties damage class is a function of building material and condition. Each residential property is assigned to one of three residential damage classes. For non-residential properties value class is primarily a function of building contents, although building material and condition are also factors. There are five commercial value classes in the ANUFLOOD model.

- Ground and Floor Levels

In order to determine a flood depth at each property, ground and floor level data must be obtained for each building. These data must be located by coordinates so as to identify the appropriate flood level for each property. These data also provided the property location coordinates as derived from accurate field survey.

5.3.2. Flood Level Data

Flood level data was derived from comprehensive 1D and 2D hydraulic modelling of the floodplain behaviour. Properties are generally scattered across the river and creek floodplains. Only rarely will a property location coincide with an hydraulic model grid location. In order to assign a flood level at each property some form of flood level interpolation between cross sections or grid points is required. This was achieved by generating an interpolated digital flood surface for each flood event of interest from each hydraulic model output. The flood surfaces were input into the GIS flood damage model, where they were overlayed onto the property data to determine flood depths at each property for each flood event. The properties inundated above floor level between the 1 in 20 year ARI flood and PMF are shown in Figure 5-3.

5.3.3. Damage Data

Damage data provides the means by which flood depths can be converted into monetary damages. The data required must cover the different types or categories of damage relevant to this flood damage assessment.

Specifically, damage data is required for both direct and indirect damages. Direct damages can be further sub-divided into internal and external damages. Following is a brief description of the damage data used for each damage type or category. All damage data was embedded in the GIS flood damage model.

- Direct Damages (Internal)

Internal direct damage curves have been taken from the ANUFLOOD program. There are eighteen internal damage curves, three for residential properties (for 3 damage classes) and fifteen (for 3 size classes by 5 value classes) for commercial properties. Each relates flood depth above floor with monetary damage. As the damage data were initially calculated in early 1992, all damage values have been adjusted to more up to date values using a Consumer Price Index (CPI) based factor of 1.16 to June 2008.

- Direct Damages (External)

An external direct damage curve has been developed using data from Floodplain Management in Australia, Volume 2 (AWRC, 1992). It assumes that external damages commence at a flood depth above ground of 0.05 m and vary linearly to an upper limit of $7,500 at a flood depth above ground of 1 m. No distinction is made between residential and commercial properties.

The assessment involved determining total damages (both extent and cost) for each of a range of flood events under given floodplain conditions. Appendix E provides a summary of the ANUFLOOD model results. For each flood scenario, the total number of properties affected above ground and above floor was computed as well as estimated external, internal and total damages.

5.3.4. Annual Average Damages

Flood risk, as a function of likelihood *and* consequence, can be determined for a given flood or can be integrated over a range of floods, to provide a single indicator of the risk to the community. This indicator is known as **Average Annual Damage (AAD)** or annual damage cost to the community for accepting a given floodplain condition. It is commonly used in flood management studies, as it is a useful single value indicator of the financial vulnerability of a community to flooding in existing conditions and of the benefit of proposed mitigation schemes. Annual average damage considers the cost of a range of flood events that would occur over an extended period of time, with the cost of damages from all the likely floods over that period integrated to a cost-per-year value.

Average annual damage is calculated as the area under a curve of total monetary damages versus flood ARI. The AAD for the Tallow Creek community under existing conditions is estimated at **$30,000** (ie, $30,000/annum), for floods up to and including the PMF event.

Understanding and quantifying flood risk becomes invaluable in assessing the economic merit of mitigation options. Mitigation options reduce flood risk and AAD. A comparison of AAD for existing conditions with AAD of a given mitigation option represents the benefit (ie. reduction in AAD) of the option. Comparing the benefit with the cost of implementation (capital works plus operation and maintenance) of the option provides a cost-benefit ratio, which assists in assessing and ranking of options on economic grounds.

5.3.5. Flood Damages Conclusion

The annual average damage in the Tallow Creek catchment of $30,000 is low, indicating that extensive structural works in the catchment are not warranted. This result indicates that floodplain risk management in the Tallow Creek catchment should primarily focus on future planning controls within the catchment rather than civil works.

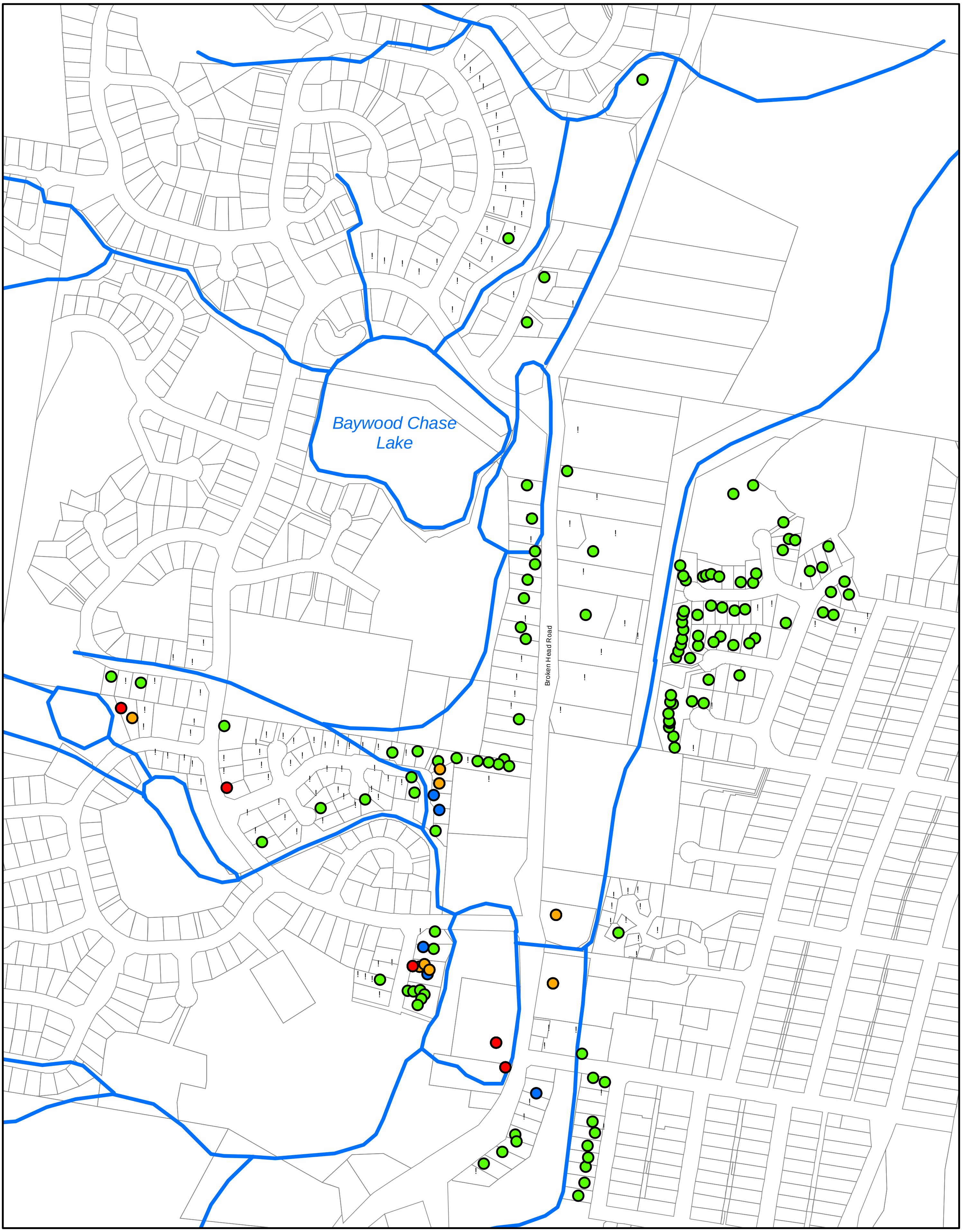

Figure 5-3 Tallow Creek Flood Risk Management Study

Properties Flooded Above Floor Level for flood events between 1 in 20 year ARI and the PMF

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Legend

- Flooded above floor level in greater than 1 in 20 year ARI
- Flooded above floor level in greater than 1 in 100 year ARI
- Flooded above floor level in greater than 1 in 500 year ARI
- Flooded above floor level in PMF
- ! Properties Surveyed (not flooded)
- drainage

0 62.5 125 250 375 500

Meters

Byron SHIRE COUNCIL

5.4. Flood Hazard Assessment

The *NSW Floodplain Development Manual* identifies land uses appropriate to various hydraulic-hazard categories of flood prone land. Land uses include residential, commercial, industrial, open space, rural/ non-urban, and special uses (ie schools, hospitals, emergency services, etc). Hazard categories are broken down into high and low hazard areas. The degree of hazard is largely based on the depth and speed of water and can be defined as:

High Hazard	Possible danger to personal safety, evacuation by trucks difficult, able bodied adults would have difficulty in wading to safety, potential for significant structural damage to buildings.
Low Hazard	Should it be necessary, trucks could evacuate people and their possessions, able-bodied adults would have little difficulty wading to safety.

Areas of high hazard and low hazard for the Tallow Creek catchment were established from the results of the hydraulic modelling. High hazard is determined as having depth greater than 1.0m, or a velocity depth product (velocity multiplied by flood depth) in excess of $0.6m^2/s$. The areas of high and low hazard for the 1 in 100 year ARI flood event are plotted in Figure 5-4.

Each hazard category includes three hydraulic categories of floodprone land – floodway, flood storage and flood fringe.

Floodway	This includes those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels.
Flood Storage	This includes those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Flood Fringe	This incorporates the remaining area of land affected by flooding.

Overall, most land uses, other than special uses, are appropriate in low hazard areas provided they are sufficiently floodproofed. Residential uses such as nursing homes may require special consideration in low hazard flood areas due to the additional time required for evacuation.

Preferred land uses from the NSW Development Manual (2005) in high hazard areas include open space, rural, commercial and industrial land uses, although these should generally avoid high hazard floodways. However, the Byron Development Control Plan 2002 - Part K2 - Flood Liable Lands indicates that many of these land uses are inappropriate in areas of high hazard.

The majority of existing land uses are appropriate for low hazard flood areas. While the Pinehaven Nursing Home is located in a low flood hazard area, this site is subject to minor flooding of the outside property only, for each of the flood events. The majority of other land uses (ie residential and commercial) are also located in low flood risk areas.

Areas of high flood risk generally incorporate existing open space and recreation uses, which is appropriate to this area.

In addition to the assessment of flood hazard, the peak depth velocity product (VxD) was calculated based on the hydraulically modelled results for a range of flood events. The results of this assessment is contained in Appendix H of this report, both for existing climate change and climate change scenarios.

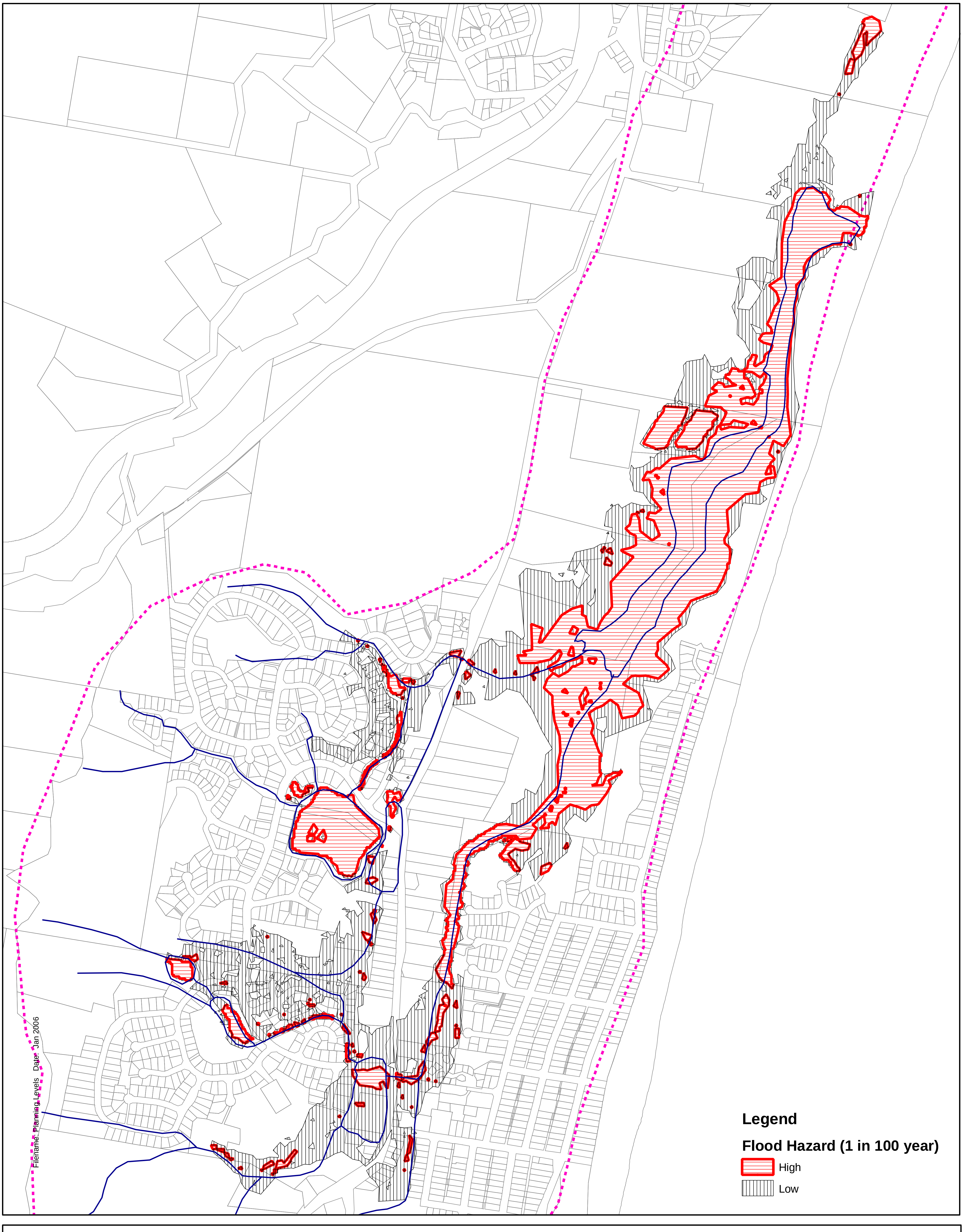


Figure 5-4: Tallow Creek Flood Risk Management Strategy - Flood Hazard Zones

1 in 100 year ARI Flood Hazard

5.5. Assessment of Tallow Lake Opening on Flood Hydraulics

Tallow Creek flows under Broken Head Road downstream of the Forest Glades wetland. From there it drains in a northerly direction into what is commonly known as Tallow Lake. Tallow Lake is a typical inter-dunal lake and is classified as a small Intermittently Closed and Opened Lake/Lagoon (ICOLL) which lies between the near-coastal dune systems. It has a surface area of approximately 14ha, and stores approximately 180-200ML of water under typical storage levels (say 1.5m AHD). The lake has a relatively narrow natural entrance and is separated from the Pacific Ocean by a sand dune system. Tallow Creek gradients downstream of Broken Head Road are very flat. Therefore, depending on the build-up of sand at the entrance, water can pond behind the sand dune for some distance upstream and will exacerbate flooding on local properties. At the time of this study these impacts have been confined to nuisance flooding on private properties adjoining the lake with no structural flooding. Some of the properties adjoining the lake are noted to contain natural wetland vegetation.

During the floodplain risk management study nuisance flooding of properties adjacent to Tallow Lake occured as a result of storm runoff being detained behind the high elevation Tallow mouth sandbar. These events did not include flooding of structural elements. The flooding necessitated the manual opening of the Tallow Lake mouth by an excavator, releasing flood waters (as shown in Figure 5-5). Manual opening is not a desirable action due to the possible environmental impacts, however when private property is inundated because the ocean outlet is closed, manual opening is required to minimise the damage to private property.

- **Figure 5-5 Manual opening of Tallow Lake mouth to relieve flooding, November 2004**

5.5.1. Hydraulic Assessment of the Tallow Creek Mouth

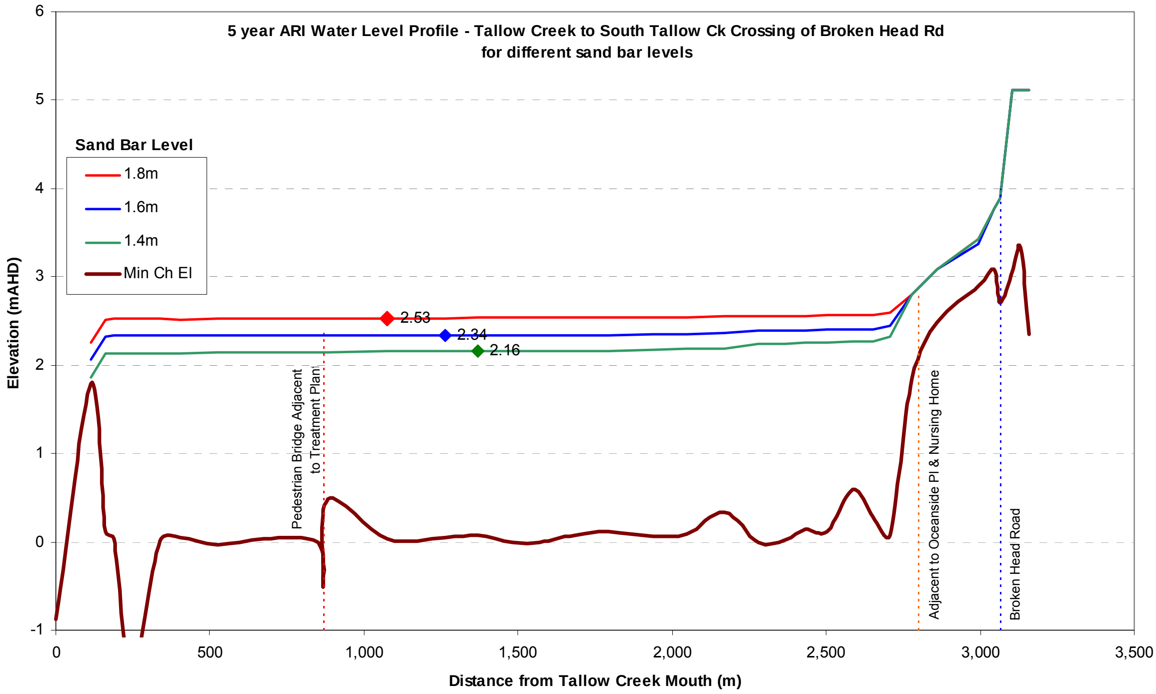
Hydraulic modelling has been undertaken to better understand the influence of the Tallow Lake mouth level on flooding conditions. The approach adopted involved the modelling of the water level upstream of the creek mouth for a range of opening levels for the peak inflow from a 1 in 5 year ARI design storm, to illustrate the flood behaviour. These water surface profiles are shown in Figure 5-6. Note that these water levels would be higher if a rarer (higher ARI event) was to occur.

It is estimated that the sandbar level was approximately at 2.5mAHD in November 2004 prior to the forced opening of the mouth. The manual opening associated with this occurrence is shown in Figure 5-5.

The modelling clearly indicates that there is no hydraulic effect of the sand bar upstream of Broken Head Road.

There is a need to relate a water level to an inundation extent in order to assess the water/sand bar level that begins to create an unacceptable level of risk to property. The flood level contours corresponding to water levels of 1.4mAHD to 1.8mAHD are mapped on Figure 5-7.

The investigation indicated that while the lower reaches of Tallow Creek are flat with flooding dictated largely by the lake-mouth sandbar level, this influence does not extend upstream of Broken Head Road. A distinct increase in channel grade is observed in South Tallow Creek approximately 2,700m upstream of the creek mouth (refer to Figure 5-6), with the modelled peak flood levels converging at this point for the range of sandbar levels. As a result, sand bar level will only effect properties downstream of the Broken Head Road crossing.



- **Figure 5-6 Tallow Lake water levels for various sand bar levels, also showing the creek invert**

At 1.8mAHD and above, the waters from Tallow Lake begin to enter the back yards of private properties as well as public access infrastructure. This is considered to raise the risk of inundation to structure footings, public infrastructure as well as raising the cost of damage from flooding through incidental damage.

Section 7.3 details the strategy for the development of long term management options for the Tallow Creek mouth. It is necessary for an approach that considers the immediate flood risk aspects of the sandbar management concurrent to establishing the environmental and cultural heritage aspects in the long term. Collection of the necessary information for this long term assessment may take some time, and would need to be based on a better understanding of the ecology of the Tallow Lake system, and potential impacts of changed hydrology. The accepted interim approach provides a means of managing flood risks in the interim, without significant risk of environmental harm.

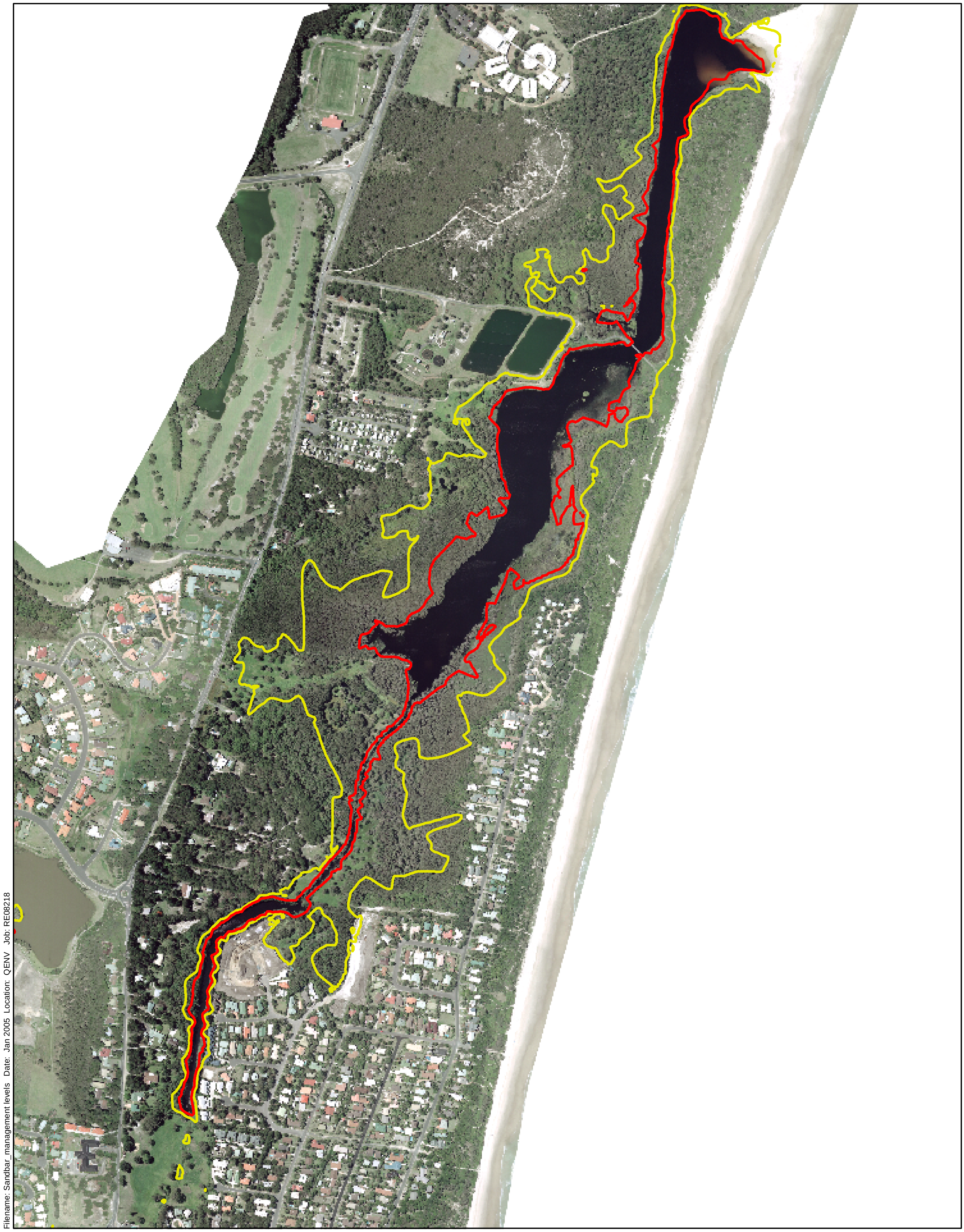
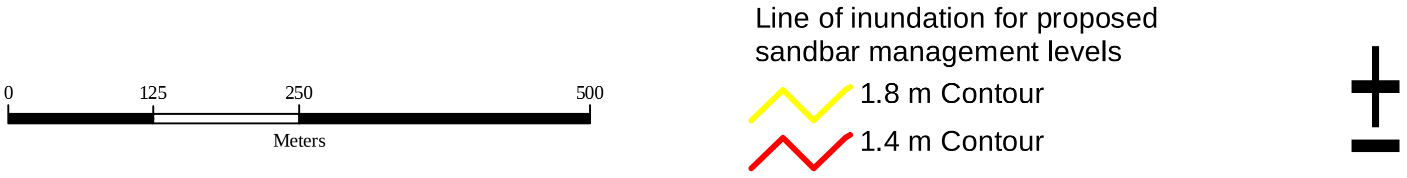


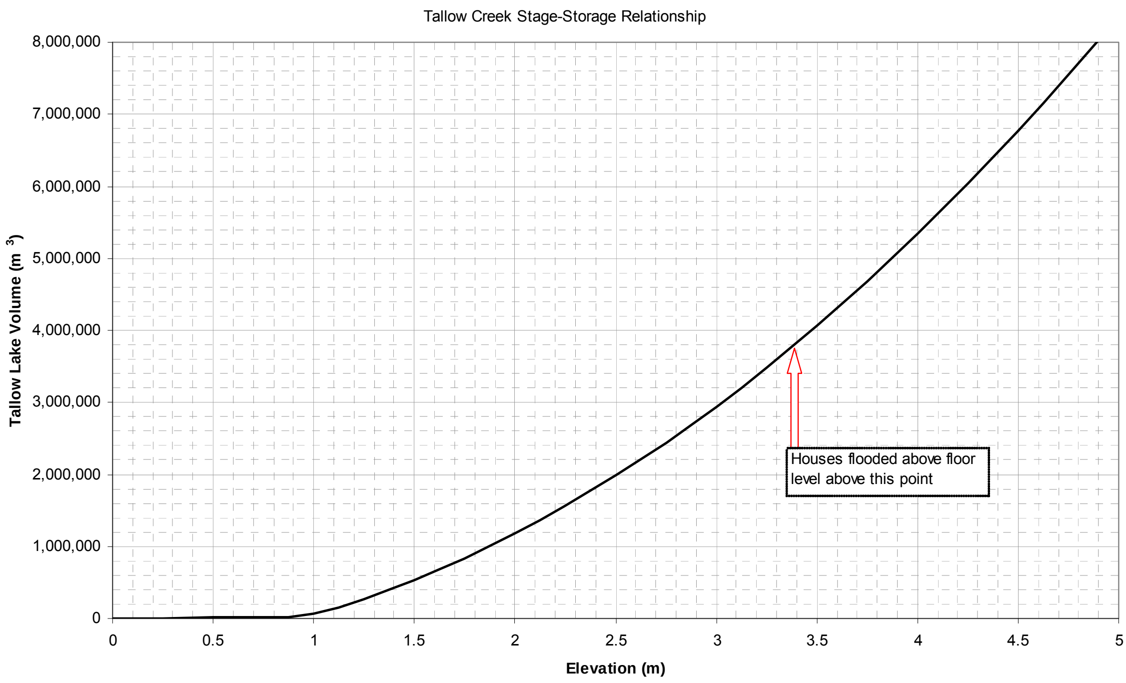
Figure 5-7: Tallow Creek Flood Risk Management Study - Sandbar Management



5.5.2. Hydrologic Analysis

The previous section of this report detailed the hydraulic effects of the Tallow Lake sand bar on water levels in the lake system. In addition to this, it is possible to assess the likelihood of encountering the rainfall conditions that will result in significant increases in lake level.

For this, it is necessary to understand the storage characteristics for Tallow Lake. The digital terrain model developed for the hydraulic analysis was used to derive a relationship between elevation and lake volume for Tallow Lake. This relationship is shown in Figure 5-8. As per Section 3.4, the lowest floor levels surveyed adjacent to Tallow Lake have an elevation of approximately 3.4mAHD, which corresponds to a lake volume of 3,800,000m^3.



▪ **Figure 5-8 Stage-Storage Relationship for Tallow Lake**

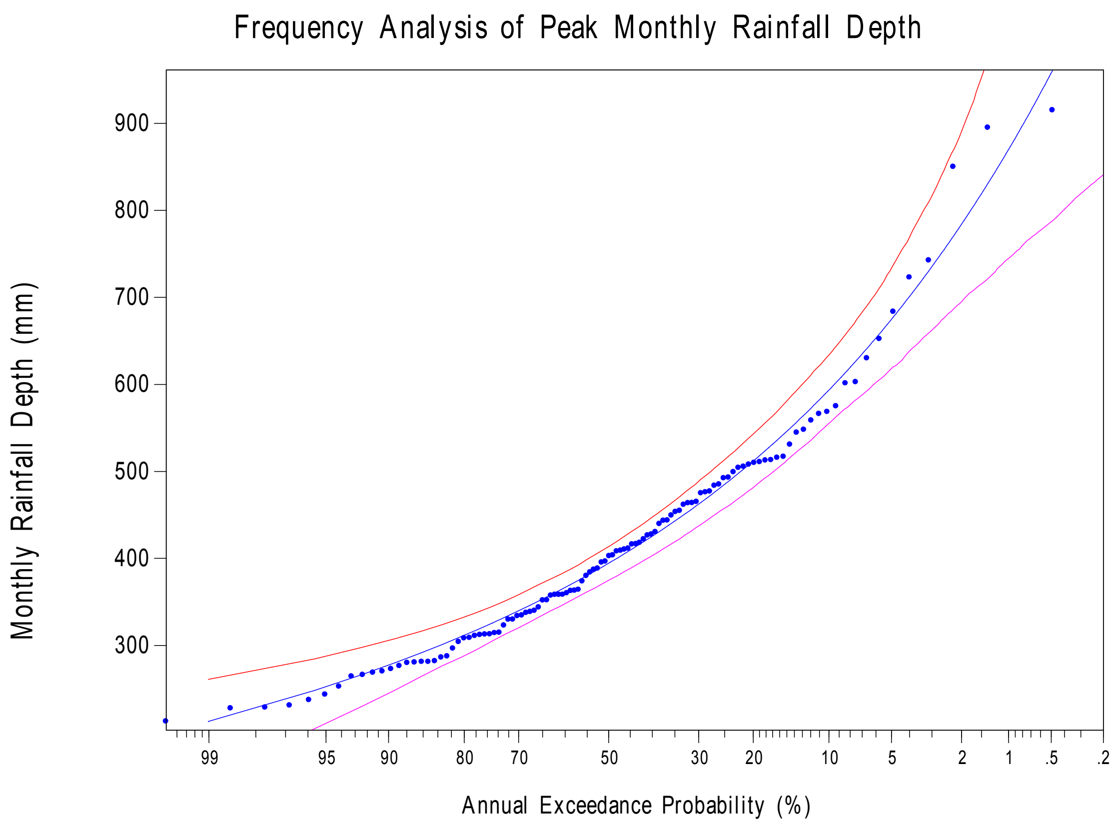
Further to this, it is possible to determine the depth of rainfall necessary to occur within the Tallow Creek catchment to generate volume increases in the lake. The catchment area for Tallow Creek is approximately 450ha, hence 1mm of rainfall on this catchment area produces 4,500m^3 of rainfall volume.

