SMEC

Impact of Wake on Tweed River Bank Erosion Study

For: Tweed Shire Council

JANUARY 18, 2012

Project Name:	Impact of Wake on Tweed River Bank Erosion Study
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PREPARATION, REVIEW AND AUTHORISATION

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EXECUTIVE SUMMARY

SMEC Australia was commissioned by Tweed Shire Council (Council) and the Tweed River Committee (TRC) to undertake an assessment of the impact of vessel wake on bank erosion on the Tweed River. Furthermore, the assessment was to include identification of measures available to reduce erosion, including if warranted, those relating to the use of vessels.

An assessment of the mechanisms for bank erosion within the Tweed River has been carried out. This found that both naturally generated wind waves and waves resulting from vessel wake have the potential to result in erosion. A comparison between wind and wake waves was undertaken. It was found that the influence of wind and wake waves vary through the Tweed River depending on the exposure of the river to the dominant wind directions and the frequency of towing activities (waterskiing and wakeboarding) occur in the area.

It was identified that towing activities are the most likely vessel activities to cause wake waves capable of causing significant bank erosion. This is due to the repetitive nature (i.e. undertaking numerous laps along the same stretch of the river) and the size of the wake waves these vessels generate when travelling at operational speeds. This assessment has demonstrated that vessel wake resulting from towing activities have the potential to cause and increase bank erosion. Based on current practice the entire stretch of river between Chinderah and Bray Park has been shown to be susceptible to bank erosion as a result of vessel wake, as this area generally experiences limited wind generated waves. Accordingly, wake waves have become the dominant erosion mechanism.

The stretch of river downstream of Chinderah is more exposed to the predominant wind directions and so is subject to larger wind generated waves. Furthermore, this area has been reported as being used less frequently than the upstream areas for towing activities (this is consistent with the exposure of the site to wind energy). Accordingly, wake from towing activities is not expected to significantly increase bank erosion in these areas given current practice. This is not to say that bank erosion does not occur in these locations (where unprotected). However, based on the wave assessment, wake from towing activities is not considered the dominant erosion mechanism. If towing activities were restricted in other areas of the river an increase in towing boats may be expected in this stretch of river resulting in wake waves becoming an increasingly significant mechanism.

A number of mitigation options have been suggested for consideration in managing the accelerated rate of bank erosion within the Tweed River based on the river characteristics and the physical mechanisms of the erosion mechanism. The possible erosion management options range from non-engineered preventative measures to engineered hard protection.

Based on the findings of the assessment a series of hypothetical management options have been subject to a cost benefit analysis as a means of broadly demonstrating the economic, social and environmental impacts of recreational vessel towing activities that generate wake in the Tweed Estuary. This analysis is presented for discussion purposes only, to inform debate on the relative merits of the types of management option considered.

The Tweed River Estuary Management Plan is being reviewed in light of information generated through the completion of this study. This will result in the formulation of bank erosion rehabilitation recommendations that will be implemented by Council. It is also intended that Council will make recommendations relating to vessel operation that will be presented to NSW Maritime for consideration in a review of the Tweed River Boating Plan of Management. These recommendations will seek to balance the demand for recreational boating in the upper estuary against the environmental and economic impacts of vessel wake generated river bank erosion. The draft review of the Tweed River Estuary Bank Management Plan will be placed on community exhibition prior to being presented to Council for adoption.

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1 INTRODUCTION

SMEC Australia was commissioned by Tweed Shire Council (Council) and the Tweed River Committee (TRC) to undertake an assessment of the impact of vessel wake on bank erosion in the Tweed River and identify measures available to reduce erosion.

The Tweed River is a vital economic, social and environmental asset for the Tweed Shire. Demand for commercial and recreational boating activities has been shown to be strong within the Tweed Estuary. Improvements in entrance navigation conditions; retiring baby boomers; and a general trend within the community of increased affluence and leisure time, could see the future demand for recreational and commercial boating activities increase dramatically. This demand will increase from both within the region and through tourist visitation. This offers economic opportunities for the Tweed Estuary but it also presents complex challenges for the planning and management of the waterway in terms of social and environmental impacts.

Upstream of the river training and armouring works in the Lower Tweed Estuary the river foreshore is characterised by extensive areas of bank erosion due to a number of factors. River bank erosion has been shown through other studies of similar estuarine environments to be significantly exacerbated by high intensity recreational boating use. Wake produced by power boats (usually associated with towing activities such as water skiing and wake boarding) produces a much more energetic wave climate than natural conditions from wind driven waves. Higher waves occurring more frequently leads to accelerated erosion of the foreshore (especially if already degraded through loss of riparian vegetation). Furthermore, the degraded bank then becomes highly susceptible to erosion as a result of natural processes such as flooding and other mechanisms.

The rise in popularity of wakeboarding in parallel (or even as preferred) to waterskiing can be seen as a significant change in the intensity of recreational boat towing activities. Wake enhancement devices on boats used for this relatively new pastime create significantly larger wake than traditional waterskiing power boats, with subsequent greater impacts. This recreational pastime shows no signs of reducing in popularity and provides even greater future challenges for bank erosion management.

1.1 Study Objectives

The study aims to determine the potential impacts of vessel wake on riverbank erosion within the Tweed River Estuary. Following this assessment the study will provide information which Council and NSW Maritime can consider for possible future implementation to reduce the impact of vessel operation on riverbank erosion. Any riverbank erosion management options implemented will need to be designed to be sustainable within the context of economic, social and environmental constraints.

The study also provides a review of specific previous investigations. The existing Tweed Estuary River Bank Management Plan (1998) is reviewed and has been updated with recent findings from field assessments undertaken as part of this study. Furthermore, the field assessments have enabled prioritisation of site specific bank erosion treatment actions to be considered by Council.

1.2 Study Area

The study area comprises the riverbank foreshore of the main arm of the Tweed River from Bray Park Weir to the confluence with Terranora Creek. This is a larger area compared to what was described in Section 2 of the Consultant Brief from Council, which stated the area from Bray Park Weir to Chinderah. The extension of the study area was requested as a project variation by Council on 17 August 2011. The study area is shown in **Figure 1.**

Figure 1 Study area extent.

1.3 Jurisdictional Responsibilities

In considering management of the Tweed River environment it is important to understand the roles of the various government agencies organisations. **Table 1** provides a summary of these roles. Council, Roads and Maritime Services (RMS) and Department of Primary industries (DPI) - Fishing and Aquaculture all have a role in determining management options.

Table 1 Areas of jurisdictional responsibilities.

Area	Organisation		
	Council	RMS	DPI - Fishing and Aquaculture
Implementing boating plans / restrictions		✓	
Construction of defences for public land	✓		
Habitat protection and rehabilitation			✓

2 LITERATURE REVIEW

A review of previous studies conducted for the Tweed River was undertaken. Review of studies investigating the impact of boat wake in similar river/estuarine environments was also undertaken. An overview of each of these is provided below along with a review of the recommended methodology for assessing vessel wake waves.

Tweed River Estuary Bank Management Plan – Patterson Britton and Partners (1998)

Patterson Britton and Partners (PBP) carried out a bank management study and prepared a formal management plan to address the issues of existing and on-going bank erosion and morphological changes of the Tweed Estuary as part of the Tweed River Estuary Bank Management Plan (*PBP, 1998*). The relevant details and findings of this study are listed below.

- The removal of riparian vegetation may have impacted wind fetches, exposing the riverbanks to larger wind generated waves.
- Areas of the river which are protected from wind generated waves may start to erode due to boating activities while erosion at sites which are already affected by wind waves may be exacerbated by boat wake waves. Heavily trafficked areas, such as Terranora Inlet and around the main boat ramps would be particularly at risk of boat wake erosion.
- It is important to identify all catchment land use activities and any changes in land use practices and employ strategic management plans which will lead to reduced runoff rates.
- Improved catchment management should look to embrace the concept of rehabilitation of riparian corridors along rivers and creeks to help stabilise the riverbanks.
- Areas of riverbank erosion were identified throughout the estuary, with much of this erosion thought to have been at least partially the result of waves resulting from boating traffic.
- The study mapped areas of bank erosion, accretion and existing riverbank protection structures on the Tweed River Estuary. Recommended management methods were detailed for each erosion section of the river, there were approximately 70 of these. A program for monitoring and assessing the river banks was also detailed.

Tweed Recreational Boating Study 2006 to 2010 – NSW Maritime, 2006

NSW Maritime carried out a recreational boating study of the Tweed River in 2006. This study was undertaken to identify and protect the recreational and environmental values of the waterway and to ensure that boating practises maximise user safety and enjoyment and provide a consistent approach to existing and anticipated future needs. Relevant details and findings of this study are listed below.

- The plan contains management strategies addressing values and issues relevant to both the entire estuary as well as location specific areas.
- In order to promote the protection and rehabilitation of the riverbanks and foreshores within the Tweed Estuary 'Minimal Wash Zones' have been introduced.

These were designed for safety and environmental reasons and have been implemented in designated reaches of the river. Through discussions with NSW Maritime it was found that these zones, which are identified through signage, are only effective to a limited degree. There are a number of reasons for this, the main reason is that the term 'minimal wash' is very subjective and as such it is difficult to enforce with the other reasons being that people might not see the signs and if they do they might not follow them if they think they can get away with it. However, there is some benefit in the zones as when people are observed to not follow the signage they can either be educated as to what they should be doing and why and in extreme cases (such as when vessels travel through at top speed or result in some noticeable damage due to their speed) it is possible to fine them accordingly.

- Creation and alteration of speed restriction areas were implemented at certain locations. These areas were generally designed to reduce riverbank erosion resulting from boat wakes, protect ecologically sensitive areas and improve safety. In addition, buoy markers were also proposed to be used to show the distance that vessels are required to stay away from the riverbank. Through discussion with NSW Maritime it was found that these area are more effective than the 'No Wash Zones' as there is no subjectivity in the speed limit and as such it is very easy to tell if someone is going above the allowed 4 knots and to fine them accordingly. However, the speed restriction areas cannot be too large as it would result in journeys taking too long.

- Educational campaigns were also initiated. This involved educating the public on the impact of irregular driving and power turning on riverbank stability and informing and educating the public with regard to all new restrictions resulting from the boating plan. Discussions with NSW Maritime has found that the educational campaign is ongoing, with monthly state wide campaigns educating water users on various subjects. The educational campaign is targeted at water users who are observed to be operating inappropriately, it has been a successful way of educating people and it also has the added benefit that the data is collated which allows NSW Maritime to determine which areas require additional effort.

- The plan predicted an increase in vessel registrations for the Tweed River of approximately 5% per year, giving a predicted number of registrations for 2009 of 3,840.

- The types of activity being undertaken by boaters was assessed over the Australia Day long weekend in January 2004, it was found that 22% of boaters were involved in towing, including skiing, wakeboarding and tubing.

- The rapidly growing population was deemed likely to expect the Tweed Estuary to provide increased opportunities for boating access, tourism and passenger transport. This will potentially put pressure on the environmental and ecological habitats of the estuary.

- River traffic is not spread evenly over all reaches of the river, with the study finding the busiest areas for waterskiing and wakeboarding were Tumbulgum ramp to the Murwillumbah weir. Waterskiing and wakeboarding was also noted between Ukerebagh Island and Tumbulgum boat ramp.

Tweed River Estuary Recreational Boating Facilities Study – PBP, 2008

Tweed Shire Council recognised the need for a strategy for the continued implementation of facilities and services to address current and future boating sector requirements. The study aimed to determine the level of facilities and services required to facilitate an appropriate level of boating use, taking into account economic, social and environmental constraints.

The study involved identification of infrastructure requirements; potential tourist and recreational boating linkages; the level of marine infrastructure required to promote Tweed Heads as a desirable boating destination; the order of costs in implementing individual strategic options and staging for individual options.

It also involved consultation with relevant boating groups and assessment of existing infrastructure adequacy; and the potential to develop a marine precinct.

The key findings of the study were:

- despite the extensive demand for trailer boat activity in the Tweed River Estuary there are no modern dry-stack boat storage facilities available;
- the Tweed River Estuary in particular, and the NSW Far North Coast generally, appear to be substantially undersupplied with appropriate modern berthing facilities for recreational vessels requiring on-water storage; and
- comparisons with other populous NSW and Queensland coastal regions would indicate that the Tweed Shire is likely to have a very high level of latent demand for formal berthing facilities which are currently not supplied in the Tweed River estuary.
- consideration of the environmental carrying capacity of the river lead to the conclusion that in some areas current usage exceeded this measure of river capacity
- a shortfall in boating infrastructure supply acts as a constraint to demand and indirectly manages boat usage on the Tweed

The early identification of a highly constrained environment lead to the development of a strategy for the provision of new boating infrastructure facilities that revolved around the centralisation of these facilities into multi-purpose marine precincts or areas. These areas would aim to provide a range of facilities and services in one location to achieve the objective of providing for the estuary wide demand for such infrastructure.

The strategy focused on the continued upgrading of parking facilities at existing sites and the provision of two new regional boat ramp and parking facilities, one in the upper estuary at Condong and one in the lower estuary. Due to the limited availability of foreshore sites in the Lower Tweed, the provision of a regional boat ramp facility would need to occur within one of the sites identified for the provision of a multipurpose maritime precinct with marina style berthing facilities.

Williams River Bank Erosion Study – GHD, 2006

This study was aimed at investigating the existing riverbank erosion within the Williams River and investigating the main factors contributing to the river bank erosion rate. Fourteen monitoring points were created along the banks of the Williams River between Seaham Weir and Raymond Terrace in order to monitor bank erosion rates. Of these monitoring points only one site exhibited measureable erosion during the study period. However, despite the lack of measureable erosion along much of the river extent there were clear indications that the river bank was eroding throughout. The assessment also demonstrated that throughout much of the Williams River boat generated wake waves have a greater contribution to bank erosion than wind generated waves and therefore boat usage along the river is a major factor contributing to the river bank erosion rate.

Williams River, Riverbank Erosion Study – WorleyParsons, 2010

As a result of the 2006 river bank erosion study a 'No Slow Tow' zone was established in 2007 within the Williams River. This was established along the middle of three reaches in the river and extended for approximately five kilometres. The restriction prevented slow towing activities which includes wakeboarding but allowed waterskiing as this is not a slow towing activity. This assessment used 3 years of monitoring data post implementation of the No Slow Tow zone to investigate the effects on river bank erosion. The findings of the study are detailed below:

- There was substantial evidence to show that erosion in the 'no slow tow' stretch of the river was reduced compared to the other stretches of the river.
- There were also indications that sections of this 'no slow tow' stretch was regenerating relative to the other reaches.

Based on the findings of the monitoring it was recommended that the ban on slow towing (including wakeboarding) be retained and that in order to reduce erosion in the other areas of the river similar restrictions on slow towing should be implemented there as well

Assessing the impact of wake boarding in the Williams estuary, NSW, Australia: challenges for estuarine health – Cameron, T. & Hill, P., 2010

This assessment is similar to that undertaken by WorleyParsons, using data collected at the same fourteen monitoring locations as in the GHD and WorleyParsons studies. This assessment found that:

- Wash from boat-generated waves causes incremental undercutting that sets up sections of stream bank for severe block failure and slumping particularly during flood events.
- Wakeboarding and Wake Enhancement Devices (WEDs) are responsible for generating the largest and most damaging erosive waves.
- Without management controls to restrict slow tow activities the river bank erosion will continue.
- The only area of the river showing signs of recovery from the erosion is the reach where the 'No Slow Tow' zone was implemented.
- It has been reported that the boating restrictions within the Williams River are contributing to increased levels of wake board activity in the Hunter River.
- The study recommends a state wide approach to restrictions on wakeboarding and other slow tow activities in coastal alluvial streams, this would prevent the issue of excessive boat wash being moved from one reach or stream to another.
- Areas of resilient waterways (eg lakes, large dams and armoured waterways) need to be identified and if suitable promoted as areas where wakeboarding can be undertaken.

It concluded, to assist in the recovery of the stream banks in the lower Williams River the wash created from recreational boating activity must be managed.

Bellingen Shire Healthy Rivers Program; Bellinger River Health Plan – Bellingen Shire Council, 2010

The Bellinger River Health Plan documents the issues which affect the river and recommends actions to address the issues and improve water quality. The plan discusses the agricultural practices, riparian and wetland management, onsite sewage management systems, boating, tourism and recreational impacts, stormwater and building construction, rural roads and bridges, forestry, logging and clearing, oil and diesel and waste spills from roads and waste water treatment plants. The key findings of the boating impacts are listed below:

- Aside from speed and wash restrictions signposted on the rivers, NSW Maritime have no written policy to address the environmental effects of boat use.
- A decision support tool designed to assess the impact of boat wake has been developed by NSW Maritime and they have been invited to trial it in the Bellinger River.
- The number of boat registrations in the Bellinger region has expanded exponentially in recent years.
- Waterskiing occurs in four distinct locations of the estuarine reaches.
- Speed limits within estuarine and riverine waters may not be as effective as well-observed and policed 'no wash' zones in reducing erosion.
- Suggested management option to ban certain activities (wakeboarding, biscuits and jet skiing) from areas of the estuary or to have restrictions on boat sizes, displacement hulls and speeds which would equate to no wake boarding.

Alternative management option to zone sections of the river to suit different recreational needs and protect sensitive areas, this would mean that wake boarding would be restricted to areas where the river is wider and erosion is not a problem.

Bellingen Shire Healthy Rivers Program; Kalang River Health Plan – Bellingen Shire Council, 2010

The Kalang River Health Plan documents the issues which affect the river and recommends actions to address the issues and improve water quality. The plan discusses the agricultural practises, riparian and wetland management, onsite sewage management systems, boating, tourism and recreational impacts, stormwater and building construction, rural roads and bridges, forestry, logging and clearing, oil and diesel and waste spills from roads and waste water treatment plants. The key findings of the boating impacts are listed below:

- A decision support tool designed to assess the impact of boat wake has been developed by NSW Maritime and they have been invited to trial it in the Kalang River.
- The number of boat registrations in the Bellinger region has expanded exponentially in recent years.
- A trial code of practise for waterskiing and other craft on the Kalang River was introduced in 1999, aiming to reduce noise and boat wash impacts around the estuary.