Using this information, it is possible to determine the rainfall depth that would be necessary to produce sufficient rainfall volume to flood properties adjacent to Tallow Lake. This assessment assumes that no runoff is released to the ocean, which replicates the conditions where the Tallow Lake is blocked above 3.4mAHD. At the time of writing, lake levels were at 1.8mAHD. To raise Tallow Lake from 1.8mAHD to 3.4mAHD requires a volume of 2,900,000m^3, which corresponds to a rainfall depth across the catchment of 640mm.

Long term daily rainfall information is available for Byron Bay at the Bureau of Meteorology gauge (058007). It was possible to conduct a frequency analysis on rainfall at Byron Bay to establish the likelihood the rainfall depth required to generate runoff volumes as discussed above. For such an analysis, it is longer duration periods of wet weather, such as a monthly basis, rather than single storm events that are likely to produce flooding from elevated lake levels.

The results of a monthly frequency analysis of peak monthly rainfall depths is shown in Figure 5-9. Note that annual exceedance probability (AEP) is the inverse of average return interval (ARI) (ie 2% AEP = 1/0.02 = 50 year ARI). From this, the rainfall depth required to increase lake levels from 1.8mAHD to 3.4mAHD of 640mm in a month has an average return interval of between a 1 in 5 year and 1 in 10 year ARI event.

A rainfall occurrence of 640mm could also occur over a period of 2 – 3 days which is an event rarer than 1 in 100 years, however demonstrates the need to proactively manage the flood risk.



▪ **Figure 5-9 Peak monthly rainfall depths, frequency analysis**

This result of 1 in 10 year ARI monthly rainfall resulting in flooding to properties adjacent to Tallow Lake was developed with a number of assumptions. It is assumed in this analysis that the full rainfall depth is converted to runoff. While losses do occur from rainfall events, these losses are very low during periods of high rainfall such as would be necessary to produce these conditions.

5.5.3. Environmental Impacts of Sandbar Management

The existing environment in Tallow Lake has adapted to the natural hydrological cycles of the system over many years. This has included extended periods when the water levels remain elevated and relatively constant due to the entrance being bar-bound. Intermittent periods of more variable water levels and flushing of the lake would have also naturally occurred following breaching of the lake entrance and regular rainfall.

It could be argued that development in the catchment in recent times has changed the natural hydrology of the lake, and that this could warrant some improvement of the lake outlet conditions. The environmental impacts of such development are likely to be small however, as the relatively large storage volume of the lake would mean that changes in water levels due to increased run-off would be minimal.

Any strategy that involves manipulation of the outlet conditions of the lake would therefore need to carefully consider the impacts on the lake hydrological cycles, and hence on the environment. The environmental impacts of more frequent periods of variable water levels and flushing of the lake resulting from periodic artificial opening of the lake entrance would need to be assessed. Further to this, as part of the development of a long term policy from this accepted interim policy it will be necessary to further determine the potential impact of this coastal manipulation on the areas of management under the NSW Marine Parks Authority and the NSW National Parks and Wildlife Service. Factors to be considered in the development of a long term strategy include investigation into the potential impact to threatened species and endangered ecological communities listed under the Threatened Species Conservation Act.

The inaccessible nature of the lake entrance and the potential local environmental and aesthetic impacts of excavating the mouth are also important issues.

It would be necessary for heavy earthmoving equipment to access the site. There is no existing road or vehicular access track to the site, meaning that access would probably be via the beach front. The environmental impacts of providing such access would need to be carefully considered and managed. The physical process of excavating the waterway and placing sand adjacent to the mouth will also have environmental and aesthetic impacts.

An important part of any Sand Bar Management Plan would be the development and implementation of an appropriate Environmental Management Plan that covers the above issues. On-going environmental monitoring of the lake environment may be required. The NSW Healthy Rivers Commission report *Coastal Lakes – Independent Inquiry into Coastal Lakes (2002)* and Philip Haine's report on *Coastal Lakes Management Strategies for a Sustainable Future (2006)* provides recommendations to minimise the intervention on the opening regime of coastal lakes. It is recommended that the development of a long term sand bar management strategy for Tallow Lake adopts the management principals detailed from this inquiry. The long term strategy should maintain the accepted interim strategy specifications whereby forced breaching of the lake does not occur, rather that levels at the mouth be maintained so that a natural mouth breaching process will occur prior to detrimental flooding impacts being experienced for properties adjacent to Tallow Lake and upstream Tallow Creek to Broken Head Road.

5.5.4. Cultural Heritage

Any excavation works in the mouth of the lake could expose aboriginal artefacts or impact on other cultural heritage values. A full assessment of potential impacts would need to be undertaken in consultation with traditional owners. An Environmental Management Plan would also need to include the required actions should artefacts be found.

5.5.5. Statutory Approvals

Approvals required for excavation of the lake entrance would include, but not be limited to:

- Rivers and Foreshores Improvement Act, Part 3a Permit (DWE);
- *NSW Fisheries Management Act 1994* (approval required under this legislation); and
- National Parks and Wildlife Act (Heritage Assessment and Threatened Species Assessment).
- Marine Parks Regulation 1999
- Arakwal Indigenous Land Use Agreement

Council would need to prepare a Review of Environmental Factors, which would be submitted as supporting documentation when applying for approvals under the above legislation. Any of the Determining Authorities could require a more extensive Environmental Impact Study to be completed, should they deem the REF is insufficient. Under the Marine Parks Regulation, a permit would be required from the Marine Parks Authority to excavate the lake entrance.

As Tallow Creek mouth is in Arakwal National Park and Cape Byron Marine Park, the Arakwal Indigenous Land Use Agreement and the Byron Bay Arakwal People need to be consulted.

5.5.6. On-going Costs

In addition to the costs associated with the planning and approvals processes outlined above, there would be on-going costs to Council for on-going monitoring of the sand bar condition, environmental monitoring of the lake (possibly), plant and equipment costs and site rehabilitation costs associated with management of the spoil excavated. Depending on the frequency of excavation, these costs could be of the order of $5000 per year.

5.6. Impacts of Future Development

Hydrologic investigations for the Tallow Creek catchment used for this investigation have adopted the existing conditions level of development within the catchment. The existing land-use zoning allows for additional development within the Tallow Creek catchment on top of current conditions, potentially increasing the magnitude of flood flows generated from the catchment. To assess the likely magnitude and impact of this, additional hydrologic assessment was undertaken to quantify the potential change in flood flows.

5.6.1. Approach

The investigation utilised the existing RAFTS hydrologic model of the Tallow Creek catchment. The model was initially developed by Water Studies (2002) for the Tallow Creek Flood Study, and was subsequently modified as part of the Tallow Creek Floodplain Risk Management Study. The Water Studies model (2002) was adopted to represent existing conditions, with a future conditions model developed by modification of the catchment impervious areas.

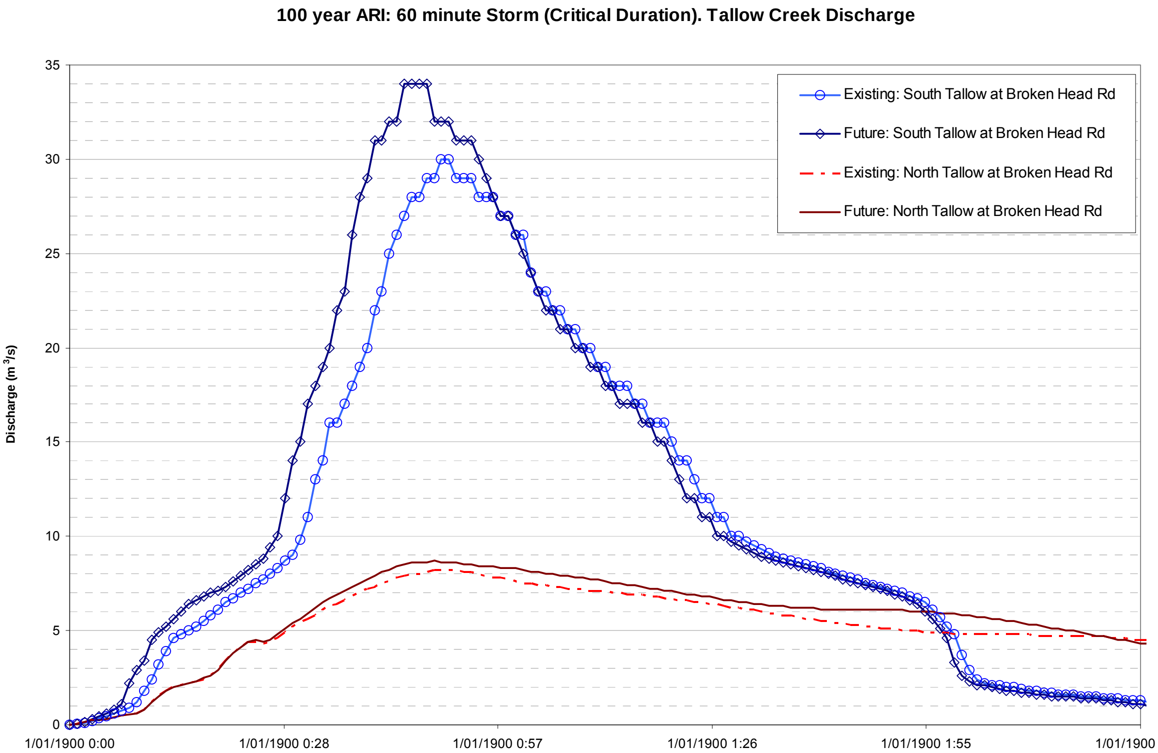
5.6.2. Establishment of Potential Future Conditions

The future conditions were determined by overlaying the land-use zone mapping over aerial photography of the catchment; allowing for the identification of the areas currently undeveloped but zoned to allow for future development. The RAFTS model for the future scenario was then modified to reflect the increased impervious areas of each subcatchment, reflective of increased catchment development. The existing conditions and future developed conditions catchment attributes are given in Appendix C of this report.

Approximately 25% of the existing Tallow Creek catchment is impervious. When fully developed as per the land use zoning, this percentage of impervious land within the catchment increases to 37% of the total catchment.

5.6.3. Results of Full Development Scenario

The RAFTS model for both the existing and developed conditions were run for a range of storm durations to establish the critical duration storm, both for fully developed and existing conditions. The 60 minute storm was found to be critical at the two key locations taken for output, that is South Tallow Crossing of Broken Head Road and the North Tallow Crossing of Broken Head Road. The existing and developed hydrographs for the 1 in 100 year ARI critical storm duration are shown in Figure 5-10. The corresponding peak discharges were extracted and are presented in Table 5-4.



- **Figure 5-10 Existing and Future Developed Hydrographs from RAFTS modelling**

- **Table 5-4 Peak Discharges for Existing and Developed Conditions, 1 in 100 year ARI Storm Peak Discharges**

	90 minute duration (m^3/s)	60 minute duration (m^3/s) *(Critical)*	45 minute duration (m^3/s)
South Tallow at Broken Head Road			
Existing	29	***30***	26
Developed	32	***34***	30
% Increase	10%	***13%***	15%
North Tallow at Broken Head Road			
Existing	9.3	***8.2***	7.2
Developed	9.9	***8.7***	7.8
% Increase	6%	***6%***	8%

5.6.4. Discussion

The largest increase in peak discharge resulting from full development of the catchment is observed at the Broken Head Road crossing of South Tallow Creek. At this location the peak discharge increases 13% during the critical duration 1 in 100 year ARI storm, from $30m^3/s$ to $34m^3/s$. This increase in peak discharge was assessed using the existing HEC-RAS model of the lower Tallow Creek, with the additional 13% flow resulting in an increase in water level of less than 10mm at Broken Head Road. This effect can be considered as a conservative estimate, as it does not include an allowance for on-site detention as required in the Byron Development Control Plan, Part N Section 5.1. This increase in peak flood level for the 1 in 100 year ARI flood event indicates that catchment flooding is not greatly susceptible to increased flooding resulting from future development for large flood events. This is the case for large flood events, such as the 1 in 100 year ARI flood event. More frequent, smaller flood events will be impacted by future unrestricted catchment development, with the existing drainage network surcharging more frequently than under existing conditions. As a result, on-site detention is required at a lot scale to restrict developed condition discharges to pre-development levels.

6. Principal Flood Risks in the Tallow Creek Catchment and Potential Mitigation Options

6.1. Flood Risks

The principal flood risks in the Tallow Creek catchment are summarised in the following sections:

6.1.1. Flood Characteristics

- Flooding is generally limited to undeveloped natural waterways. Some localised flooding of upper catchment areas occurs around Coogera Court, Beech Drive and Pepperbush Street, mainly as a result of inadequate stormwater systems. This flooding is shallow, and does not cause house flooding above floor level. Similarly, localised flooding of properties in Hazelwood Close, Suffolk Park has been observed resulting from backwater effects from the Broken Head Road wetland.
- The catchment can be segmented into two parts with specific hydraulic characteristics. Flooding in the area upstream of Broken Head Road is typically a result of stormwater runoff exceeding drainage system capacity. Flooding in this area is unaffected by outlet conditions at the mouth of Tallow Creek. Downstream of Broken Head Road flooding is more strongly influenced by the condition of the opening of the Creek mouth. Flooding is characterised by inundation from Tallow Creek itself, and from the associated wetland areas.
- Broken Head Road, the primary access and egress for the area and a secondary access to Byron Bay, has a very low flood immunity at the crossing of South Tallow Creek. Overtopping of the road by South Tallow Creek flood flows is estimated to occur in flood events with return period approximately 1 in 5 years ARI and greater. This flooding is the result insufficiently sized culverts under Broken Head Road. Given the reliance on this road for evacuation and emergency services access during a flood event, a higher flood immunity for Broken Road is recommended, through increased under-road drainage capacity.
- The detention basin near Coogera Court has a design standard of about 1 in 5 year ARI, and has no formal overflow provision. Localised low-level flooding occurs around and downstream of Coogera Court as a consequence of these overflows in events larger than 1 in 5 year ARI.
- The small catchment size limits the potential for flood warning systems to significantly mitigate flood risks.

6.1.2. Flood Damages

- Generally the damages caused by flooding in the catchment are minor. Modelling indicates that 13 houses would be flooded above floor under the 1 in 100 year ARI event (based on the floor level survey), and 18 dwellings would be flooded above floor under the 1 in 500 year ARI event. The Average Annual Damage for all flood events up to and including the PMF event is approximately $30,000.

6.1.3. Human Life Risk

- Flood hazard assessment indicates that high hazard areas (velocity depth product > $0.6m^2/s$ or depth > 1.0m) for the 1 in 100 year ARI storm are limited to the main creek waterway, and to detention basins/lakes. This suggests that the risks to human life caused by flooding is relatively low. Current land use zoning does not incorporate this flood hazard risk.
- Assessment of the social profile of the catchment indicates that development is largely low risk urban type. There is some commercial development around Broken Head Road/Beach Road/Clifford Road, and a nursing home is located on Broken Head Road just north of the Clifford Road intersection. Flooding in the Tallow Creek catchment does not present a significant direct risk to human life.

6.1.4. Climate Change

The science of climate change and the potential impacts of this on flooding behaviour was a rapidly evolving area at the time of this study. The progression of climate change considerations is detailed in Section 5.2 of this report. In this Section it was identified that climate change is predicted to result in adverse impacts to the Tallow Creek catchment by increasing the magnitude of the design floods such that additional existing properties are subject to inundation.

6.2. Potential Flood Management Options

The main risk management strategy applicable to the Tallow Creek catchment is the implementation of effective planning controls to limit the impacts of future development in the catchment. This approach is considered key to responding to the climate change considerations. Upgrading of the overflow capacity of the Coogera Court detention basin would also be necessary.

At present Byron Shire Council's planning provisions in relation to flooding are embodied in the *Byron Local Environment Plan 1988 (LEP)*. There is opportunity to modify these provisions to better address flooding risks in the catchment.

Table 6-1 provides an overview of the more common management measures available to mitigate flood risks.

- **Table 6-1 Floodplain Management Measures**

Measure	Issues/Options
Measures which Modify Flood Behaviour	
Flood Mitigation Dams	Capture of water upstream of development areas similar to detention basins.
Levees	Levied areas should not be treated as completely flood free - unless designed to withstand the PMF. Environmental and social impacts need to be properly accounted for.
Bypass Floodways	are floodways designed to pass flood flows through an area to avoid developed areas and/or provide additional flood conveyance capacity. Environmental impact and the downstream implications of the floodway need to be accounted for.
Channel Improvements	increase the capacity of the watercourse to discharge flood flows by opening up the waterway area and the clearing of obstructions to flow. Can accentuate downstream flooding, can incur recurrent maintenance costs and significant environmental impact.
Detention Basins	provide temporary flood storage to offset the effects of increased runoff, similar to flood mitigation dam.
Floodgates	The strategic use of floodgates to control flows along particular flood paths can have beneficial effects depending on what flood conditions are being faced and by whom.
Land Management	Modification or management of land influences runoff from that land and the hydraulic behaviour of floods which pass over it. Catchment management in upstream areas can mitigate the effects of floods, and management of riparian and floodplain vegetation and land use can influence flood levels and downstream impacts.
Property Modification Measures	
Land Use Zoning	incorporated into Local Environmental Plan (LEP) or Development Control Plan (DCP). Need to be based on flood hazard. Best measure available to deal with cumulative impact of potential inappropriate development. Does not deal effectively with existing development.
Voluntary Purchase	where flood mitigation is impractical and existing people and property (including those sent for rescue) are exposed to unacceptable risks.
House Raising	is generally suitable only for low hazard areas of the floodplain and suitable structures.
Development on fill	will need to consider the effect on flood behaviour, risk of overtopping design level and isolation during floods.
Flood proofing of buildings	is the design and construction with appropriate water resistant materials to minimise flood damages. Only as an adjunct to other measures - social and economic costs remain. May impact on flood behaviour.

Measure	Issues/Options
Flood access	Consideration needs to be given to provision of access under flood conditions, including by road, boat and air. Access to critical facilities such as water, sewerage and hospitals.
Building and Development Control	control new development through local planning instruments in consultation with relevant authorities. General elements may include: ▪ access to site during floods ▪ fill or excavation in the floodplain ▪ freeboard ▪ flood works ▪ minimum floor levels ▪ building materials ▪ services ▪ impact on flood behaviour ▪ flood awareness - emergency plans
Response Modification Measures	
Flood awareness	Awareness of flooding and its consequences cannot be assumed. Requires ongoing public education and inculcation.
Section 149 Certificates	Information to property owners and occupiers on flood information and policies affecting the property. Could be issued to owners/occupiers on a regular basis.
Flood preparedness	The ability of flood affected people to defend their communities from flood threat by preparatory measures such as moving goods and possessions to higher ground. Some public education desirable.
Flood warning	Dependent on sufficient lead time for early warning to allow for controlled evacuation response.
Flood Plans	The SES develops detailed flood plans which can be integrated with the broader findings of the Floodplain Management Plan.
Recovery Planning	Besides general clean up activities and assistance following the flood peak, flood-related data and experience should be compiled to better deal with future flood planning and management.

The management options most appropriate for the Tallow Creek catchment are discussed below.

Land use zoning: Land use zoning is a means of preserving important waterways or flood overflow paths. In the Tallow Creek catchment, where the pressures of urbanisation have the potential to impinge on the main waterway areas, preservation of the main Creek waterway via appropriate zoning appears warranted.

A copy of the current Zoning Map for the Tallow Creek Catchment is shown in Figure 3-4.

Development on fill: In-filling flood prone areas to elevate development levels above designated Flood Planning Levels (FPL's) is a common practice, however the impacts of this on the flooding behaviour of the floodplain must be considered, as loss of floodplain storage by in-filling can increase flood levels elsewhere. There are a number of areas along the Tallow Creek waterway and near-floodplain that are currently zoned Residential which are flood prone.

Building and development control: Building and development controls commonly include:

- Designation of Flood Planning Levels, which defines the minimum level to which floor levels can be constructed. This should be made with consideration for climate change impacts.
- The requirement for proponents to demonstrate that developments will not adversely affect other land in the vicinity.

Civil upgrade works: Constraints in the stormwater system design can result in localised flooding. Civil upgrade works to the stormwater system may elevate flooding in some areas.

Sandbar management: Sandbar management commonly includes:

- Development of an Environmental Strategy for long term management of the sandbar for the purposes of water quality and flood mitigation.
- Monitoring of the level of the lake and sandbar.
- Maintenance earthworks to maintain the sand bar level such that a storm event will breach the mouth prior to flooding impacts.

Flood Warning: The Tallow Creek catchment is relatively small and steep, meaning the dominant flooding mechanism for the catchment is flash flooding from short duration rainfall events. As a result of the short available warning time there is insufficient time for controlled evacuation response, hence a flood warning system has not been recommended. However, installation of a flood gauge along Broken Head Road near the BP service station is recommended to increase public awareness of the flooding potential in the catchment as well as to assist SES operations during a flood event response.

7. Proposed Flood Risk Mitigation Strategy

The proposed Tallow Creek Floodplain Risk Management Strategy incorporates the findings of existing and future conditions catchment investigations. The proposed risk mitigation strategy has been developed to address existing areas identified as having unacceptable levels of flood risk, as well as to address potential causes of exacerbated flooding in the future.

The proposed mitigation strategy adopts the aspects of the following areas:

- Planning Controls;
- Stormwater system upgrades
- Ecological Impacts; and
- Sandbar management.

These are discussed in detail in the following sections. For existing conditions, the level of flood damages in the Tallow Creek catchment is low, precluding large scale structural flood mitigation options on an economic basis. As a result, the proposed strategy predominantly adopts future planning controls to ensure future development is controlled, preventing any worsening of the flood risk in the catchment.

7.1. Planning Controls

- Planning control changes are proposed to ensure that future development in the catchment is constrained so that it does not increase the impacts of flooding. Section 3.6 of this report details the existing planning controls imposed on the Tallow Creek catchment. The following sections detail the proposed amendments to the planning controls to secure the catchment from future worsening of flooding impacts through inappropriate development. These amendments are proposed to the existing planning controls.

7.1.1. Local Environment Plan

Amendments are proposed to the Byron Local Environment Plan 1988 (LEP) to more robustly protect existing development from increased flooding impacts resulting from future development. These proposed changes fit within the existing framework, utilising planning controls currently under-utilised in the Tallow Creek catchment.

High Hazard Flood Liable Land

Clause 24 of the LEP relates to development on flood liable land. The LEP defines “flood liable land” as either land identified as flood liable within a flood management plan, or land inundated by the 1 in 100 year ARI flood event. It should be noted that the NSW

Floodplain Development Manual (2005) defines flood liable land as land susceptible to flooding by the probable maximum flood (PMF).

The Byron LEP established a High Hazard Flood Liable Zone (5b. High Hazard Flood Liable Zone). This zone has not previously been defined within the Tallow Creek catchment, as the inputs required to define high hazard flood liable areas were not available. These areas have been determined from the results of the hydraulic modelling, and it is proposed that the existing land zoning of the LEP be amended to utilise the High Hazard Flood Liable Zone.

Both the Low and High Hazard flood zones have been determined from the hydraulic modelling, and these are discussed in the report in Section 5.4, and illustrated in Figure 5-4. The flood hazard zones are shown overlaying the existing land use zoning of the LEP. High flood hazard occurs as a result of predicted high velocity flood water, predicted deep flood water, or a combination of the two. The existing land zoning of the LEP includes areas in both South and Middle Tallow Creeks currently zoned as residential (2a) that lie within an area of high flood hazard. In South Tallow Creek this is generally restricted to the Tallow Creek channel between Broken Head Road and Tallow Lake where high flood depths and velocities are predicted. In Middle Tallow Creek, the high hazard areas occur at the existing flood detention basin and man-made lake at Baywood Chase, as well as along the flood drainage corridors.

It is recommended that Council commence undertakings to rezone the land identified as high flood hazard for the 1 in 100 year ARI flood event to preclude these areas from future development as illustrated on Figure 5.4.

7.1.2. Development Control Plan

Establish Flood Planning Levels

Flood planning levels (FPLs) are used to determine the extent of land that is subject to flood related development controls. Flood planning levels are defined in the Byron Development Control Plan 2002 (DCP 2002) as the 1 in 100 year ARI flood level plus 500mm. Flood planning levels provide the primary planning basis for managing the potential impacts of climate change. It is recommended that the adopted flood planning levels for the Tallow Creek catchment utilise the Scenario 4 climate change case (refer to Section 5.2.3).

The results of the hydraulic modelling have been used to establish the new FPL for Tallow Creek.

It is proposed that the FPL shown in Figure 7-1 be adopted as part of the DCP 2002 as the extent of flood prone land in the Tallow Creek catchment. By the LEP, any proposed development within the defined flood liable land will require the assessment of Council. A larger reproduction of this figure, including 0.25m level contours, is contained in Appendix G of this report.

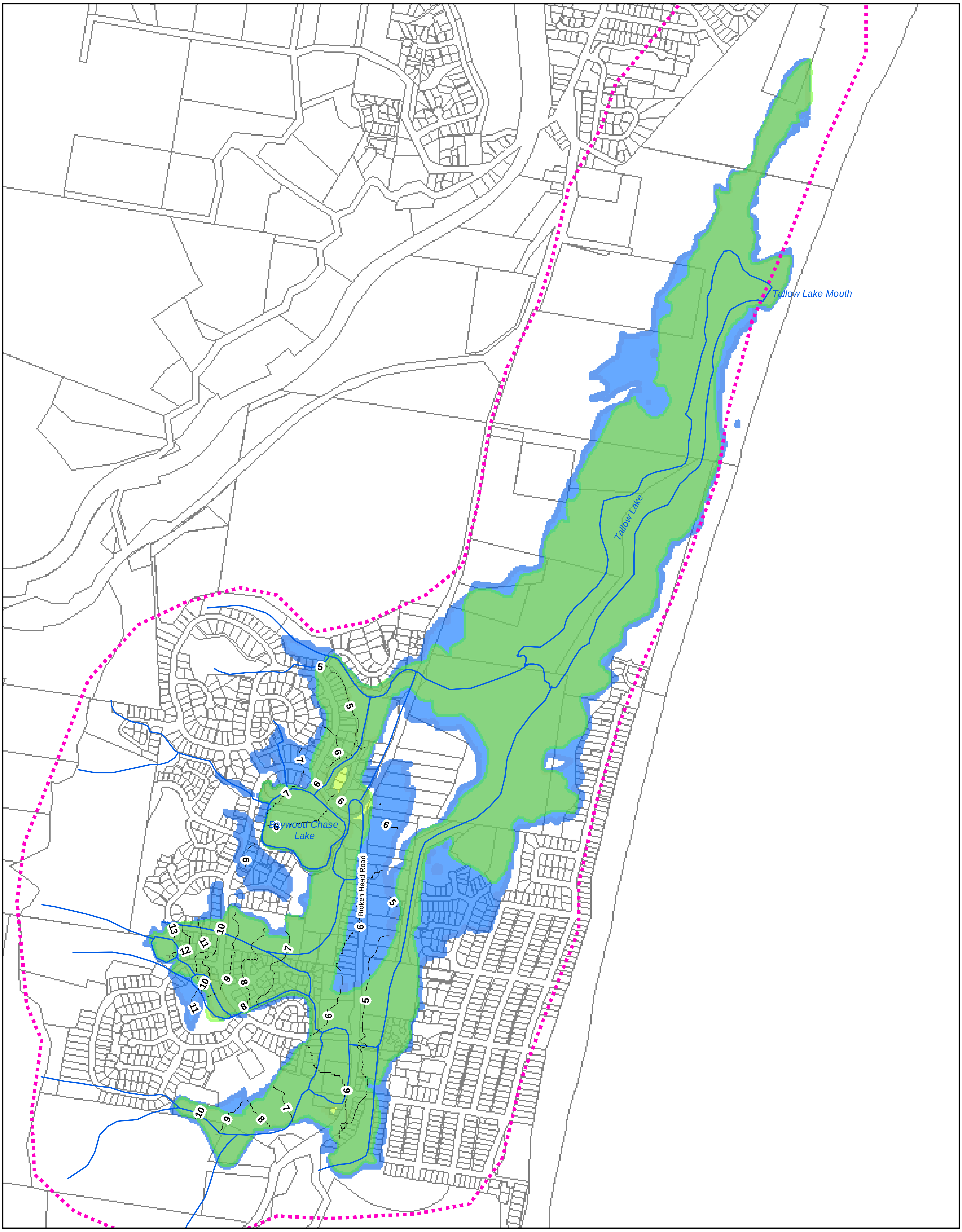


Figure 7-1: Tallow Creek Flood Risk Management Study - Flood Planning Levels

Filename: FPL+500mm Date: Sep 2008

Legend

- Catchment Boundary
- Cadastral Boundaries
- Flood Planning Level (FPL)
- Flood Planning Level with Climate Change (FPL)
- Water Surface Level Contour (m AHD)
- Streams

0 125 250 500 750 1,000 Meters

Byron Shire Council

Limit Floodplain Filling

Under both the existing and proposed amended planning controls, filling of land within the FPL is allowable for a development at the discretion of Council in the areas other than the no fill zones, provided that the filling will not adversely affect other land in the vicinity. Council will also need to consider the cumulative impact of filling at this time. It is recommended that any proposed filling within the floodplain be assessed for potential impact on flood levels including the cumulative impact of filling. The hydraulic flood analysis conducted for this investigation has additionally identified areas within the FPL where floodplain filling specifically should not occur. This is because existing development has heavily constrained flood drainage and storage and future additional filling will impact on flood levels. The Tallow Creek catchment has been broken into five regions for the purpose of outlining the filling constraints. These regions are shown in Figure 7-2 and discussed in the following sections.

South Tallow Creek Between Broken Head Road and Tallow Lake

A floodplain filling exclusion zone is proposed on South Tallow creek between Broken Head Road and Tallow Lake. This land is currently primarily zoned Residential 2a, under private ownership. Currently, DCP No. 9 – Suffolk Park requires a 10m wide reserve measured from the centre of Tallow Creek for recreation purposes, with an additional 5m exclusion zone defined for all buildings as part of a development application. These zones have been identified primarily for recreational purposes. Existing development has heavily constrained this reach of South Tallow Creek.

An encroachment assessment for this reach identified that an 80m wide waterway corridor, measured 40m either side of the centreline of Tallow Creek is required to be free from floodplain filling to maintain the stream flood conveyance. Filling within this proposed waterway corridor will result in an increase in flood levels. The extent of the 80m wide waterway corridor is shown in Figure 7-3.

Land outside of the proposed waterway corridor within the FPL between Broken Head Road and Tallow Lake could potentially be filled, however this is dependent on the adopted land form. An assessment based on specific proposed terrain configurations should be undertaken to demonstrate no adverse cumulative impacts. It is, further, imperative that filling within the FPL does not result in impediment to flood events larger than the 1 in 100 year ARI flood event. The 1 in 500 year ARI flood inundation extent (refer Appendix B) indicates that significant overtopping occurs at Broken Head Road north of the existing petrol station. To ensure that filling does not impede larger flood events, it is proposed that the DCP for Suffolk Park be amended to limit floodplain filling in the area.

South of Clifford Street

This area does not require mandated restrictions on filling within the FPL. Assessment of any proposed filling to be considered based on impact assessment.

South Tallow Creek, West of Broken Head Road

The existing land zoning in this area precludes fill in important areas already. For the areas where filling is allowable by the existing land use zoning, no mandated filling exclusion zone applies. Assessment of any proposed filling to be considered based on impact assessment.

Central Tallow, West of Broken Head Road

Filling is to be completely excluded from within the FPL within the Central Tallow area, West of Broken Head Road and East of Coogera Circuit. The drainage corridor in this area is currently poorly defined within the existing planning controls and additional filling would worsen current flooding conditions. The extent of this exclusion zone is shown in Figure 7-4.

Tallow Lake

Filling within the FPL should be prevented within the Tallow Lake area. This represents only a limited amendment to the current planning control position, as there is limited area within the Tallow Lake FPL that is currently zoned to allow floodplain modification.

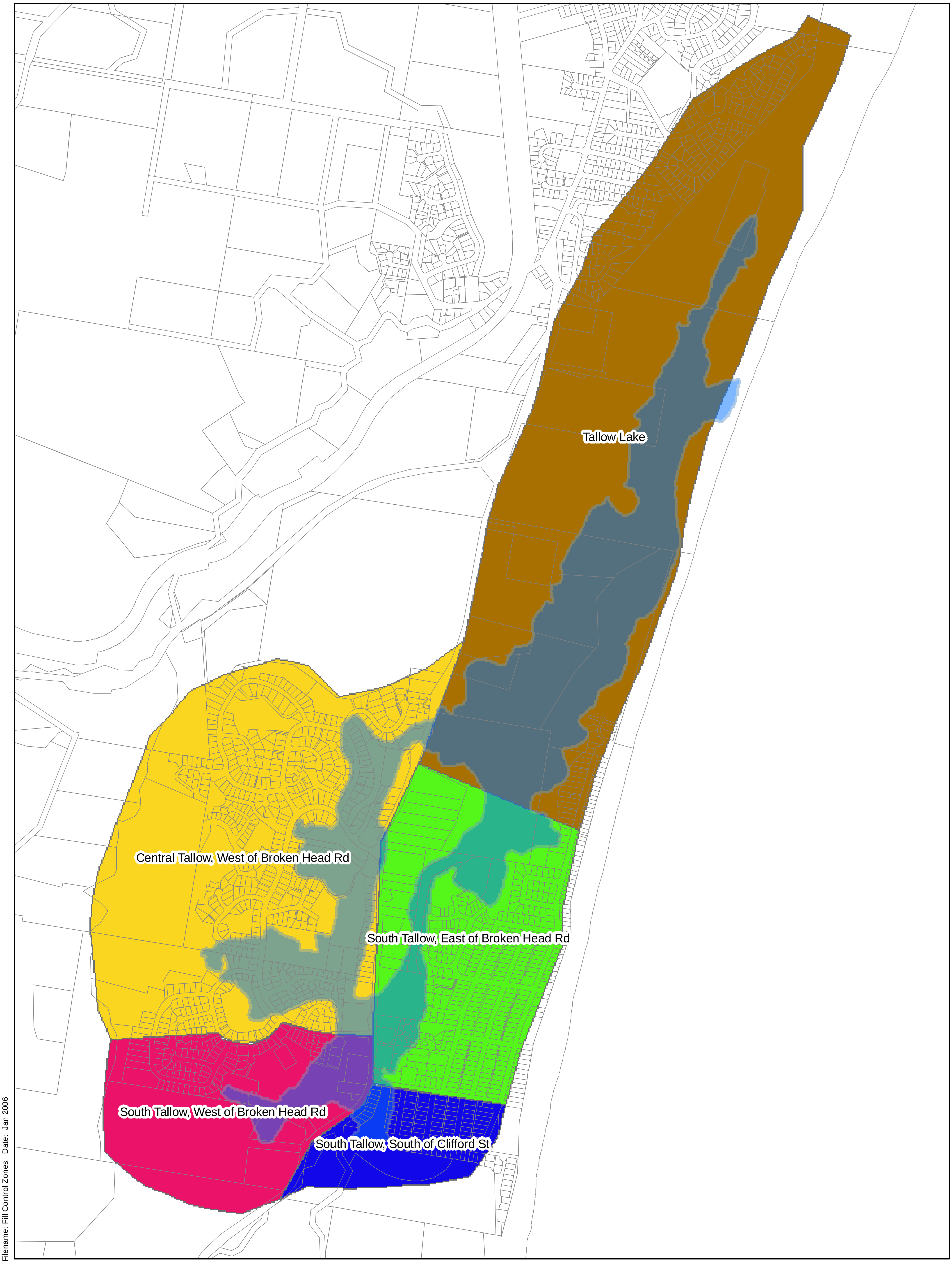


Figure 7-2: Tallow Creek Flood Risk Management Strategy - Regions of Tallow Creek subject to filling controls within the FPL

Legend

Flood Planning Level (FPL)

0 125 250 500 750 1,000 Meters

Figure 7-3: Tallow Creek Flood Risk Management Study - Filling Exclusion Zone

Broken Head Road to Tallow Lake

Legend

Stream Centreline

Filling Exclusion Zone

Flood Planning Level (FPL)

0 25 50 100 150 200 Meters

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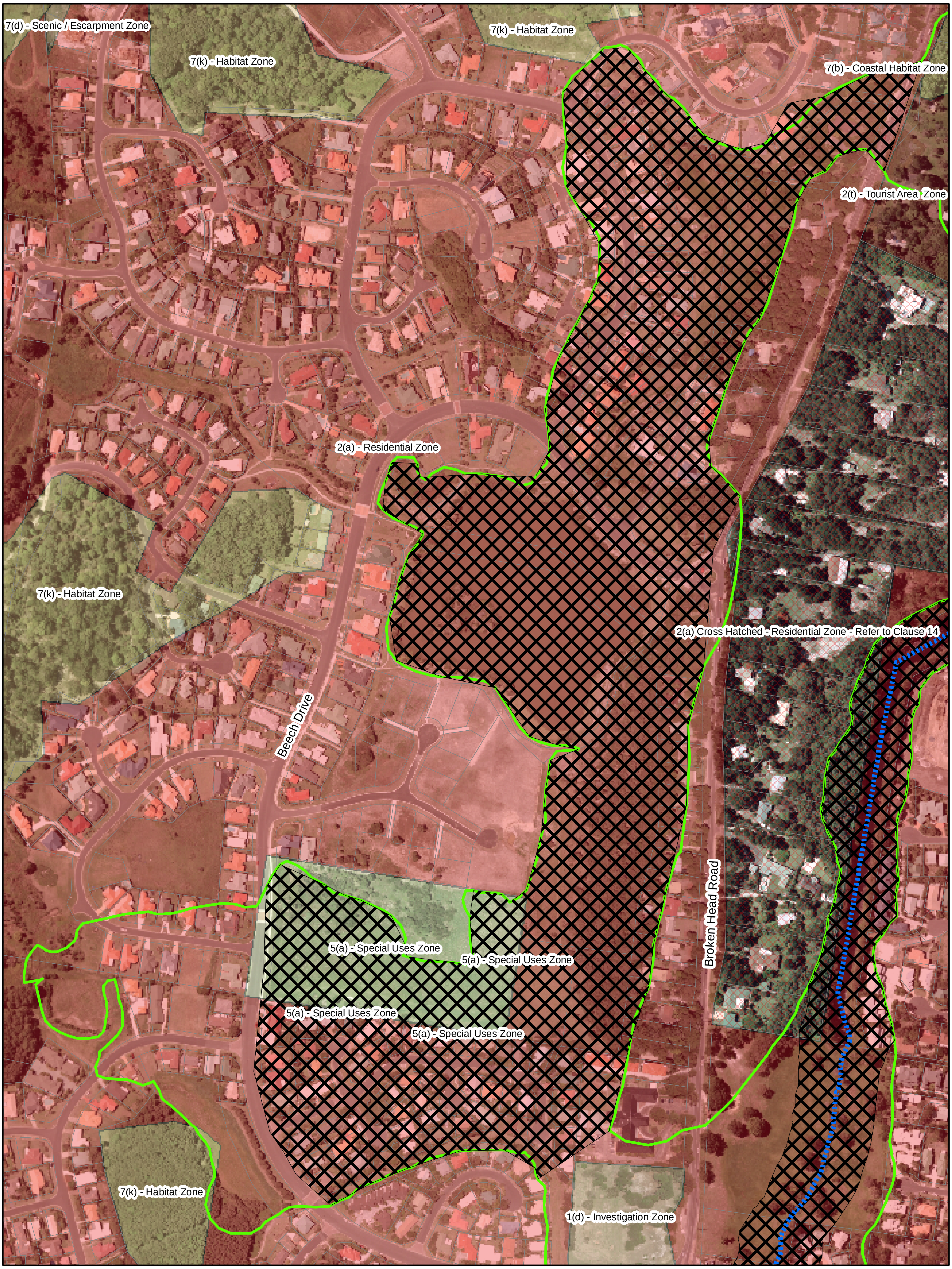


Figure 7-4: Tallow Creek Flood Risk Management Study - Filling Exclusion Zone

Central Tallow, West of Broken Head Road

Legend

- Stream Centreline
- Filling Exclusion Zone
- Flood Planning Level (FPL)

0 50 100 200 300 400 Meters

Byron Shire Council

7.1.3. Limit Developed Area Runoff Rates

The Tallow Creek catchment will be exposed to increases in peak runoff as a result of future development of currently undeveloped land. Increases in peak discharge result from development that increases the proportion of impervious areas within the catchment. As this increases the amount of rainfall that is converted to runoff and the travel time of the runoff is reduced, this has the potential to create large runoff events that occur faster. It is proposed that all future development in the Tallow Creek catchment be subject to the approval condition that peak discharges from developed sites be restricted to pre-development rates.

It was identified in Section 5.6 that while the flooded extent from large flood events (in the order of 1 in 100 year ARI) will not greatly increase from future catchment development, more frequent flood events (1 in 10 year ARI) will surcharge the existing drainage system more often with extensive future development resulting in increased occurrence of localised flooding. It is therefore necessary that future development maintain flood runoff for more frequent flood events (of return period between 1 in 2 year and 1 in 10 year ARI) at pre-development levels.

Peak discharge from a developed site can be restricted to pre-development rates by the following means:

- Runoff detention, and
- Maintaining the pervious/impervious area site ratio.

Indicative pre-development peak runoff rates have been established for the Tallow Creek catchment for a range of average catchment slopes. The formulation of these indicative rates is described in Appendix D.

7.2. Stormwater System Upgrades

An assessment of the existing stormwater infrastructure in the Tallow Creek catchment identified two sites where existing drainage infrastructure is exacerbating flooding impacts. These two sites were:

- Broken Head Road crossing of South Tallow Creek; and
- Coogera Circuit Detention Basin spillway relief.

Each of these sites is addressed in the following two sections.

7.2.1. Broken Head Road Crossing of South Tallow Creek

Broken Head Road is a key access and egress road for the study area, acting as the primary link to the South of Byron Bay. Flood modelling identified that the Broken Head Road crossing of Tallow Creek will be impassable in a flood event less than the 1 in 5 year ARI flood event. Given the importance of Broken Head Road for egress and emergency services access during a flood event, a higher flood immunity is recommended. To achieve this, increasing the capacity of the creek crossing of Broken Head road is required.

Existing Configuration

The existing Broken Head Road crossing consists of a series of culverts. On the upstream side of Broken Head Road is a small wetland which was in poor environmental condition at the time of this investigation, with flow passing over a weir prior to draining under Broken Head Road.

The existing culvert configuration utilises 2 x 1050mm diameter and 2 x 450mm diameter reinforced concrete pipe culverts. During a flood of larger than a 1 in 5 year ARI flood event the inflow to the Broken Head Road wetland exceeds the capacity of these culverts, with the excess inflow flooding Broken Head Road. The 1 in 5 year ARI flood depths are shown in Figure 7-5.

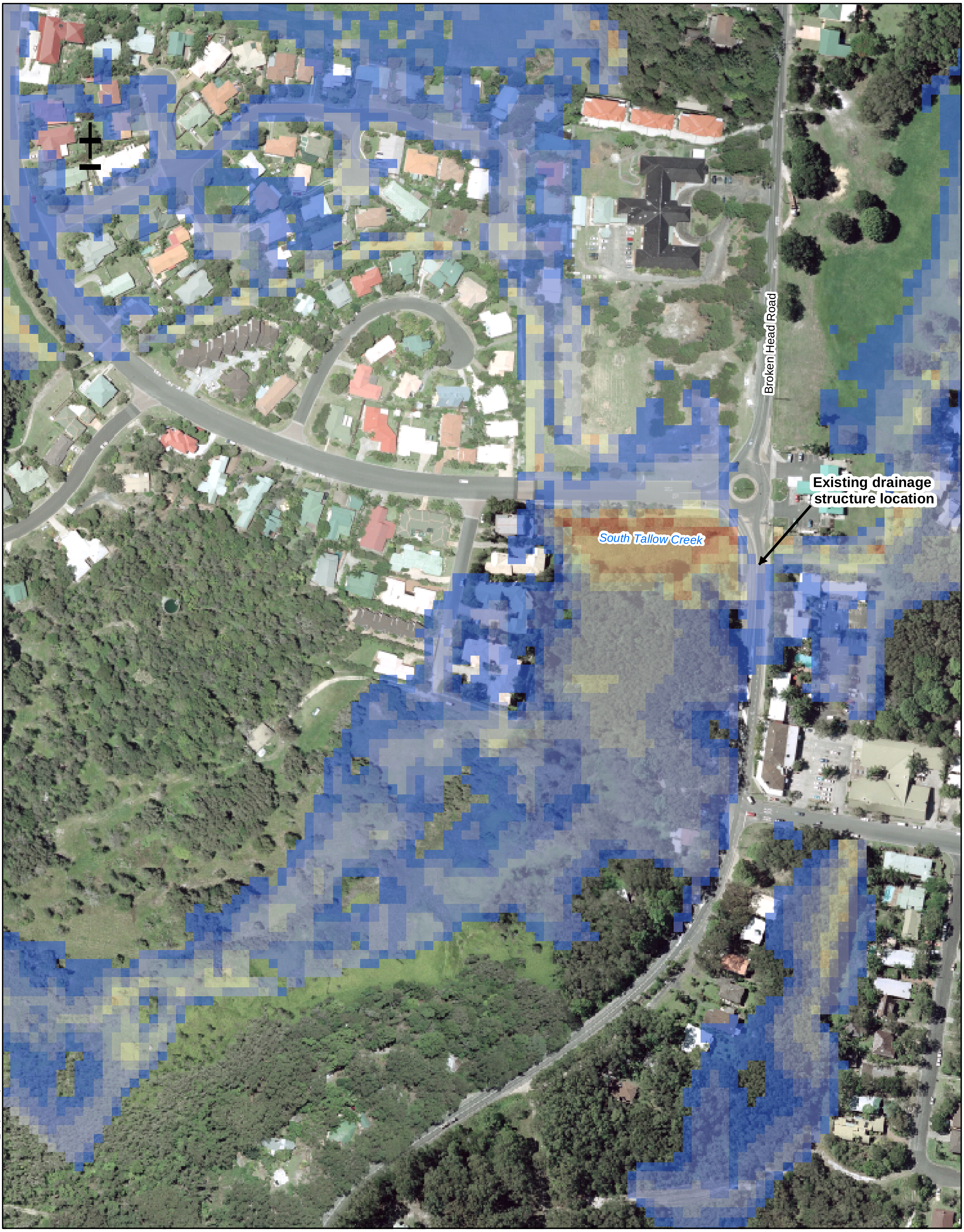


Figure 7-5: Tallow Creek Flood Risk Management Study - Hazelwood Close Flooding

Flood Depth (1 in 5 year ARI)

0.0 - 0.1	0.2 - 0.4	0.6 - 0.8	1.0 - 1.5	2.0 - 2.5
0.1 - 0.2	0.4 - 0.6	0.8 - 1.0	1.5 - 2	2.5 - 5

0 15 30 60 Meters

Byron Shire Council

Recommended Upgrade

It is recommended that the flood immunity of Broken Head Road be increased by the upgrading of the waterway area of Broken Head Road crossing. Preliminary calculations have been performed to establish the upgrade required to achieve flood immunity up to and including the 1 in 10 year ARI flood event.

A single span pre-cast concrete bridge has been investigated as the preferred spanning for the crossing, due to the increased hydraulic capacity relative to the existing culverts. A 4.5m span bridge is required to achieve a 1 in 10 year ARI flood immunity for Broken Head Road at South Tallow Creek. The replacement of the existing culverts with a 4.5m span bridge reduces the peak water level immediately upstream of Broken Head Road by 0.5m for the 1 in 10 year ARI flood event. It is through this dramatic reduction in peak water levels that 1 in 10 year ARI flood immunity is achieved for Broken Head Road. The 1 in 100 year ARI peak flood level immediately upstream of Broken Head Road is reduced by 270mm for the proposed upgraded conditions when compared to existing conditions with an increase in downstream levels of 10mm extending approximately 85m downstream of the bridge. No properties are adversely impacted by this water level increase.

Decreased peak water levels upstream of any hydraulic structure by increased hydraulic capacity can result in increased peak water levels downstream of the structure. Peak flood levels for the 1 in 10 year ARI flood event are increased by approximately 160mm immediately downstream of the bridge with this mitigating to 30mm within 20m of the bridge. These impacts in the 10 year ARI flood event mitigate to 0mm approximately 300mm downstream of Broken Head Road. For the 1 in 100 year ARI flood event a 90mm increase in flood levels is predicted immediately downstream of the bridge, with this impact mitigating to 10mm within approximately 25m of the bridge. This effect is considered to be negligible for this return period. Additional analysis should be conducted where the proposed upgrade is to be adopted to ensure compliance with all relevant Council impact requirements.

7.2.2. Coogera Circuit Detention Basin – Overflow provision

The existing detention basin situated to the South of Coogera Circuit was identified as an ineffective drainage element of the Tallow Creek catchment. The existing spillway is poorly configured, with the following deficiencies:

- The spillway has insufficient capacity given the basin catchment size;

- The bunding surrounding the detention basin is too low, with the basin frequently overtopping to the North-East.

As a result of the basin configuration, nuisance flooding has been recently reported for the properties to the North-East of the existing detention basin.

It should be noted that this basin is situated on private land. Development controls are in place such that development of the site requires approval of the basin details by Council.

To reduce the instances of nuisance flooding, an auxiliary flood overflow is proposed for the Coogera Circuit detention basin. Existing development greatly reduces the options for storm water relief structures from the detention basin. A combination of pipe and open channel drainage links are proposed to convey additional flood flows from the existing detention basin to link in with an existing flood flow path. The proposed alignment utilises a piped drainage link from the detention basin to Coogera Circuit, incorporating a pipe junction with a second pipe link constructed down Coogera Circuit. The proposed alignment converts to open channel flow across open land prior to joining into the existing flood flow path draining to the North. This configuration is shown in Figure 7-6.

The critical storm duration for the existing Coogera Circuit detention basin is 60 minutes. The 1 in 100 year ARI peak inflow to the detention basin is $12m^3/s$. The RAFTS model was used to determine the additional pipe drainage requirements for the existing detention basin to be able to convey the 1 in 100 year ARI flood event without overtopping. The flood overflow required a capacity of $3m^3/s$ to achieve the flood reduction objective, for a basin peak level of 12. 5mAHD. A single 1200mm diameter pipe culvert is required, with inverts as detailed in Figure 7-7.

Downstream of Beech Drive, the proposed flood overflow reverts from pipe flow to open channel flow. The average channel grade for the proposed alignment is relatively steep at 1.7%, and as a result only a small open channel is required to convey the flood overflow. A 6m top width 0.4m deep channel is proposed, with side slopes of 1V:4H.

Figure 7-6: Tallow Creek Flood Risk Management Study - Coogera Circuit Flood Overflow Alignment

0 50 100 200 300 400

Meters

Legend

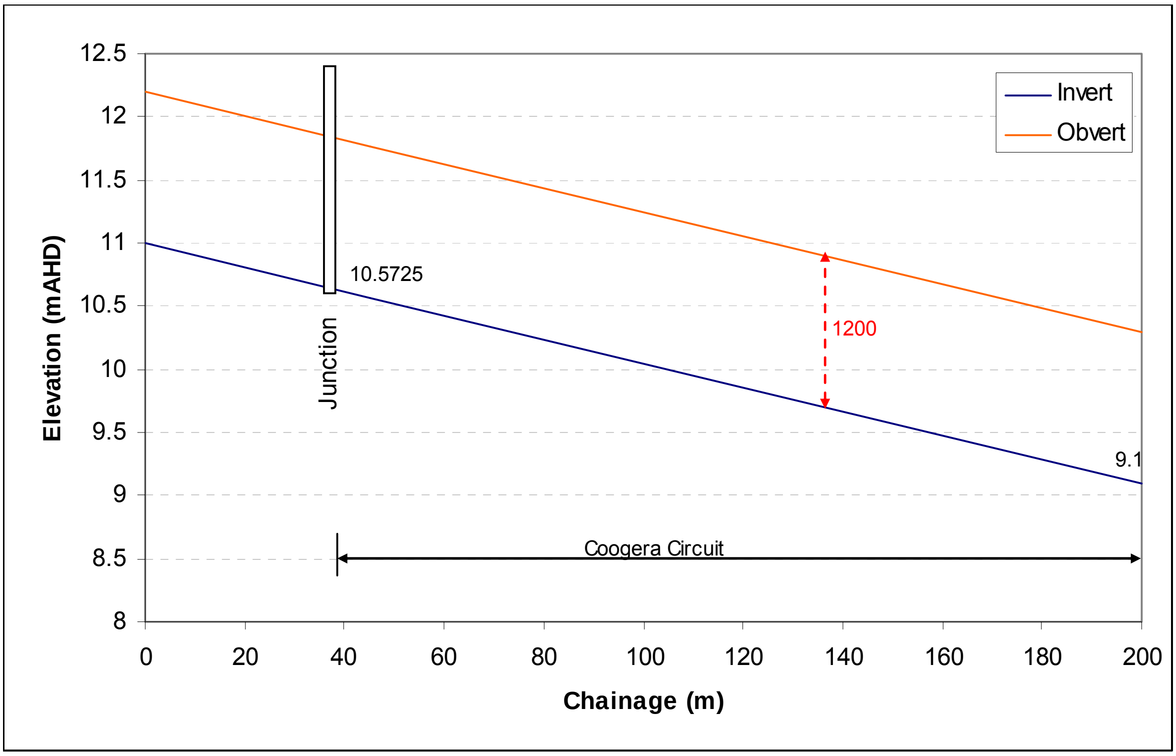
Basin Overflow

Open Drain

Pipe

Cadastre

Drainage



- **Figure 7-7 Preliminary levels for proposed Coogera Circuit Basin flood overflow pipe element**

7.2.3. Costing of Stormwater Infrastructure upgrades

The estimated construction and engineering cost to undertake both the Broken Head Road crossing upgrade and Coogera Circuit Basin overflow is $974,000 plus GST as summarised in Appendix E. This estimate has been prepared for preliminary budget purposes only and to assist with the feasibility of this option.

The following comments regarding this cost estimate should be noted.

Civil Works

Broken Head Road Bridge Crossing

The identified works are required to provide a crossing of South Tallow Creek comprising of a bridge approximately 12m wide (2 x 3.5m traffic lane, 2 x 2.5m footpaths) and 4.5m in length. Height of the bridge above the existing channel is approximately 1 to 1.5m. The bridge is to replace existing culverts under the road.

Coogera Circuit Detention Basin Flood Overflow Stormwater Drainage

The following identified works are required to provide a piped flood overflow alignment from the Coogera Circuit Detention Basin to the open space area east of Beech Drive.

- Construction of a 3m x 1.5m overflow pit at the basin
- 50m of 1200mm RCP from the overflow pit via an adjacent clear lot to Coogera Circuit
- Manhole in Coogera Circuit
- 150m of 1200mm RCP in Coogera Circuit from manhole to east of Beech Drive
- Headwall/outlet structure just east of Beech Drive

Cost Rates

The unit cost rates used in this estimate are July 2005 rates applicable to residential subdivision works in Brisbane. The rates have been increased to be current for September 2008 and allow for Byron Bay Shire location. The rates exclude GST. It should be noted that rates for civil works are currently increasing at about 1%/month. The cost estimate is based on both projects being constructed concurrently. Should this not occur then additional mobilisation costs would apply.

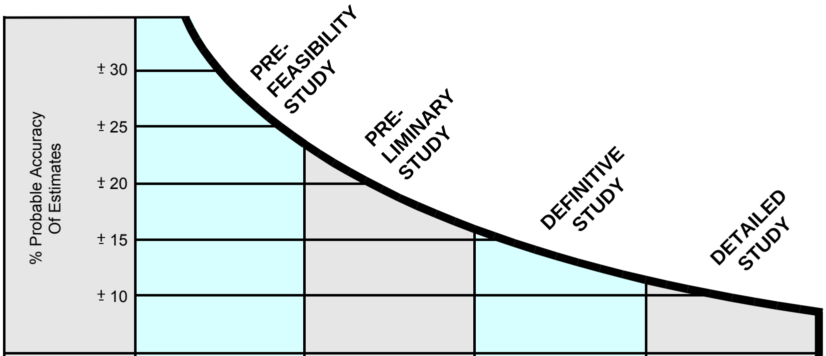
The Pre - Feasibility cost estimate dated 18 September 2008 is included in Appendix E.

Please note that the following items have NOT been included in the estimate.

a) Landscaping costs;
b) Project management fees;
c) Council fees;
d) Works to the floodway, existing channels;
e) GST

Contingency

Any engineering cost estimate requires a contingency sum to account for the uncertainty associated with the level of investigation at the time of preparation of the estimate. Figure 7-8, Definition Chart for Engineering Estimates, indicates the level of contingency that is applicable for various types of studies. The investigation undertaken as part of a floodplain risk management strategy would lie in the preliminary study category. As such a contingency of +-20% is recommended.



Type of Estimate	Order of Magnitude	Preliminary	Definitive	Detailed
Documentation Provided	• Product capacity and Location • Cost Data on Similar Projects • Major Equipment List	• Preliminary Equipment List • Engineering Line Diagram • Plant Outline General Arrangement • Maps and Surveys • Bench Test Results • Nature of Facilities	• Equipment Specifications and Vendor Quotations • Construction Schedule • Electrical One Lines • Piping and Instrumentation Flow Diagrams • Soil Data and Architect Features • Site Survey and Labour Complete	• Bulk Material Specifications and Vendor Quotes • Construction Specification and Sub Contractor Quotations • Engineering Advanced Approximately 10%
Definition of Scope of Work	Conceptual	Approximate	Clearly Described Essentially Complete	Complete. Well Detailed
Estimating Procedure	Factoring	Combination of Factoring and Quantity Take-Off	Most Quantity Take-Off. Very little Factoring	Complete Quantity Take-Off
Use of Study	Comparison/ Rejection	Final Feasibility	Budget	Funding

- **Figure 7-8 Figure Definition Chart for Engineering Estimates**

7.2.4. Develop and Implement Asset Management and Maintenance Plan

Infrastructure maintenance is important to the Tallow Creek catchment to so that flooding and drainage conditions are not adversely impacted upon. At the time of this study Council was developing and implementing an asset management and maintenance program for stormwater infrastructure in the form of a Stormwater Asset Management Plan. In the context of the Tallow Creek catchment this asset management and maintenance will achieve greatest benefits to flooding conditions by the maintenance of drainage features so that they are able to operate in a manner consistent with their design intent.

7.3. Sandbar Management

The cost of opening and managing the Tallow Creek mouth is borne by Council despite the mouth of the creek being within the Arakwal National Park. Council has the responsibility to maintain the sandbars as they create flood risk, even if the Sandbar is located within the National Park.

Section 5.5.1 of this report showed how Tallow Lake mouth berm levels affect the flood immunity of Suffolk Park downstream of Broken Head Road, by resulting in nuisance flooding to private property and decreasing the flood immunity of property floor levels. Effectively, a higher berm means less rain is needed to result in flooding above floor level, therefore it is essential that Byron Shire Council manage the height of the berm at Tallow Lake mouth in order to protect private property from flooding and increased inundation, and to maintain an acceptable risk of flooding to private property. A schematic of the proposed sand bar management is shown in Figure 7-11.

7.3.1. Existing Conditions

Tallow Creek discharges to the ocean at the Northern extent of Tallow Lake. The Tallow Creek mouth is obstructed by a naturally forming sand-bar that contains Tallow Lake, with the lake breaching periodically during local storm events. Sand-bar crest levels have been identified as the key factor in nuisance inundation (flooding to below floor level) at a number of properties adjacent to Tallow Lake and reducing the flood immunity to properties susceptible to flooding above floor level. Maintenance of the Tallow mouth sand-bar to a prescribed range will achieve a reduction in the risk of flooding for properties adjoining Tallow Lake.

The processes that create and erode the sand-bar are complex. Similarly, there is limited understanding of the habitat significance and cultural heritage of the Tallow Creek mouth. Because of these complications, an interim sand-bar management strategy has been developed. This will achieve the goal of reducing flood risk to adjoining properties to Tallow Lake, during the period where further investigation can be conducted into the Tallow Creek mouth.

7.3.2. Environmental Factors

The sandbar management strategy needs to consider the impacts on the surrounding environment. The environment in Tallow Lake has adapted to the natural hydrological cycles of the system over many years. This includes extended periods of elevated levels and intermitted periods of naturally occurring breaking of the lakes entrance. This is discussed further in Section 5.5.3.

The development of a long term policy for sandbar management will require further assessment of the potential impact on the environment. In particular, this will need to consider the potential impacts on threatened species, endangered ecological communities and wetland vegetation. **Figure 3-2** and **Figure 3-3**, in **Section 3.3** illustrate the location of threatened species and their habitat.

The sandbar management strategy will require heavy earthmoving equipment to access the site. As there is no existing road access to the site, access will most likely occur via the beach front. This would minimise any potential impacts on inland threatened habitat surrounding Tallow Lake. The environmental impacts of this access and the physical process of excavating the waterway will require further assessment.

The Environmental Management Plan is to incorporate a Sand Bar Management Plan and a Biodiversity Conservation Management Plan to address any environmental issues. This may include a provision for ongoing monitoring of the lake and surrounding environment. The plan would also consider the management strategies outlined in the NSW Health Rivers Commissions Inquiry into coastal lakes.

7.3.2.1. Climate Change

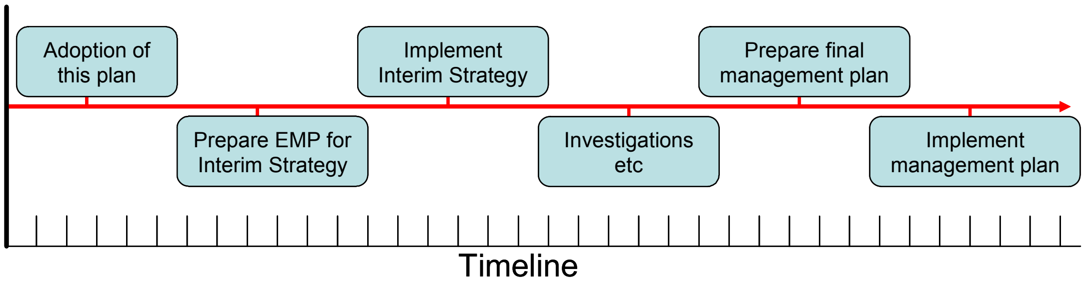
The sandbar management strategy needs to consider the impacts of any artificial entrance modification under climate change scenario. The report *Coastal Lakes Management Strategies for a Sustainable Future (Philip Haines, 2006)* states that climate change is expected to have a range of impacts on ICOLL's, particularly increasing sea levels which will result in higher sandbar and lake water levels. These rising sea levels are expected to worsen the existing inundation.

Section 5.2 of this report assesses the potential impacts of climate change on flood levels. The results of this assessment were used to develop a flood planning level to guide future planning controls and development in the area. This analysis sits within Strategy 3 of the Coastal Lakes Management Strategies for a Sustainable Future, providing Council with the necessary information to set development zones that consider future environmental change thereby minimising the need for artificial entrance works.

The *Coastal Lakes Management Strategies for a Sustainable Future (Philip Haines, 2006)* also identifies the risk of rising sea levels progressively diminishing the relative difference between the level at which the sand bar is artificially opened and natural water levels in the ICOLL. Any long term sandbar management strategy will need to consider these effects with the potential to increase the trigger level for sand bar modification in line with the increased lake levels from sea level rise. For this reason the strategy should include a review every 5 years. Under Strategy 6 an interim management strategy has been developed to reduce the risk of flooding for existing developments in the Tallow Creek catchment. This is discussed further in **Section 7.3.3**.