The management options discussed to reduce riverbank erosion resulting from boat wakes include banning wake boarding and waterskiing, restricting waterskiing to wider sections of the river, reducing vessel speeds or no wash zones in sensitive areas and no ballast boats or jet skis except in lower area of the estuary

Creek to Coast: Great Lakes Environment News – Issue 4, Summer 08/09

The newsletter provides details of a memorandum of understanding (MOU) which was agreed by the various stakeholders who use the river in 2004, with an aim of helping improve the health of the Wallamba River. Details of the MOU are provided below:

- Restricted waterskiing to the area downstream of the Cattle Crossing at Failford to the no-ski zone in the lower reach of the river, this is approximately a nine kilometre stretch.
- Rehabilitation works have been implemented to help deal with erosion and sedimentation issues in the lower Wallamba.
- Riverbank erosion continues to be a significant issue for landholders and fishing industries based in Wallis Lake.
- There is a need to review to MOU to reflect changes in the recreational river use and the lessons learnt from the first four years of the MOU.

Key proposed addition to the MOU is the removal of activities from the Wallamba River which generate a large wake and shift them to a wide zone with gently sloping banks behind Wallis Island.

Wallis Lake Estuary Management Plan – Wallis Lake Estuary Management Committee, 2005

The Wallis Lake Estuary Management Plan was designed to help coordinate management efforts for the area. The plan details a schedule of management actions which have been developed and are endorsed by all stakeholders. One of the management objectives in this plan was to reduce the contribution of power boat activities (specifically waterskiing, wakeboarding and jetskiing) to riverbank erosion. The main management strategy was to ensure commitment to a memorandum of understanding (MOU) implemented in 2004 which restricts waterskiing and other power boat recreational activities to a nine kilometre stretch of the Wallamba River. In addition, it was identified that it was necessary to assess the long term impacts of waterskiing and wakeboarding on the lower Wallamba River (where waterskiing and wakeboarding was permitted in 2005) and mitigating the effects as required.

http://www.greatlakesadvocate.com.au/news/local/news/general/wakeboards-banned/2026264.aspx, 05/09/2011

The news article on the Great Lakes Advocate website provides details of the additions in 2010 to the original 2004 memorandum of understanding (MOU) for the Wallamba River. Details of the article are given below:

- Wakeboarding was banned on the Wallamba River in February 2011.
- The wakeboarding area was transferred to the western side of Wallis Island.
- The changes to the MOU were the result of concerns by landowners about riverbank erosion caused by wakeboarding, specifically the height, energy and frequency of waves as wakeboarding had grown in popularity as a sport since the original 2004 MOU.

In addition, the MOU has been changed to ban all devices designed to increase wake from the river, restricting displacement vessels greater than 6.5m and non-displacement vessels greater than 7m to a 'no-wash' designation.

Investigation into the effect of wash of boats and wind waves on the Swan River – Australian Maritime College, 2009

This study assesses the comparative impact of waves generated by boat wakes and wind generated waves on river bank erosion in the Swan River. The relevant details and results from the assessment are described below:

- There have been specific concerns regarding the influence of vessel wash on identified areas of bank erosion within the Swan River.
- The Swan River has experienced a gradual increase in vessel traffic over the last century, with regular high-speed commercial ferry services introducing a potentially erosive wave regime.
- The growing popularity of high-powered, high-speed recreational craft has also been found to have the potential to create considerable damage to the banks of sheltered waterways.
- For sites in the upper river it was found that shoreline erosion is very likely as a result of vessel generated waves where a blanket speed limit of 8 or 9 knots is imposed as the energy and power of the maximum waves generated by the vessels far exceed that of the maximum wind waves.
- In the upper river if the vessel speed was reduced to 5 or 6 knots then the potential for erosion would be dramatically reduced.
- The assessment for the lower reaches of the river was more difficult as it found that two of the commercial vessels were likely to generate waves that possess far greater energy and power than the other vessels and also the predicted maximum wind waves.
- In the lower river in order to reduce riverbank erosion it would be necessary to design any speed restriction to the vessels found to generate the largest waves, but this would be overly restrictive for other vessel classes.

Based on this assessment it is likely that a five knots speed limit be imposed in the Swan River, this limit would incorporate both recreational and commercial vessels (http://www.sciencewa.net.au/3086-jessie-parrish.html).

Ship Operations and activities on the Maroochy River: Discussion Paper – Department of Transport and Main Roads, 2009

The paper is focused on the safe operations of ships within the Maroochy River as opposed to addressing river bank erosion. However, much of the discussion is still focused around high-speed ship operations such as waterskiing and wakeboarding as there has been a significant increase in the numbers of these vessels within the river. The recommended management options include:

- Expanding the existing 6 knot speed limit zones.
- Expanding the existing waterskiing prohibitions to include additional areas of the river.
- Reduce the water skiing prohibition in wider areas of the river with no erosional problems.

Erecting new signs to clearly define the speed limits and water skiing prohibitions.

A Decision Support Tool for Assessing the Impact of Boat Wake Waves on Inland Waterways – William C. Glamore (WRL-UNSW, for NSW Maritime)

A study was previously undertaken by William C. Glamore from the Water Research Laboratory at the University of New South Wales in order to develop a decision making tool for estimating the erosion potential of boat wake waves along sections of river bank. The decision tool is based on a number of factors relating to boat wake waves, wind wave energy and the local waterways erosion potential. In addition, the tool assesses the cumulative impact of wave energy at the particular investigation site.

The report undertaken by William C. Glamore (WRL) titled *A Decision Tool for Assessing the Impact of Boat Wake Waves on Inland Waterways* discussed different wake wave management criteria based on wave characteristics such as maximum wave height (H_{max}), wave energy, wave period and speed. The report outlined the following criteria as developed by Patterson Britton and Partners in 2001 (**Table 2**). However, the study adopted a different criteria, as discussed further below in this section of the report.

Table 2 Wake wave management criteria as adopted in the PBP Report (2001)

Max wave height (H_{max})	Wave management criteria
<20cm	No action on bank stabilisation required
20-30cm	Requires monitoring
30-40cm	Requires bank engineering assessment and remediation

As part of the study by Glamore, a full scale field test was undertaken using a range of wakeboarding and waterskiing vessels in order to analyse the wave characteristics produced by these vessels under a variety of vessel operating conditions, such as with and without skiers, varying speeds and using a variety of ballast configurations. Wave measurements were measured 22m from the vessel sailing line and demonstrate that the H_{max} produced by the wakeboard boat is approximately double that of the waterskiing boat.

Furthermore, the wave energy produced by the wakeboard boat was almost five times greater than that produced by the waterskiing boat. It is important to note that these particular measurements were taken whilst each respective vessel was travelling under typical operating conditions (i.e waterskiing at 30 knots & wakeboard at 19 knots). However, the report also highlights that the maximum wave energy is typically produced at slower velocities of around 8 knots and not under typical operating velocities. The estimated H_{max} produced by waterskiing and wakeboarding vessels travelling at 8 knots is similar.

The report also describes how the damage caused by a boat wake is a function of both wave height and wave period. As a result, the report recommended the wave energy (wave height & wave period) as the 'preferred criteria' when analysing the relative effects of waves.

The report suggests that over time a particular reach of river will establish an equilibrium with the local wind-wave environment, provided there are no large flooding events over that period. Therefore, if the wave energy produced by vessels within the stretch of river exceeds the energy of natural wind waves within the stretch of river, erosion of the river bank would be likely to occur.

River Styles Framework

The *River Styles Framework* provides a geomorphic tool for catchment wide assessment of river character, behaviour, evolution and condition. When implemented it can provide the necessary instruments for interpreting river character, behaviour, condition and the recovery potential of a particular river system. The framework is commonly used as a tool in the decision making process in river management.

To undertake a full assessment using the Rivers Styles Framework is beyond the scope of this study. However, the River Styles Framework has been used as a basis to apply a simplified framework to the present investigation. The framework has been used to provide an indication of the potential for the Tweed River to recover provided existing anthropogenic activities are removed.

3 FIELD OBSERVATIONS

A field data collection exercise was undertaken in order to update information provided in previous studies and collect additional data as required. The fieldwork was used to help compile a full inventory of current bank erosion areas, areas at risk from erosion and the management options to mitigate bank erosion. The present condition of existing protection structures along the river was also assessed.

3.1 Findings

Site visits were conducted on 13/09/2011 and 14/09/2011 in order to undertake an assessment of the state of the river banks and to assess any bank revetment projects which were carried out between 2003 and 2011.

Details of the current state of the river bank are provided in **Figure 2** to **Figure 7** with a summary of the bank condition provided in **Table 3**. Comments relating to the numbered points in **Figure 2** to **Figure 7** are shown in **Table 4**.

Table 3 Bank condition assessment summary.

Bank Condition	Total Length (m)
Visible Erosion Areas	10,149
Exposed Areas	15,401
Light Vegetation or Sparse Trees	13,594
Natural Vegetation	28,066
Ad-hoc, poor or failing defences	2,117
Seawall, Revetment or Rocky Foreshore	9,468
Total	**78,795**

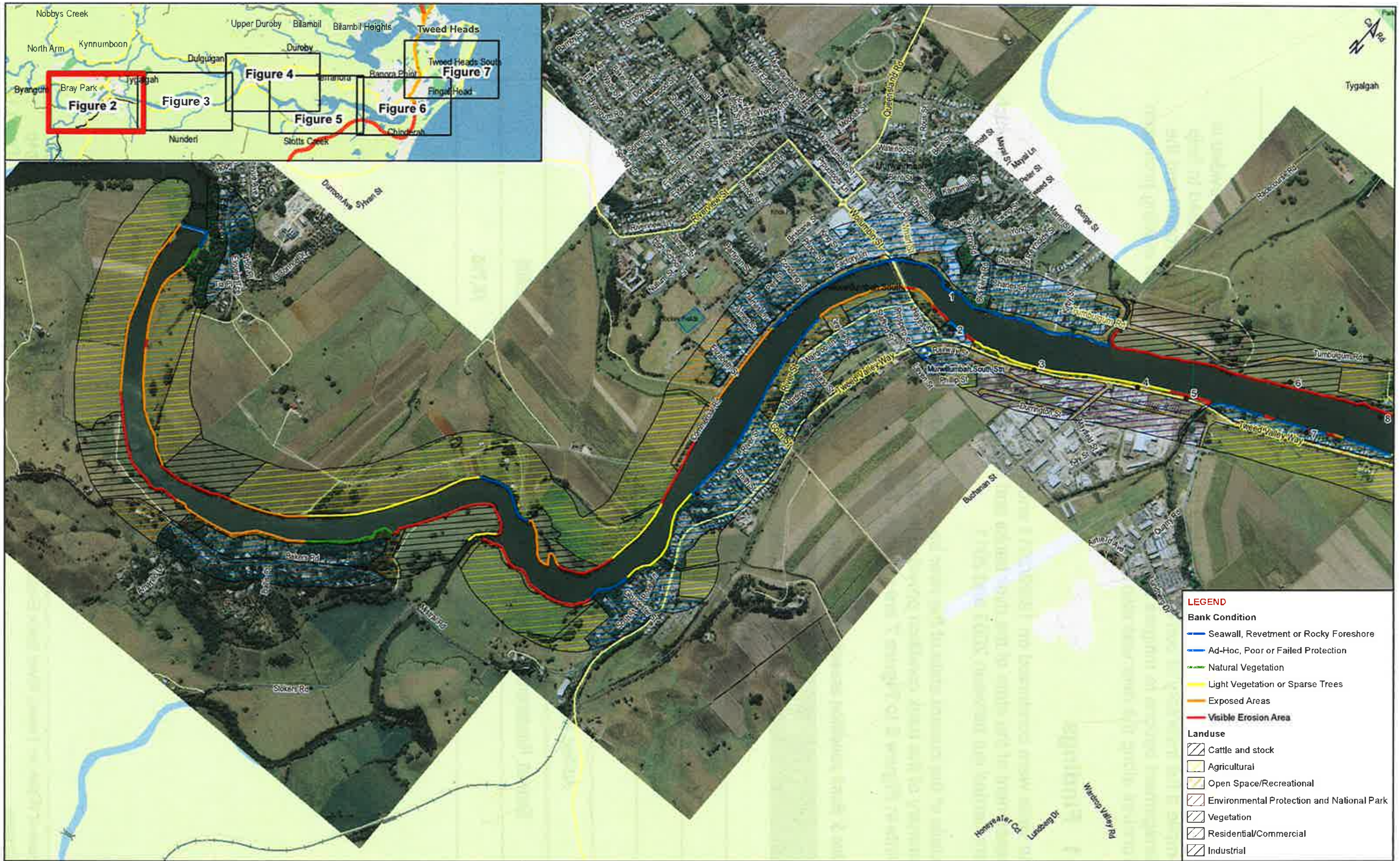

FIG NO. Figure 2

FIGURE TITLE Field Map of the Tweed River around Murwillumbah

DATE 03/01/2012

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PAGE SIZE A3

COORDINATE SYSTEM MGA Z56

PROJECT NO. 3001906

PROJECT TITLE Tweed Heads Bank Wake Erosion Study

CREATED BY D. GUNN

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Location: F:\Newcastle_Tweed_Heads\Maps\Figures2_6_FieldMaps.mxd

FIG NO. Figure 3

FIGURE TITLE Field Map of the Tweed River around Condong

PROJECT NO. 3001906

PROJECT TITLE Tweed Heads Bank Wake Erosion Study

DATE 03/01/2012

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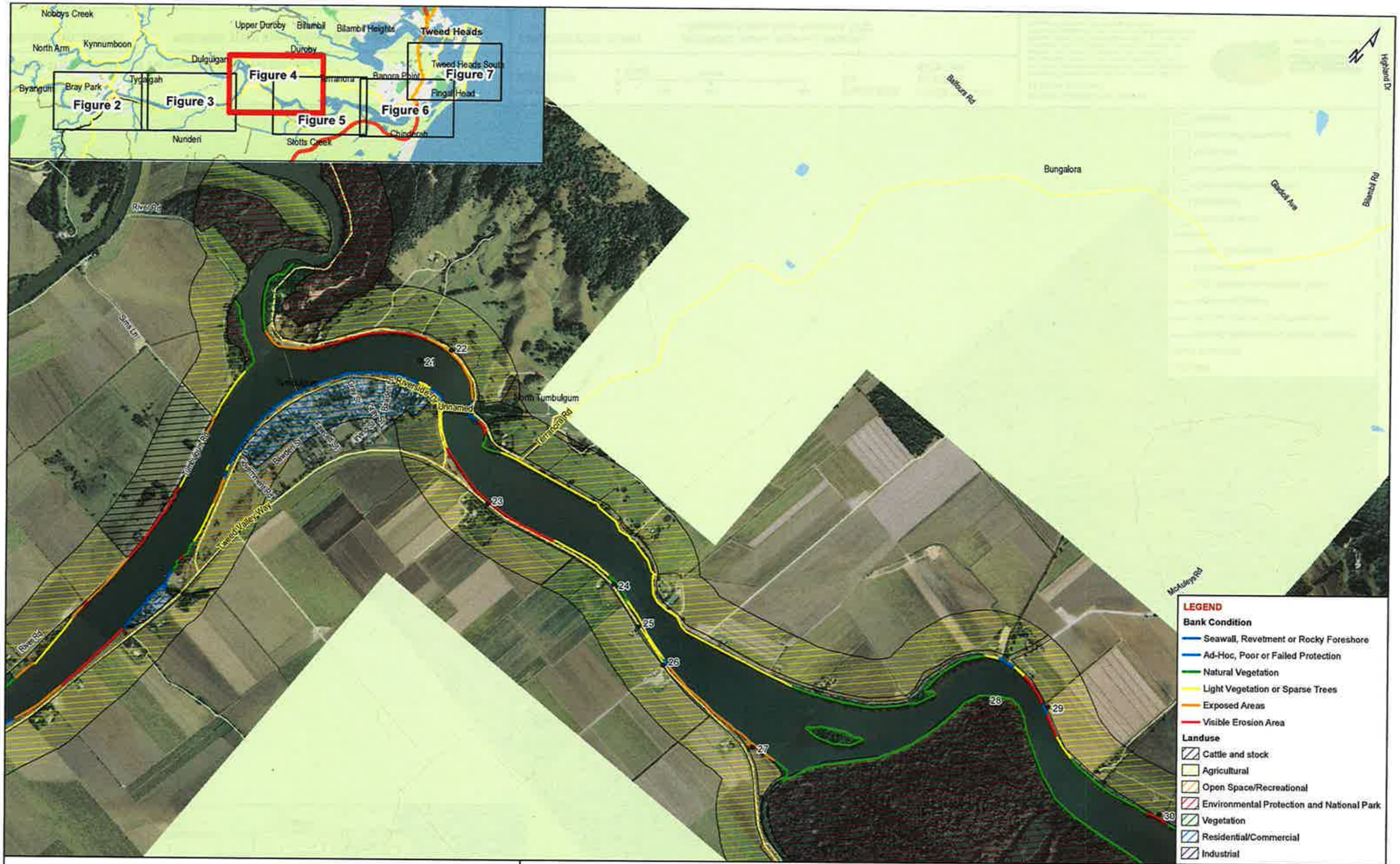