7.3.3. Accepted Management Strategy

A management strategy has been developed to allow the process of managing the Tallow Creek lake mouth to progress. This strategy was developed considering the need for a short term approach for controlling public health, while concurrently considering environmental and cultural heritage issues. The approach has been developed through consultation with New South Wales Marine Parks Authority and National Parks and Wildlife Service and was accepted on the 16th of July 2008. The timeline for this process shown in Figure 7-9.



▪ **Figure 7-9 Process for development and implementation of sandbar management plan**

7.3.3.1. Interim Management Plan

The interim management plan for the Tallow Lake mouth considers two potential triggers to manual intervention at the creek mouth. These are water quality based and water level based, reflective of the potential human health and ecological aspects and flood risks respectively. These interim measures have been accepted for application by National Parks and Wildlife Service.

The water level triggers to the interim management approach consider that standing lake levels should not exceed 2.2m AHD. When the water level is above 1.8m AHD Council will carry out water sampling at the locations shown in Table 7-1, if the water quality results are outside the objectives given in Table 7-1 a manual intervention will be triggered due to human health risks. Manual intervention will also minimise adverse ecological impacts. The water sampling is event based, with Council's maintenance programmer inspecting the lake level on a weekly basis using the manual water level gauge at Byron @ Byron as the reference level.

▪ **Table 7-1 Water quality parameters for the Tallow Lake**

Parameter	Unit	Site 1#	Site 1A	Site 2#	Site 3#	Site 4	Site 4D	Site 5
Health								
Enterococci	EC/100mL	>70	>70	>70	>70	>70	>70	>70
Faecal coliforms	FC/100mL	>300	>300	>300	>300	>300	>300	>300
Cyanobacteria (toxic species only)	cells / mL	>5000	>5000	>5000	>5000	>5000	>5000	>5000
Physical								
Chlorophyll a	µg/L	>10	>10	>20	>10	>10	>15	>10
Total phosphorus	mg/L	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15
Total nitrogen	mg/L	>1.0	>1.0	>1.0	>2.0	>2.0	>3.0	>2.0
Dissolved oxygen	mg/L	<5	<5	<5	<5	<5	<5	<5
pH (outside range)	no units	6 to 8	6 to 8	6 to 8	6 to 8	6 to 8	6 to 8	6 to 8
Turbidity	NTU	>20	>20	>20	>20	>20	>20	>20
Mosquito larvae	Larvae per 100mL	>100	>100	>100	>100	>100	>100	>100
Atmospheric Sulfur Dioxide	ppm	> 100	> 100	> 100	> 100	> 100	> 100	> 100

Key:

Site 1 - Entry point from Byron Hills stormwater drainage system – Broken Head Road near BP station
Site 1A - Stormwater drain into Tallow Creek on boundary of Byron @Byron, near the weir
Site 2 - End of Maroudia Place
Site 3 - Behind 34-38 Acorn St
Site 4 - Tallow Creek 200 metres upstream from STP discharge point
Site 4D - Tallow Creek at point of South Byron STP discharge
Site 5 - Tallow Creek 200 metres downstream from STP discharge point
- these points are not within Tallow Lake and hence will not drive sandbar management, however these points are included as these are common to Council water quality monitoring sites.

If the water level is beyond 1.8m AHD Council will inspect the beach berm regularly to ensure the sandbar is not at a height which would affect a natural breaching of the berm during the next rainfall event. If the lake levels go beyond 2.2m AHD a manual intervention will be triggered, no matter what the water quality, this is due to the serious flood risks involved with high lake levels. It is noted that Council must complete an EMP/REF for the above works in consultation with and with consent from National Parks and Wildlife Services.

The proposed Tallow Lake mouth levels have been adopted to reduce the risk of flooding to properties adjacent to Tallow Lake. The range of land inundated for a 1.4mAHD and 1.8mAHD Tallow Lake level has been determined and is shown in Figure 7-10, with the 1.4mAHD contour shown to illustrate that this elevation does not inundate wetland vegetation. It is noted that the 1.8mAHD contour shows impact on natural wetland vegetation, and should be further assessed in the development of a long term management strategy.

7.3.3.2. Environmental Management Plan (EMP) for Interim Management Strategy

The EMP is to be implemented for 5 years, with a review of data commencing after 3 years, to guide the development of the comprehensive long term plan of management. The review of the strategy every 5 years is to be based on an adaptive management framework, with the EMP identifying limits of acceptable and unacceptable change, ensuring that false detection and real change errors are minimised. Examples where adaptive management may be applied:

- When additional climate change flooding and sea level rise data becomes available.
- Flexibility to allow different flood heights to trigger action for ecological reasons
- Flexibility to allow changed use of machinery for ecological reasons such as breeding season of birds and potential damage to nests.

The EMP is to address:

- Threatened flora, ecological communities and habitats;
- Threatened fauna habitat and habitat use;
- Natural successional changes;
- High tides, blown sand and storm waves;
- Sandbar management including beach engineering works (prevention of natural development of shingle features);
- Fill in the catchment;
- Feral animals;
- Predation by native and feral animals;
- Introduction and spread of weeds;
- Climate change;
- The need for studies of:
  - The marine, freshwater, and estuarine environments within the study area;

    - Meiobenthos, macroinvertebrates, birds, snail, small ground-dwelling mammals, aquatic vertebrate and invertebrate fauna;
    - Aquatic flora (eg algae and seagrasses), vascular plant assemblages (forested wetlands, saltmarsh, dunal vegetation, littoral rainforest and any additional vegetation assemblages recognised in the study area);
    - Saltwater-freshwater dynamics, algal blooms, increased wave penetration from opening, flood mitigation management, floodwater impacts, sedimentation and shoaling, water quality and pollutant loads;
    - Creek ecology functioning, management of creek entrance; and
    - Sea level rise and back swamp land management
- Environment and ecological impacts of proposed structural upgrades at Broken Head Road Crossing of south Tallow Creek and Coogera Circuit Detention Basin overflow provision; and
- EPBC Act listed species known from the area eg White-bellied Sea Eagle, Spangled Drongo, Rainbow Bee-eater, Great Egret".

Figure 7-10: Tallow Creek Flood Risk Management Study - Sandbar Management

7.3.3.3. Final Management Strategy Considerations

The following headings detail some of the considerations required in the development of the final management plan for the Tallow Lake mouth.

Constraints and Responsibilities for the Strategy
Byron Shire Council will be responsible for the monitoring of water levels of Tallow Creek. Any proposed changes to the sand bar level is subject to the approval of relevant government agencies and in accordance with the Interim Management Plan (7.3.3.1), and the accepted interim management strategy will work towards a non intervention scenario. Any proposed alteration to the sand-bar level is subject to the approval of relevant government agencies including National Parks and Wildlife, Marine Parks Authority and the traditional land owners.

The Tallow Creek mouth and sand-bar serves as a bird nesting site, during the period of September to May. Due to the environmental sensitivity of the site during this period, it is recommended that any intervention at Tallow Lake mouth be conducted outside of this period.

Byron Shire Council will be required to develop an Environmental Management Plan prior to the implementation of the sandbar management strategy and the interim one. The potential impact of this accepted interim control strategy on the existing wetland vegetation communities should be assessed as part of ongoing development of a long term management strategy for Tallow Lake.

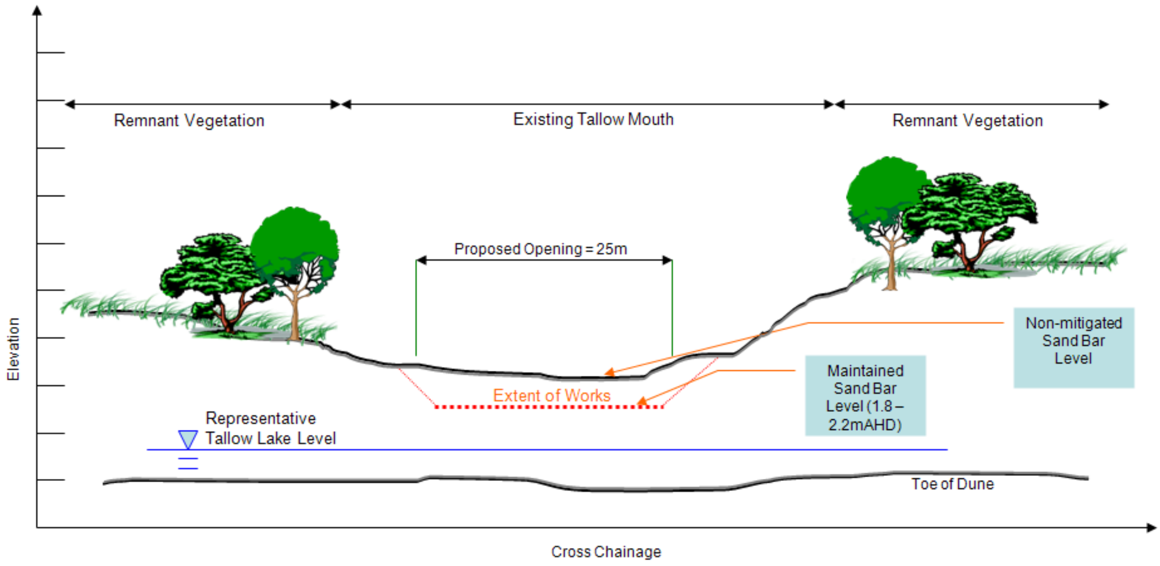
Application of the Strategy
The interim and proposed sand-bar management strategy is outlined below:

- Byron Shire Council would inspect the sand bar and record its level every year just prior to the onset of the rainy season (say late August); and the arrival of Little Terns and other migratory species;
- Byron Shire Council would undertake any earthworks necessary to provide an opening 25m wide with a level not more than a pre-determined value. Hydraulic modelling indicates that this level would be in the range of 1.8 – 2.2 mAHD to ensure reasonable flood protection upstream. The opening would be preferably located at the southern side of the creek mouth as it has been observed that openings on the northern side of the creek have resulted in substantial erosion of the northern bank of the creek mouth;
- Earthworks will be conducted by sand scraping, with sand removed to within the bounds outlined above. This process will not result in a forced breaching of Tallow

Lake, rather reduce the level at which the sand bar will breach and only when threatened species are not or have not been utilising the location and subject to assessments and approvals/consents.

- The level of the opening would be monitored during the rainfall season (say to the end of March). Should the sand bar level exceed the level of 2.2mAHD during this period, maintenance earthworks would be undertaken to restore the level to 1.8 – 2.2 mAHD (the sand bar is estimated to have been 2.5mAHD prior to the mouth opening of November, 2004). To avoid excessive disturbance of the area, any such maintenance works would only be undertaken once during a rainfall season.

The accepted interim strategy allows for the natural breaching process of Tallow Creek mouth to occur during a large runoff event, while reducing the flood risk to properties adjoining Tallow Lake. As sand bar scraping will not reduce sand levels to the extent that the standing water level in the lake will be impacted, adverse environmental outcomes such as fish kills from forced releases will be avoided. The reduced sand-bar level will act as a fuse, breached only at times of natural flooding. During the implementation of the accepted interim strategy, environmental monitoring and investigations will be undertaken to increase the data on lake levels and flora and fauna, will need to be competed in order to ensure the long term management plan is sustainable.



- **Figure 7-11 Schematic cross-section of proposed sand bar management plan in application (Not to scale)**

7.3.4. Cost of Accepted Interim Sand Bar Management Strategy

A cost for implementation of the on-the-ground works for the accepted interim sandbar management strategy has been developed to allow for assessment against existing flood damages resulting from Tallow Lake mouth closure. The element of difficulty in developing a cost estimate is that it is unclear how frequently manual intervention will be necessary at the Tallow Creek mouth.

Based on these assumptions, excavation of a 25m wide by 50m long swathe to a depth of 1m will cost approximately $10,200 (excl GST). Excavation to a lesser depth will reduce the operating time and associated costs, however the plant mobilisation cost will be unchanged. Ie. Excavation to 0.5m would cost approximately $6,000 (excl. GST).

These costs do not consider the costs associated with the development of the final sand bar management strategy. The costs associated with this include environmental monitoring, including monitoring of lake and sand bar levels, and the development of a final management plan. Such studies are expected to cost in the order of $240,000.

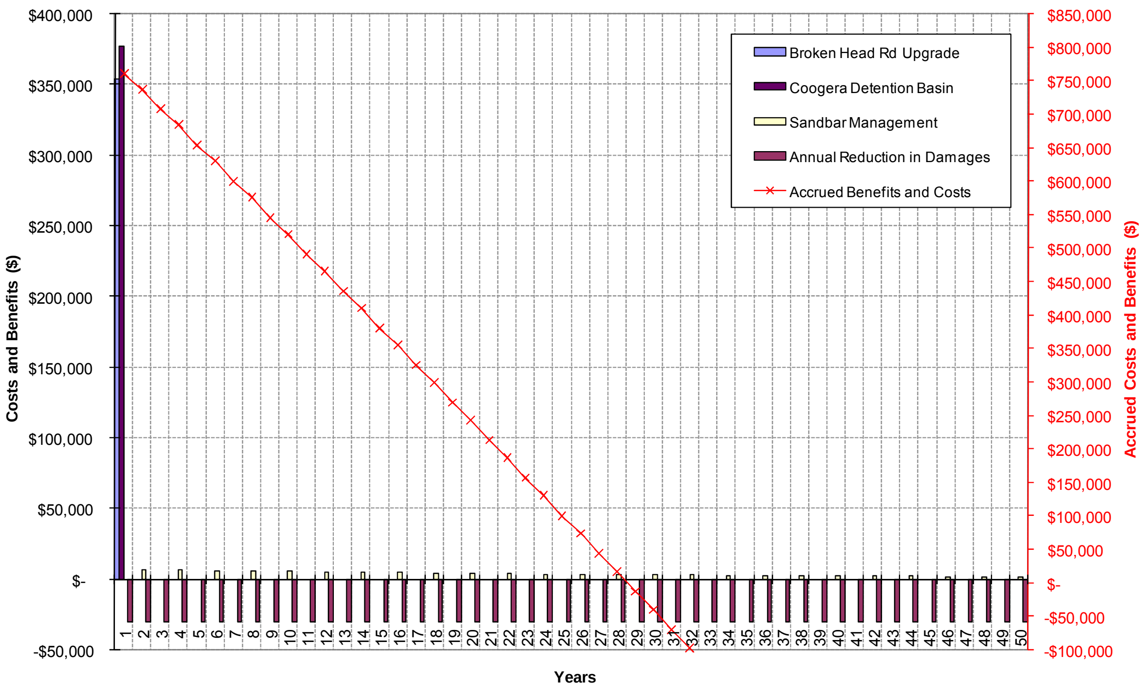
7.4. Benefit Cost Analysis

A benefit-cost analysis was conducted for the proposed capital works of the floodplain risk management strategy. The annual average damages in the Tallow Creek catchment is very low, estimated as $30,000 annually. Because of this, even small scale capital works are unlikely to achieve a favourable benefit-cost ratio. This is shown in the benefit cost analysis, shown graphically in Figure 7-12.

This analysis indicates that the proposed capital works do not offset these works costs, even with the following assumptions:

- Complete reduction in annual average damage to $0 ($30,000 annual benefit)
- Indexation rate of 3% on future expenses
- 50 year design life on capital works

With a reduction in annual average damages to $0, a 29 year design life is required to offset the proposed capital costs. Where the capital works achieve a 50% reduction in average annual damages, a 51 year design life is required to offset capital costs.



- **Figure 7-12 Cost Benefit Analysis: 50 year Analysis with complete reduction in annual flood damages – Accrued Benefits and Costs Line Reference Right Hand Axis**

The benefit cost ratio for the proposed capital works over the 50 year design life is 1.82 where a complete reduction in flood damages to $0 is assumed. The benefit cost ratio reduces to 0.91 where a reduction in damages from $50,000 to $30,000 is assumed.

These results indicate that the proposed works require a large design life to justify the expense on a benefit basis. However, the proposed capital works such as the upgrade of Broken Head Road are necessary to achieve an acceptable flood immunity of a key access and ingress road for Suffolk Park and surrounding areas. Intangible social benefits have not been considered in this analysis. These include:

- Stress reduction
- Disruption to workers through loss of income
- Illness.

7.5. Action Plan for Byron Shire Council

The following provides an action plan to address the proposed flood risk mitigation strategies.

Task	Action	Responsibility	Costs	Timing
1. Planning Controls	a. New Byron Local Environment Plan to more robustly protect existing development from increased flooding impacts resulting from future development and update to be in line with NSW Floodplain Development Manual (2005)	▪ Byron Shire Council	▪ STAFF	▪ 2010
	b. Commence undertaking to rezone the land identified as high flood hazard for the 1 in 100 year ARI flood to preclude these areas from future development	▪ Byron Shire Council	▪ STAFF	▪ 2010
	c. Adopt FPLs as part of the DCP 2002 as the extent of flood prone land in the Tallow Creek catchment that consider climate change conditions (Scenario 4)	▪ Byron Shire Council	▪ STAFF	▪ 2010
	d. Implementation of design measures and evacuation plans to minimise impacts on future planned community uses as identified in the DCP No. 9	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
	e. Adopt prescribed areas of fill exclusion.	▪ Byron Shire Council	▪ STAFF	▪ Jan 09
	f. Ensure future developments within the catchment utilise on-site stormwater detention measures to maintain pre-development peak runoff characteristics.	▪ Byron Shire Council	▪ STAFF	▪ Nov 08
	g. Adopt new version of the hydraulic model to allow for assessment of all proposed development	▪ Byron Shire Council	▪ STAFF	▪ Nov 08
	h. Prepare a section contribution plan for all civil works in this plan.	▪ Byron Shire Council	▪ $20k	▪ Jan 09
	i. Update 149 certificates and any lots with additional controls over them, including add 1495 certificates for lots effected by PMF and not within	▪ Byron Shire Council	▪ STAFF	▪ Jan 09

Task	Action	Responsibility	Costs	Timing
	the FPL.			
2. Emergency Response Planning	a. Establish relationship between flood return period, sand bar levels and flooding conditions in Tallow Lake to assist in SES flood evacuation planning	▪ Byron Shire Council	▪ $10k	▪ Oct 09
	b. Support SES in inclusion of Suffolk Park in Flood Response Plan	▪ SES	▪ nil	▪ Oct 09
	c. Install flood gauge at Broken Head Road culvert showing example flood levels	▪ Byron Shire Council	▪ $500	▪ Oct 09
	d. Install lake level and rainfall monitoring station on Tallow Lake and connect to Council's flood warning system	▪ Byron Shire Council	▪ $25k	▪ Oct 09
3. Stormwater System Upgrades	a. Upgrade Broken Head Road Crossing of South Tallow Creek	▪ Byron Shire Council	▪ $355k	▪ June 09
	b. Upgrade Coogera Circuit Detention	▪ Byron Shire Council	▪ $380k	▪ June 09
	c. Raise footpath at Tallow Lake footbridge to ensure trafficable up to a lake level of 2.5mAHD.	▪ Byron Shire Council	▪ $20k	▪ June 09
	d. Develop and implement asset management and maintenance plan	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
4. Sandbar Management	a. Implement interim management plan through water level and quality monitoring	▪ Byron Shire Council	▪ STAFF	▪ Dec 08
	b. Develop data collection program for variables such as sand bar and lake stored level, to support development of long-term management plan.	▪ Byron Shire Council	▪ Refer to 7.3.4	▪ Ongoing
	c. Inspect the sand bar and record its level every year prior to the onset of the rainfall season	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
	d. Monitor the level of the opening during the rainfall season and undertake maintenance earthworks to restore the level as per the accepted Interim Sandbar Management Strategy.	▪ Byron Shire Council	▪ STAFF	▪ Ongoing
5.	a. Update Council Geographic Information Systems (GIS) to	▪ Byron Shire Council	▪ STAFF	▪ Nov 08

Task	Action	Responsibility	Costs	Timing
GIS/IT	include outputs of this plan and update any lots with additional controls over them. b. Ensure authority uses the GIS layers to prepare property reports. c. Add adopted document to Council's website, plus additional A1 pdf of FPL.			

8. Summary and Conclusion

Mitigation of the flood risk in the Tallow Creek catchment is proposed to be achieved by implementation of structural solutions to existing flooding ‘hot spots’, however the primary risk of flooding in the Tallow Creek catchment exists from the potential for inappropriate future development. This risk is further exacerbated by the potential and predicted impacts of climate change.

The elements of the proposed floodplain risk management strategy for Tallow Creek are summarised as follows:

- It is proposed that classification of high flood hazard areas be adopted in the land use zoning of the Local Environment Plan to preclude these areas from future development;
- Flood planning levels are to be defined for the Tallow Creek catchment based on the 1 in 100 year ARI flood level for the climate change scenario (Scenario 4 from Section 5.2), plus 500mm freeboard. The extent of inundation determined from the flood planning level defined the flood liable land which initiates development approval requirements via the development control plan;
- Filling is to be precluded within certain areas of the defined FPL. This is to occur in areas where the existing development has obstructed flood flows such that additional filling is certain to adversely impact on flood levels;
- Future developments within the Tallow Creek catchment are to constrain developed conditions peak discharge to pre-development levels. The purpose of this control measure is to ensure that flood peak runoff rates do not increase with future development of the catchment;
- Structural upgrades are proposed for the Broken Head Road crossing of South Tallow Creek and for a flood relief structure for the Coogera Circuit detention basin. The flood immunity of Broken Head Road is too low given the reliance of the community on the road for access and as an escape route during a flood emergency. The Coogera Circuit detention basin has no formalised overflow provision, with frequent overtopping of the basin resulting in overland flood flows inundating adjacent properties;
- It is proposed that water level and quality in the Tallow lake be monitored regularly, with intervention required where either water level or water quality objectives are exceeded.
- Further investigation is required into the Tallow Creek mouth, to allow for the progression of the accepted interim sandbar management strategy into a long term

strategy, including assessment of the potential impact on existing wetland vegetation communities;

- The cost benefit analysis conducted for the proposed capital works indicates that, using reduction in average annual damages exclusively, a design life of between 25 and 50 years is necessary to justify the capital expenditure. The 50 year design life for the civil works results in a benefit cost ratio for the proposed works of between 0.91 and 1.82, dependent on the achieved reduction in flood damages; and
- It is recommended that Council incorporate the digital GIS information developed from this study into Council systems.

9. References

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Appendix A Threatened Species List

Table A-1 Threatened Fauna

Scientific Name	Common Name
Amaurornis olivaceus	Bush-hen
Anseranas semipalmata	Magpie Goose
Botaurus poiciloptilus	Australasian Bittern
Burhinus grallarius	Bush Stone-curlew
Chalinolobus nigrogriseus	Hoary Wattled Bat
Crinia tinnula	Wallum Froglet
Haematopus longirostris	Pied Oystercatcher
Ixobrychus flavicollis	Black Bittern
Lophoictinia isura	Square-tailed Kite
Miniopterus australis	Little Bentwing Bat
Miniopterus schreibersii	Common Bentwing Bat
Monarcha leucotis	White-eared Monarch
Myotis adversus	Large-footed Myotis
Nyctophilus bifax	Eastern Long-eared Bat
Nyctophilus bifax	Eastern Long-eared Bat
Pandion haliaetus	Osprey
Petalura gigantea	Giant Dragonfly
Phascolarctos cinereus	Koala
Planigale maculata	Common Planigale
Potorous tridactylus	Long-nosed Potoroo
Pseudomys gracilicaudatus	Eastern Chestnut Mouse
Pteropus alecto	Black Flying-fox
Pteropus poliocephalus	Grey-headed Flying-fox
Ptilinopus regina	Rose-crowned Fruit-dove
Ptilinopus superbus	Superb Fruit-dove
Saccolaimus flaviventris	Yellow-bellied Sheathtail-
Scoteanax rueppellii	Greater Broad-nosed Bat
Sterna albifrons	Little Tern
Syconycteris australis	Eastern Blossom-bat
Thersites mitchellae	Mitchell's Rainforest Snail
Tyto novaehollandiae	Masked Owl

Table A-2 Threatened Flora

Scientific Name	Common Name
Acronychia baeuerlenii	Byron Bay Acronychia
Acronychia littoralis	Scented Acronychia
Archidendron hendersonii	White Laceflower
Archidendron muellerianum	Veiny Laceflower
Callerya australis	Blunt-leaved Wisteria
Chamaesyce psammogeton	Sand Spurge
Cordyline congesta	Toothed-leaved Palm Lily
Cryptocarya foetida	Stinking Cryptocarya
Elaeocarpus williamsianus	Hairy Quandong
Endiandra floydii	Crystal Creek Walnut
Endiandra hayesii	Rusty Rose Walnut
Endiandra muellerii subsp bracteata	Green-leaved Rose Walnut
Floydia praealta	Ball Nut
Macadamia tetraphylla	Rough Shelled Bush Nut
Niemeyera whitei	Rusty Plum
Owenia cepiodora	Onion Cedar
Phaius australis	Swamp Orchid
Pterostylis nigricans	Dark Greenhood
Syzygium hodgkinsoniae	Red Lilly Pilly
Syzygium moorei	Coolamon, Durobby
Tinospora tinosporoides	Arrow-head Vine
Xylosma terrae-reginae	Xylosma

Appendix B Flood Inundation Extents

B.1 Existing Climate Conditions

- Figure B-1: Flood Inundation Extent: 1 in 5 year ARI Flood Event
- Figure B-2: Flood Inundation Extent: 1 in 20 year ARI Flood Event
- Figure B-3: Flood Inundation Extent: 1 in 50 year ARI Flood Event
- Figure B-4: Flood Inundation Extent: 1 in 100 year ARI Flood Event
- Figure B-5: Flood Inundation Extent: 1 in 500 year ARI Flood Event
- Figure B-6: Flood Inundation Extent: Probable Maximum Flood

B.2 Climate Change Conditions

- Figure B-7: Flood Inundation Extent: 100 year ARI Flood Event Climate Change Scenario 2
- Figure B-8: Flood Inundation Extent: 100 year ARI Flood Event Climate Change Scenario 3
- Figure B-9: Flood Inundation Extent: 100 year ARI Flood Event Climate Change Scenario 4
- Figure B-10: Flood Inundation Extent: PMF Event Climate Change Scenario 4

Figure B-1: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 5 year ARI Flood Extent and Depth (5 year ARI Storm Surge)

Legend

Catchment Boundary

Cadastral Boundaries

Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1
0.11 - 0.2
0.21 - 0.4
0.41 - 0.6
0.61 - 0.8
0.81 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 <

Byron Shire Council

Filename: Inundation_1inx Date: Jan 2006

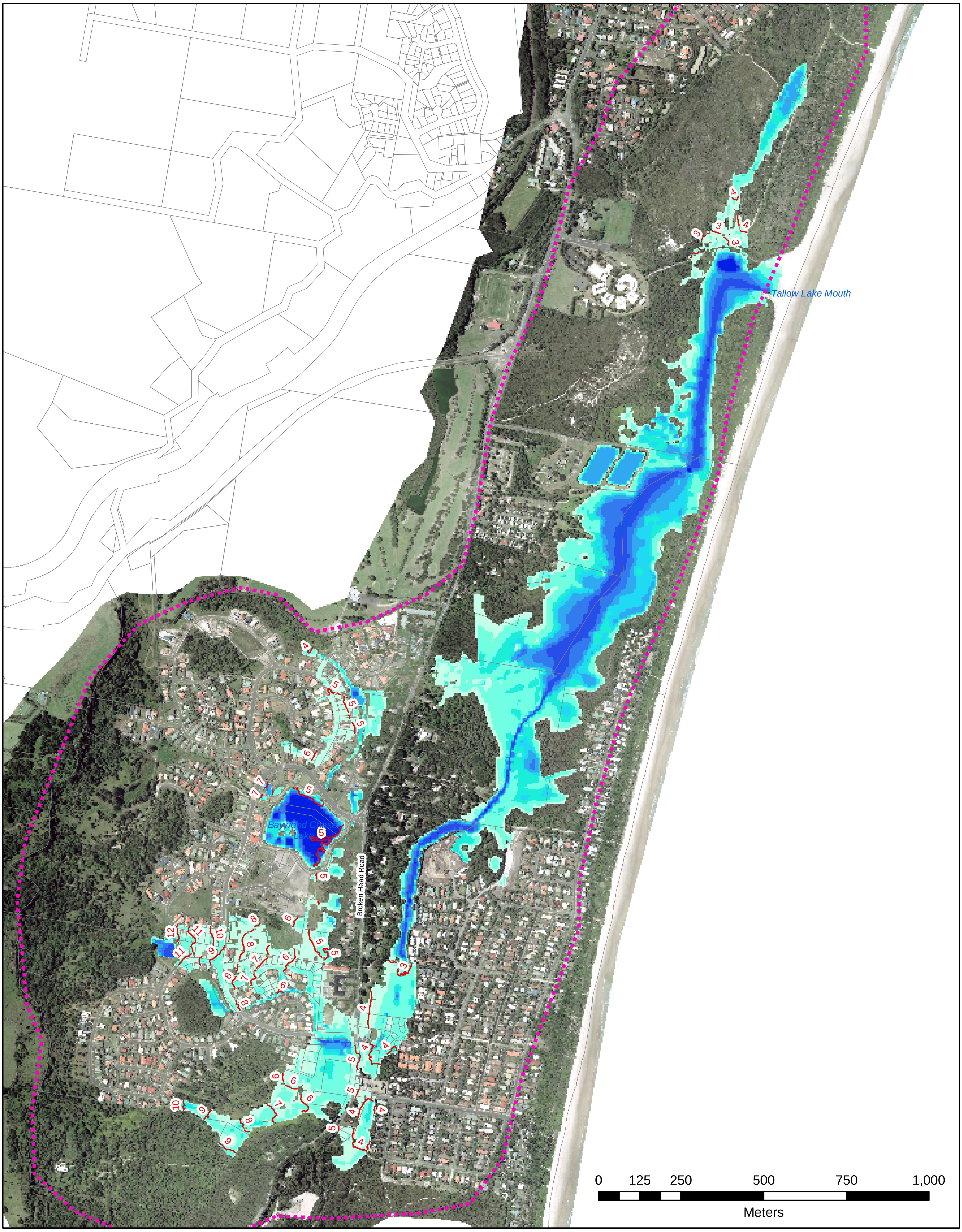

Figure B-2: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 20 year ARI Flood Extent and Depth (5 year ARI Storm Surge)

Legend

Catchment Boundary

Cadastral Boundaries

Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1	0.41 - 0.6	1.01 - 1.5	2.51 <
0.11 - 0.2	0.61 - 0.8	1.51 - 2	
0.21 - 0.4	0.81 - 1	2.01 - 2.5	