FIG NO. Figure 4

FIGURE TITLE Field Map of the Tweed River around Tumbulgum and Stotts Island

PROJECT NO. 3001906

PROJECT TITLE Tweed Heads Bank Wake Erosion Study

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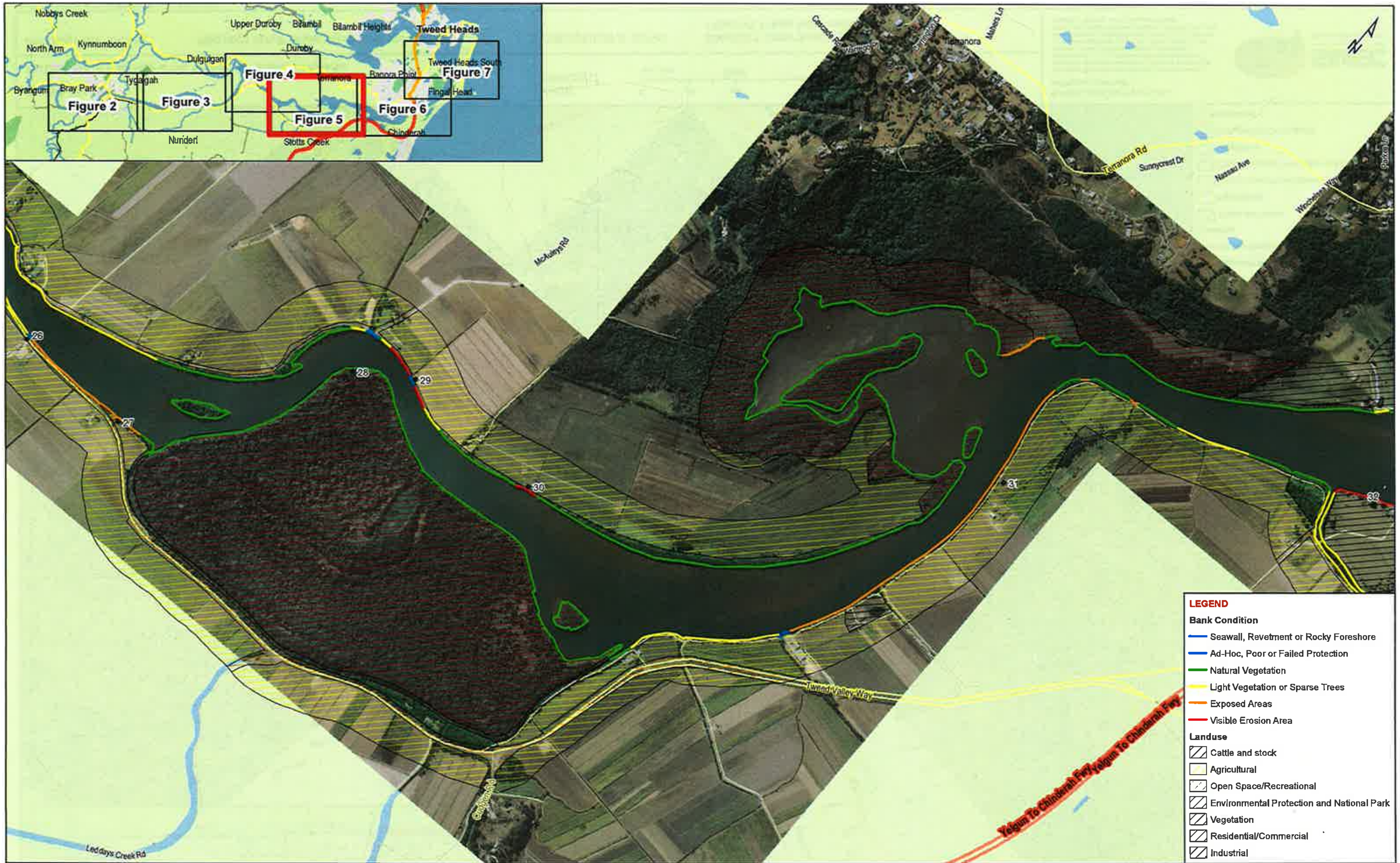

FIG NO. Figure 5	**DATE** 03/01/2012	0 200 400 800 Meters 1:15,000	**PAGE SIZE** A3	**COORDINATE SYSTEM** MGA Z56
FIGURE TITLE Field Map of the Tweed River around Stotts Island and Tweed Broadwater				
PROJECT NO. 3001906	**PROJECT TITLE** Tweed Heads Bank Wake Erosion Study	**CREATED BY** D. GUNN	**SOURCES** Vector Backdrop Mapping - Roadnet, © Map Data Sciences 2012	

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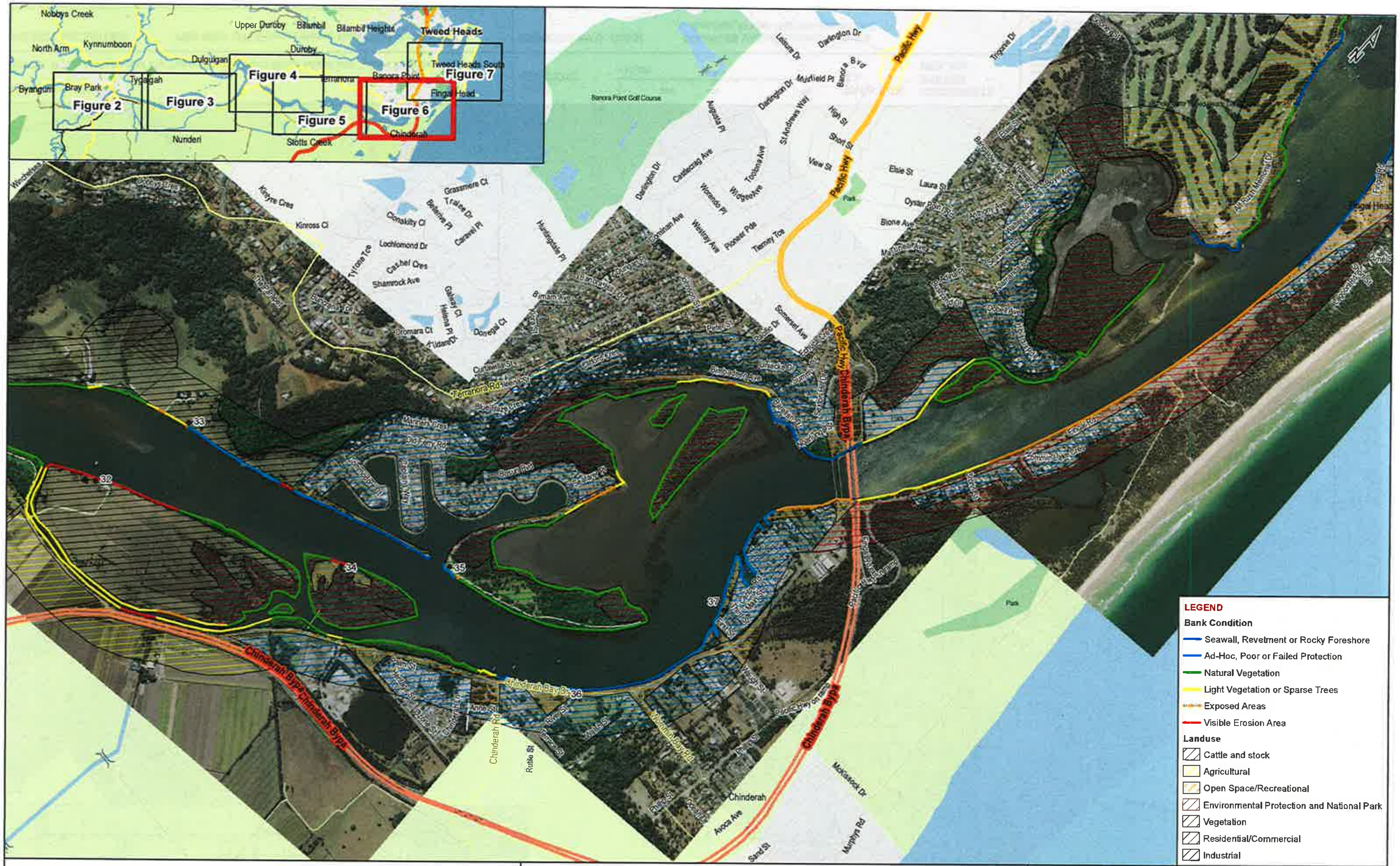

FIG NO. Figure 6

FIGURE TITLE Field Map of the Tweed River around Chinderah

PROJECT NO. 3001906 **PROJECT TITLE** Tweed Heads Bank Wake Erosion Study

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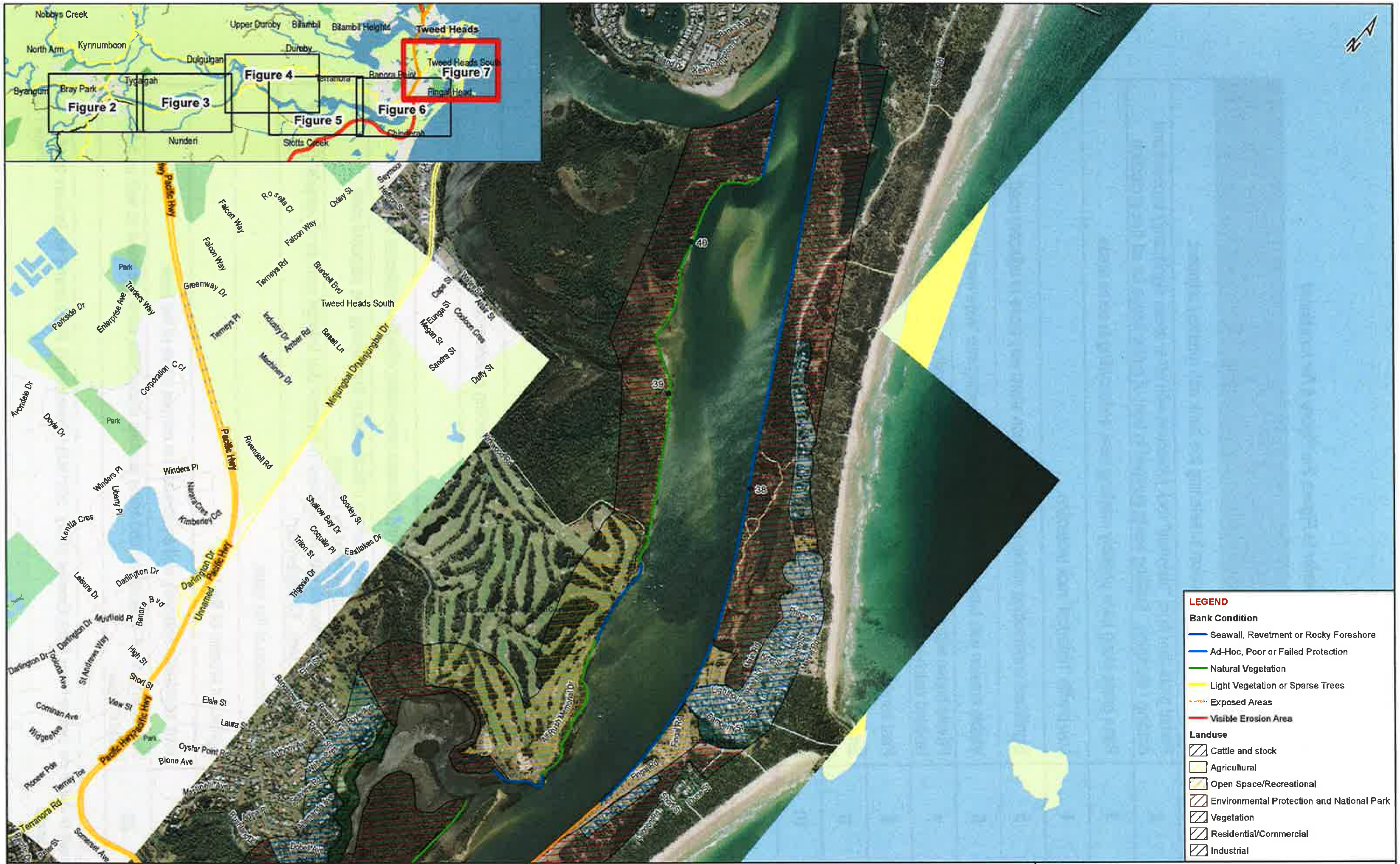

FIG NO. Figure 7

FIGURE TITLE Field Map of the Lower Tweed River up to Terranora Creek

PROJECT NO. 3001906 **PROJECT TITLE** Tweed Heads Bank Wake Erosion Study

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Table 4 Field observation comments (refer to Figure 2 to Figure 6 for locations)

Location Reference Number	Comments
1	Steep bank, possible erosion threatening this bank with roadway adjacent.
2	Partial protection from "historical" rock protection with other areas significantly exposed and eroding / slumping. Building waste dumped in front of public house for ad-hoc protection.
3	Bana grass along bank possibly masking bank undercutting in some areas.
4	Low profile "historical" rock protection.
5	Significant undercutting visible with large erosion scarp very close to adjacent road.
6	Visible erosion with bank alignment likely to be receding into "wide river terrace".
7	Private house with mixed protection work of various quality, slope and material. Isolated patches of erosion where bank not protected by private revetments.
8	Past sandy feature in the river has disappeared.
9	Erosion issues in this area seem to have been mitigated by formal protection works along this section.
10	Exposed area with isolated patches of erosion.
11	Isolated 20m patch of eroded bank.
12	Ancillary boat ramp at Condong.
13	Isolated 25m patch of erosion with reeds either side at Condong ramp and pontoon facility.
14	Exposed area with undercutting of large tree with roots system but showing signs of recovery with low juvenile mangroves on low tide terrace. Low profile small stone wall.
15	Bank erosion where vegetation is sparse.
16	Visible erosion east of Island.
17	Large recently constructed rock revetment protecting private property.
18	Active visible erosion.
19	Some patches of erosion occurring between reasonably effective protected sections.
20	Small isolated spots of very localised critical erosion threatening the adjacent road. Protection should be considered by Council.
21	This area can be "awash with vessel wake in summer due to large number of vessels" (P Miller 2011, pers. comm., 13 September).
22	Gradual erosion of the bank.
23	Significant erosion of the bank.
24	Bank vegetation relatively well established on convex curve of the bank.
25	Vegetation has re-established and some juvenile mangroves were observed as well as a few mature trees.

Location Reference Number	Comments
26	Ad-hoc historical protection.
27	Visible erosion appears slow and there is some remaining vegetation.
28	Very large pine tree fallen into river due to strong winds with the root system taking a portion of bank with it. Undercutting erosion contributed to demise of tree.
29	Visible erosion in part limited by the presence of small rock works.
30	Localised erosion.
31	Exposed area with some rocks placed within intertidal zone being effective at limiting further erosion.
32	Visible erosion where there is no bank vegetation.
33	Failed *ad-hoc* revetment with visible erosion on highwater line that could be also due to upstream/downstream end-effect of adjacent revetments.
34	Visible undercutting of areas where there is no vegetation.
35	Failed revetment and exposed geotextile likely due to flood/entrance effects.
36	High crested, recently constructed formal seawall predominantly in good condition protecting road section.
37	*Ad-hoc* protection with some old broken up concrete slabs mainly used in very informal manner.
38	Stable riverbank protection is present; the habitat could be enhanced by planting mangrove seedlings amongst rocks.
39	Bank is slowly receding as a result of longshore processes.
40	Sandy banks are receding with some undermining of the foreshore vegetation.

The upstream areas of the Tweed River appear to be more prone to erosion based on observations during field exercises. River bank erosion was found to be most common between Bray Weir and Tumbulgum. A total of 10,149m of the Tweed River bank has been identified as areas showing 'Visible' signs of erosion. It is likely that erosion along these areas will continue and could be exacerbated with no change to existing management. In addition, areas which have been identified as 'Exposed' have the potential to become areas with visible erosion depending on the continued management of the area.

Throughout the study area a range of structures designed to prevent riverbank erosion were identified. These ranged from being well designed rock armouring to assorted items (such as building waste) being placed along the river bank in an attempt to prevent erosion.

The current state of the river banks has been compared with the state recorded for the Tweed River Estuary Bank Management Plan (PBP, 1998). However, when assessing the differences between the state of the river banks it is important to consider the subjectivity in assessing the bank condition as well as how the bank condition might reflect recent events (such as large flood events). The changes observed between the current state of the river banks and the state recorded for the previous assessment, are summarised below:

Murwillumbah to Condong – a slight increase in the areas of the riverbank subject to erosion was observed.

Condong to Tumbulgum – there has been a reduction in the areas of the riverbank showing signs of erosion, with these areas now being classed as exposed but not showing signs of erosion.

Downstream area around Chinderah – new defences have been implemented in areas which were previously eroding. A section of well designed rock revetment has been added adjacent to Chinderah Bay Drive and some *ad-hoc* defences have been added in two locations.

Further details of the river bank assessment is provided in **Appendix A** and further detail of the bank revetment projects are provided in **Section 8.3** and **Appendix B**.

3.2 Recommendations

Based on the findings of the field exercise, a prioritised list of sites to be considered for bank stabilisation measures has been provided. Considering has been given to the severity of the existing erosion; the ecological, public and private assets at risk and the vulnerability to further degradation.

Table 5 details the priority areas for any future bank stabilisation measures. A number of areas of erosion where the Tweed Valley Way (No. 40) runs adjacent to the south bank of the Tweed River have been identified between Stotts Island and Murwillumbah. These areas of erosion are generally located between well vegetated stretches of the bank which have not been subject to such high rates of erosion. It is critical that the bank is stabilised in these areas as otherwise the road will start to be impacted by the erosion, in some cases there is currently just a couple of metres between the river bank and the edge of the road. Owing to the immediate threat of the erosion on a very important public asset it is suggested that the best management option for these areas of erosion would be to implement hard engineering methods such as rock revetment works. The erosion in these areas is generally occurring in numerous relatively small areas and as such extensive works will not be required, and it will be appropriate to defend the areas which are currently subject to extensive erosion. The area of erosion at Location 23 extends along the Tweed Valley Way and also onto an adjacent lay-by, hard and soft engineering methods have been recommended for this area as it is assumed that the stretch adjacent to the road will be defended by hard engineering methods, while the area adjacent to the lay-by could be defended by more soft engineering methods.

For the other areas of erosion identified as part of the site assessment it is recommended that ongoing maintenance is adopted and if erosion rates are seen to increase or if the erosion starts to put public or private assets at risk then appropriate management options would need to be adopted. In addition, the areas which have been noted as exposed during the site assessment should be monitored and management options considered if they start showing signs of erosion and the local ecological, public and private assets at risk require this.

Table 5 Bank stabilisation priority sites (refer to Figure 2 to Figure 6 for locations).

Site	Erosion Severity	Future Erosion	General Description	Mechanism or Factor	Risks	Priority	Bank Erosion Management Options	Supplementary Bank Enhancement Measures
20	Critical	Yes	Small isolated spots of very localised critical erosion, through scarping and undercutting of the bank, very close to the road.	• Boat wave action • Wind wave action • Fluvial Processes	Public Road	HIGH	• Engineered rock revetment • Add rock armour as required	• Re-establish riparian vegetation • Vessel management to restrict boat wake waves
23	High	Yes	Significant current scarping and undercutting of the bank for approx. 600m stretch.	• Boat wave action • Fluvial Processes	Public Road	HIGH	• Engineered rock revetment • Regrade bank and re-vegetate	• Vessel management to restrict boat wake waves
5	High	Yes	Significant undercutting visible with large erosion scarp close to adjacent road.	• Boat wave action • Wind wave action	Public Road	HIGH	• Engineered rock revetment • Wave wall with phragmites behind	• Re-establish riparian vegetation • Vessel management to restrict boat wake waves
18	High	Yes	Small area of active erosion with scarping and undercutting occurring.	• Boat wave action • Wind wave action • Fluvial Processes	Public Road	MED	• Engineered rock revetment • Add rock armour as required	• Re-establish riparian vegetation • Vessel management to restrict boat wake waves
19	Moderate	Yes	Some patches with undercutting and scarping occurring between reasonably effective protected sections.	• Boat wave action • Wind wave action • Fluvial Processes	Public Road	MED	• Engineered rock revetment • Add rock armour as required	• Re-establish riparian vegetation • Vessel management to restrict boat wake waves
2	Moderate	Likely	Partial protection from "historical" rock protection with other areas significantly exposed and eroding / slumping. Building waste dumped in front of public house for ad-hoc protection.	• Boat wave action • Wind wave action • Geomorphic recession of bank (fluvial processes)	Public Park & Private Business	MED	• Engineered rock revetment	• Re-establish riparian vegetation • Vessel management to restrict boat wake waves

4 CONTRIBUTING FACTORS – BANK EROSION

Bank erosion is the wearing away of the sediment in the river bank resulting in a retreat of the bank position. Generally the mechanisms for river bank erosion are bank scour and mass failure. It is a natural process which occurs in all rivers, although the rate at which erosion occurs in stable rivers is generally much slower and of a smaller scale than that which it occurs in unstable systems, or those significantly disturbed by anthropogenic influences. Natural events such as flooding can result in sudden and large scale bank erosion. However, river and adjacent land usage can also influence factors (such as loss of riparian vegetation) which trigger and accelerate bank erosion.