Byron Shire Council

Filename: Inundation_1in20 Date: Jan 2006

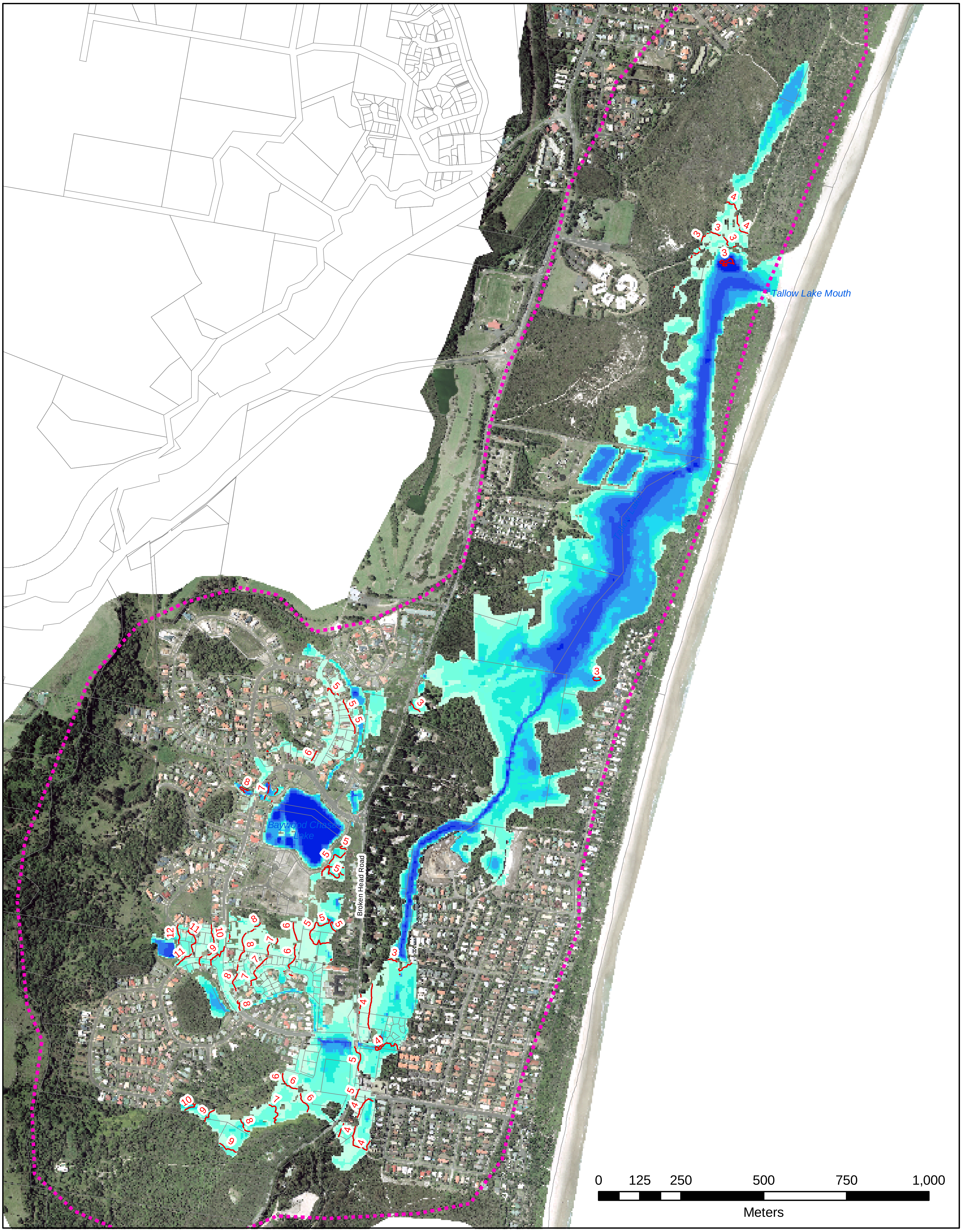

Figure B-3: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 50 year ARI Flood Extent and Depth (5 year ARI Storm Surge)

Filename: Inundation_1in50 Date: Jan 2006

Legend

Catchment Boundary

Cadastral Boundaries

Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1	0.41 - 0.6	1.01 - 1.5	2.51 <
0.11 - 0.2	0.61 - 0.8	1.51 - 2	
0.21 - 0.4	0.81 - 1	2.01 - 2.5	

Byron Shire Council

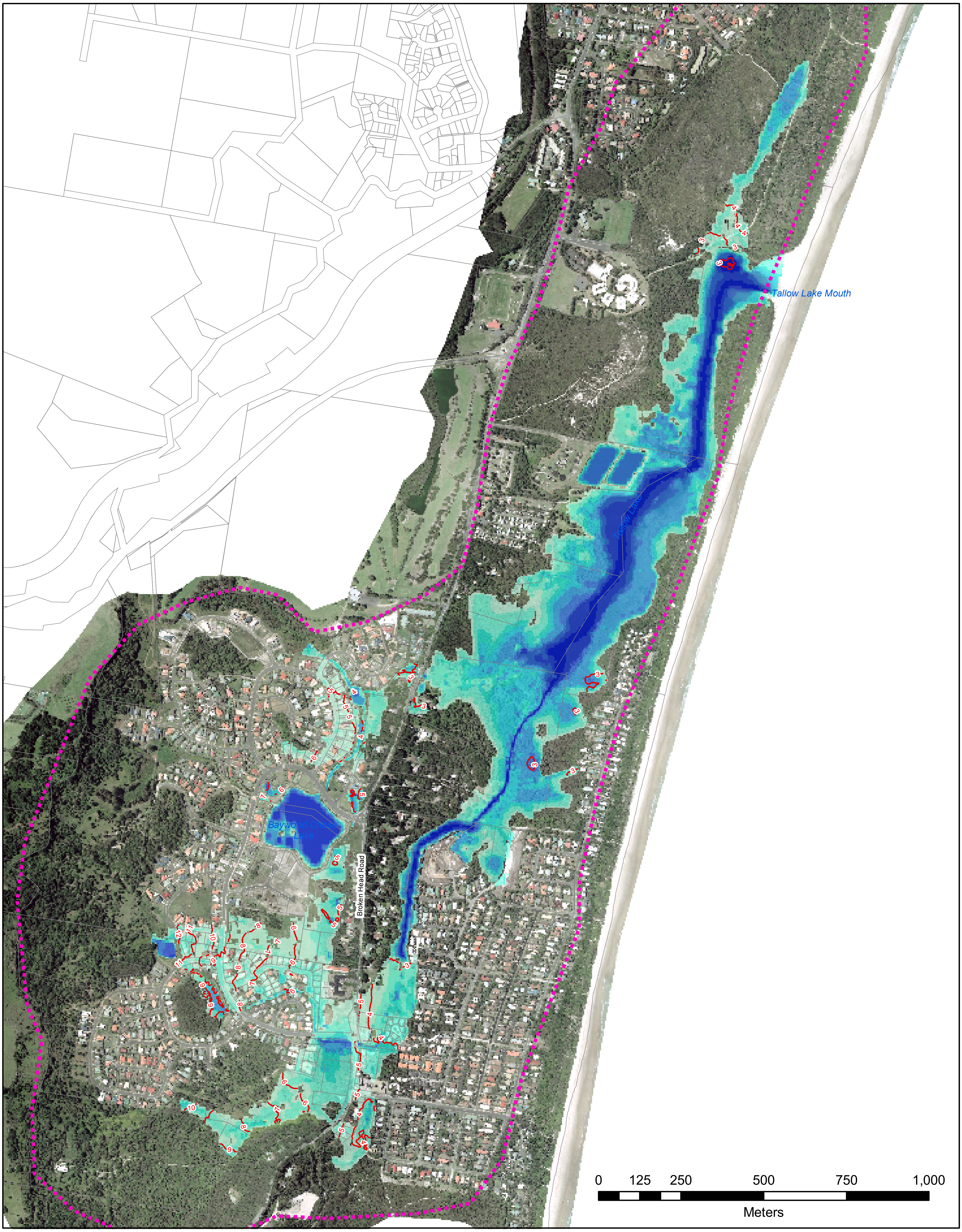

Figure B-4: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 100 year ARI Flood Extent and Depth (20 year ARI Storm Surge)

Filename: Inundation_1nx Date: Jan 2006

Legend

- Catchment Boundary
- Cadastral Boundaries
- Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1	0.41 - 0.6	1.01 - 1.5	2.51 <
0.11 - 0.2	0.61 - 0.8	1.51 - 2	
0.21 - 0.4	0.81 - 1	2.01 - 2.5	

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Byron Shire Council

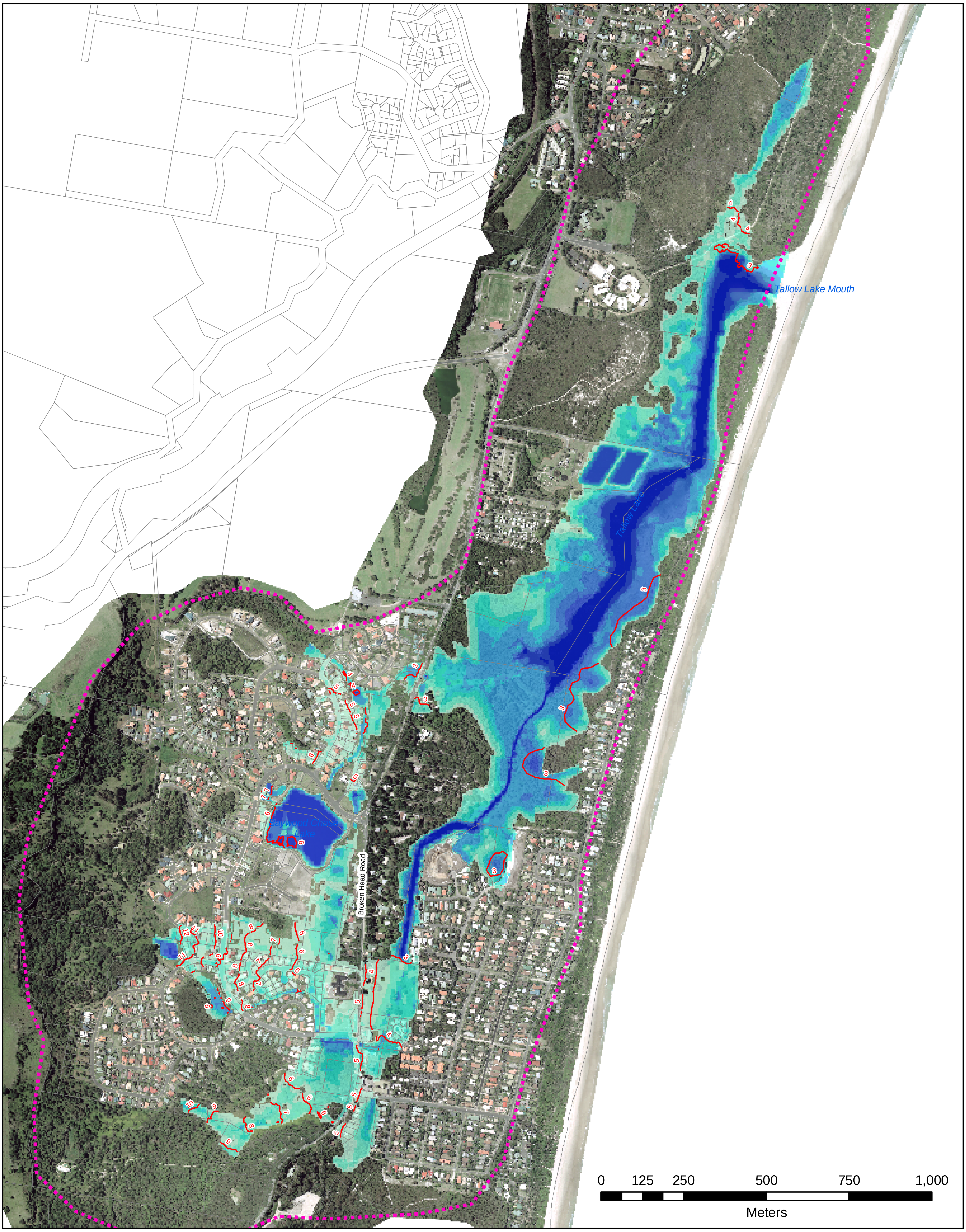

Figure B-5: Tallow Creek Flood Risk Management Study - Flood Extent

1 in 500 year ARI Flood Extent and Depth (100 year ARI Storm Surge)

Filename: Inundation_1inx Date: Jan 2006

Legend

Catchment Boundary

Cadastral Boundaries

Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1
0.11 - 0.2
0.21 - 0.4
0.41 - 0.6
0.61 - 0.8
0.81 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 <

Byron SHIRE COUNCIL

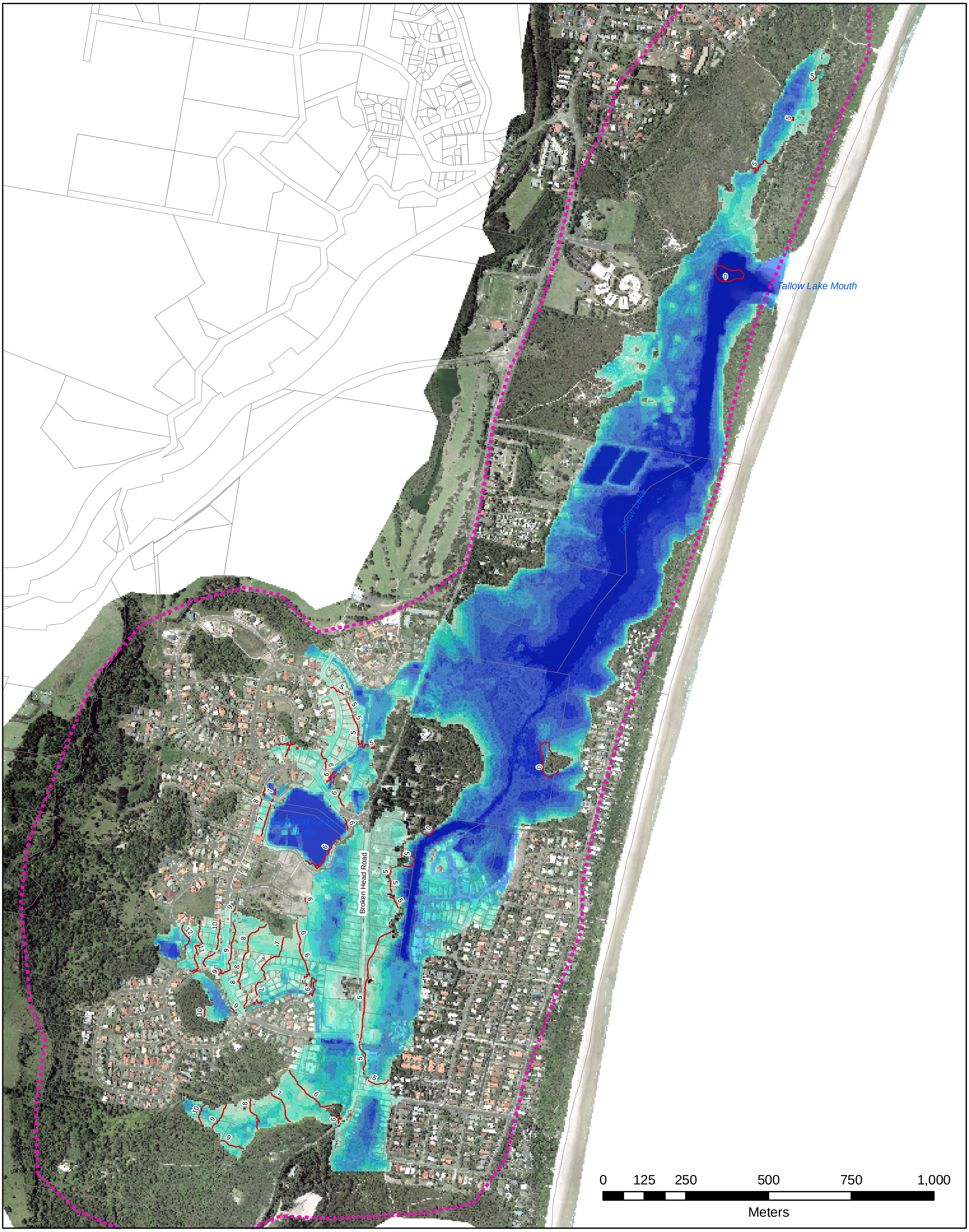

Figure B-6: Tallow Creek Flood Risk Management Study - Flood Extent

Probable Maximum Flood (PMF) Extent and Depth (100 year ARI Storm Surge)

Legend

- Catchment Boundary
- Cadastral Boundaries
- Water Level Countours (mAHD)

Peak Flood Depth (m)

0.00 - 0.1	0.41 - 0.6	1.01 - 1.5	2.51 <
0.11 - 0.2	0.61 - 0.8	1.51 - 2	
0.21 - 0.4	0.81 - 1	2.01 - 2.5	

Byron Shire Council

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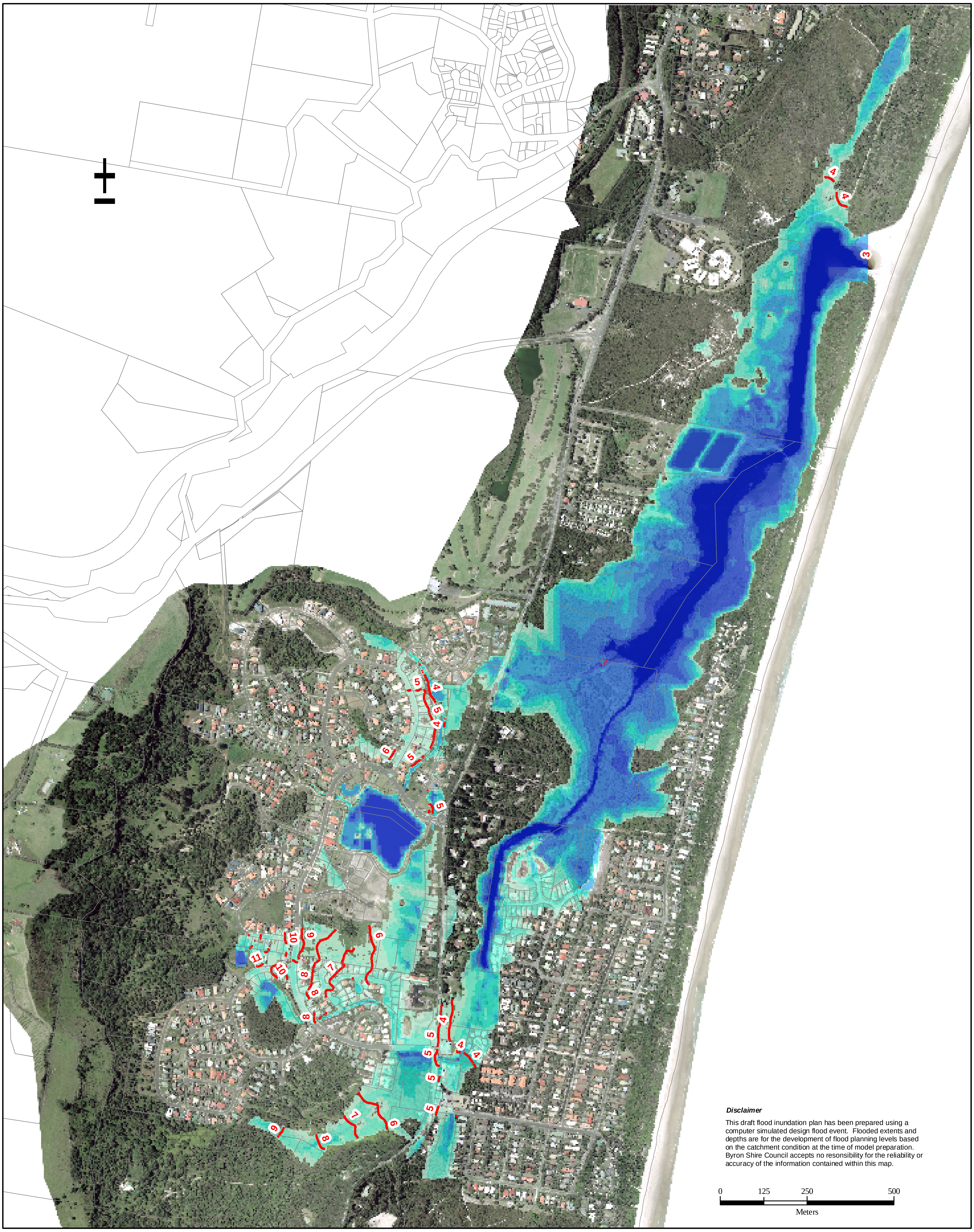


Figure B-7: Tallow Creek Climate Change Flood Risk Study - Flood Inundation Map

Maximum Flood Depth (m)

- 0.001 - 0.1 m
- 0.1 - 0.2 m
- 0.2 - 0.4 m
- 0.4 - 0.6 m
- 0.6 - 0.8 m
- 0.8 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2 m
- 2.0 - 2.5 m
- > 2.5 m
- Water Surface Level Contour (m AHD)

100 Year ARI Flood Event Scenario 2
10% Increased Rainfall Intensity
Initial Tailwater Level: 2.91m

Byron Shire Council

Filename: Flood Map Date: Feb 2008 Location: QENV Job: RE08218

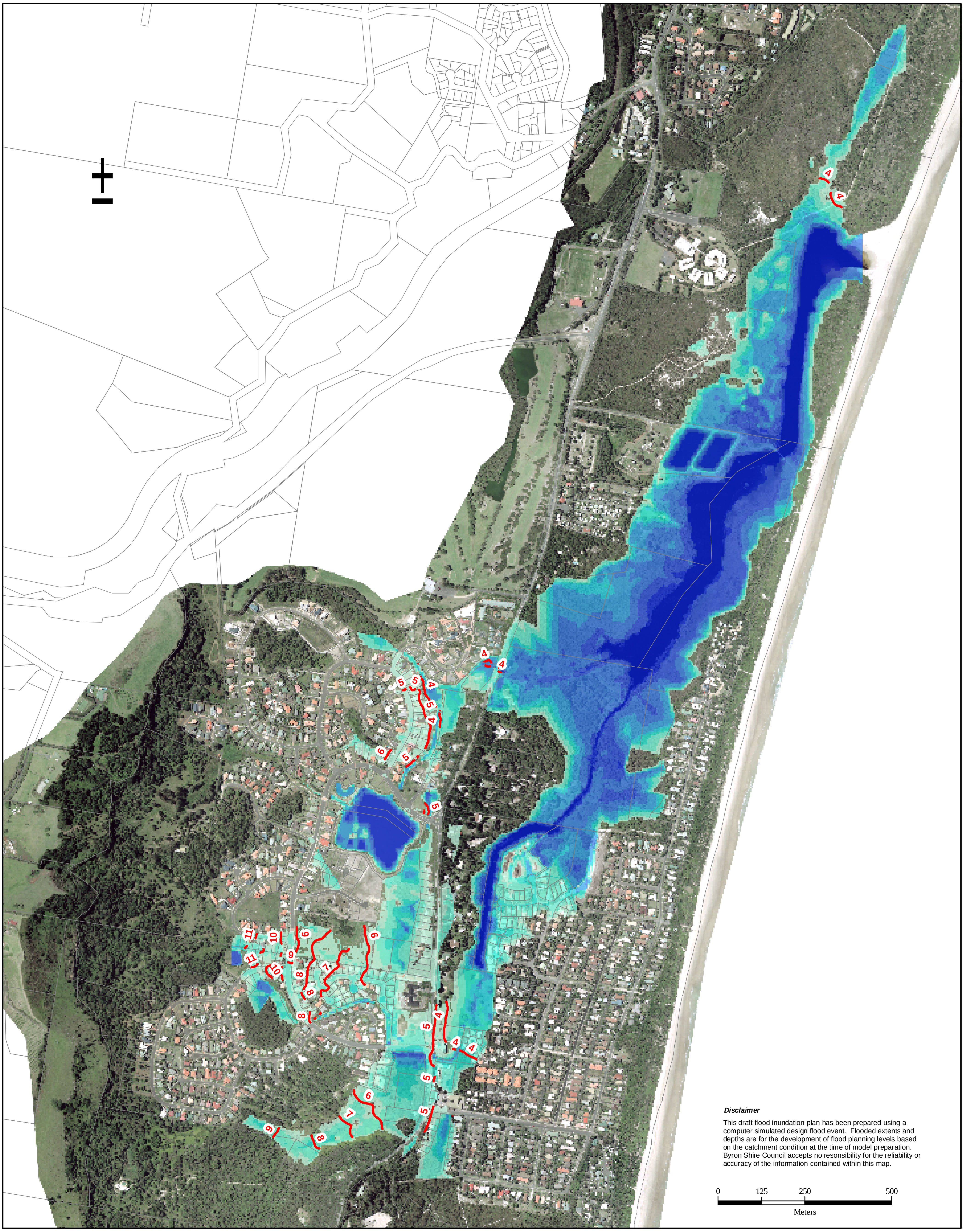


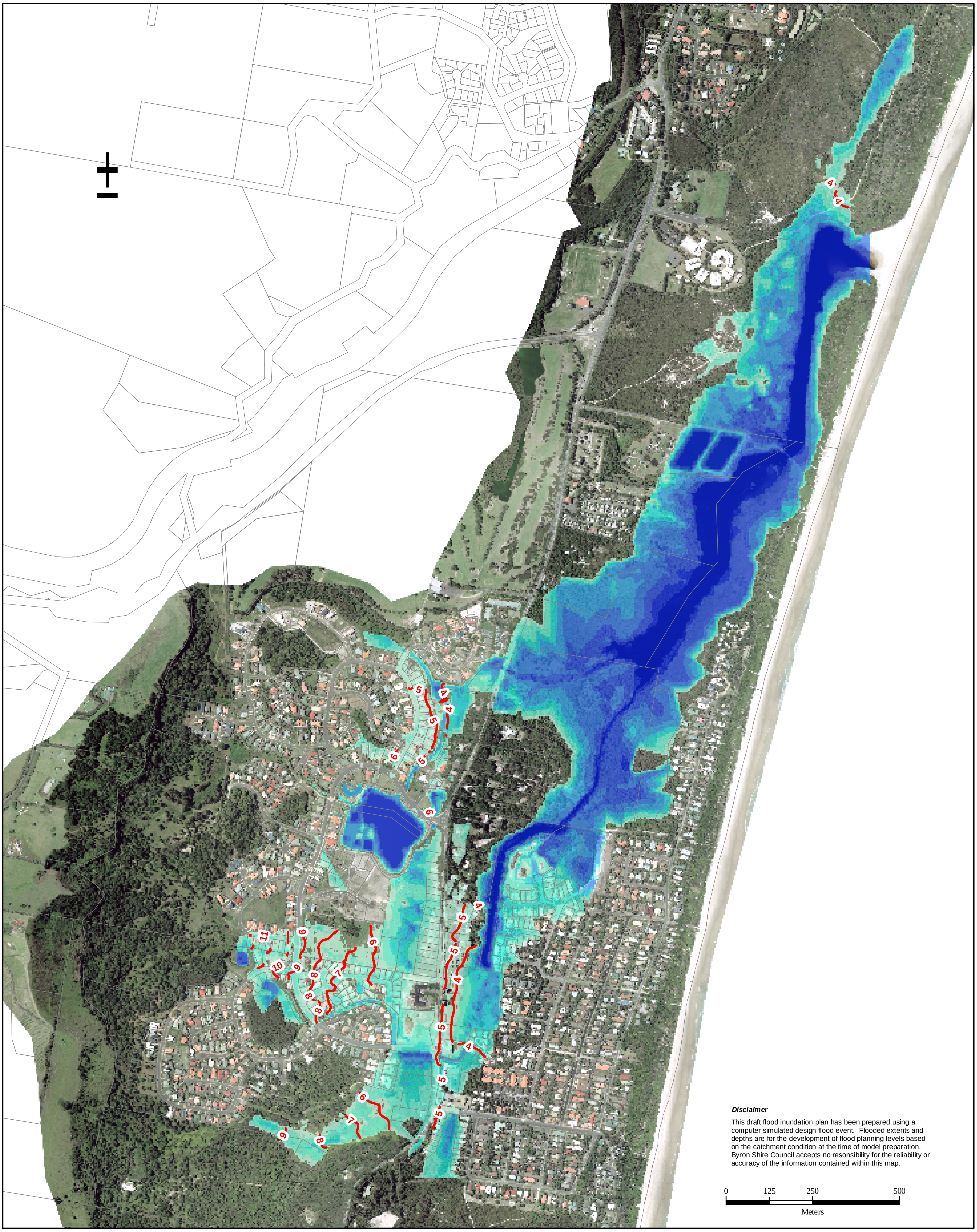
Figure B-8: Tallow Creek Climate Change Flood Risk Study - Flood Inundation Map

Maximum Flood Depth (m)

- 0.001 - 0.1 m
- 0.1 - 0.2 m
- 0.2 - 0.4 m
- 0.4 - 0.6 m
- 0.6 - 0.8 m
- 0.8 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2 m
- 2.0 - 2.5 m
- > 2.5 m
- Water Surface Level Contour (m AHD)

100 Year ARI Flood Event Scenario 3
20% Increased Rainfall Intensity
Initial Tailwater Level: 3.31m

Byron Shire Council



Filename: Flood Map Date: Feb 2008 Location: QENV Job: RE08218

Figure B-9: Tallow Creek Climate Change Flood Risk Study - Flood Inundation Map

Maximum Flood Depth (m)

0.001 - 0.1 m
0.1 - 0.2 m
0.2 - 0.4 m
0.4 - 0.6 m
0.6 - 0.8 m
0.8 - 1.0 m
1.0 - 1.5 m
1.5 - 2 m
2.0 - 2.5 m
> 2.5 m
Water Surface Level Contour (m AHD)

100 Year ARI Flood Event Scenario 4
40% Increased Rainfall Intensity
Initial Tailwater Level: 3.62m

Byron Shire Council

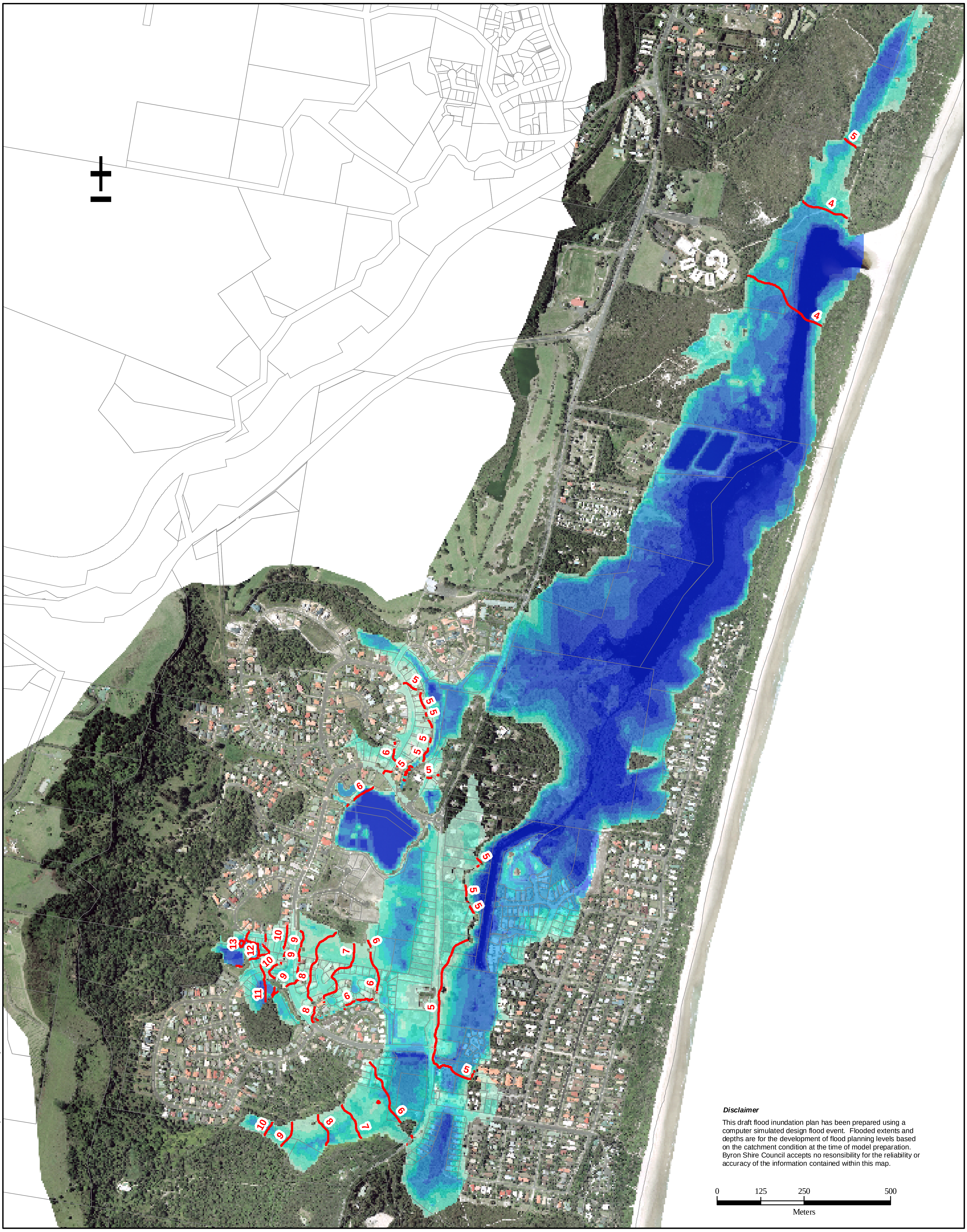


Figure B-10: Tallow Creek Climate Change Flood Risk Study - Flood Inundation Map

Maximum Flood Depth (m)