River bank erosion is presently occurring through the tidal reaches of the Tweed River as a result of both natural processes and anthropogenic factors. The process of river bank erosion can result in major environmental and social issues. Directly, it may threaten private property, public property and infrastructure, and natural resources (including areas of high environmental value). Indirectly, increased river suspended sediment load resulting from bank erosion can have detrimental effects (reduced water quality, smothering of aquatic vegetation). Accordingly, minimisation of bank erosion should be encouraged through passive and active river management aimed at maintaining a stable river bank as close to natural condition as possible.

PBP (1998) describes failure mechanisms (bank erosion) for the Tweed River. Physical processes contributing to river bank erosion on the Tweed Estuary are summarised, or elaborated on in the case of wake erosion in the following section.

4.1 Tidal and Fluvial Processes

4.1.1 Natural River Evolution and Human-Induced Factors

The overall Tweed River estuary is relatively stable due to the presence of scour resistant estuarine clay over most of the river bed. Indeed, the river channel has only been subject to minor changes in the alignment of the river with maximum bend migration of around 20m. The locations of the bend migrations were determined by PBP (1996) from the 1884 Royal Navy hydrographic survey and are represented in **Figure 8**. It is noted that most of the scour erosion generated by tidal and flood current is located on the outside of the river bends where the impact of the river flow is most significant.

The Tweed River is currently undergoing natural changes to reach a geomorphic equilibrium. Natural processes would result in the creation of point bar and mid-channel shoals due to the deposition of sediment from the upstream catchments. Such phenomena may generate higher flood velocities and bank erosion. Furthermore, anthropogenic factors such as urbanisation and vegetation clearing would increase the sedimentation rate within the river due to increased runoff and destabilised embankments. Other developments such as construction of flow training walls and dredging may also impact on the bank recession rate.

4.1.2 Tidal Impact

Tidal impact generally depends on the tidal prism and the average cross-sectional area along the river. A report from NSW Public Works (1991) measured higher current velocities in the lower reaches of the river (where the tidal prism is larger) and cross-section averaged value of around 0.6m/s were given for the lower estuary. Local effects could be generated at specific locations such as on the outside of the river bends and may result in twice this velocity. These “everyday” currents could contribute to bank undermining and erosion.

Cross-section averaged tidal velocities in the upper estuary are in the order of 0.1m/s which would not be expected to have a significant impact on bank erosion.

4.1.3 Flood Impact

Bank erosion is exacerbated by flood events. During such events, the current velocities within the channel are significantly increased and shear stress on the outside of the river bends would be considerably accentuated and could result in destabilisation and undermining of the river embankment. Such erosion would also depend on the type of sediment (as the sand located downstream is more erodible than the estuarine mud located upstream) and the human-related factors such as increased runoff due to urbanisation or vegetation clearing.

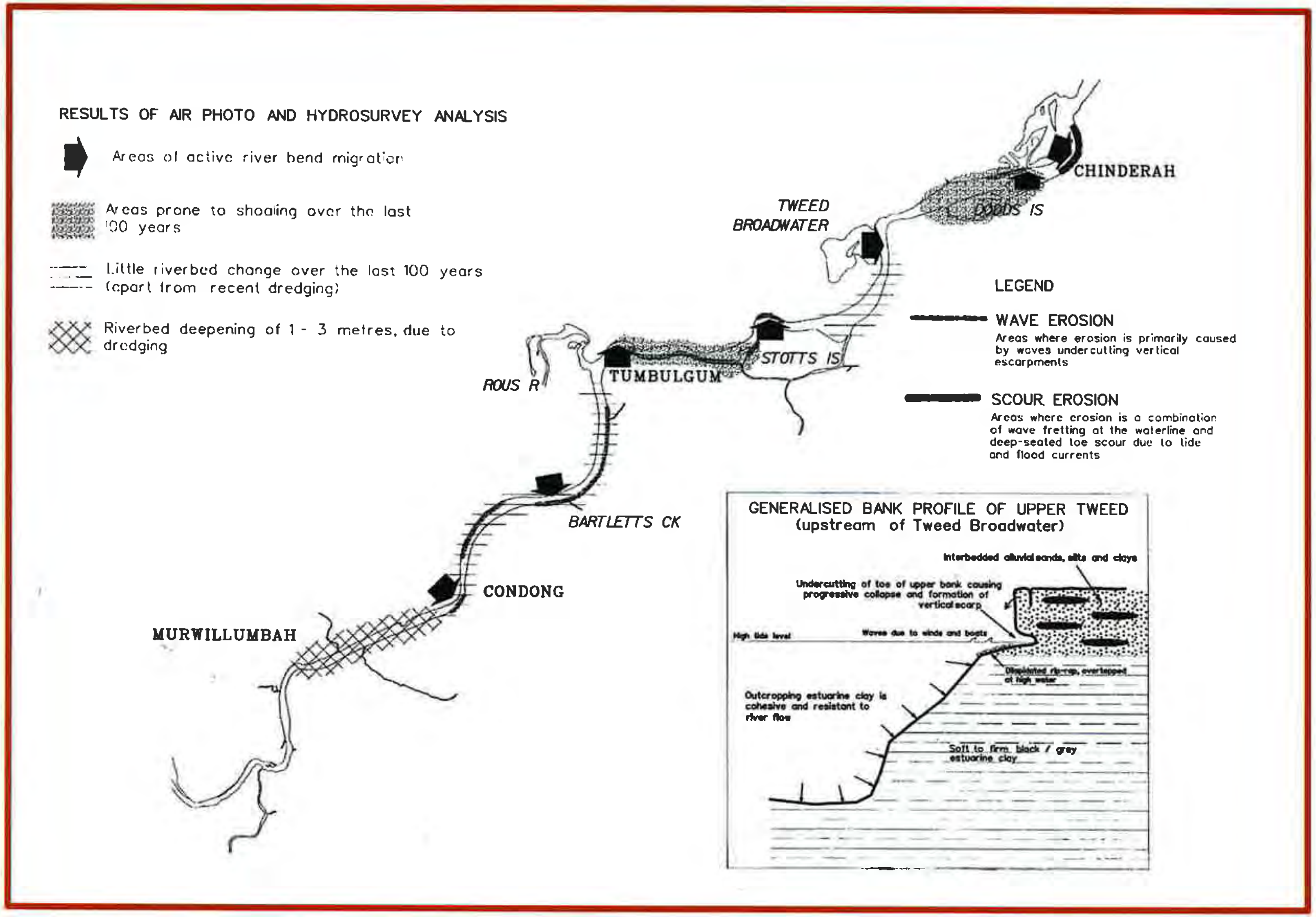

Figure 8 Results of aerial photography and hydrosurvey analysis (PBP, 1996)

4.1.4 Saturated Bank Soils

Large differences in level between groundwater and the free river surface flow exacerbates the erosion of river beds through dislodgement of bank material as a result of seepage processes. This is most likely to occur immediately following a major flood when the ground would be saturated (high groundwater level) and the river level has dropped to normal tide levels. Removal of riparian vegetation can raise groundwater levels and exacerbate the susceptibility of river banks to seepage failure.

4.2 Wind-Wave Environment

Erosion of river banks due to wind waves is predominantly related to the exposure of the site to wind fetches and hence the generation of wind waves.

Glamore (2008) suggests that over time a particular reach of river will establish equilibrium with the local wind-wave environment, provided there are no large flooding events over that period. Therefore, if the wave energy produced by other mechanisms (such as vessel wake) within the stretch of river exceeds the energy of natural wind waves within the stretch of river, erosion of the river bank would be likely to occur. Removal of riparian vegetation may also be a factor in upsetting the equilibrium by exposing the banks to higher wave energy despite the wind climate being unchanged.

4.3 Boat Wake Environment

The Tweed Estuary has experienced an increase in vessel traffic in recent years. PBP (2008) reported an annual growth of 5% in vessel registrations and in the Tweed Shire. Visitation from outside of the Tweed Shire also contributes to growing vessel usage. As these vessels travel along the river they generate wake in the form of waves which propagate away from the vessel. The height and period of these waves vary depending on a number of vessel and local environment parameters. Wake waves resulting from any vessels have the potential to result in erosion of the riverbank.

On average non-towing recreational vessel activities only result in boat wake waves occurring along a stretch of river for a short period of time as they pass through that area. Towing vessel activities are more likely to do laps along the same stretch of river and result in wake waves occurring for a more prolonged period. In addition to the frequency of the waves impacting the same stretch of river bank, towing activities such as wakeboarding specifically generate large wakes, while other towing activities require the boat to travel at high speeds which can also result in potentially significant wake. Therefore, boat wake waves constitute a major factor in the bank erosion along rivers, particularly where towing activities are current practice.

The Tweed River is well-known in NSW for its wakeboarding and water-skiing activities and is commonly frequented by people from the adjacent Gold Coast (and further afield) as the waterways in this area are either not suited to safe towing activities or in some cases towing activities are not permitted. Data collected regarding QLD vessel registrations *(NSW Maritime, 2006)* has shown that the estimated proportion of Queenslanders being 60% of Tweed River users on a peak day *(PBP, 1997)* to be of the correct order.

Towing activities are generally undertaken in flat water and so when sections of the river are subject to wind generated waves the towing activities are likely to move to areas sheltered from the wind generated waves. This means that the periods when larger wind waves occur and when wake waves from towing activities occur will not coincide. Accordingly, the duration (or percentage of time) the potentially erosive waves (wind or boat wake generation) occur is significantly increased.

It is common practice in towing activities to remain closer to the river bank than the centre of the channel as this tends to be where the flatter water is located. If the wind direction is perpendicular to the channel then towing activities will specifically stay as close as possible to the upwind channel bank to remain in flatter water, this means that the downwind bank will be subject to wind generated waves while the upwind bank which is sheltered from the wind generated waves will be subject to waves resulting from the towing activities.

Typically, naturally occurring waves on the Tweed River of similar magnitude to wake generated by towing vessels only occur occasionally during extreme wind events. As these potentially erosive wind waves do not occur frequently the river banks have time between events to naturally adapt to the resultant erosion. Adaptation occurs through processes such as changing the profile slope and allowing vegetation growth. Conversely, as boat wake waves occur on a regular basis there is no time for the river banks to adapt or recover between wave events as would occur with natural wind waves. Accordingly, banks are likely to be constantly eroding with the frequent wake waves preventing them from adapting/recovering.

Vessel wake management is a relatively complex issue. Indeed, it is difficult to determine a standardised approach as the impact of boat waves depends on various criteria including the shape and speed of the boat, the depth of the waterway, the type and condition of the embankment. Numerous different wake wave management criteria have been developed previously, as illustrated in **Table 6**.

Table 6 Wake wave management criteria (Glamore, 2008)

Wave Characteristic	Wave Management Criteria	Source
Maximum Wave Height (H_{max})	28 cm from peak to trough measured 300 m from sailing line in deep water.	Stumbo *et al.* (1999).
Maximum Wave Height (H_{max})	< 20 cm no action on bank stabilisation required. 20-30 cm requires monitoring. 30-40 cm requires bank engineering assessment and remediation.	Patterson Britton and Partners (2001).
Maximum Wave Height (H_{max})	Based on wave height criteria: $H_h \leq 0.5\sqrt{\frac{4.5}{T_h}}$ Where H_h is H_{max} and T_h is mean wave period. (Equates to 0.75m for 2.0 second wave period.)	Parnell and Kofoed-Hansen (2001)
Wave Energy	< 2450 joules/m (150 lb/ft) in the highest significant wave of the wave train as measured 300m from sailing line in deep water.	Stumbo *et al.* (1999).
Wave Energy, Wave Period and Speed	Energy: $1962H_m^2T_m^2<60$ joules/m or <180 joules/m: Period: Comparison of boat length and energy in the from of $3.04\sqrt{L}$ Speed: Blanket Speed Limit of 5-6 knots	Australian Maritime College (2003)

Propagation of vessel wake is schematised in **Figure 9.** Field tests on boat wake waves have been undertaken for a range of vessel types, sizes and speeds by Glamore & Hudson (2005). The study detailed wake resulting from a range of vessels; however, it is beyond the scope of the present investigation to discuss all of these.

As previously discussed, towing activities are the most likely recreational boat activities to result in significant erosion of the river banks owing to the comparative high energy and repetitive nature of the activity. These activities represent a large proportion of the wake energy produced. Accordingly, this assessment investigates wake energy resulting from typical vessels used for towing activities (waterskiing and wakeboarding) to quantify the order of magnitude of erosion potential due to vessel wake.

Results from field tests undertaken for average size vessels running at a suitable operational speed for waterskiing and wakeboarding are shown in **Table 7,** while the maximum possible wake wave resulting from the vessels is shown in **Table 8**. Investigations by Glamore (2005 and 2008) reported the following:

- a wave train (i.e. group of fully formed boat waves) initially appears as an accumulation of super-imposed waves travelling away from the sailing line
- wake waves becomes fully developed (maximum wave height) at approximately 22m (2.5 to 3 boat lengths) from the sailing line
- as waves propagate further away from the sailing line, attenuation occurs resulting in a decreasing wave height while the wave period remains constant.
- wave conditions shown in **Table 7** and **Table 8** were recorded at the location of the maximum wave height
- Peak maximum wave heights which are shown in **Table 8** to occur when both vessels travel at 8 knots (transitional speed where the vessel is just below the speed required to be planning, likely to be maintained for a short time/distance while they accelerate up to operational speed).

As part of this assessment it has been assumed that fully developed waves resulting from the boat wakes reach the shore without any attenuation. This is a reasonable assumption as towing activities are generally undertaken closer to the river bank than the centre of the channel because the water is often calmer. Furthermore, the Tweed River is relatively narrow and minimal wave attenuation is likely to occur. It has also been assumed that the vessels are constantly at operational speed and not running at the lower speed which results in larger wake waves.

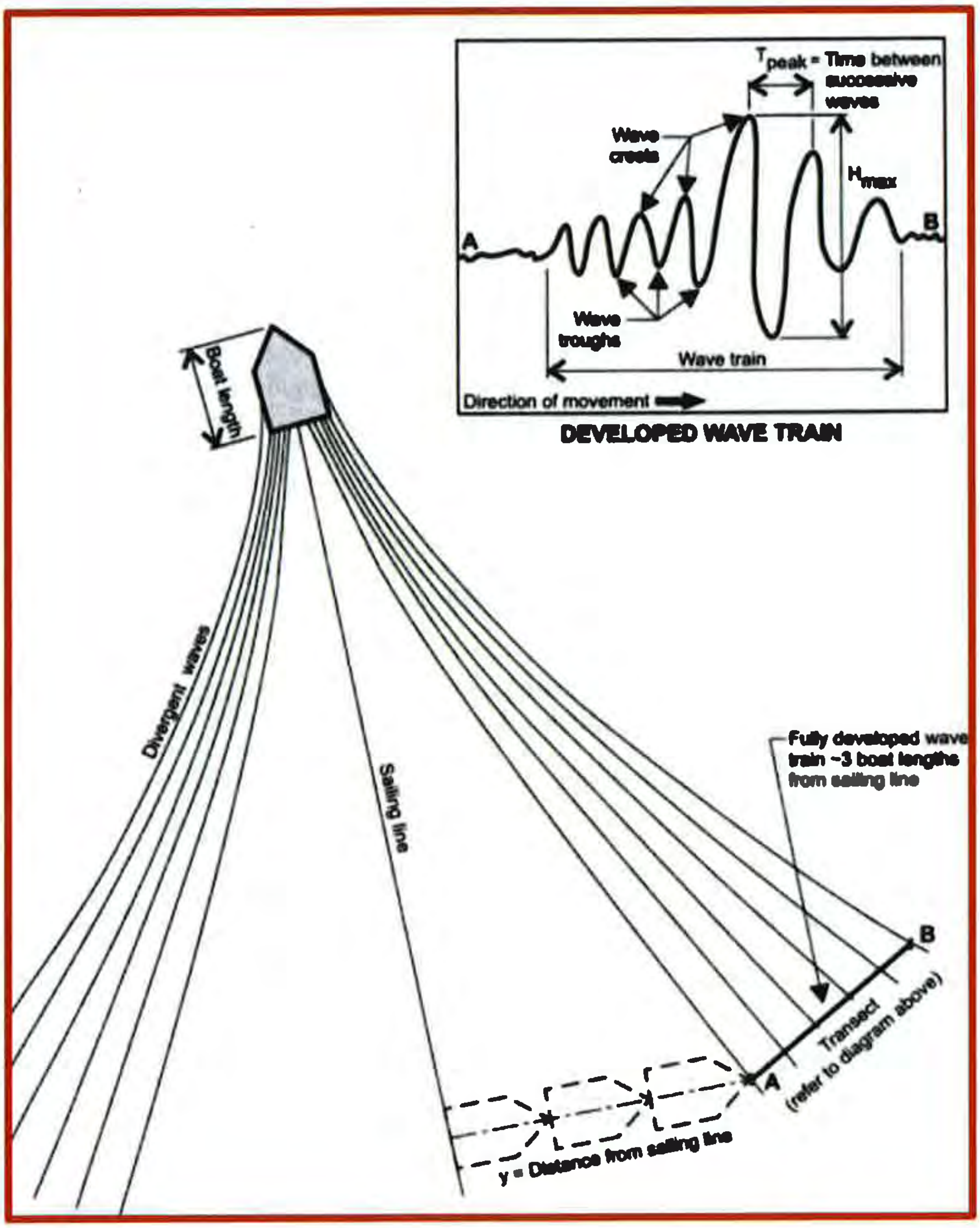

Figure 9 Boat wake wave generation (Glamore, 2008)

Table 7 Wake waves generated in operating condition (Glamore, 2008)

Boat	Velocity (knots)	Velocity (m/s)	H_{max} (m)	T_{peak} (s)	Boat Length L_w (m)	F_L	Energy H_{max}
Waterski	30	15.42	0.12	1.50	6.1	2.0	62
Wakeboard	19	9.76	0.25	1.57	6.1	1.3	293

Table 8 Maximum wake waves as predicted by the length based Froude Number (Glamore, 2008)

Boat	Velocity (knots)	Velocity (m/s)	H_{max} (m)	T_{peak} (s)	Boat Length L_w (m)	F_L	Energy H_{max}
Waterski	8	4.11	0.35	1.73	6.1	0.5	701
Wakeboard	8	4.11	0.33	1.86	6.1	0.5	700

4.4 Land-Use Practices And Catchment Management

Maps of land-use practises along the Tweed River are shown in **Figure 2** to **Figure 7**. These show the majority of land adjacent to upper to mid stretches of the Tweed River is used for agriculture. The downstream reaches of the river are made up predominantly of vegetated areas; although there are also residential properties and areas with cattle and stock grazing. The land-use mapping indicates that the mid and upper reaches of the Tweed River are more at risk from river bank erosion owing to the lack of vegetated river bank.

It is important to identify any future changes in land use practises which could result in the generation of sediment and nutrients within the Tweed River. It would then be necessary to employ strategic management plans to reduce runoff rates and therefore the potential input of both water and sediment to the river channel. It may also be necessary to employ a management plan to help stabilise the river banks if the change in land use practise is deemed to increase the potential for river bank erosion.

Wherever possible the catchment management should be improved by using the concept of rehabilitation of riparian corridors. These areas should be focused along rivers and creeks and when established will provide a healthy, viable habitat which will help to stabilise the riverbanks.

A number of management plans have been developed to address the long term management of the Tweed River. The plans are as follows:

- Cobaki and Terranora Broadwater Coastal Zone Management Plan (2010);
- River Management Plan – Lower Tweed Estuary (1991);
- Upper Tweed Estuary Management Plan (1996); and
- Tweed River Estuary Bank Management Plan (1998) (under review).

5 WIND WAVE ENVIRONMENT

Bureau of Meteorology (BoM) weather stations were assessed to determine the most appropriate station to provide representative winds for the Tweed River. It was determined that the weather station at Coolangatta (Station 040717) would be most appropriate. Half hourly wind data for this station was provided from July 1994 to June 2011, giving just under 17 years of half hourly wind data. An assessment of the wind data has shown that the dominant wind directions are from the north and south with peak wind speeds of 18.6m/s (67km/hr) recorded over the period (**Figure 10**). **Figure 11** shows that the dominant wind direction varies through the year, with northerly winds being dominant during spring, northerly and southerly winds both being dominant during summer, southerly to south-westerly winds being dominant during winter and southerly winds dominating in autumn.

To determine the wind generated wave environment within the Tweed River, a series of 19 sites within the river were selected to calculate the wave climate. These sites are located between the confluence with Terranora Creek near Tweed Heads and the weir at Bray Park (**Figure 1**). The sites were positioned to ensure the longest fetch lengths were included and to ensure all the most popular towing locations were also covered.

The potential fetch length was calculated for all possible directions at 22.5° increments for each site. Wind generated wave conditions were then calculated for the entire wind data time series at the 19 sites. The waves were calculated using numerical modelling algorithms for depth/fetch limited waves in shallow water environments. As part of this assessment it was assumed that there was a constant water depth of 5m at each site.

Summary results from the wind generated wave assessment are provided in **Table 7** and shown as a series of wave roses in **Figure 12.** The results show that sites 3 and 11 are subject to the largest wind generated waves. **Figure 1** shows that Site 3 has a fetch of approximately 2km to the SSW and 1.8km to the N, while Site 11 has a fetch of 2km to the south. Results from the wind data analysis shows that winds from these directions dominate in the area both in terms of durations and magnitudes. The remaining sites within the Tweed River are relatively sheltered from locally generated wind waves, with the wave roses showing that wave heights of less than 0.05m occur most frequently.

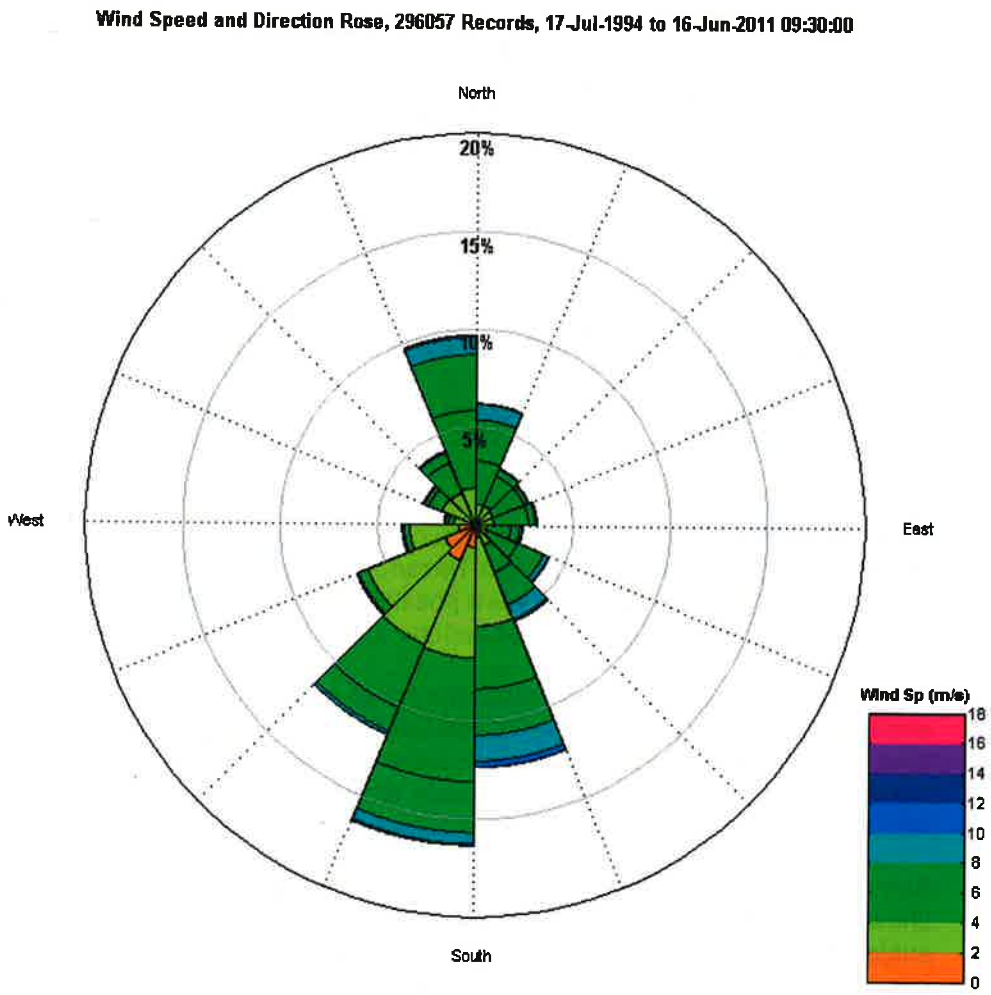

Figure 10 Wind rose showing annual wind climate for Coolangatta (July 1994 to June 2011).

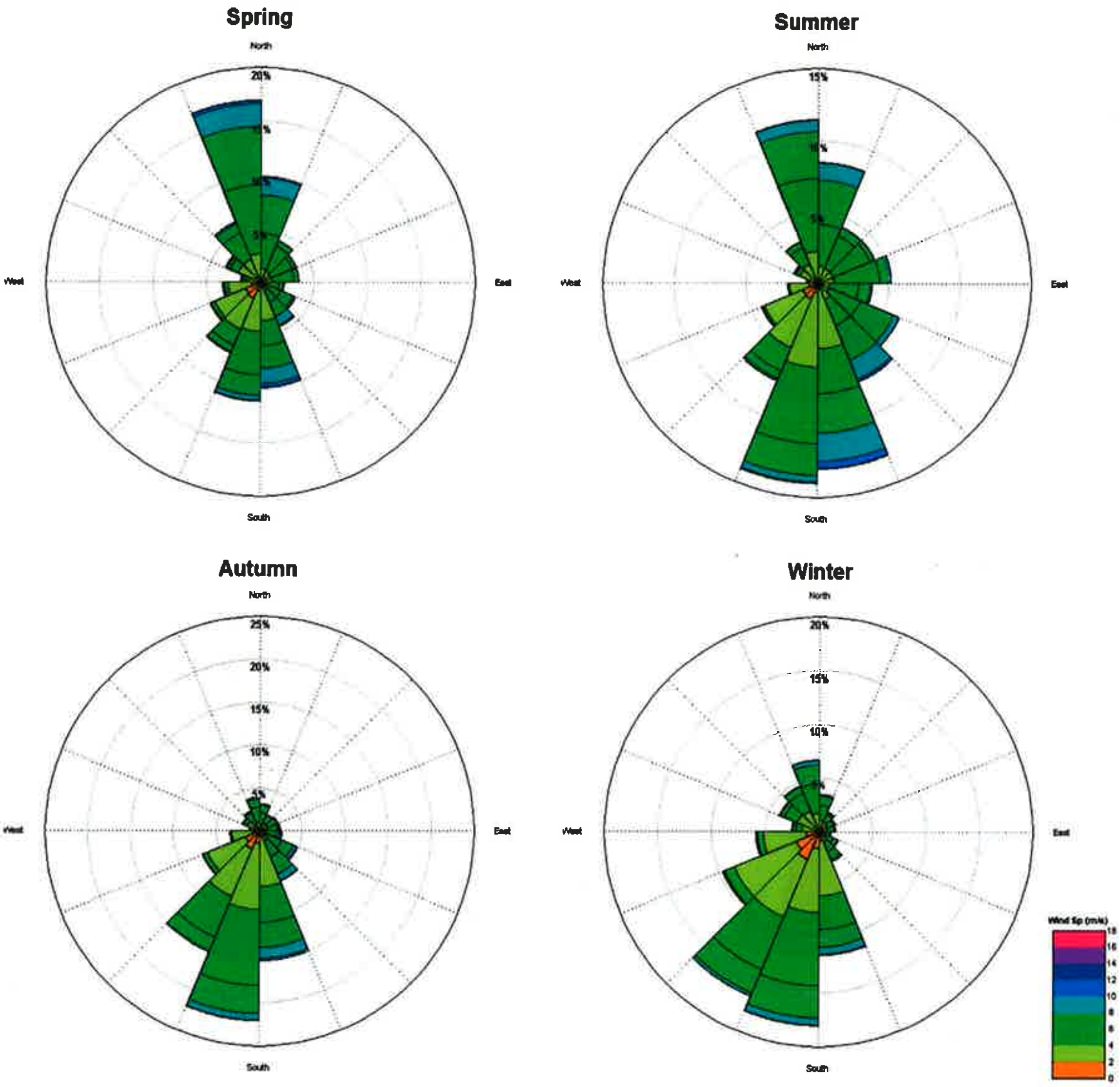

Figure 11 Wind roses showing seasonal wind climates for Coolangatta (July 1994 to June 2011).

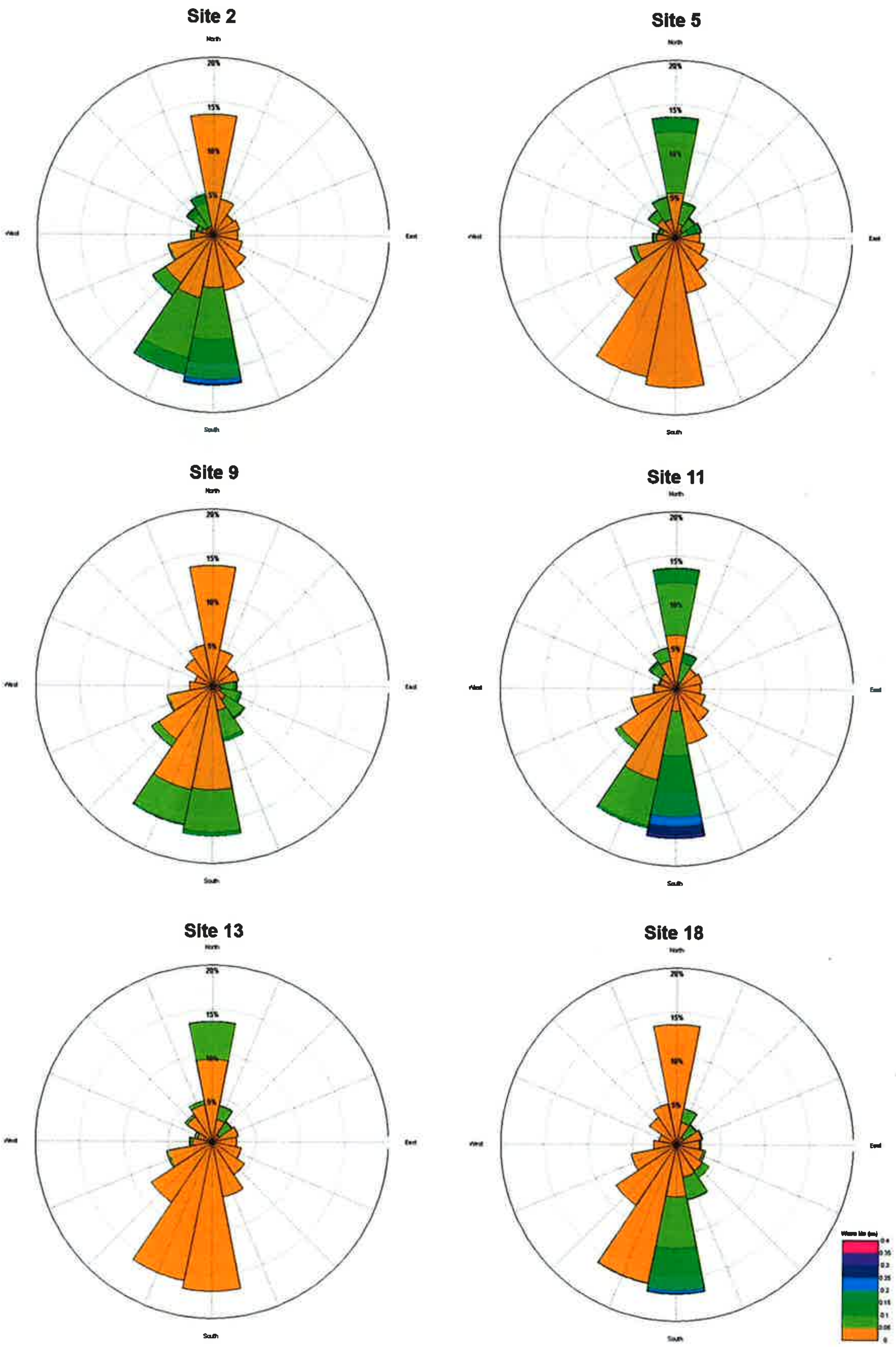

Figure 12 ***Wind generated wave climate roses at a series of sites within the Tweed River.***

Table 9 Percentile exceedance values for wind generated waves at the 19 site locations.

Site Number	Hs (5% Exceedance) (m)	Tm (5% Exceedance) (s)	Hs (1% Exceedance) (m)	Tm (1% Exceedance) (s)
1	0.13	1.19	0.2	1.42
2	0.13	1.2	0.19	1.39
3	0.18	1.49	0.27	1.72
4	0.1	1.07	0.15	1.28
5	0.1	1	0.14	1.3
6	0.13	1.13	0.17	1.26
7	0.08	0.9	0.13	1.16
8	0.1	1.01	0.14	1.13
9	0.09	0.88	0.11	1.01
10	0.08	0.84	0.1	1.02
11	0.17	1.45	0.26	1.68
12	0.14	1.21	0.19	1.35
13	0.07	0.77	0.09	0.89
14	0.07	0.84	0.11	1.1
15	0.11	1.18	0.17	1.37
16	0.08	0.99	0.12	1.24
17	0.08	0.82	0.15	1.38
18	0.11	1.12	0.17	1.29
19	0.12	1.17	0.19	1.35

6 WAKE IMPACT ASSESSMENT

Section 4.3 describes general vessel wake processes and how they contribute to bank erosion. Analysis has been undertaken to quantify the increased frequency of wave events due to towing vessel wake. Wake from non-towing vessels has not been considered due to the relatively short duration of impacts from these vessel types. This exclusion would not significantly impact on the outcome of the analysis.

Included is investigation of the duration that waves resulting from towing activities occur compared with similar wind generated wave heights expected to occur naturally. The probability of exceedance curves for wave height are plotted for wind waves alone and for wind waves with vessel waves to determine the influence of towing vessel wake on the wave climate throughout the Tweed River study area.

6.1 Existing Level of Wake Impacts

6.1.1 Boat Usage in the Tweed River

Boat usage was reported by PBP (2008) and NSW Maritime (2006). A survey of the number of boats along the Tweed River was undertaken over the Australia Day long weekend, 24-26 January 2004. A summary of the survey is represented in **Table 10**. This relative pattern of boat usage is still considered current following discussion with NSW Maritime and other river users.

From this table, it is noted that the section of the river potentially most impacted by boat wake from towing activities is the reach upstream of Tumbulgum to the no-skiing area south of Murwillumbah (sites 8 to 19). Towing activities are less frequent between Tumbulgum and Ukerebagh Island but they do occur and as such these sites have also been assessed (sites 1 to 7). As the previous assessment had been surveyed during a typical peak boating weekend, it is assumed that around 70% of the boats would be present on a normal weekend and 20% of the number of boats would be present on week days. The assumed number of towing activities for the different sites is shown in **Table 11**. It is also assumed that each vessel would do 18 laps during a weekday, with 3 people doing 3 laps each time and having 2 turns; and 48 laps during a weekend, with 8 people doing 3 laps each time and having 2 turns. For both cases each lap would generate 6 waves.

Table 10 Vessel activity along the Tweed River (from NSW Maritime (2006)).