- 0.001 - 0.1 m
- 0.1 - 0.2 m
- 0.2 - 0.4 m
- 0.4 - 0.6 m
- 0.6 - 0.8 m
- 0.8 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2 m
- 2.0 - 2.5 m
- > 2.5 m
- Water Surface Level Contour (m AHD)

PMF Flood Event Scenario 4
40% Increased Rainfall Intensity
Initial Tailwater Level: 2.6m

Byron SHIRE COUNCIL

Appendix C Future Conditions Catchment Percentage Impervious

- **Table C-1 Existing Conditions RAFTS model areas Upstream of Broken Head Road**

	Subcatchment 1		Subcatchment 2				
	Pervious		*Impervious*				
Sub-catch	Total Area (ha)	% Impervious	Total Area (ha)	% Impervious	TOTAL AREA (ha)	Impervious Area (ha)	% Imperv
11	8.5	5	7.6	100	16.1	8.025	50%
31a	9.9	5	0.001	100	9.901	0.496	5%
31b	5.1	5	0.7	100	5.8	0.955	16%
32	12.4	5	2	100	14.4	2.62	18%
33	12.7	5	0.3	100	13	0.935	7%
34	3.1	5	1	100	4.1	1.155	28%
35	3.2	5	0	0	3.2	0.16	5%
36	8	5	0	0	8	0.4	5%
103	0	0	0	0	0	0	
10	9.3	5	5.6	100	14.9	6.065	41%
9	13	5	8.1	100	21.1	8.75	41%
8	14.2	5	1.8	100	16	2.51	16%
26	13.1	5	0	0	13.1	0.655	5%
29	6.3	5	0.5	100	6.8	0.815	12%
25	15.4	5	0	0	15.4	0.77	5%
28	6.5	5	3.7	100	10.2	4.025	39%
24	4.6	5	1.5	100	6.1	1.73	28%
27	5.8	5	4.1	100	9.9	4.39	44%
19	6.4	5	1.5	100	7.9	1.82	23%
15	2.4	5	1.2	100	3.6	1.32	37%
12	2.7	5	1.8	100	4.5	1.935	43%
23	10.8	5			10.8	0.54	5%
22	11.9	5	0.2	100	12.1	0.795	7%
21	8.5	5	4.5	100	13	4.925	38%
20	6.6	5	2.4	100	9	2.73	30%
17	2.1	5	1.7	100	3.8	1.805	48%
16	2.4	5	2	100	4.4	2.12	48%
14	1.9	5	0.7	100	2.6	0.795	31%
37	5	5	0.7	100	5.7	0.95	17%
13	2	5	1.7	100	3.7	1.8	49%
				TOTAL :	269.101	65.991	(ave:) 25%

Table C-2 Future Conditions RAFTS model areas Upstream of Broken Head Road

FULL DEVELOPED CASE

		Subcatchment 1		Subcatchment 2			
		Pervious		*Impervious*			
	Developed % Impervious	Total Area	Impervious	Total Area	Impervious	TOTAL AREA	Area Impervious
11	50%	8.5	5	7.6	100	16.1	8.025
31a	5%	9.9	5	0.001	100	9.901	0.496
31b	40%	3.77	5	2.03	100	5.8	2.2185
32	40%	9.36	5	5.04	100	14.4	5.508
33	40%	8.45	5	4.55	100	13	4.9725
34	28%	3.1	5	1	100	4.1	1.155
35	5%	3.2	5	0	0	3.2	0.16
36	5%	8	5	0	0	8	0.4
10	41%	9.3	5	5.6	100	14.9	6.065
9	41%	13	5	8.1	100	21.1	8.75
8	16%	14.2	5	1.8	100	16	2.51
26	30%	9.825	5	3.275	100	13.1	3.76625
29	20%	5.78	5	1.02	100	6.8	1.309
25	45%	9.24	5	6.16	100	15.4	6.622
28	39%	6.685	7	3.515	100	10.2	3.98295
24	28%	4.675	10	1.425	100	6.1	1.8925
27	44%	6.005	11	3.895	100	9.9	4.55555
19	40%	5.135	13	2.765	100	7.9	3.43255
15	40%	2.34	14	1.26	100	3.6	1.5876
12	43%	2.79	15	1.71	100	4.5	2.1285
23	38%	7.236	15	3.564	100	10.8	4.6494
22	40%	7.865	16	4.235	100	12.1	5.4934
21	38%	8.725	17	4.275	100	13	5.75825
20	30%	6.72	18	2.28	100	9	3.4896
17	48%	2.185	19	1.615	100	3.8	2.03015
16	48%	2.5	22	1.9	100	4.4	2.45
14	35%	1.82	23	0.78	100	2.6	1.1986
37	17%	5.035	24	0.665	100	5.7	1.8734
13	49%	2.085	25	1.615	100	3.7	2.13625

Appendix D Pre-development runoff rates

Existing conditions runoff rates from undeveloped catchments have been determined for the Tallow Creek catchment, to act as a guide in establishing the peak runoff mitigation methods necessary in developing sites in the catchment. Peak discharges have been estimated for the 1 in 10 year ARI flood event, as this return period corresponds to the typical design criteria for major stormwater drainage systems. It is important in restricting future catchment flooding that peak discharge from future developments are constrained such that post development storm runoff is controlled to not exceed the pre-development peak discharge for flood events up to and including the 1 in 100 year ARI flood event.

D.1 Method

Peak discharges from undeveloped sites have been estimated for catchment areas between 1 and 50 hectares, and for average catchment slope ranging between 0.5% and 10%. The peak discharges were estimated using the RAFTS computer hydrologic model, representing the each undeveloped catchment as a single catchment node. The adopted RAFTS parameters are listed in Table D-1.

- **Table D-1 RAFTS Parameters**

Description	Value
Manning's Roughness (n)	0.1
Catchment Percentage Impervious (%)	0 %
Initial Loss (mm)	10 mm
Continuing Loss (mm/hr)	2.5 mm/hr

A range of storm events were modelled to establish the critical storm duration for each catchment size and average slope. Average catchment slope for the Tallow Creek catchment is contained in the main body of the report.

D.2 Results

The critical storm duration and corresponding catchment peak discharge for Tallow Creek is shown in Table D-2. These results are plotted in the main body of the report.

Table D-2 Catchment Peak Discharges

	Slope 0.5%		Slope 1%		Slope 2%		Slope 3%		Slope 5%		Slope 10%	
Area (ha)	Critical Duration (min)	Peak Flow (m^3/s)	Critical Duration (min)	Peak Flow (m^3/s)	Critical Duration (min)	Peak Flow (m^3/s)	Critical Duration (min)	Peak Flow (m^3/s)	Critical Duration (min)	Peak Flow (m^3/s)	Critical Duration (min)	Peak Flow (m^3/s)
1	180	0.076	120	0.106	90	0.145	90	0.174	90	0.211	60	0.273
5	180	0.286	120	0.378	120	0.537	120	0.631	90	0.798	60	1.063
10	270	0.522	180	0.696	120	0.93	120	1.11	120	1.38	90	1.858
20	360	0.921	180	1.2	180	1.631	120	1.972	120	2.44	90	3.26
35	360	1.43	270	1.938	180	2.589	120	3	120	3.78	90	5.067
50	540	1.978	270	2.59	180	3.414	180	4.04	120	5.08	120	6.745

Appendix E Cost Summary Estimate for Proposed Civil Works

Project:	Coogera Circuit Detention Basin, Byron Bay			Date Updated:	18/09/2008
Task:	Pre-feasibility cost estimate			Prepared by:	SPJ
				Job No:	QE08218
Item 1	**Flood Overflow Stormwater reticulation**				
		Unit	Rate	Qty	Amount
a)	Mobilisation/demobilisation	Item	10000	1	$10,000
b)	1200 dia RCP Class FJ	m	1260	200	$252,000
c)	1500mm ext 600 manhole	no	4600	3	$13,800
d)	1200mm dia outlet with outlet protection	no	2500	1	$2,500
e)	Overflow pit - 3m x 1.5m	Item	13000	1	$13,000
f)	Topsoil	m2	10	86	$860
g)	Kerb & channel	m	60	5	$300
h)	Subsoil drainage	m	25	5	$125
i)	Pavement	Item	11600	1	$11,600
j)	Saw Cut	m	19	305	$5,795
k)	Concrete footpath 1.2m wide	m	62	5	$310
l)	Erosion and sediment control	m	10	30	$300
m)	Enviornmental measures	Item	10000	1	$10,000
n)	Open cut drain and restoration	Item	5000	1	$5,000
o)	Provision for traffic, 3 weeks	Item	7500	1	$7,500
p)	Provision for alterations/working around existing services in constructed road	Item	20000	1	$20,000
	Contingency	%	20%		$70,618
				Subtotal	$423,708
	Consultants				
	Engineering	Item	48000	1	$48,000
	Surveying	Item	3000	1	$3,000
				Subtotal	$51,000
				Item 1 Sub Total	$474,708
Item 2	**Bridge Crossing**				
a)	Culvert demolition and removal from	Item	5000	1	$5,000
b)	12m wide bridge, 4.5m length, 2x3.5m traffic lanes, 2 x 2.5m pedestrian paths	m2	3000	54	$162,000
c)	Provision for traffic, 6 weeks	Item	15000	1	$15,000
d)	Provision for alterations,/working around existing services in constructed road	Item	10000	1	$10,000
	Contingency	%	20%		$38,400
				Subtotal	$230,400
	Consultants				
	Engineering	Item	30000	1	$30,000
	Surveying	Item	2000	1	$2,000
	Geotechnical	Item	5000	1	$5,000
				Sub Total	$37,000
				Item 2 Sub Total	$267,400
				ITEM 1 & 2 TOTAL	$742,108
	Locality Increase Brisbane to Byron Bay (Based on Rawlinsons 2005)	%	1.05		$779,213
	Rates increases to September 2008 (rates supplied June 2005)	%	1.25		$974,017
				Total Cost Estimate	$974,017

NOTE:

1) Costs are current at September 2008

2) GST is additional

3) This schedule is to be read in conjunction with SKM reporting

4) Excludes landscaping , project management

5) Surveying, planning and DA approvals costing indicative only

Appendix F Revision of TUFLOW Hydraulic Model

Discussion Paper
Review of Tallow Creek
TUFLOW Model

Prepared For:	Sinclair Knight Mertz
Prepared By:	WBM Oceanics Australia

Offices

Brisbane
Denver
Karratha
Melbourne
Morwell
Newcastle
Sydney
Vancouver

DOCUMENT CONTROL SHEET

WBM Oceanics Australia		
	Document:	R.B14617.001.00.Hydraulic_Model_Discussion_Paper.doc
	Title:	Discussion Paper - Review of Tallow Creek TUFLOW Model
	Project Manager:	Bill Syme
	Author:	Lloyd Heinrich, Rosana Niven , Bill Syme
	Client:	Sinclair Knight Mertz
	Client Contact:	Ralph Birch
	Client Reference:	
	Synopsis:	This report outlines WBM's findings from the review of the existing Hydraulic model of Tallow Creek.

REVISION/CHECKING HISTORY

REVISION NUMBER	DATE	CHECKED BY		ISSUED BY	
0		WJS		LEH	

DISTRIBUTION

DESTINATION	REVISION										
	0	1	2	3	4	5	6	7	8	9	10
SKM WBM File WBM Library											

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1 INTRODUCTION

Tallow Creek is located near Byron Bay in Northern New South Wales. Tallow Creek has a natural entrance, which is relatively small, has a low tidal range and is subsequently closed off at times. The Tallow Beach embayment is bounded in the south by Broken Head and in the north by Cape Byron. The catchment is a mixture of urban and rural land as well as low lying costal flats.

In November 2002 Water Studies Pty Ltd completed the Tallow Creek Flood Study for Byron Shire Council. This study involved the development of a hydrologic (RAFTS) and a hydraulic (ESTRY/TUFLOW) model. These models were used in the original study to produce information on a number of key flooding conditions. Subsequently, Byron Shire Council is undertaking a Floodplain Risk Management Study (FRMS) for the area to analyse the risk defined in the Flood Study and to determine suitable ways in which the risk can be managed.

Sinclair Knight Merz (SKM) have been commissioned by Byron Shire Council to undertake the FRMS and WBM have been sub-contracted by SKM to carry out the hydraulic modelling component of the study using TUFLOW.

This document outlines the technical review undertaken by WBM on the original TUFLOW, 1D/2D flood model generated by Water Studies. The review involved an assessment of the suitability of the model for use in the FRMS and a full review of the current model set-up. This review includes the hydraulic model only and does not extend to the hydrological modelling.

2 DATA RECEIVED

As part of the review process WBM have collected data required for the modelling component of this study. This data has predominantly come directly from Water Studies, however, some data has been gathered from Council and SKM. The following datasets have been collected as part of the review process:

Data Type	Description	Source
Documents	Brief for the preparation of the Tallow Creek FRMS	SKM
	Tallow Creek Flood Study	Byron Shire Council
GIS	TUFLOW GIS Layers	Water Studies
	Aerial Photography	Water Studies
ESTRY	Control Files	Water Studies
	Cross Section Definition Files	Water Studies
TUFLOW	Control Files	Water Studies
	Geometry Files	Water Studies
	Manning's Definition	Water Studies
	Results Files	Water Studies

3 HYDRAULIC MODEL REVIEW

A detailed review of the most recent hydraulic model of Tallow Creek, developed by Water Studies, has been carried out by WBM. In general, the model was found to be a sound representation of the creek system and its conveyance and storage functions. The model developed by Water Studies has been supplied in its entirety, including results generated for the original Flood Study and includes components of the recent developments within the catchment. This has enabled WBM to not only review the structure but also the outputs from the model.

Although the model is generally a good representation of the Tallow Creek system, the following issues, which must be addressed, were found with the model:

1. Boundary condition application in one region was in error. This would need to be amended before further model runs were to be undertaken

2. Some significant problems have been uncovered with respect to the projections of data layers used by the 2D model. These projection errors could incorrectly place certain features within the model.

3. The interface between the 1D and 2D domains is misaligned in areas. For best performance of the models, these interfaces should always be aligned.

4. Connections between the 1D and 2D domains are redundant (not “snapped”) in a number of locations.

5. Inappropriate variation in topography has been observed in one location adjacent to a 1D-2D interface.

6. The model simulation does not appear to have been run for sufficient time to allow the downstream areas (as shown in Appendix A) to reach their peak water levels.

Preliminary testing of the model has indicated that these errors will not have a dramatic effect on flood levels or flood flow distribution within the modelling domain. It is recommended that these errors be amended and that the existing modelling results be verified. An upgrade of the model to the latest TUFLOW edition is also recommended.

Table 1 provides a summary of the review undertaken by WBM. These findings, in addition with the specific technical data presented in Appendix A, form the documentation of the review.

Table 3.1 WBM TUFLOW Review Summary

Check	Description	Result	Required Remedy
Mass Balance	• Check that conservation of mass is achieved.	• Mass is conserved within the model	• None
Boundary Conditions	• Check that the correct upstream and downstream boundary conditions are being referenced and that these are being applied to the model correctly.	• Correct upstream and downstream boundary conditions referenced. • One boundary condition not applied to the model correctly at a 1D/2D interface.	• Modify boundary condition set up.
GIS Data Layers	• Ensure that correct projection has been used in all layers used by the model. • Check that layers are spatially consistent.	• A number of layers found to have an incorrect projection. • Some special inconsistencies found between 1D and 2D boundary condition layers	• Reproject layers • GIS work required to align layers
1D Cross Sections	• Check that area designated by 1D channel is correctly represented in 2D domain	• Satisfactory representation found	• None
1D-2D Connections	• Check that connections between the 1D domain and the 2D domain are made correctly.	• In a number of positions, connection between 1D and 2D components has not been achieved	• Work required to satisfactorily connect 1D to 2D.
Ground Elevation	• Ensure that the representation of the topography that TUFLOW is using reflects the modelled situation.	• All features intended for inclusion have been interpreted by TUFLOW	• None
File Referencing	• Check that all files referenced are correct for the specific run.	• File referencing on a whole is consistent and correct	• None
Manning's n Allocation	• Check that materials GIS layer has been set up correctly referencing areas of similar roughness • Ensure that the values assigned are consistent with common theory.	• Each Material layer has an appropriate Manning's n assigned • Assigned values appear reasonable	• None
1D Topography	• Review 1D channel topography and ensure that no significant variations in elevation occur at the interface.	• One area of concern identified.	• Correct topography in area of concern

4 RECOMMENDATIONS

After reviewing the model, it has been found that some work is required to rectify a number of the problems documented. Some of the issues faced with the model are minor and are not expected to have any real influence on the results. Others however will need to be amended before confidence can be placed in results obtained from future modelling. WBM also recommends that checks be undertaken to identify any significant changes to the flood levels obtained in the original study.

Although we would recommend that all issues raised above be rectified, the key components that we believe are essential to achieving reliable flooding information are items 1, 2, 4 and 6 of Section 3. An indicative cost schedule to carry out this work is provided in Table 1.

Table 1 - Cost Schedule

Item	Cost
1 – Boundary Condition	$140
2 – Data Projection	$530
3 – 1D/2D Interface	$195
4 – 1D/2D Connection	$160
5 - Topography	$175
6 – Simulation Time	$260
Comparison between old and new results	$890
Total Indicative Cost	**$2350**

APPENDIX A: MODEL REVIEW DETAIL

The WBM review of the Tallow Creek TUFLOW model by Water Studies involved the assessment of various components of the hydraulic model. The components of a hydraulic model are numerous, thus typically a representative area of the model is assessed. WBM have carried out a review of a reasonable proportion of the model in order to verify the validity of modelling carried out thus far. The outcome of the review is detailed under the components below.

A.1 Graphical Information System (GIS) Data Layers

Examination of the GIS data layers identified two areas of concern.

The geographical reference or "projection" of several of the GIS data layers differed from the projection of the TUFLOW control files. The TUFLOW model projection is defined as GDA94 MGA Zone 56, however, several GIS data layers were projected in WGS84 UTM56 Southern Hemisphere. Table A.1 outlines the GIS data layers with differing projection.

Table A.1 GIS Data Layers with Differing Projection

GIS Data Layer	Description
1d_BC_tallow	1D boundary conditions
1d_nwk_tallow	1D network
2d_BC_tallow	2D boundary conditions
2d_BC_tallow_null	2D boundary condition null polygons/1D domain identifier
2d_code_tallow	2D model extent
2d_PO_tallow	2D plot output locations

The GIS data layers representing the 2D boundary conditions and 1D domain were not geographically consistent. The 2D boundary condition data layer did not coincide with the edge of the 1D domain. This may potentially be attributed to user error.

A.2 File references

Examination of the TUFLOW model verified the correct file references for both TUFLOW and ESTRY control files with respect to the ARI and SS of the simulation and the modelling scenario.

A.3 Ground Elevation

An assessment of the ground elevations interpreted by TUFLOW was undertaken with satisfactory results. A Digital Elevation Model (DEM) of the z-points check file was created in order to assess the inclusion of ridgelines and gullies into the TUFLOW model. Analysis of this DEM indicates that the model is successfully interpreting all ground features intended for inclusion.

A general comment is that the DEM grid resolution is coarser than the 2D grid, making the use of such a fine grid somewhat redundant. Usually, the 2D grid would be coarser in resolution than the DEM. As we are unaware of the basis for the DEM, no further comment is made.

One area was identified that displayed a moderate variation in ground topography adjacent to a 1D-2D boundary. Model instabilities were observed in this region. Figure A.1 presents the region of topography variation.

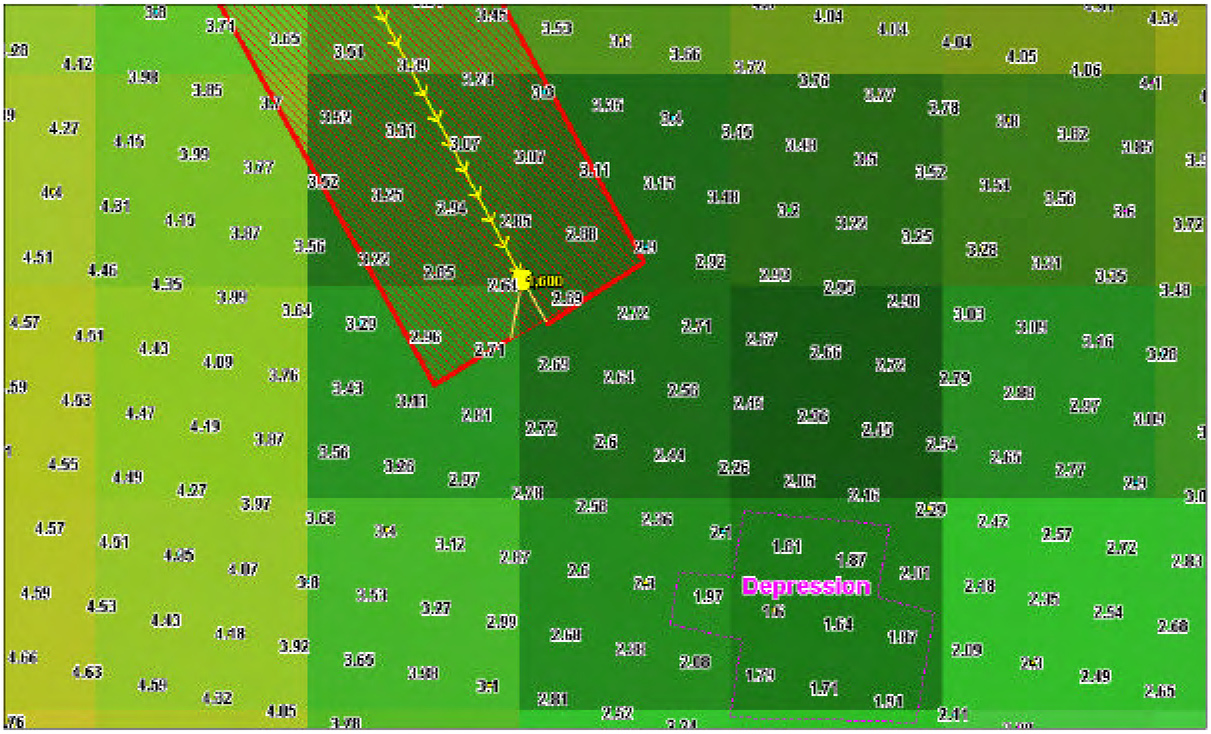

Figure A-1 Location of variation in topography

A.4 Materials and Manning's n Allocations

An evaluation of the allocation of materials and Manning's n values undertaken with the applied values deemed appropriate.

Table A.2 outlines the range of materials used in the TUFLOW model and the associated Manning's n value.

Table A.2 Water Studies TUFLOW Model Manning's n Allocations

Code	Material	Manning's n
1	Water	0.025
2	Thick vegetation	0.100
3	Short grass	0.040
4	Suburban areas	0.050
5	Houses and flow blockages	0.200
6	Roads	0.025

A.5 1D Channels

A review of the 1D topography identified that all 1D channels were represented as prismatic normal flow channels. A smooth progression of channel inverts was largely observed, however, in some areas the application of normal flow channels resulted in significant stepped changes of channel invert. In general, the inverts of the 1D channels appeared to be at a lower level than the surrounding land.

A.6 1D Node Storage

Assessment of the Tallow Creek 1D network indicated that all 1D nodes utilise the storage and inverts of the channels. In general, the channel lengths and cross-sections provide sufficient nodal water storage. A review of the cell inverts on the 1D-2D boundary was also undertaken with no indication of large invert variation and no water surges observed.

A.7 1D Cross-sections

A review of the 1D cross-sections of the TUFLOW model was undertaken with satisfactory results. The review was primarily concerned with the sections of the two-dimensional (2D) model designated as 1D domain. The defined flow width of the 1D channels must correspond with the width of the section of the 2D model designated as 1D domain in order to maintain 1D-2D consistency.

A comparison of the 2D null polygon and the 1D cross-sections indicated consistency of flow width.

A.8 Structures

Examination of the structures within the model was undertaken with satisfactory results. All structure inverts were at or below the upstream and downstream 1D channel inverts, thus no large oscillations in water levels were observed.

However, the representation of one culvert and the associated downstream channel was of a concern due to model instabilities observed in the vicinity. Figure A-2 depicts the location of this culvert.

Figure A-2 Location of 1D Culvert of Concern

A review of this culvert and downstream channel is recommended in any further hydraulic modelling.

A.9 Boundary conditions

The boundary conditions of the TUFLOW model were examined for consistency and validity. Examination of the control files for the TUFLOW model verified the correct representation of boundary conditions with respect to the Average Recurrence Interval (ARI) and Storm Surge (SS) for all simulations.

One 2D boundary condition was identified as a concern. Figure A-3 depicts the location of this 2D boundary condition.

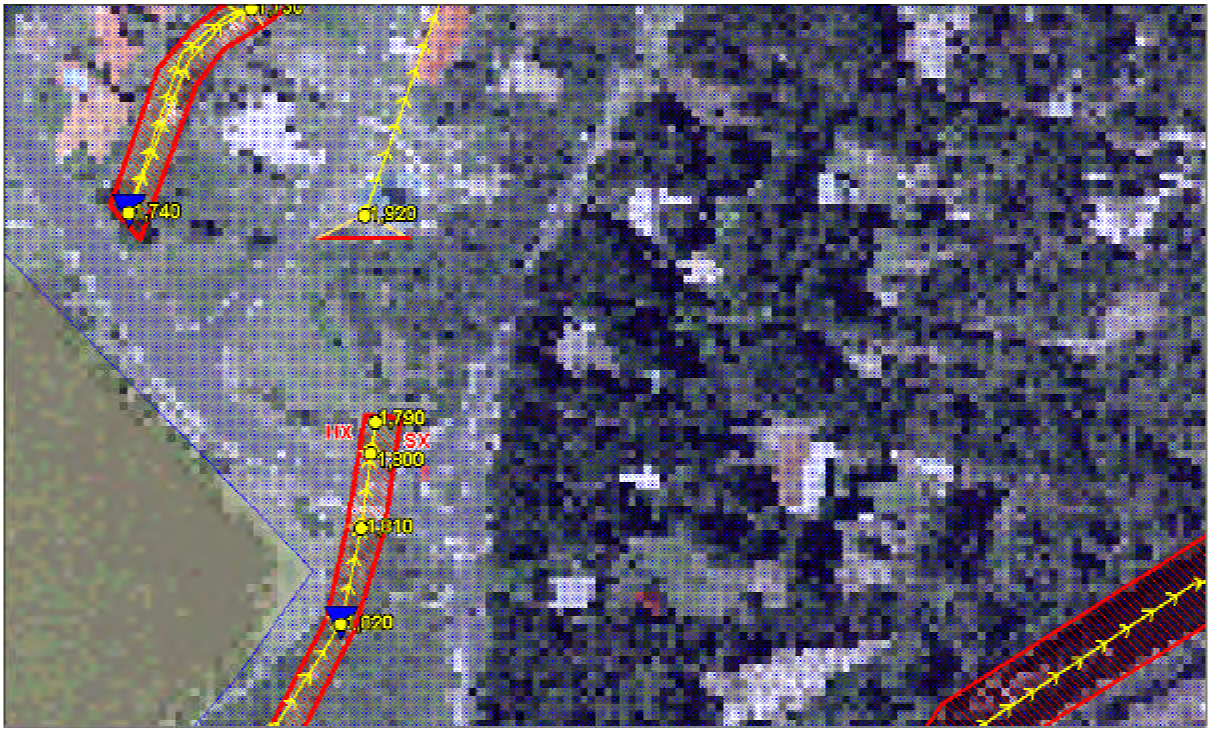

Figure A-3 Location of 2D Boundary Condition Concern

The difference in the 2D boundary condition from one side of the 1D domain to the next suggests an incorrect boundary condition representation. It is believed that the 2D boundary needs to be adjusted to a boundary condition type of “HX”, water level from a 1D model, rather than of type “SX”, a source of flow from a 1D model.

It should be noted that the arrangement of the ocean boundary is no longer supported in the latest release of TUFLOW. This will be corrected at no charge in any further modelling requirements.

A.10 1D-2D Connections

The 1D-2D model connections were reviewed with respect to the establishment of connections between the 1D and 2D domains. Several connections were identified that failed to link the 1D and 2D domains. Adjustment of these connections will be required for further hydraulic modelling.

A.11 Mass Balance

Calculations of mass conservation were carried out at a few locations in the model. The results of the analysis indicate that mass is conserved within the TUFLOW model.

A.12 Peak Flood Levels

A review of the time series results from the model indicates that the downstream part of the model does not attain the peak of the flood. This problem must be addressed for any further modelling requirements. Figure A-4 depicts the extent of the model that attains the peak of the food. The area shown in pink has not reached the peak in the existing runs.