Area	Cruising	Fishing	Moored	Sailing	Skiing	Wakeboard	PWC	TOTAL	Total %
B004AA	20	9	0	0	0	0	5	34	12.1%
B004AB	9	4	0	0	2	0	4	19	7.0%
B004AC	2	4	0	0	1	0	1	9	3.1%
B004AD	12	12	0	1	1	2	3	32	11.4%
B004AE	2	3	0	0	1	0	0	7	2.4%
B004AF	4	1	0	0	4	2	1	13	4.7%
B004AG	0	0	0	0	0	0	0	0	0.0%
B004AH	13	4	0	0	12	10	11	51	18.3%
B004AI	7	1	2	0	7	3	4	24	8.6%
B004AJ	2	1	2	0	14	0	3	23	8.2%
B004BA	10	7	0	0	0	0	3	20	7.0%
B004BB	18	15	0	0	0	0	0	33	11.9%
B004BC	6	9	0	0	0	0	0	14	5.2%
B004BD	0	0	0	0	0	0	0	0	0.0%
Grand Total	105	72	4	1	43	18	35	277	100%

B004AA – Entrance to Entrance Terranora Inlet
B004AB – Ukerebagh Is to Rocky Point
B004AC – Rocky Point to Barneys Point Bridge
B004AD – Barneys Point Bridge to Tweed Broadwater
B004AE – Tweed Broadwater to Rawson Island
B004AF – Rawson Island to Tumbulgum Boat Ramp
B004AG – Rous River
B004AH – Tumbulgum Ramp to Condong Ramp
B004AI – Condong Ramp to Murwillumbah Bridge
B004AJ – Murwillumbah to the Weir
B004BA – Terranora Creek to Dry Dock
B004BB – Dry Dock to Big Island
B004BC – Terranora Broadwater
B004BD – Cobaki Broadwater

Table 11 Assumed number of boats at the 19 sites.

Site Locations	Assumed number of wakeboard boats	Assumed number of water-ski boats
Sites 1 and 2	1 per day on weekend 2 during week days	1 per day on weekend 2 during week days
Site 3	1 per day on weekend 1 during week days	1 per day on weekend 1 during week days
Sites 4 and 5	1 per day on weekend 2 during week days	1 per day on weekend 2 during week days
Sites 6 and 7	1 per day on weekend 1 during week days	1 per day on weekend 1 during week days
Sites 8, 9 and 10	3 per day on weekend 1 per day on week days	3 per day on weekend 1 per day on week days
Sites 11, 12, 13, 14 and 15	8 per day on weekend 2 per day on week days	8 per day on weekend 2 per day on week days
Sites 16 and 17	4 per day on weekend 1 per day on week days	4 per day on weekend 1 per day on week days
Sites 18 and 19	5 per day on weekend 1 per day on week days	5 per day on weekend 1 per day on week days

6.1.2 Comparison of Wake and Wind Waves

Annual Wave Durations

To allow comparison between waves predicted to result from vessel wake and the locally generated wind waves at each site, the annual duration that certain wave conditions occur as a result of wake and wind waves have been calculated.

For the waves resulting from boat wakes the annual duration that the waves would occur was calculated for each site location using the equation below:

$$Annual\ Duration\ (hrs) = \frac{No.Boats \times L \times 6 \times T}{3600 \times 24}$$

Where: *No. Boats* = the annual number of boats predicted for the area of the river (calculated based on Table 7).

L = the number of laps the boat is assumed to do. Note: this changes between the week and the weekend and so separate calculations are required for weekdays and weekends.

T = wave period for the boat wake waves, assumed to be 1.5s for waterskiing and 1.57s for wakeboarding (Glamore, 2008).

For the wind generated waves, the wave conditions predicted to occur at each site were analysed to give a frequency of occurrence for the wave heights. Based on this analysis the percentage of time was calculated for which the wind generated wave height was equal to or greater than the wave resulting from waterskiing and wakeboarding. The percentage, which is based on 17 years of hindcast wave data, was converted to number of hours per year when wind generated waves were equal to, or larger than, wake waves resulting from towing activities.

Figure 13 and **Figure 14** show the annual duration that waves resulting from slow towing and fast towing boat wakes occur and the additional duration that similar or larger wind-generated waves occur. These plots highlight how the waves from boat wakes add to the existing wave conditions and how the natural wind generated wave conditions vary between the sites. These plots show that at the majority of sites within the river the waves from wake markedly increases the annual duration that certain size waves occur.

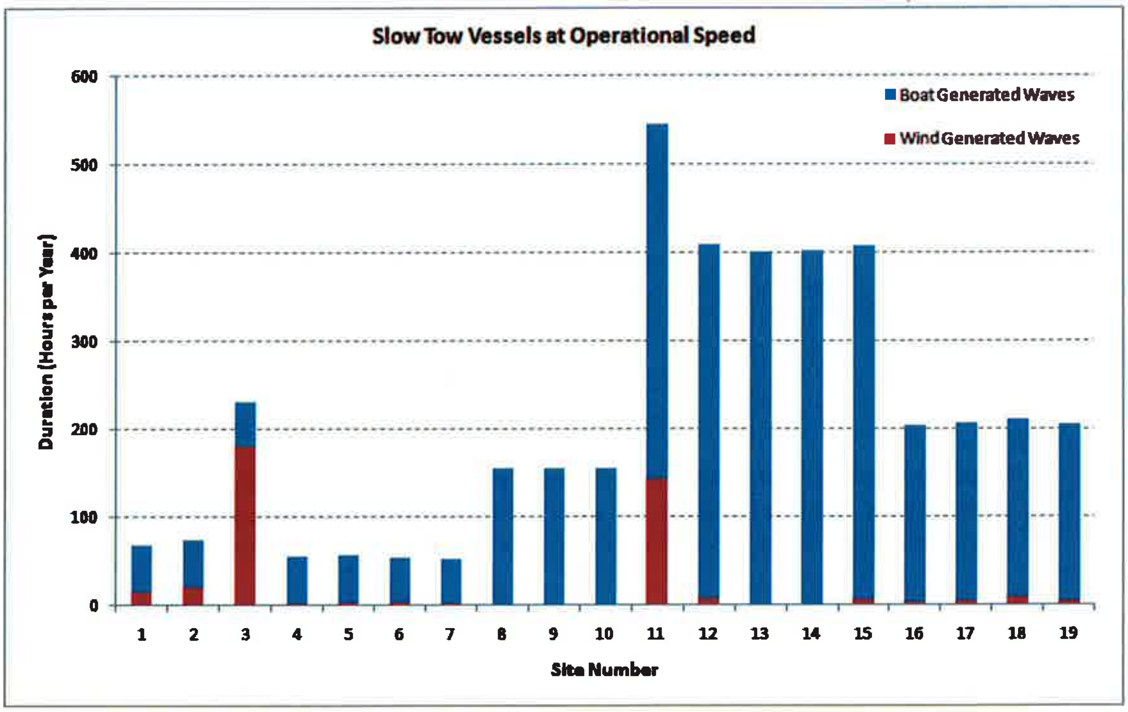

Figure 13 *Annual duration; slow towing wake (Hs = 0.25m) and similar wind waves.*

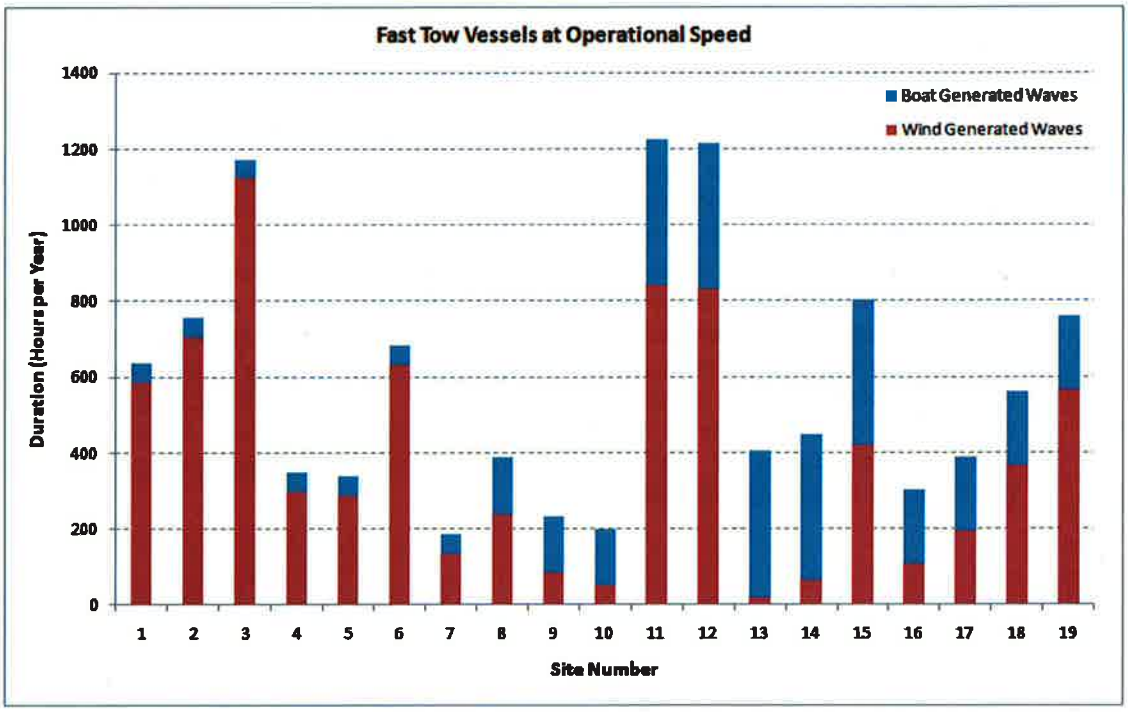

Figure 14 *Annual duration; fast towing boat wake (Hs = 0.12m) and similar wind waves.*

Wave Energy

The energy of waves per unit width of wave crest can be calculated using the following equation:

$$E = \frac{\rho g^2 H^2 T^2}{16\pi}$$

Where: ρ = water density (kg/m^3)

H = wave height (m)

T = peak period (s)

Maximum operational wave height occurs 22m from the sailing line. Maximum attenuation of the wave was calculated for each site using the following equation and assuming a lateral distance from the sailing line equal to the half of the river width:

$$\frac{H_y}{H_0} = y^{-\frac{1}{3}}$$

Where: y = lateral distance from the sailing line (m)

H_y = wave height at y metres from the sailing line (m)

H_0 = wave height when generated (m)

Once the energy of the maximum wave height of the wave train is calculated, the total energy of the wave train generated by the vessel can be calculated using the following equation (Glamore, 2008):

$$E_{Tot} = 10.8E_{Hmax}^{0.82}$$

The results of the wake energy calculation are compared to the wind wave energy for natural wind waves of corresponding annual occurrence for the selected sites in **Table 11**. The wave energy resulting from wakeboarding wake is larger than for waterskiing wake. The lowest value in the wave energy range resulting from wakeboarding is larger than the wind wave energy at all sites except for sites 1-3, 5-6 and 11 and the largest value in the wave energy range is larger at all sites except site 3. The table demonstrates that the energy resulting from towing activities is generally significantly greater than the equivalent naturally occurring wind generated wave energy. Glamore (2008) suggests that erosion of the river bank is likely to occur when the wave energy for a particular reach of river exceeds the energy of the natural wind waves. Potential erosion rates would be proportional to the excess wave energy.

Table 12 ***Wake and wind wave energy based on annual occurrence waves.***

	Operational Waterski Wake Wave		Operational Wakeboard Wake Wave	
Site Number	Boat Wake Energy Range * (J/m)	Equivalent Wind Wave Energy (J/m)	Boat Wake Energy Range * (J/m)	Equivalent Wind Wave Energy (J/m)
1	14-64	234	66-302	234
2	13-64	195	64-302	195
3	23-64	477	110-302	477
4	21-64	96	100-302	96
5	15-64	96	73-302	96
6	27-64	154	128-302	154
7	25-64	72	118-302	72
8	23-64	38	110-302	38
9	21-64	34	100-302	34
10	21-64	20	100-302	20
11	25-64	143	118-302	143
12	28-64	75	133-302	75
13	29-64	10	140-302	10
14	33-64	10	155-302	10
15	31-64	41	147-302	41
16	28-64	20	133-302	20
17	29-64	48	140-302	48
18	39-64	75	188-302	75
19	35-64	85	164-302	85

**energy range depends on the location of the boat in the channel, maximum wave energy occurs 22 m from the sailing line when the boat wake wave is fully developed and minimum energy occurs when the sailing line is down the centre of the channel.*

__Wave Probability of Exceedance__

To demonstrate further how the waves resulting from vessel wake change the wave climate within the river, a series of probability of exceedance curves have been created. The plots have a curve showing the natural wind generated wave climate and a curve showing the combined wave climate for both wind generated waves and boat wake waves caused by towing activities. The plots have been created for a number of sites to provide an indication of the variability throughout the study area (**Figure 15** to **Figure 21**).

The probability of exceedance curves for sites 2 and 3, located in the downstream area of the Tweed River, show only a slight change as a result of waves from vessel wakes. This is due to the wind generated wave climate at these sites being more energetic than the majority of the river and as this downstream area is not used as frequently for towing activities as the sites further upstream. For all sites upstream of site 3 the probability of exceedance curves show a distinct change as a result of vessel wake. The changes demonstrate how larger waves occur more frequently as a result of vessel wake.

The extent of the change is dependent on how exposed the site is to natural wind generated waves combined with how frequently tow vessels operate. For example, at site 13 which is used very frequently by towing vessels and which is sheltered from wind generated waves, the wave height which would be exceeded for 1% of the year is 0.08m by naturally wind generated waves. However, when waves resulting from vessel wake is included the wave height which would be exceeded for 1% of the year is 0.25m. While at site 18 which is used less frequently by towing vessels and is more exposed to wind generated waves, the wave height which is exceeded for 1% of the year is 0.17m for wind generated waves, and 0.25m when waves resulting from wake vessels are included.

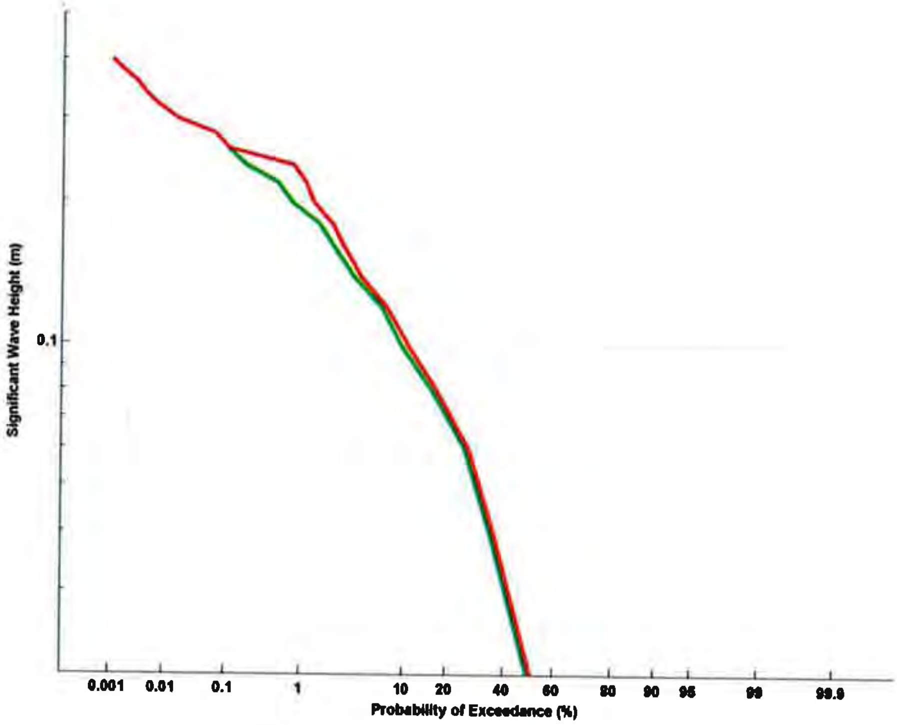

Figure 15 Probability of exceedance of wave height at Site 2. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)

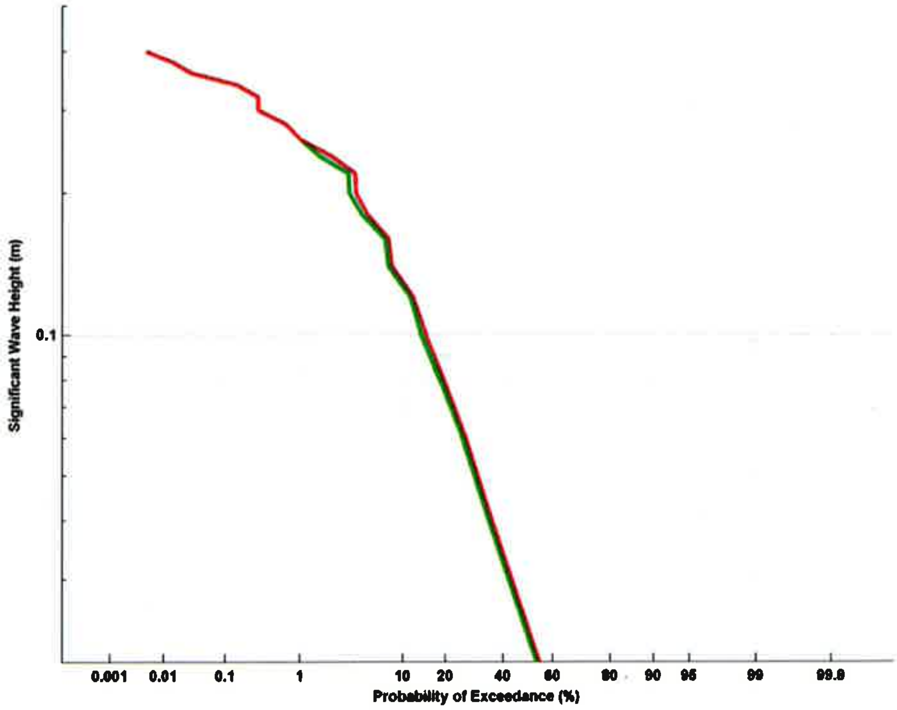

Figure 16 Probability of exceedance of wave height at Site 3. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)

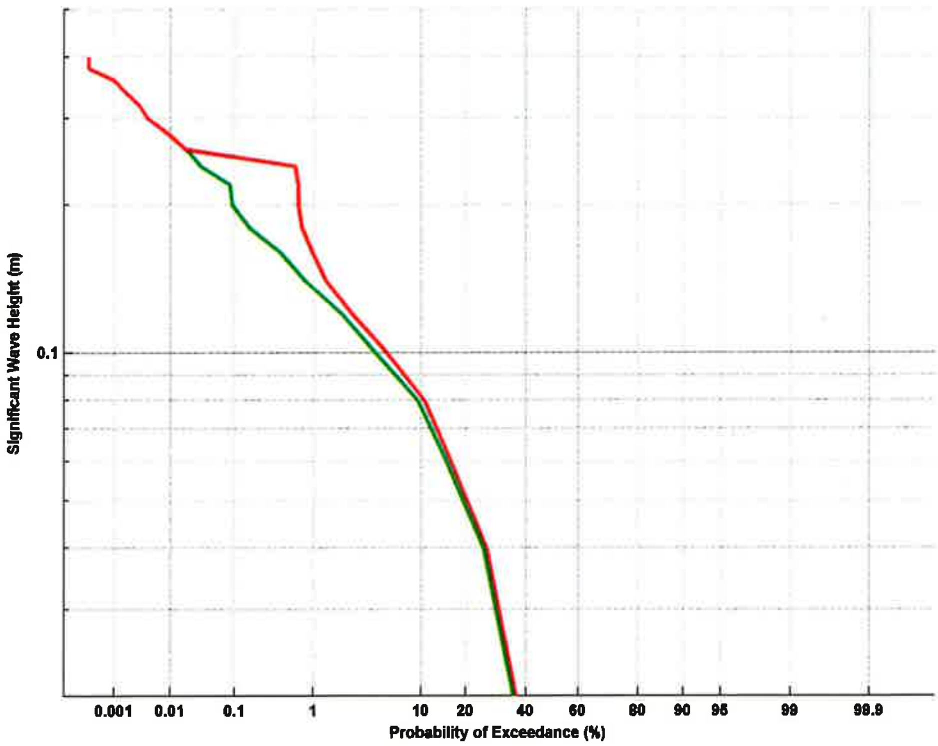

Figure 17 Probability of exceedance of wave height at Site 5. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)