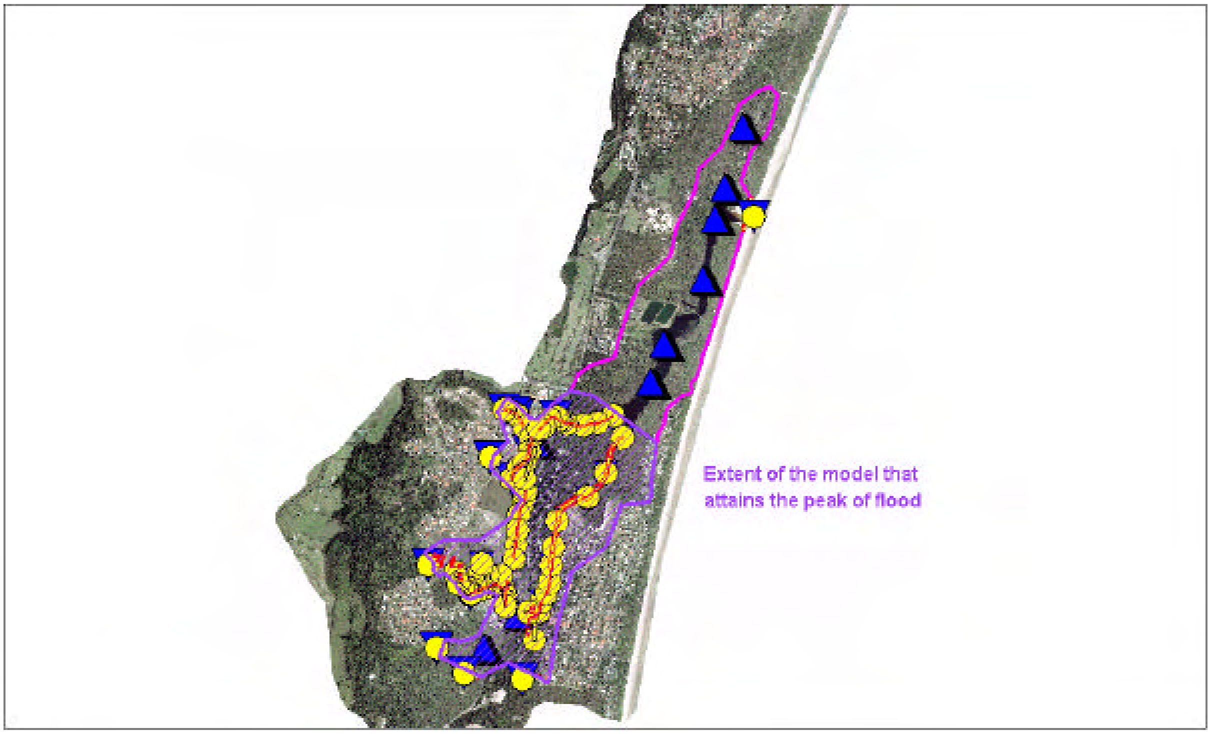

Figure A-4 Peak of Flood Extents

Appendix G Flood Planning Levels for Southern Tallow Creek

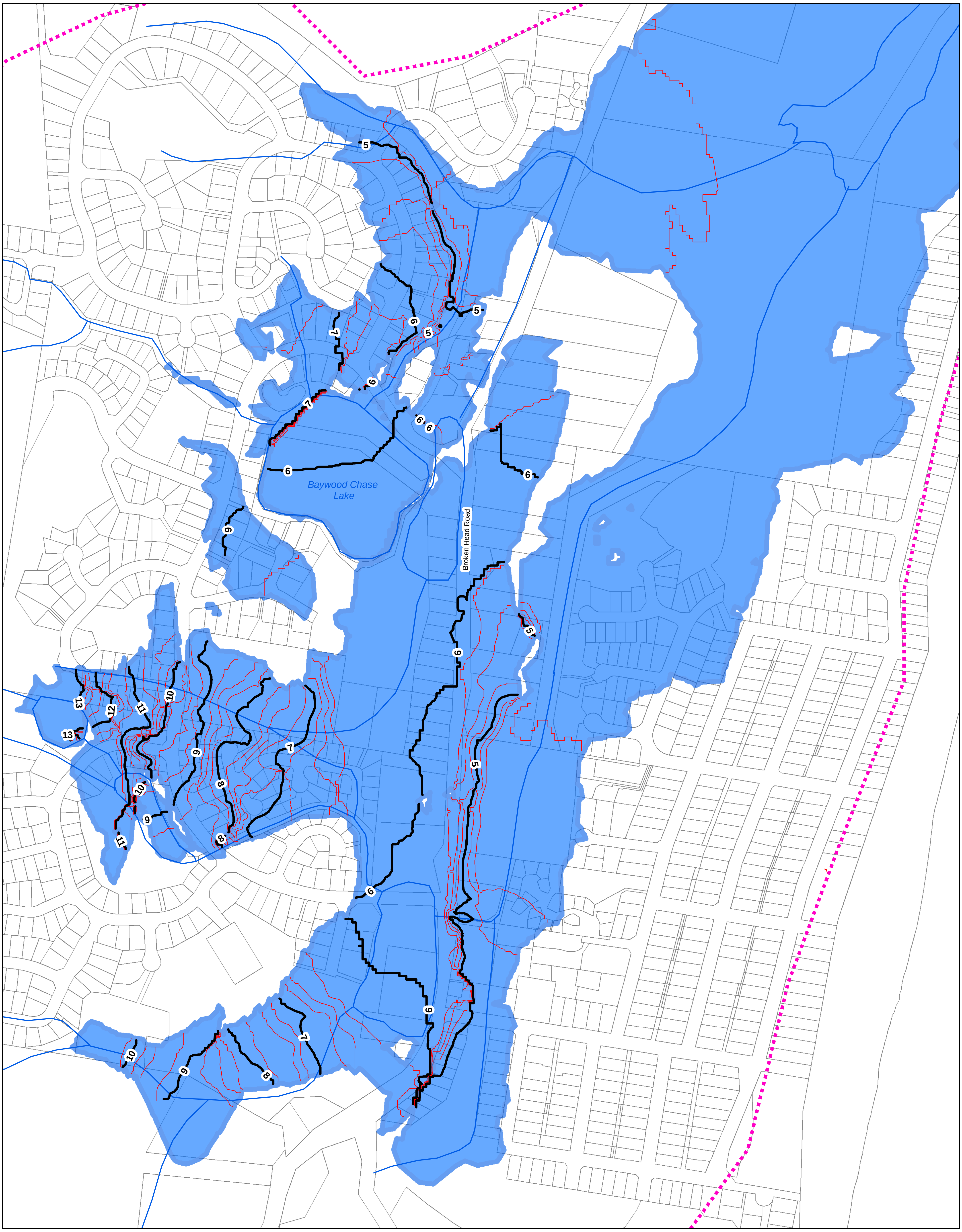

Figure G-1: Tallow Creek Flood Risk Management Study - Flood Planning Levels

Legend

- Major Water Surface Level Contours (mAHD)
- Minor Water Surface Level Contours (0.25m interval)
- Streams
- Catchment Boundary
- Flood Planning Level with Climate Change (FPL)
- Cadastral Boundaries

0 62.5 125 250 375 500 Meters

1:5,000 in A3

Filename: FPL+500mm Date: Nov 2008

Byron Shire Council

Appendix H Flood Modelling Velocity Depth Product

H.1 Existing Climate Conditions

- Figure H-1: Velocity Depth Product: 1 in 5 year ARI Flood Event
- Figure H-2: Velocity Depth Product: 1 in 20 year ARI Flood Event
- Figure H-3: Velocity Depth Product: 1 in 100 year ARI Flood Event
- Figure H-4: Velocity Depth Product: Probable Maximum Flood

Figure H-1 Tallow Creek Flood Risk Management Study - Flood Extent

1 in 5 year ARI Flood Velocity Depth Product (5 year ARI Storm Surge)

Legend

Catchment Boundary

Cadastral Boundaries

High In-Channel VxD

Velocity Depth Product (m2/s)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- > 2

Filename: 005y_VelXdep.mxd Date: June 2009

Figure H-2 Tallow Creek Flood Risk Management Study - Flood Extent

1 in 20 year ARI Flood Velocity Depth Product (5 year ARI Storm Surge)

Filename: 020y_VelXdep.mxd Date: June 2009

Legend

- Catchment Boundary
- Cadastral Boundaries
- High In-Channel VxD

Velocity Depth Product (m2/s)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5

Byron Shire Council

Figure H-3 Tallow Creek Flood Risk Management Study - Flood Extent

1 in 100 year ARI Flood Velocity Depth Product (20 year ARI Storm Surge)

Legend

Catchment Boundary

Cadastral Boundaries

High In-Channel VxD

Velocity Depth Product (m2/s)

< 0.1

0.1 - 0.25

0.25 - 0.5

0.5 - 0.75

0.75 - 1

1 - 1.5

1.5 - 2

2 - 2.5

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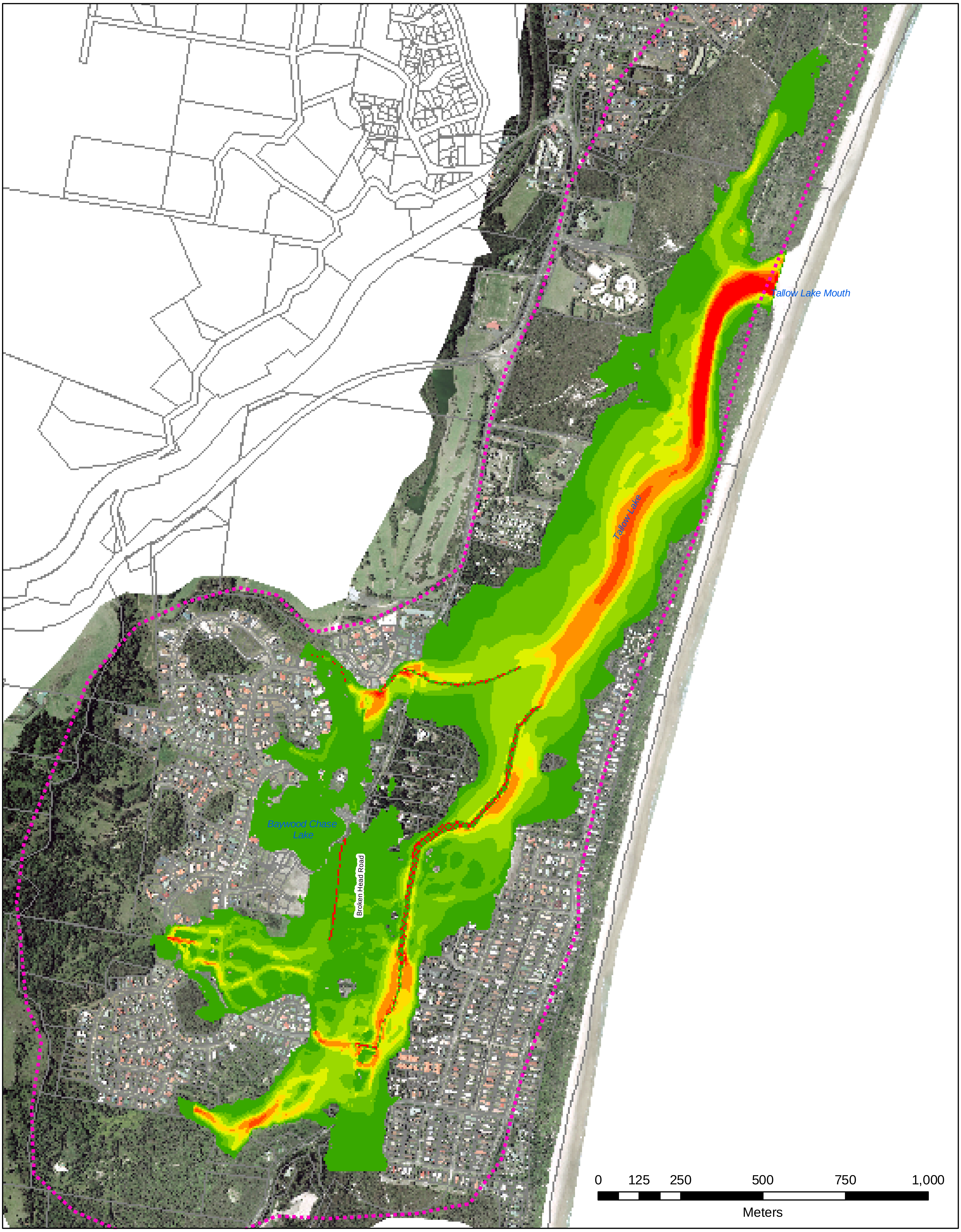
Filename: 100y_VelXdep.mxd Date: June 2009



Filename: PMF_VelXdep.mxd Date: June 2009

Figure H-4 Tallow Creek Flood Risk Management Study - Flood Extent

Probable Maximum Flood Velocity Depth Product (100 year ARI Storm Surge)

Legend

- Catchment Boundary
- Cadastral Boundaries
- High In-Channel VxD

Velocity Depth Product (m2/s)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5

Byron Shire Council

H.2 Climate Change Conditions

- Figure H-5: Velocity Depth Product: 100 year ARI Flood Event Climate Change Scenario 2
- Figure H-6: Velocity Depth Product: 100 year ARI Flood Event Climate Change Scenario 3
- Figure H-7: Velocity Depth Product: 100 year ARI Flood Event Climate Change Scenario 4
- Figure H-8: Velocity Depth Product: PMF Event Climate Change Scenario 4

Figure H-5 Tallow Creek Flood Risk Management Study - Flood Extent

100 Year ARI Climate Change Velocity Depth Product

Filename: 100yCC_VelXdep.mxd Date: June 2009

Legend

- Catchment Boundary
- Cadastral Boundaries
- High In-Channel VxD

Velocity Depth Product (m2/s)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5

Climate Change Scenario 2
10% Increased Rainfall Intensity
Inital Tailwater Level 2.91 m AHD

Byron SHIRE COUNCIL

Figure H-6 Tallow Creek Flood Risk Management Study - Flood Extent

100 Year ARI Climate Change Velocity Depth Product

Legend

Catchment Boundary

Cadastral Boundaries

High In-Channel VxD

Velocity Depth Product (m2/s)

< 0.1

0.1 - 0.25

0.25 - 0.5

0.5 - 0.75

0.75 - 1

1 - 1.5

1.5 - 2

2 - 2.5

Climate Change Scenario 3
20% Increased Rainfall Intensity
Initial Tailwater Level 3.31 m AHD

Filename: 100yCC_S3_VelXdep.mxd Date: June 2009

Filename: 100yCC_S4_VelXdep.mxd Date: June 2009

Figure H-7 Tallow Creek Flood Risk Management Study - Flood Extent

100 Year ARI Climate Change Velocity Depth Product

Legend

- Catchment Boundary
- Cadastral Boundaries
- High In-Stream VxD

Velocity Depth Product (m2/s)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5

Scenario 4
40% Increased Rainfall Intensity
Initial Tailwater Level 3.62 m AHD

Byron Shire Council

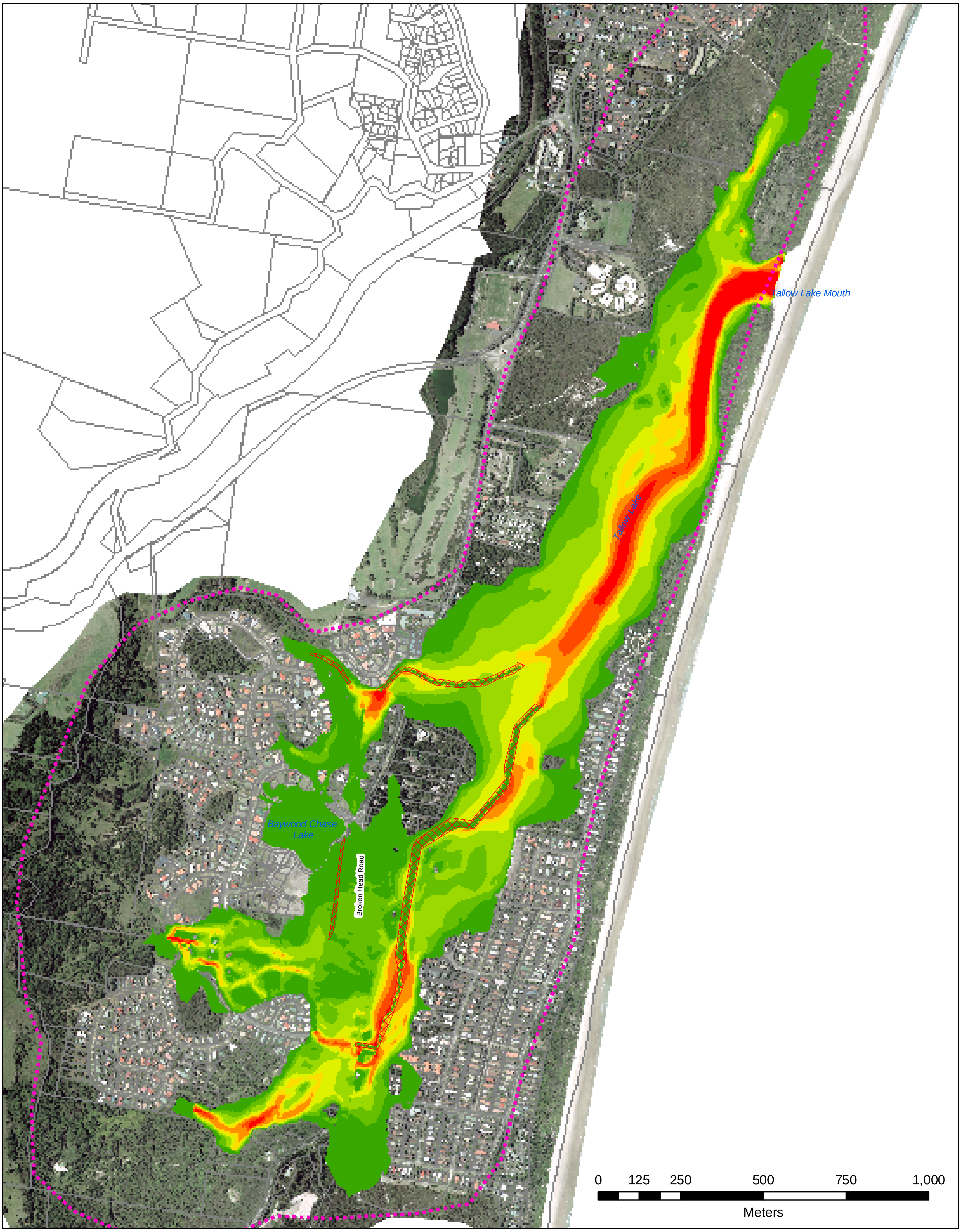


Figure H-8 Tallow Creek Flood Risk Management Study - Flood Extent

PMF Climate Change Velocity Depth Product

Legend

- Catchment Boundary
- Cadastral Boundaries
- High In-Channel VxD

Velocity Depth Product (m2/s)

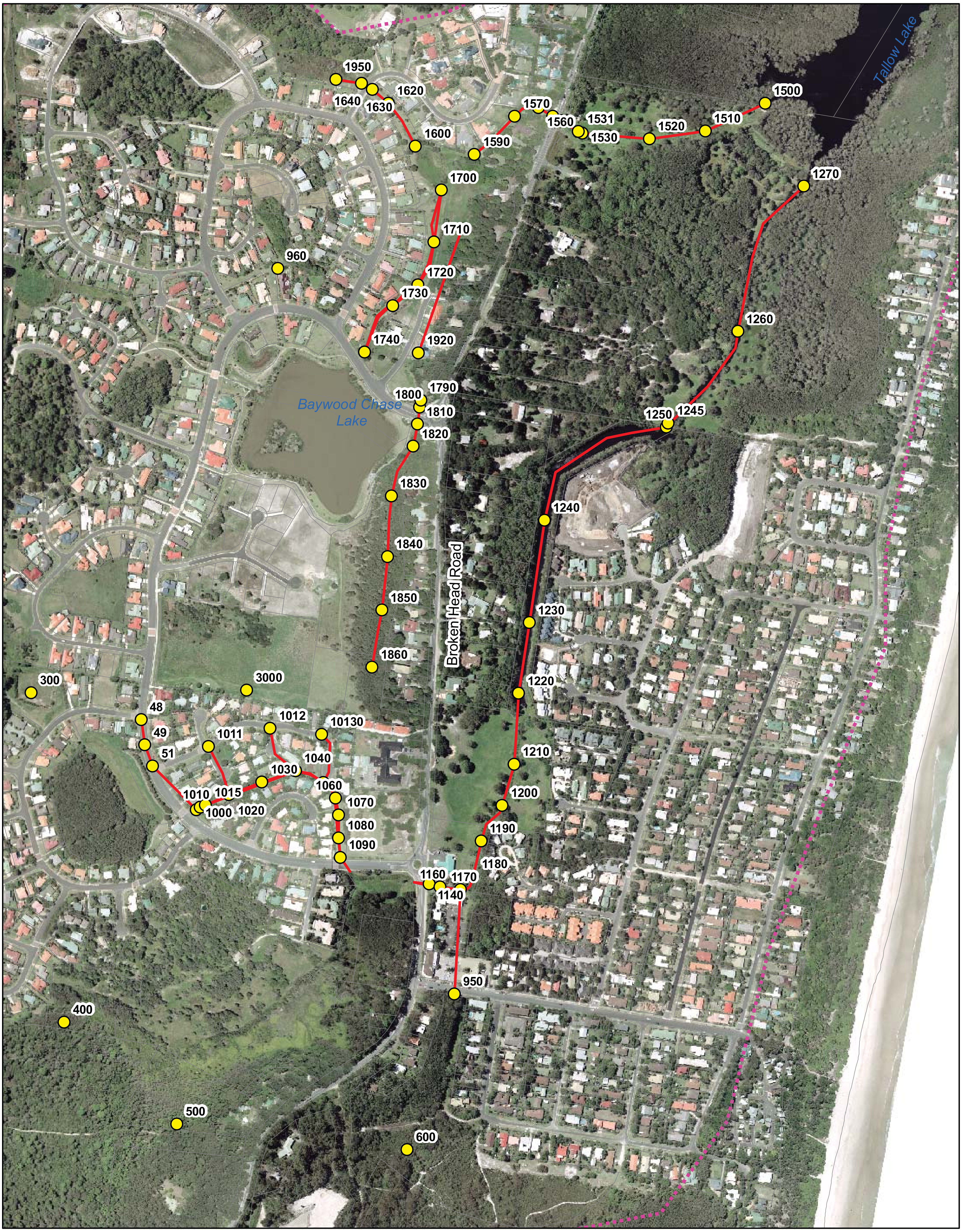
- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5

Climate Change Scenario 4
40% Increased Rainfall Intensity
Initial Tailwater Level 3.36 m AHD

Byron Shire Council

Filename: PMFCC_VelXdep.mxd Date: June 2009

Appendix I Hydraulic Model Node Results



Tallow Creek Flood Risk Management Study - Design Flood Levels

100 year ARI with Climate Change

Legend

Catchment Boundary
Cadastral Boundaries
Flood Model Node
Flood Model Network

0 62.5 125 250 375 500

Meters

N

Filename: Tallow_Nodes.mxd Date: July 2009

Tallow Creek Flood Risk Management Study
Design Flood Levels
Prepared on 17/07/2009

Climate change water levels are based on a computer simulated design flood event for a given climate change scenario. Water surface levels are provided for the development of flood planning levels based on the catchment condition at the time of model preparation. Byron Shire Council accepts no resonsibility for the reliability or accuracy of the information contained within this table.

TABLE 1: 100 year ARI Climate Change Flood Levels and Flood Planning Levels

Node	100 year ARI Climate Change Water Level (m AHD)	Flood Planning Level (m AHD)
48	9.03	9.53
49	8.82	9.32
51	8.55	9.05
300	12.59	13.09
400	9.99	10.49
500	8.53	9.03
600	4.47	4.97
950	4.48	4.98
960	6.8	7.3
1000	7.02	7.52
1010	6.81	7.31
1011	7.22	7.72
1012	6.27	6.77
1015	6.63	7.13
1020	6.45	6.95
1030	6.28	6.78
1040	6.15	6.65
1050	5.75	6.25
1060	5.61	6.11
1070	5.59	6.09
1080	5.56	6.06
1090	5.54	6.04
1140	4.42	4.92
1160	4.4	4.9
1170	4.2	4.7
1180	4.15	4.65
1190	3.89	4.39
1200	3.81	4.31
1210	3.8	4.3
1220	3.76	4.26
1230	3.75	4.25
1240	3.75	4.25
1245	3.75	4.25
1250	3.75	4.25
1260	3.74	4.24

Node	100 year ARI Climate Change Water Level (m AHD)	Flood Planning Level (m AHD)
1270	3.75	4.25
1500	3.83	4.33
1510	3.81	4.31
1520	3.84	4.34
1530	3.87	4.37
1531	3.85	4.35
1540	3.84	4.34
1550	3.92	4.42
1560	3.99	4.49
1570	3.92	4.42
1580	3.93	4.43
1590	3.95	4.45
1600	4.01	4.51
1620	4.13	4.63
1630	4.17	4.67
1640	4.27	4.77
1700	4.01	4.51
1710	4.35	4.85
1720	4.7	5.2
1730	4.95	5.45
1740	5.42	5.92
1800	5.37	5.87
1810	5.52	6.02
1820	5.52	6.02
1830	5.52	6.02
1840	5.52	6.02
1850	5.52	6.02
1860	5.52	6.02
1920	5.06	5.56
1950	4.27	4.77
3000	6.93	7.43
10130	5.79	6.29
105.2	5.52	6.02
140.1	5.5	6
960.2	3.92	4.42

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James Flockton
Byron Shore Council
PO Box 219
Mullumbimby NSW 2482

4 July 2014 QE06960

Dear James,

Tallow Creek revised Flood mapping

Introduction

Following Councils decision to adopt the Climate Change Strategic Planning Policy on the 26th June 2014 the Tallow Creek Tuflow model has been re-run for the scenarios outlined in the policy.

Previous modelling was undertaken in 2008 using the more conservative but similar climate change scenarios. For the purposes of this work, the existing model has been used with the only changes be made as a result of changes to the catchment inflow initial water levels/tail water levels as per the policy.

Modelled Scenarios

The scenarios modelled are in line with Table 1 of the Climate Change Strategic Planning Policy with the exception of an additional two requested scenarios. The modelled scenarios outlined in Table 1 below.

As noted the results have been enveloped in post processing where multiple simulations produce a single scenario.

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Table 1 – Modelled Scenarios

Scenario	Catchment Inflow (AEP)	Tailwater Condition (mAHD)	Enveloping Approach
10% AEP	10% AEP	2.1m	No enveloping required
1% AEP	5% AEP	2.6m	Results enveloped
	1% AEP	2.2m	
1% AEP 2050	5% AEP	2.6m	Results enveloped
	1% AEP	2.4m	
1% AEP 2100	5% AEP	3.1m	Results enveloped
	1% AEP	2.9m	
Sensitivity run 1	5% AEP +10%	2.6m	Results enveloped
	1% AEP +10%	2.4m	
Sensitivity run 2	5% AEP +30%	3.1m	Results enveloped
	1% AEP +30%	2.9m	
Sensitivity run 3	1% AEP +30%	3.1m	No enveloping required
PMF	PMF	3.6m	No enveloping required

Hydrology

As with the hydraulic model, the hydrologic model (XP-RAFTS) has been adopted where possible. There was no requirement to modify the structure of the model however new design events were included to produce catchment inflows for the 10% AEP, 5% AEP + 10%, 5% AEP + 30%, 1% AEP + 10% and 1% AEP + 30%.

The rainfall depths applied and temporal patterns have remained as those generated with Australian Rainfall and Runoff 1987.

Hydraulic Software

As noted in the proposal, the model was not fully compatible with the latest version of the software. As a result of the age of the model build and the numerous upgraded releases of the software between the model build and now, the limit of backwards compatibility switches was surpassed. As a result the model was re-run using TUFLOW Build-2007-07-DB.

Model Outputs

Three paramaters being peak depth (d), peak water surface level (h) and peak depth velocity product (Z0) have been produced for each of the scenarios modelled excluding PMF which has been run for flood extent only.

Subsequent to this, the 2050 and 2100 scenarios have been used to provide peak water surface maps with a 500mm freeboard applied.

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In order to do this an extrapolated extent has been approximated by projecting the resultant water surface level outward until an intersection with the digital terrain model has been achieved.

Conclusions/Recommendations

It is noted that due to the topography of the Tallow Creek catchment there are two distinct areas with Tallow Lake peak water levels being driven by tailwater levels and the managed level of the Tallow creek Sandbar, and the upper catchment being driven by response to rainfall.

With this in mind the results of the 1% AEP, 1% AEP 2050 and 1% AEP 2100 will all produce the same results in the area driven by rainfall.

Yours sincerely

Shannon Dooland
Section leader, Water Resources
3026 7237
Shannon Dooland@Jacobs.com

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Table 2 100year ARI Climate Change Flood levels and Planning Levels

Node	1% AEP 2050 (mAHD)	1% AEP 2050 + 500mm Freeboard (mAHD)	1% AEP 2100 (mAHD)	1% AEP 2100 + 500mm Freeboard (mAHD)
48	8.93	9.43	8.93	9.43
49	8.73	9.23	8.73	9.23
51	8.43	8.93	8.43	8.93
300	12.44	12.94	12.44	12.94
400	9.83	10.33	9.83	10.33
500	8.46	8.96	8.46	8.96
600	4.13	4.63	4.13	4.63
950	3.73	4.23	3.77	4.27
960	6.67	7.17	6.67	7.17
1000	5.44	5.94	5.44	5.94
1010	5.44	5.94	5.44	5.94
1011	7.12	7.62	7.12	7.62
1012	6.04	6.54	6.04	6.54
1015	5.44	5.94	5.44	5.94
1020	5.44	5.94	5.44	5.94
1030	5.44	5.94	5.44	5.94
1040	5.44	5.94	5.44	5.94
1050	5.44	5.94	5.44	5.94
1060	5.44	5.94	5.44	5.94
1070	5.44	5.94	5.44	5.94
1080	5.44	5.94	5.44	5.94
1090	5.44	5.94	5.44	5.94
1140	3.75	4.25	3.79	4.29
1160	3.75	4.25	3.78	4.28
1170	3.72	4.22	3.76	4.26
1180	3.70	4.20	3.74	4.24
1190	3.34	3.84	3.41	3.91
1200	3.16	3.66	3.26	3.76

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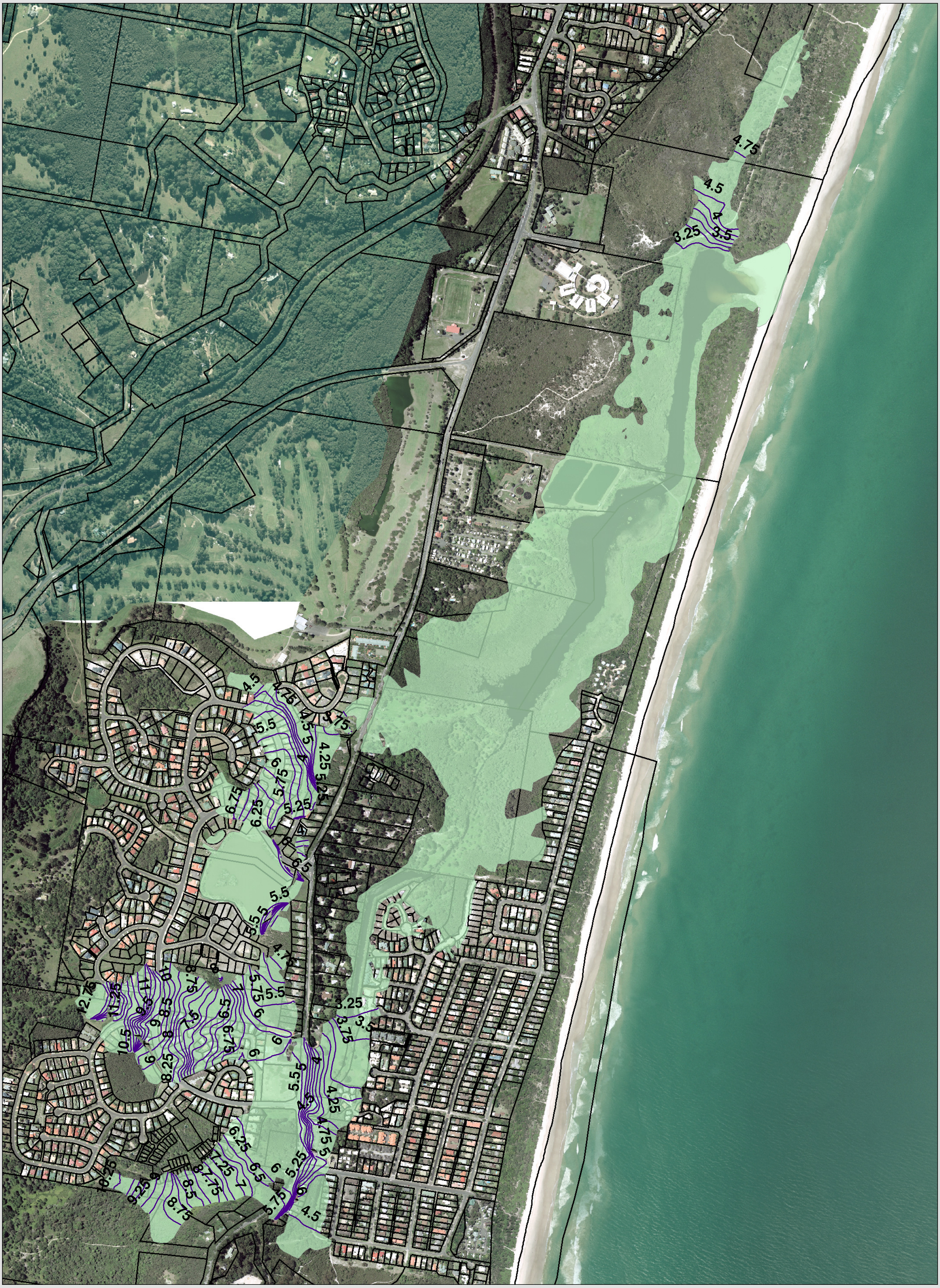
Node	1% AEP 2050 (mAHD)	1% AEP 2050 + 500mm Freeboard (mAHD)	1% AEP 2100 (mAHD)	1% AEP 2100 + 500mm Freeboard (mAHD)
1210	3.11	3.61	3.23	3.73
1220	2.73	3.23	3.16	3.66
1230	2.72	3.22	3.16	3.66
1240	2.71	3.21	3.15	3.65
1245	2.69	3.19	3.15	3.65
1250	2.70	3.20	3.15	3.65
1260	2.68	3.18	3.14	3.64
1270	2.66	3.16	3.13	3.63
1500	2.66	3.16	3.13	3.63
1510	2.66	3.16	3.13	3.63
1520	2.66	3.16	3.13	3.63
1530	2.66	3.16	3.13	3.63
1531	2.67	3.17	3.14	3.64
1540	2.67	3.17	3.14	3.64
1550	2.73	3.23	3.15	3.65
1560	2.74	3.24	3.15	3.65
1570	2.75	3.25	3.15	3.65
1580	2.75	3.25	3.15	3.65
1590	2.75	3.25	3.15	3.65
1600	3.80	4.30	3.80	4.30
1620	3.80	4.30	3.80	4.30
1630	3.80	4.30	3.80	4.30
1640	3.80	4.30	3.80	4.30
1700	3.82	4.32	3.82	4.32
1710	3.83	4.33	3.83	4.33
1720	3.83	4.33	3.83	4.33
1730	3.83	4.33	3.83	4.33
1740	3.83	4.33	3.83	4.33
1800	4.20	4.70	4.20	4.70