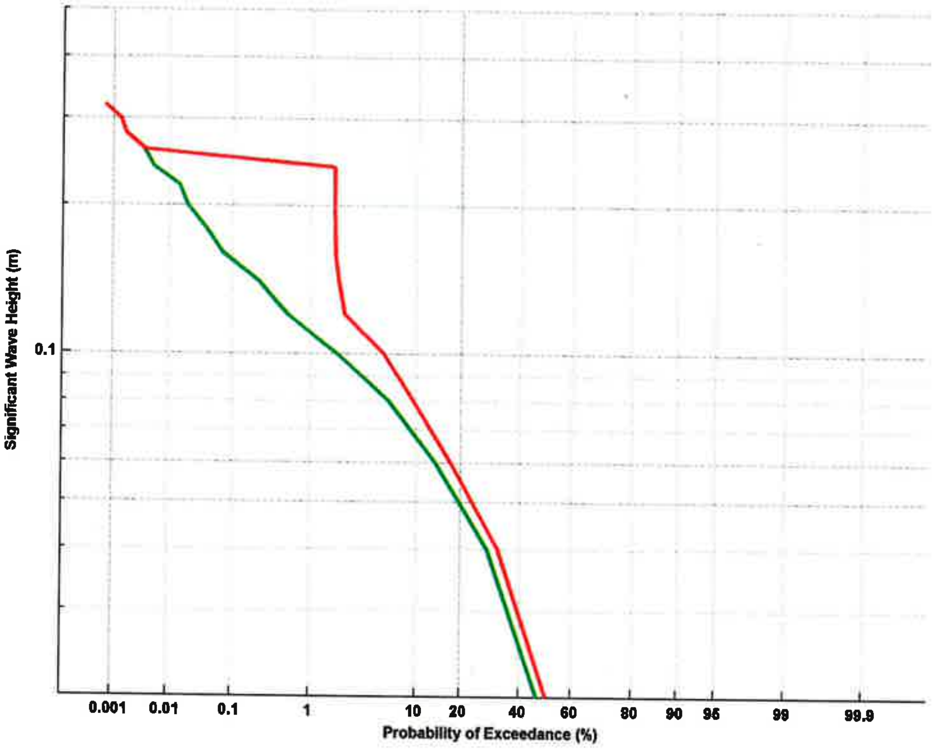

Figure 18 ***Probability of exceedance of wave height at Site 9. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)***

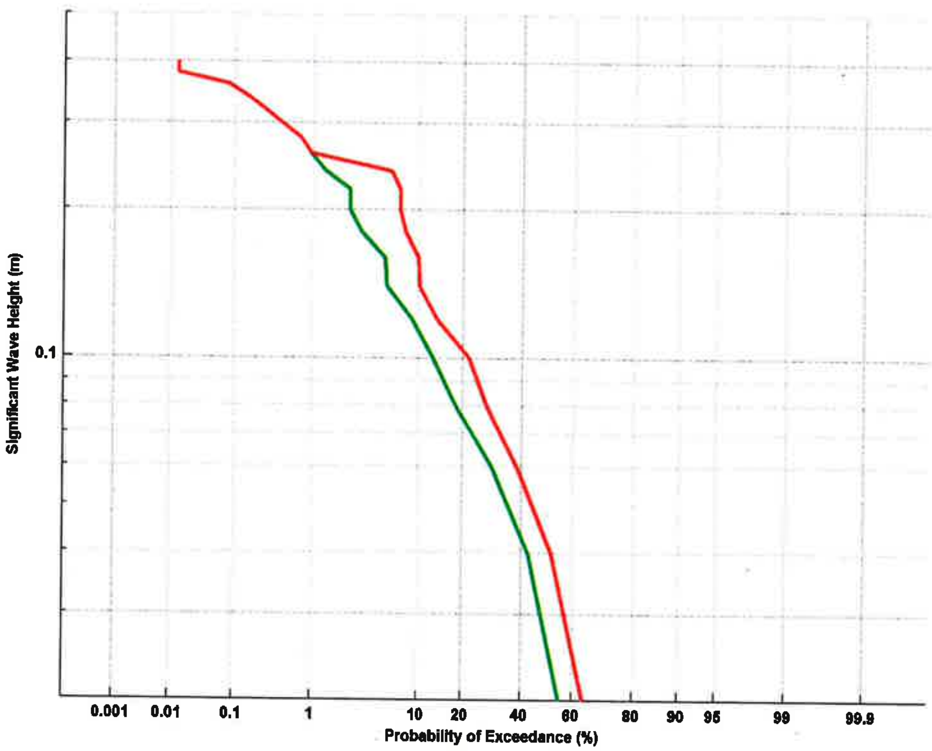

Figure 19 ***Probability of exceedance of wave height at Site 11. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)***

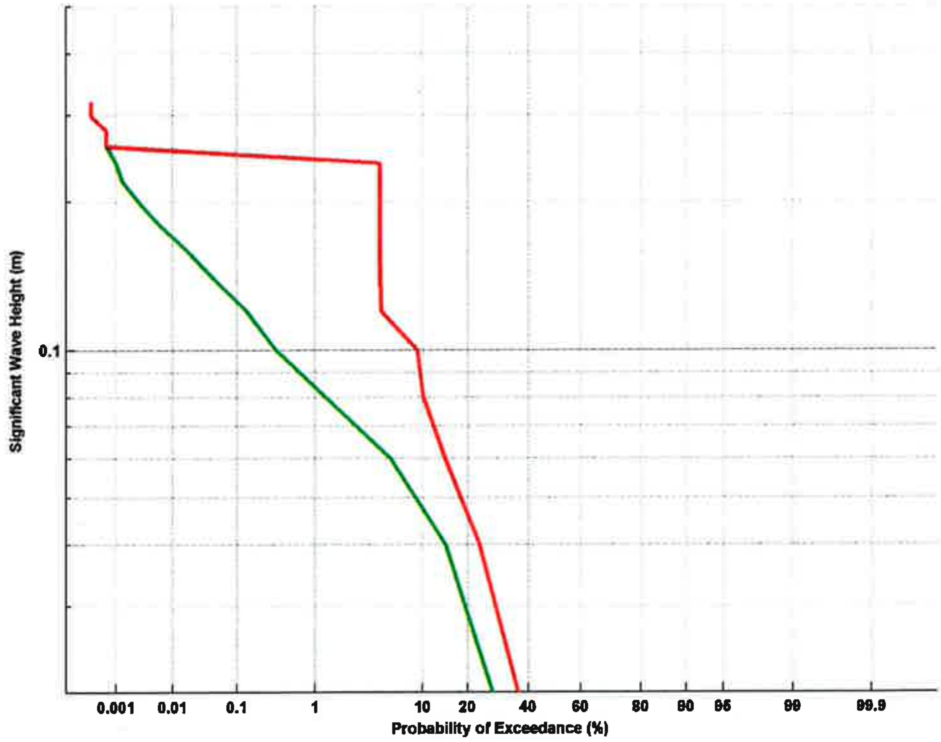

Figure 20 Probability of exceedance of wave height at Site 13. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)

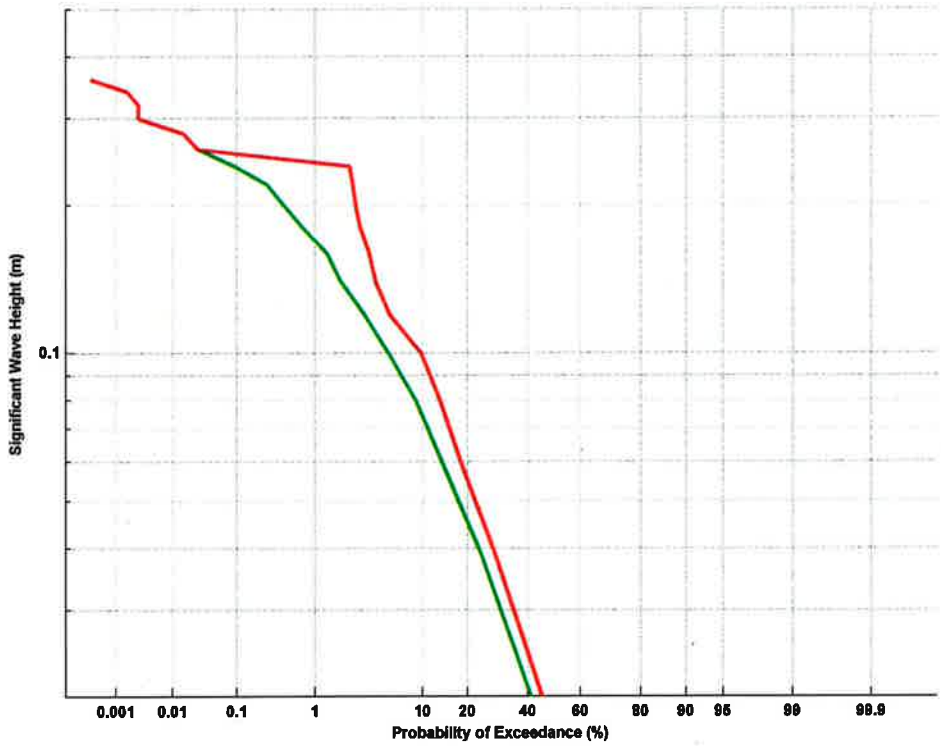

Figure 21 Probability of exceedance of wave height at Site 18. (Note: the green line shows wind waves and the red line wind waves with the vessel wake included)

6.1.3 Discussion

Wind wave hindcasting has shown the following:

- wind generated waves between Ukerebagh Island and Bray Park in the Tweed River are greater than 0.2m for less than 5% of the time.
- most exposed to wind generated waves are sites 1, 3 and 11, with a 1% probability of exceedance in excess of 0.2m.
- moderately exposed to wind waves are sites 2, 4, 6, 12, 15, 17, 18 and 19, with a 1% probability of exceedance wave height of between 0.2m and 0.15m.
- more sheltered to wind generated waves are sites 5, 7, 8, 9, 10, 14 and 16 which all have 1% probability of exceedance wave heights of between 0.15m and 0.1m.
- most sheltered is site 13 with a 1% probability of exceedance wave height of less than 0.1m.

Based on previous research, towing activities are expected to account for the majority of vessel wake energy produced on the Tweed River. Accordingly, quantitative calculations have investigated wake energy produced by these vessel types to indicate the impact of vessel wake on river bank erosion.

Waves generated from vessel wake during towing activities variable depending on the vessel speed and have the following characteristics:

- largest waves occur when the vessels are at a low transitional speed of approximately 8 knots (maximum wave heights predicted to be 0.35m for waterskiing and 0.33m for wakeboarding). Accordingly, minimising periods that vessels are at these speeds should be encouraged.
- at operational speeds, approximately 30 knots for waterskiing and 19 knots for wakeboarding, maximum wave heights are 0.12m and 0.25m for waterskiing and wakeboarding, respectively.
- waterskiing and wakeboarding vessels have the potential to result in similar size waves when they are travelling at low transitional speeds.
- wakeboarding vessels result in larger waves the majority of time they are on the water.

The location of the towing vessel within the channel has an effect on the height of the wake waves which will reach the river bank; the maximum wave height occurs 22m from the vessel and the minimum wave height will reach the river bank if the vessel travels down the centre of the channel. Due to the nature of the optimum conditions for the recreational pastime of waterskiing and wakeboarding (i.e. smooth water), these vessels generally try and stay close to the river banks as the water tends to be flatter. Accordingly, it is likely that the waves which impact the river bank will be close to the maximum. Furthermore, recreational towing activities are likely to occur in areas where the water is sheltered from the prevailing wind conditions such as:

- where bank vegetation is high and provides protection from the wind;
- where the river is narrow (limited fetch for development of wind waves); and
- close to the bank which is not exposed for a particular cross wind direction.

These locations change with particular wind directions. Therefore, these recreational activities add wave energy to the overall wave climate at times when the particular stretch of bank would be naturally experiencing low wave energy based on the wind environment.

When assessing potential river bank erosion it is important to consider wave energy, as this is what influences the potential erosion rate. Wave energy is proportional to the wave height squared and the wave period squared, which means that any increases in wave height or period result in much larger increases in wave energy. For example if the wave height is doubled from 0.15m to 0.3m and the wave period is also doubled from 1s to 2s, the wave energy is increased by sixteen times. This highlights how relatively small increases in wave height and period can result in significantly higher potential rates of river bank erosion.

The assessment has demonstrated that vessel wake has the potential to cause and increase erosion of river banks within the study area. Based on current practices the entire stretch of river between Chinderah and Bray Park has been shown to be susceptible to bank erosion due to a high occurrence of recreational towing activities and a naturally limited wind wave climate. Accordingly, wake from towing activities becomes a dominant bank erosion mechanism.

The stretch of river downstream of Chinderah is more exposed to the predominant wind directions and so is subject to larger wind generated waves. Furthermore, this area has been reported as being used less frequently than the upstream areas for towing activities (this is consistent with the exposure of the site to wind energy). Accordingly, wake generated from towing activities is not expected to significantly increase river bank erosion in these areas given current practices. This is not to say that bank erosion does not occur in these locations (where unprotected). However based on the wave assessment, wake from towing activities are not considered the dominant mechanism. If towing activities were restricted in other areas of the river an increase in towing vessels may be expected in this stretch of river which would likely result in wake waves becoming increasingly significant. This is discussed further in **Section 6.2** .

Locations for wakeboarding and waterskiing are specifically selected for their flat water which explains why a large number of the sites which are most frequently used for these activities are also areas of the river which experience smaller and less frequent wind waves. All areas of the Tweed River which are used for wakeboarding/waterskiing also receive some degree of wind generated waves and so will be prone to possible erosion for the duration that natural wind waves of a certain magnitude occur in addition to the duration that wakeboarding/waterskiing occurs. This is because wakeboarding/ waterskiing will only occur when wind generated waves are small, during periods of larger wind waves towing activities will not occur along the exposed reach of the river but will likely move to more sheltered areas of the river.

Similar magnitude waves to those generated by tow boat wakes only occur intermittently as wind generated waves in the Tweed River. As these potentially erosive wind waves do not occur frequently the river banks have time between events to adapt to any bank erosion. However, as boat wake waves generally occur on a regular basis there is no time for the river banks to adapt to the changes caused by the erosion between wave events which would be the case for natural wind generated waves. Accordingly, the banks are likely to be constantly eroding and the frequency of the wake waves will be preventing any adaption of the banks to the erosion processes.

6.2 Increased Usage

It is recognised that vessel usage data used to develop wake generated wave statistics is 7 years old (collected in 2004 by NSW Maritime). In other locations, such as the Wallamba River, it was found that wakeboarding increased significantly between 2004 and 2011. However, within the Tweed River, PBP (2008) reported that peak usage demand was somewhat constrained by the provision of services (i.e. boat ramp and parking capacity) and therefore the peak numbers are not expected to have increased dramatically. However, usage may have since intensified at times other than the peak.

Furthermore, the rapid increase in popularity of wake boarding (as an alternative to water skiing) may have changed the proportion of usage types significantly.

Discussion in **Section 6.1.3** has indicated that areas upstream of Chinderah are experiencing significant wave energy in excess of the wind wave climate as a result of towing activities. It stands to reason that any increase of these activities or relative change in the wakeboarding to waterskiing ratio towards more wakeboarding would have further detrimental impacts regarding bank erosion processes.

In the area downstream of Chinderah, wake waves are indicated to be a less dominant component of wave energy due to the relatively high exposure to wind generated waves and the low reported usage patterns in this area. However, anecdotal evidence (observations by Fingal Head Community Association) has suggested that boat usage patterns in this area have increase significantly over the past few years. Considering this anecdotal evidence the sensitivity of this downstream area to a change in usage patterns has been examined.

Probability of exceedance curves have been recalculated for sites 2 and 3 assuming two and five fold increases in the number of tow vessels (**Figure 22** to **Figure 25**). These plots demonstrate that as boat usage increases in the downstream areas of the Tweed River so the probability of exceedance curves show greater change relative to the natural wind wave climate. The changes demonstrate how larger waves occur more frequently as a result of the towing boat wakes. Indicating that even in these downstream areas, which experience a more energetic wind generated wave climate than the upstream areas, waves resulting from tow boat wakes can significantly alter the natural climate if towing activities occur frequently.