Node	1% AEP 2050 (mAHD)	1% AEP 2050 + 500mm Freeboard (mAHD)	1% AEP 2100 (mAHD)	1% AEP 2100 + 500mm Freeboard (mAHD)
1810	4.20	4.70	4.20	4.70
1820	4.20	4.70	4.20	4.70
1830	4.20	4.70	4.20	4.70
1840	4.20	4.70	4.20	4.70
1850	4.20	4.70	4.20	4.70
1860	4.20	4.70	4.20	4.70
1920	3.27	3.77	3.26	3.76
1950	3.80	4.30	3.80	4.30
3000	6.88	7.38	6.88	7.38
10130	5.74	6.24	5.74	6.24
105.2	5.40	5.90	5.40	5.90
140.1	5.37	5.87	5.37	5.87
960.2	3.32	3.82	3.31	3.81



Tallow Creek 2014 Update
2050 Flood Planning Level Map

0 55 110 220 330 440 Metres

Byron Shire Council

Byron Shire

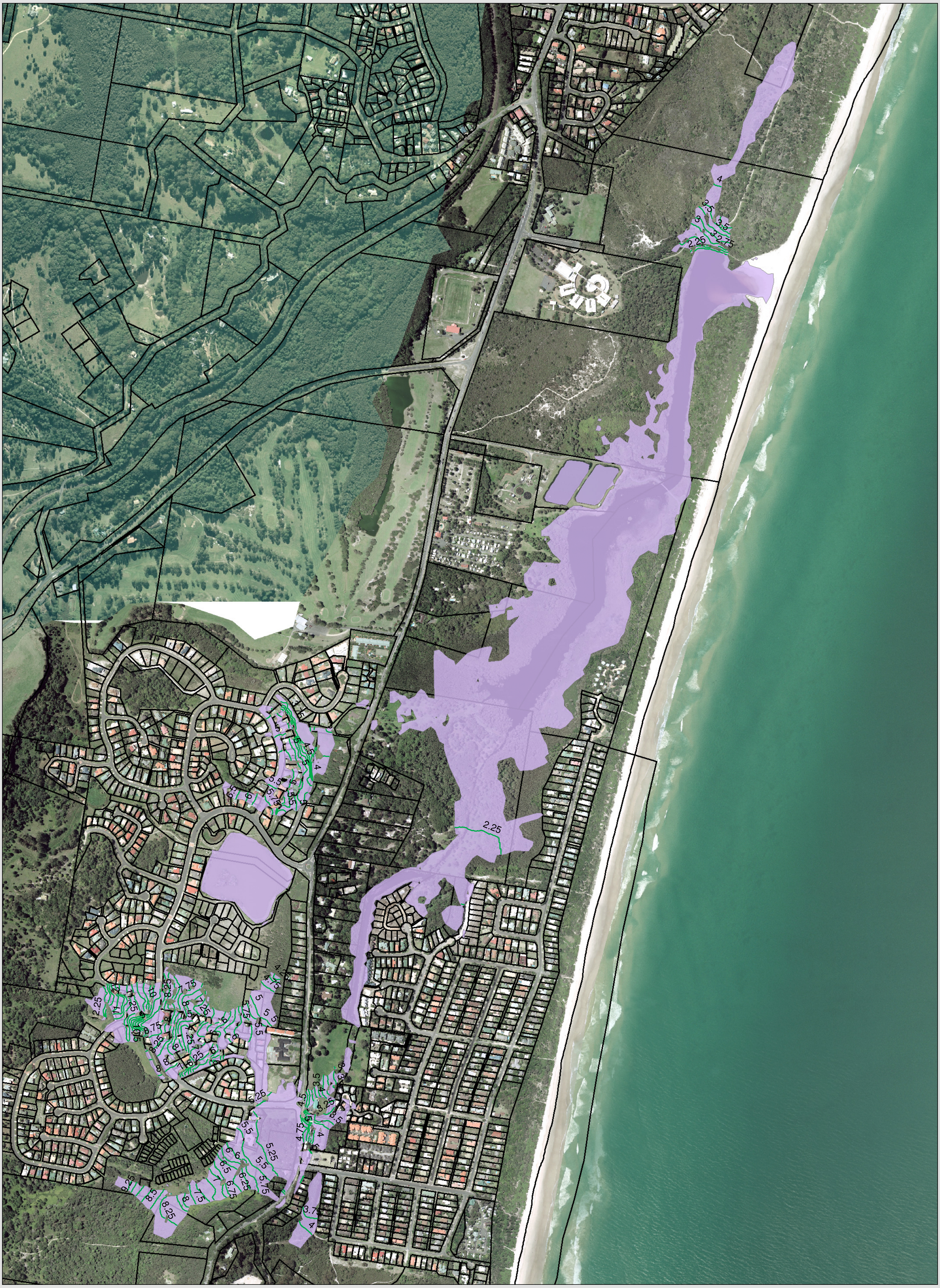
Tallow Creek 2014 Update
2100 Flood Planning Level Map

0 55 110 220 330 440 Metres

Byron Shire Council

Pacific Ocean

Byron Shire

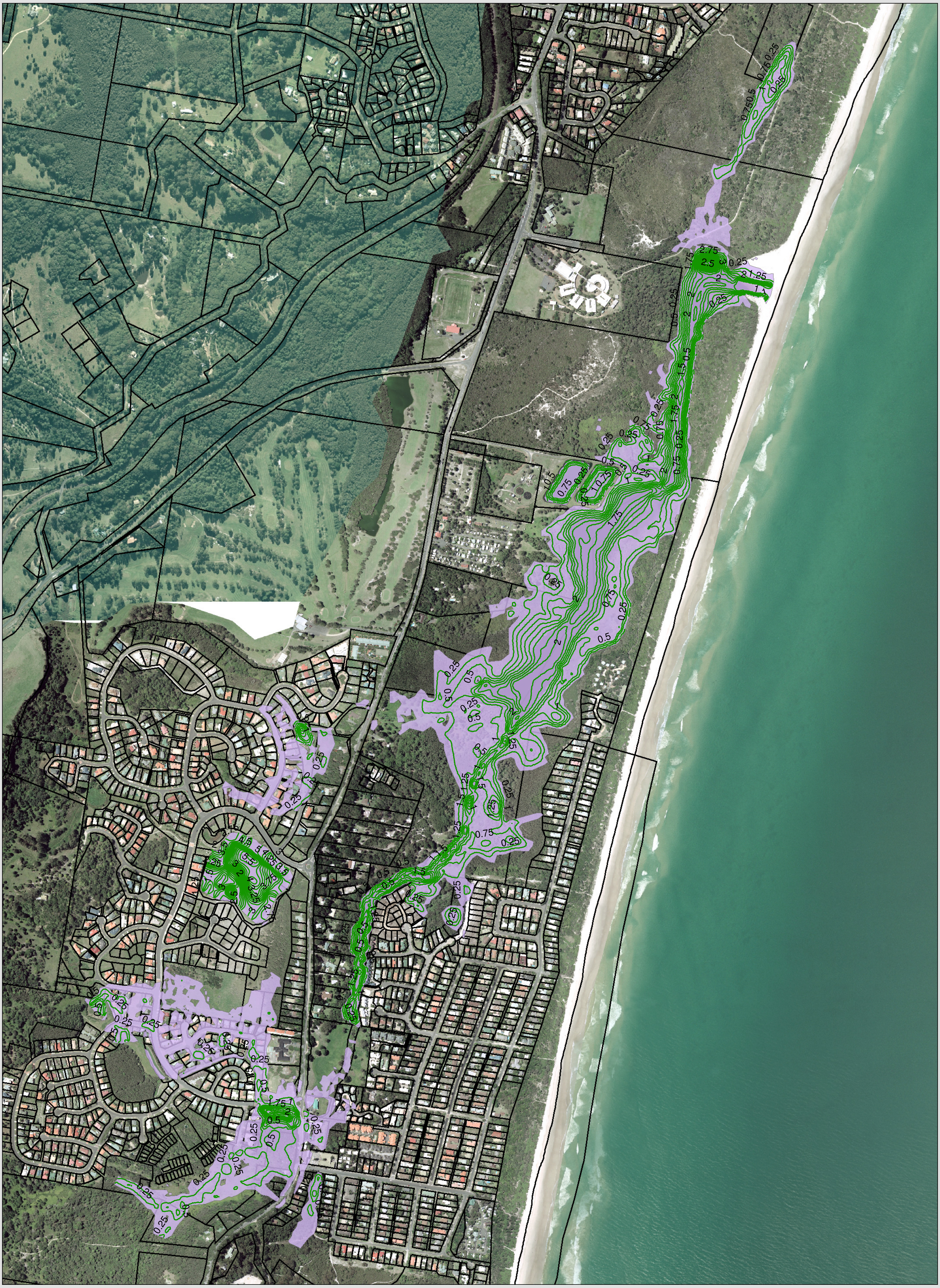


Tallow Creek 2014 Update
10 Year Flood Water Surface Level Map

0 40 80 160 240 320 Metres

Byron Shire Council

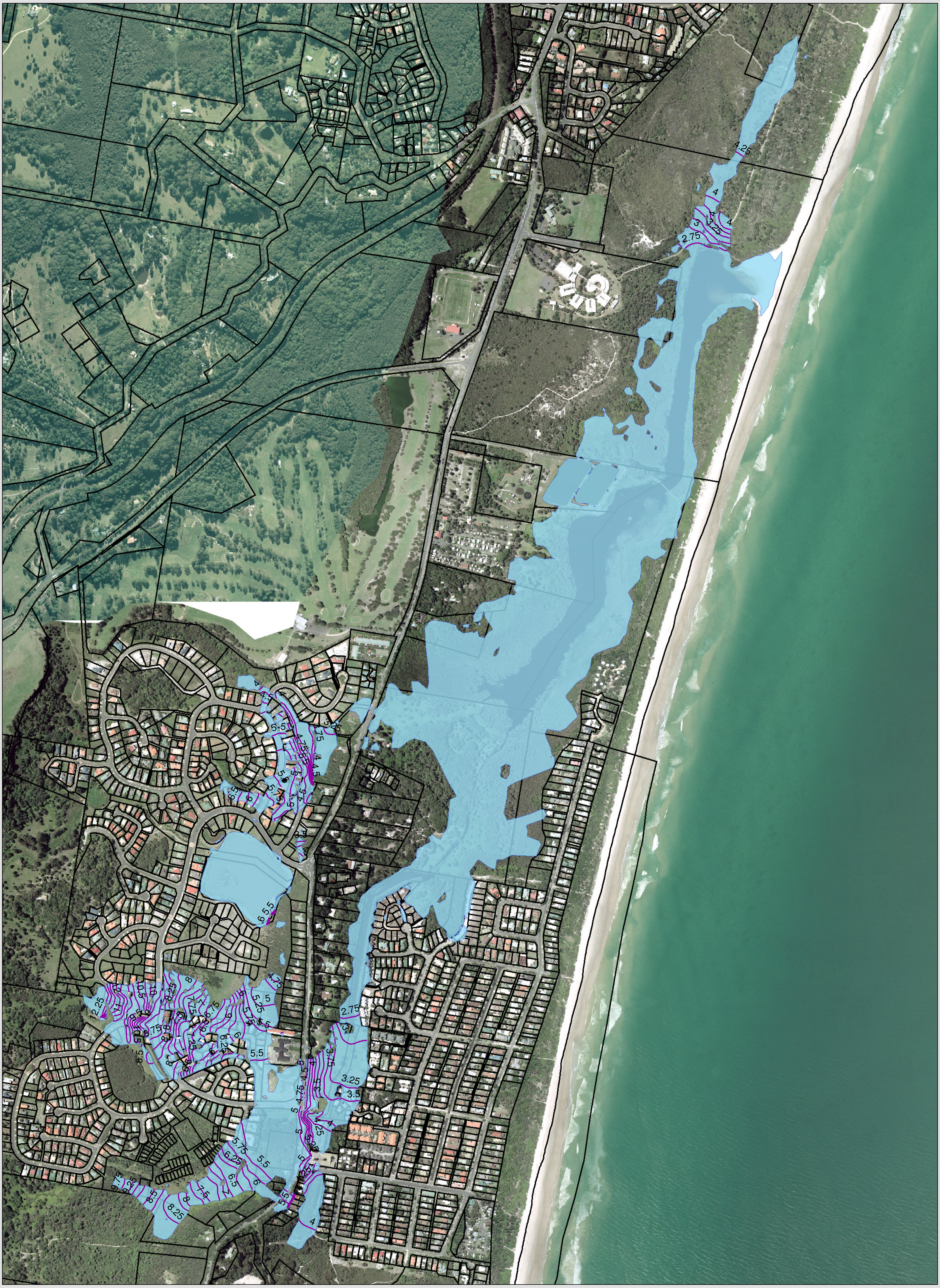
Byron Shire



Tallow Creek 2014 Update
10 Year Flood Water Depth Map

Metres
0 40 80 160 240 320

Byron Shire

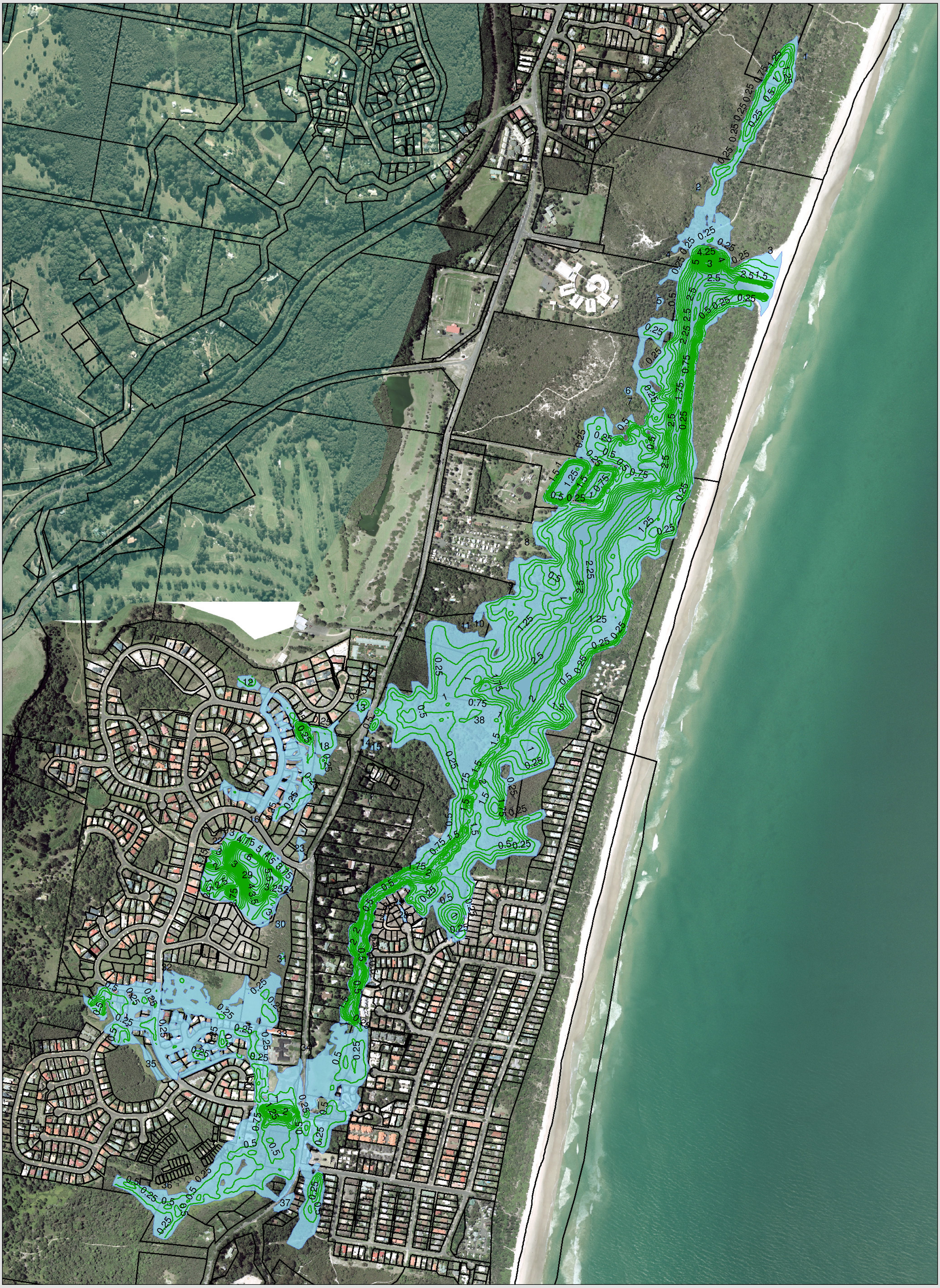


Tallow Creek 2014 Update
100 Year Flood Water Surface Level Map

0 40 80 160 240 320 Metres

Byron Shire Council

Byron Shire



Tallow Creek 2014 Update
100 Year Flood Water Depth Map

Metres
0 40 80 160 240 320

Byron Shire Council

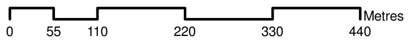
Pacific Ocean
Byron Shire

Tallow Creek 2014 Update
100 year flood 2050 Water Surface Level Map

0 55 110 220 330 440 Metres

Pacific Ocean
Byron Shire

Tallow Creek 2014 Update
100 year flood 2050 Depth Map



Tallow Creek 2014 Update
100 year flood 2100 Water Surface Level Map

Byron Shire Council

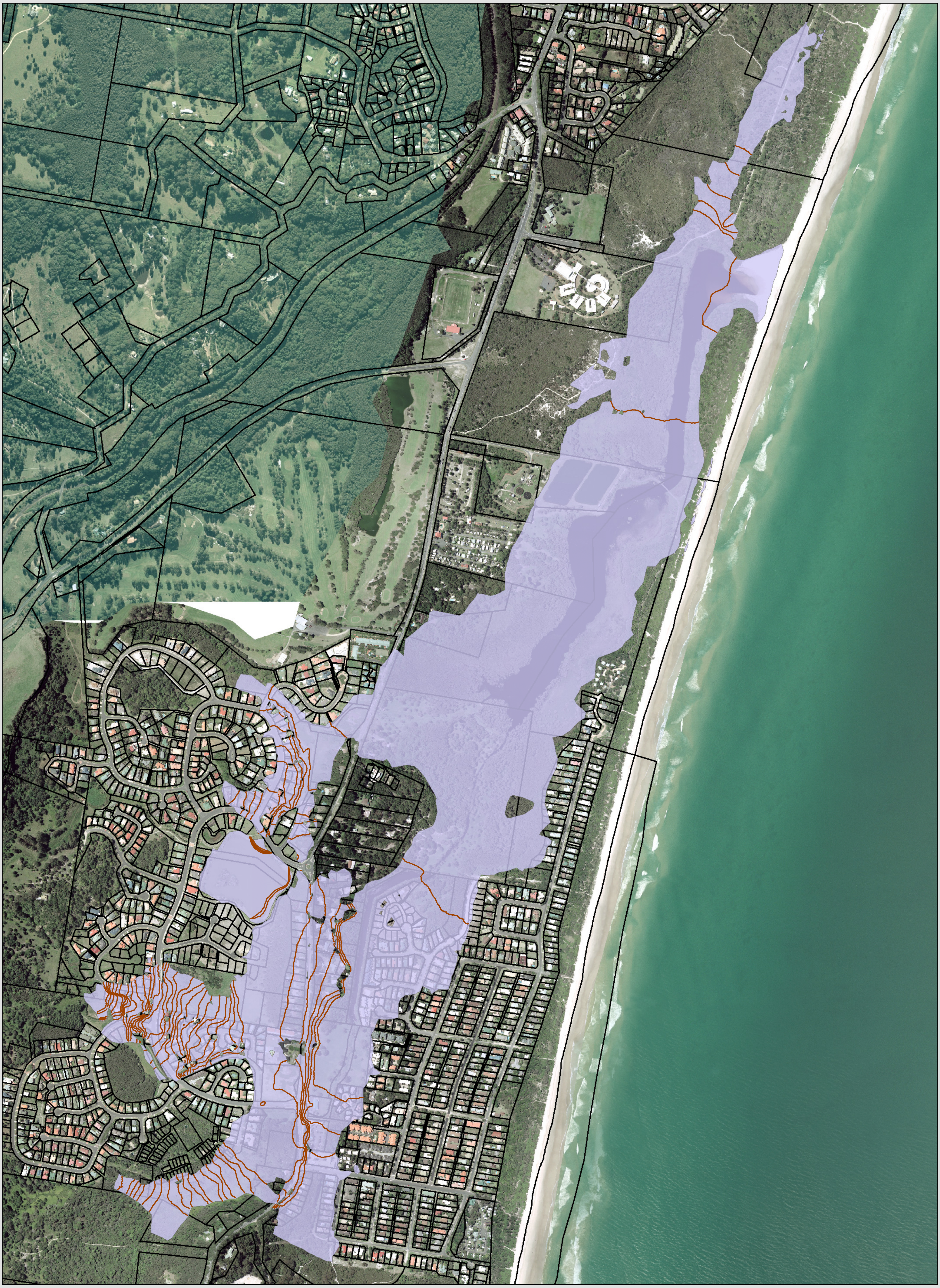
Byron Shire Council

Tallow Creek 2014 Update
100 year flood 2100 Depth Map

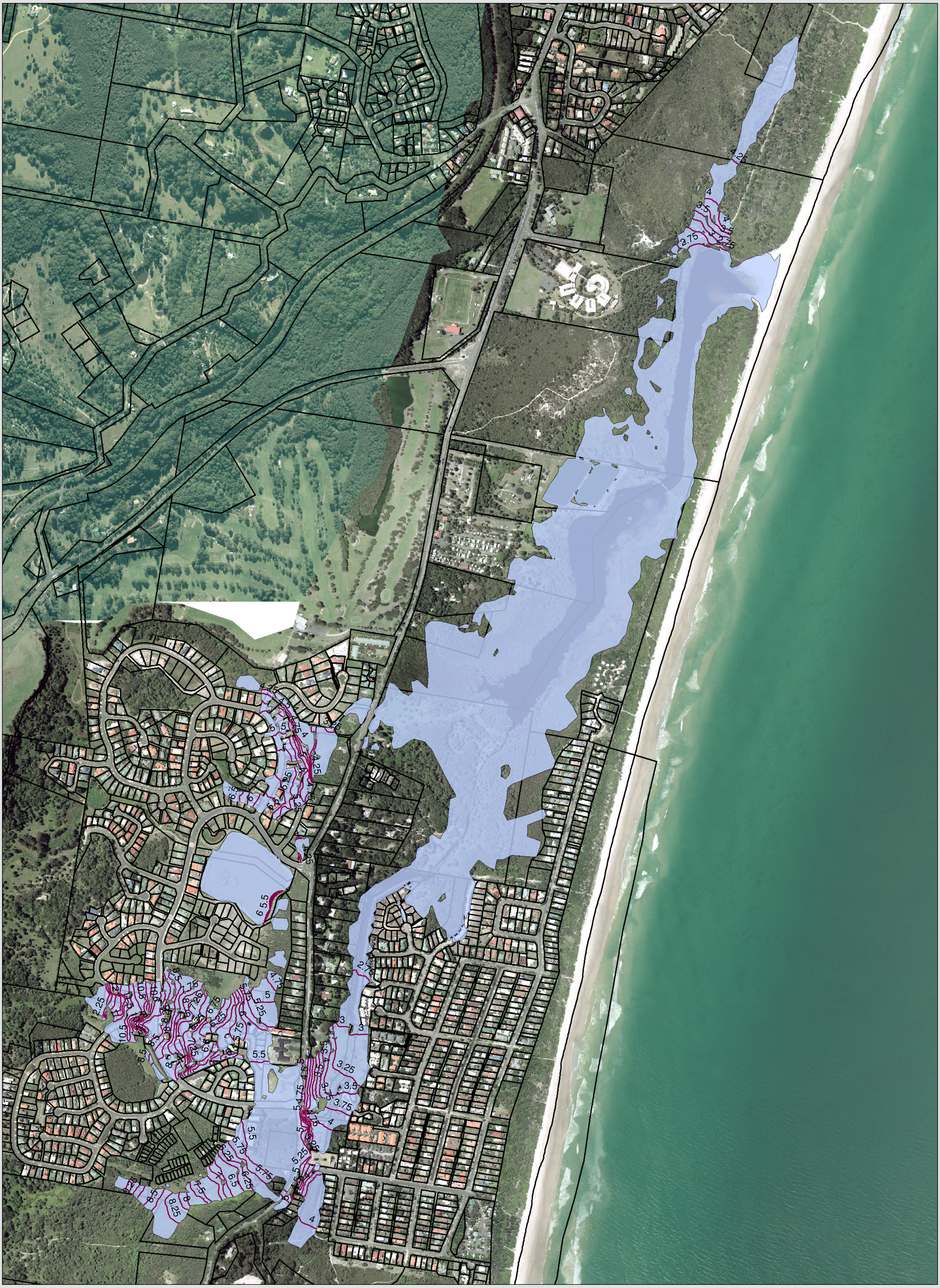
0 55 110 220 330 440 Metres

N

Pacific Ocean
Byron Shire



Tallow Creek 2014 Update
PMF Water Surface Level Map



Tallow Creek 2014 Update
100 Year Flood Sensitivity Test 1 Water Surface Level Map
10% Rainfall Increase / 2.6m & 2.4m Ocean Level Envelope

0 40 80 160 240 320 Metres

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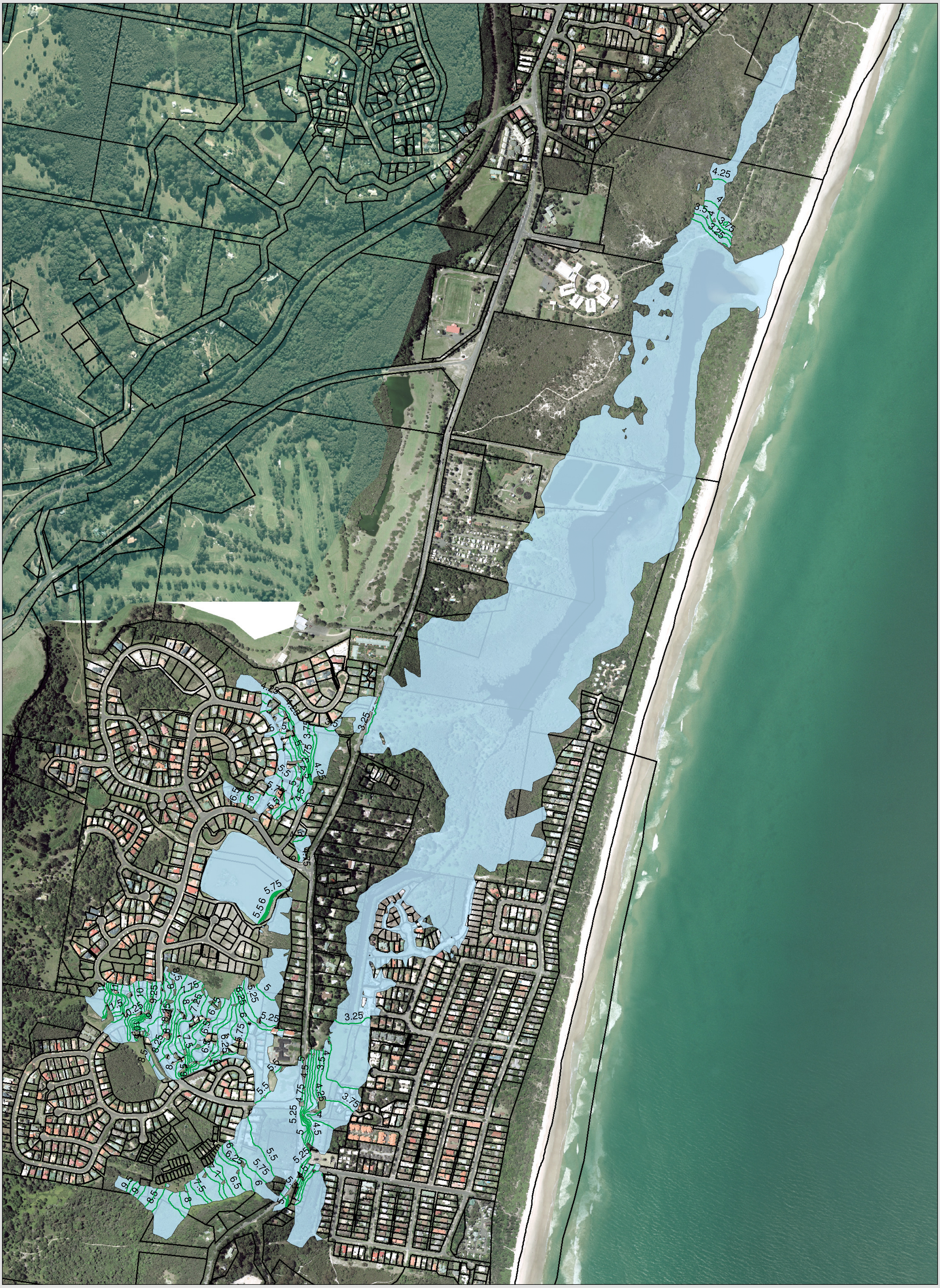

Tallow Creek 2014 Update
100 Year Flood Sensitivity Test 2 Water Surface Level Map
30% Rainfall Increase / 3.1m & 2.9m Ocean Level Envelope

Metres
0 40 80 160 240 320

Byron Shire

Tallow Creek 2014 Update
100 Year Flood Sensitivity Test 3 Water Surface Level Map
30% Rainfall Increase / 3.1m & 3.1m Ocean Level Envelope

0 40 80 160 240 320 Metres

Byron Shire Council

Byron Shire