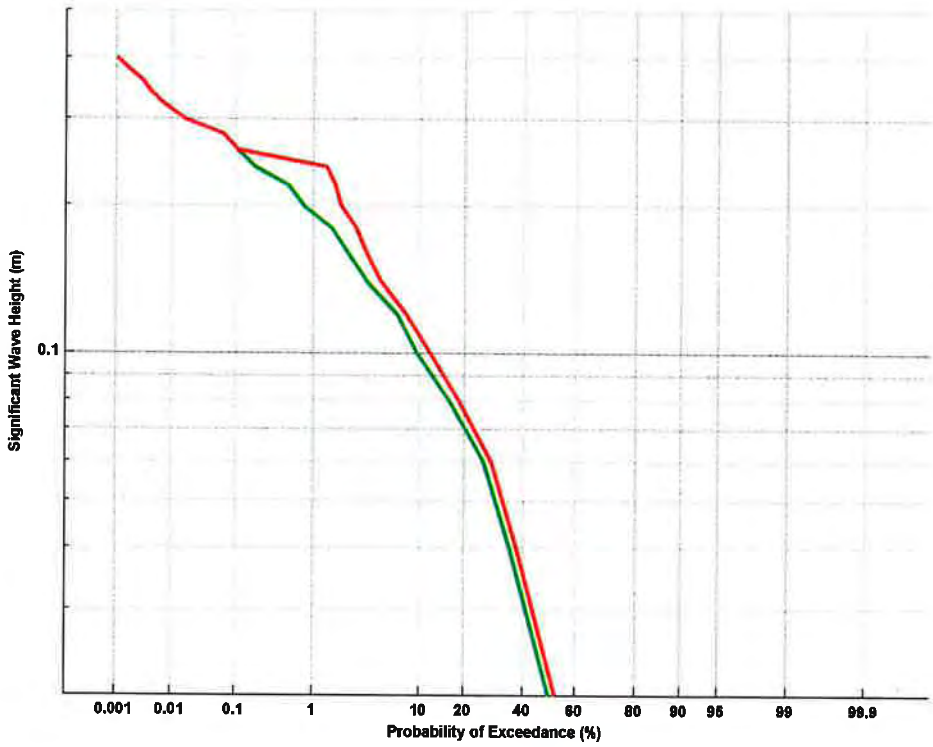

Figure 22 Probability of exceedance of wave height at Site 2 assuming a two fold increase in tow vessels. (Note: the green line shows wind waves and the red line wind waves with vessel waves included)

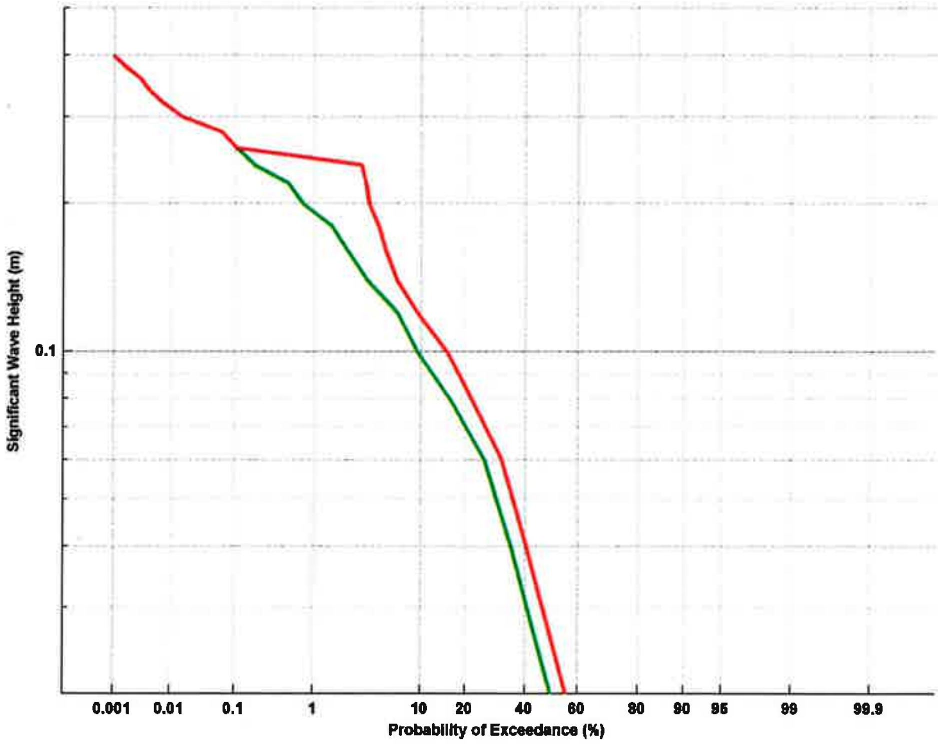

Figure 23 ***Probability of exceedance of wave height at Site 2 assuming a five fold increase in tow vessels. (Note: the green line shows wind waves and the red line wind waves with vessel waves included***

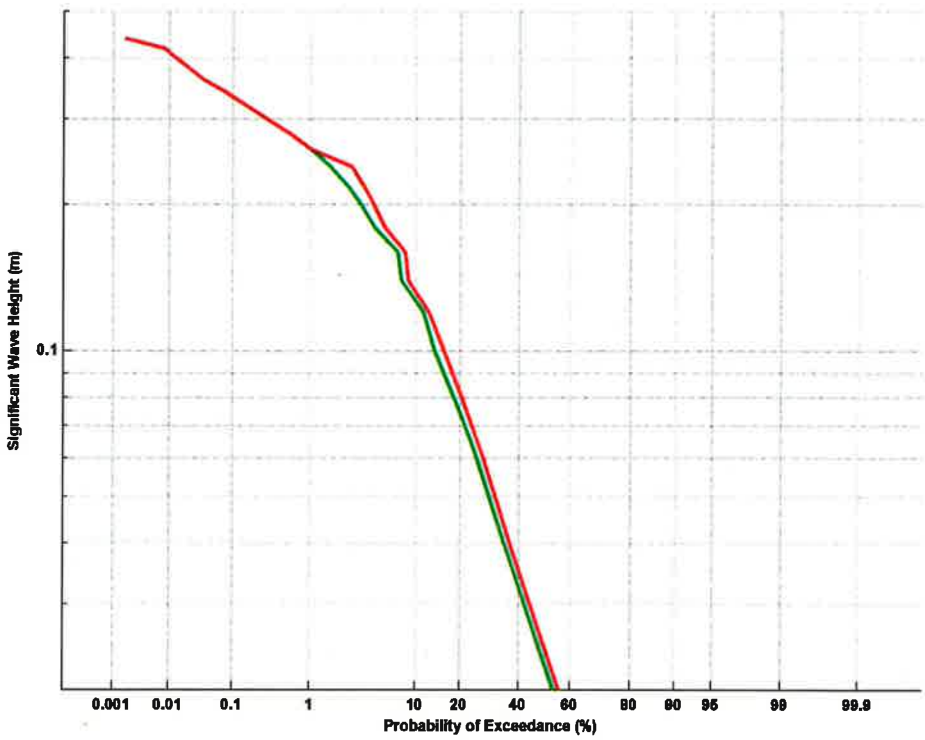

Figure 24 ***Probability of exceedance of wave height at Site 3 assuming a two fold increase in tow vessels. (Note: the green line shows wind waves and the red line wind waves with vessel waves included***

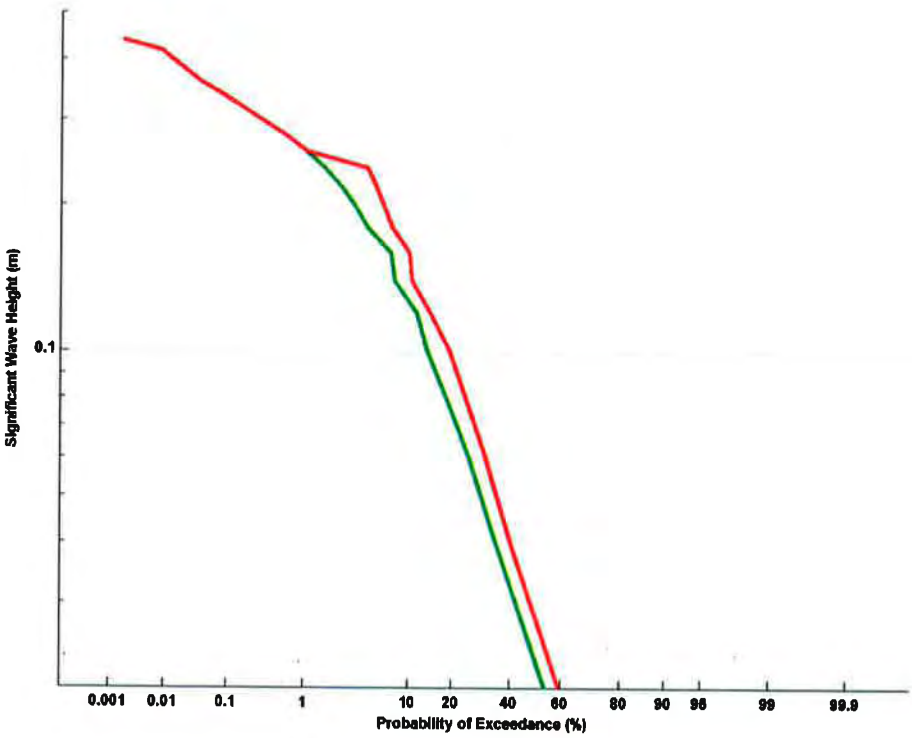

Figure 25 Probability of exceedance of wave height at Site 3 assuming a five fold increase in tow vessels. (Note: the green line shows wind waves and the red line wind waves with vessel waves included

A new large marina has been proposed within Terranora Creek adjacent to the Boyds Bay Bridge Tick Gates. If this development proceeds, it has the potential to cause a significant increase in the vessel traffic in Terranora Creek between the marina and the Tweed River. Based on the results of the present assessment, any increase in vessel traffic has the potential of increasing erosion of the adjacent river banks. The majority of the south bank of Terranora Creek between the proposed marina location and the confluence with the Tweed River is fronted by the Ukerebagh Nature Reserve. Erosion of this nature reserve should be avoided. Accordingly, any development application for the marina should include an assessment of the potential wake impacts as part of the Environmental Assessment process. This should incorporate an appraisal of the predicted vessel wake impacts and possible mitigation options.

6.3 Management Considerations

From the wake impact assessment presented, there is evidence that wave energy significantly in excess of the prevalent wind wave environment is being produced as a result of vessel wake. Based on the work of Glamore (2008), and supporting site observations, the excess energy translates to accelerated bank erosion rates (especially where the bank is unprotected).

The following issues and corresponding possible mitigation options are suggested for consideration in managing the accelerated rate of bank erosion associated with vessel wake based on the river characteristics and the physical mechanisms causing the erosion.

Table 13 ***Possible wake management options***

Issue	Management Options
Environmental The relatively narrow character and steep banks of the Tweed River does not allow for significant wave attenuation prior to impact on the river bank. The natural wind wave climate is relatively benign. Any vessel wake is likely to cause an acceleration of bank erosion.	▪ Restricting certain vessels sizes, displacement hulls and vessel speeds on the Tweed River ▪ Restricting towing activities (or slow towing) on the Tweed River ▪ Identifying an alternative water body (natural or constructed) within the Shire which is resilient to wake impacts for use as a towing (or slow towing) recreational boating area ▪ Introducing user pay fees to offset the cost of any constructed facilities/protection works
Within the Tweed Estuary are areas of significant ecological value which could be impacted by increased erosion as a result of vessel activity (Ukerebagh Reserve and Stotts Island Reserve).	▪ Implementation of no towing area in the river reach adjacent to these areas ▪ Implementation of speed restrictions (no wash zones) for general vessel traffic in these reaches
Social The Tweed River is recognised by enthusiasts as an ideal water skiing/wake boarding location (based on criteria related to the recreation only) and there is strong demand for continued usage.	▪ Restriction of towing activities to particular areas within the river and protecting the adjacent river banks with engineered embankments ▪ Placing buoy markers along any areas where towing activities are permitted to show distance vessel is required to be from the bank ▪ Introducing user pay fees to offset the cost of any constructed facilities/protection works
If relatively unrestricted usage is allowed, there will be continued intensification in towing activities (rise in popularity of wake boarding and the impacts of restrictions on other waterways in the area). This may include commercial activities capitalising on the tourism drawcard that would change the pattern of usage (intensification of the off peak periods).	▪ Usage to be restricted to recreational only ▪ Peak usage will be "managed" by the restriction due to limited boat ramp facilities and car parking as discussed by PBP (2008) ▪ Off peak usage would be managed by social restrictions (work commitments etc.) ▪ No commercial towing activity operators ▪ Bank protection measures would continue to be required
Wake resulting from towing activities impact on the enjoyment of the river by other users. Wake may also result in increased bank erosion on private properties which have to invest in revetments.	▪ Implementation of no towing areas in the river ▪ Implementation of speed restrictions for general boat traffic in these areas ▪ Restriction of towing activities to particular areas within the river and protecting the adjacent river banks with engineered embankments
Economic Restrictions on commercial usage (related to towing activities) may be limiting a potential tourism income for the Tweed Shire.	▪ Restriction of commercial towing activities to particular areas within the river and protecting the adjacent river banks with engineered embankments ▪ Charging an environmental levee for commercial operators to pay for capital and maintenance works for engineered embankments and other facilities. ▪ Placing buoy markers along any areas where towing activities is permitted to show distance

Issue	Management Options
	vessel is required to be from the bank
Restrictions on use of Tweed River for towing activities will have an impact on the income resulting from existing recreational users for the Tweed Shire.	▪ Implementing sufficient 'tow zones' within the river to ensure no impact to existing recreational users ▪ Identifying an alternative water body (natural or constructed) within the Shire which is resilient to erosion for use as a towing (or slow towing) recreational boating area ▪ Introducing user pay fees to offset the cost of any constructed facilities/protection works

6.3.1 Further Investigations

<u>Bank Erosion Monitoring</u>

Accurate quantification of erosion rates based on the analysis undertaken for this study is not feasible. To do this would require monitoring of the erosion locations and given the slow rates of erosion it would be expected that at least 18 months (or longer) of a monitoring program would be required to establish any trends.

For consideration of non structural management options (e.g. boating restrictions) NSW Maritime may require detailed information, such as long term monitoring relating to rates of erosion if it were to consider implementing further boating restrictions.

It is recommended that Council should commence a monitoring program. A skeleton outline of a methodology to undertake such a monitoring program is provided below.

- establish control reaches, where only wake is likely to be the cause of erosion. e.g. flooding is unlikely to cause significant erosion on straight sections of river, etc, only on outside of bends;
- establish required number of monitoring sites (spread of sites to include sites that are on the inside and outside of bends, in straights where there is livestock access (probably not an issue on the Tweed), no livestock access, etc.);
- establish baseline river bank profiles, then periodic (suggest quarterly) re-survey, and photograph. GPS coordinates would be used to maintain consistent survey and photo locations as much as possible;
- establish control sites where control measures have been instigated (e.g. limiting of livestock access, or limiting of wake boarding, or limiting of all towing activities) assess and demonstrate site recovery over time. This would be critical to demonstrating to NSW Roads and Maritime Services that towing activities (or slow towing) should be removed from certain degraded or sensitive reaches; and
- assessment of monitoring outcomes.

<u>Alternate Towing Area/Facility Feasibility Study</u>

A study to identify alternative water bodies in the Council LGA (natural or constructed) and the feasibility of creating purpose built facilities for towing activities could be considered. Such a facility/area would offset towing restrictions (if implemented) on the river.

7 BANK RECOVERY POTENTIAL

In order to assess the bank recovery potential a simplistic River Styles Framework assessment has been undertaken.

The area of the Tweed River under assessment is located within a coastal plain and the river style is tidal. Low recovery potential reaches are common on the coastal plain and reflect the impacts of intensive agriculture and urbanisation. Reaches within the coastal plain often undergo channel expansion associated with bed degradation, this liberates substantial sediment to downstream reaches which then adjust in response to the increased sediment load.

The River Styles Framework details that stretches of river which are within a coastal plain setting are considered sensitive to adjustment as the river has the capacity to freely deform its bed and banks. This can be seen for the Tweed River as clearance of the floodplain and riparian vegetation has greatly increased the lateral activity of the river since European settlement, resulting in significant changes to river morphology. Throughout the majority of the Tweed River being assessed the riparian vegetation is currently pasture, although a few reaches still display remnant native vegetation.

The capacity for adjustment of the tidal river style for the Tweed River is deemed to be high. This is demonstrated by the fact that these stretches of river have been shown to be sensitive to any changes to the natural conditions and explains why areas of the river have been subject to enhanced rates of river bank erosion as a result of increasing numbers of vessels generating large wakes as observed on the Tweed River.

The geomorphic condition of the area of the Tweed River under assessment has previously been categorised as degraded (*Lampert et al, 1999*). This means that considerable geomorphic alteration to the functioning of the system has occurred when compared with the pre-disturbance condition. As such, the prospects for the river to return to a pre-disturbance condition are limited. Management strategies must therefore be designed to adopt river rehabilitation strategies that work with contemporary catchment conditions, and not try to rehabilitate rivers to periods prior to European settlement.

Based on the simplified River Styles Framework undertaken, the Tweed River is likely to have a low recovery potential. Agriculture and urbanisation have heavily impacted the channel and as such the pre-disturbance character of these rivers cannot be regained, and management strategies must work with the prevailing boundary conditions in these unstable reaches to rehabilitate the river course. However, provided suitable management options are implemented the recovery potential of eroded river banks to become healthy river banks is moderate owing to the high capacity for adjustment of this river style. Signs of visible recovery for erosional riverbanks could be achieved within a decade, but the area will require a long term strategy involving increased riparian vegetation to ensure successful recovery.

8 MANAGEMENT OPTION ASSESSMENT

When considering management options in response to bank erosion it is important to have a thorough understanding of the processes initiating the problem. When management options are implemented in response to symptoms, rather than the underlying causes of the problem, the option may prove ineffective or even result in detrimental effects elsewhere.

There are a range of possible management options which could be adopted. These range from non-engineered preventative measures through to hard structural protection.

- Non-engienered options
    i. Improved catchment management
    ii. Improved waterway management
    iii. Adaptive hazard management
- Engineered options
    i. Hard engineered protective works
    ii. 'Soft' engineered protective or adaptive works
    iii. Combine hard and soft works

This section details the management options available to prevent riverbank erosion, particularly focussing on methods which enhance the environmental benefits, where possible.

8.1 Non-Engineered Option – Vessel Management

It is considered the most effective non-engineered options to manage erosion rates in the Tweed River would be to further enhance existing vessel management strategies to include more guidelines regarding towing activities. This approach involves tackling the cause of erosion instead of reacting to its consequences. Wakeboarding and other power boat activities which generate significant wake and involve undertaking numerous laps of the same section of the river could be restricted to specific areas of the river. 'No tow' areas could be implemented where towing vessels have been shown to result in significant bank erosion. Furthermore, where adjacent banks have areas of high environmental value 'no wash' zones could be implemented restricting the speed of all vessels.

Minimising all power boats travel at a speed of 8 knots would be beneficial, as this speed has been shown to result in the largest possible wake waves. This could be achieved by ensuring speed limits are not set close to 8 knots and by educating river users. It would also be beneficial to encourage towing (where permitted) to occur as close to the centre of the channel as possible to ensure maximum attenuation of any wake waves before they reach the channel bank. This may not be possible in some areas owing to the shallow nature of the Tweed River and the definition of navigational channels.

Vessel wake has been identified as a factor contributing to river bank erosion within numerous rivers in Australia. Generally wake associated with waterskiing, wakeboarding and other towing activities has the greatest potential to contribute to river bank erosion. Accordingly, regulatory measures to restrict the areas where these towing activities are permitted has been suggested as a management option at numerous rivers including Bellinger River, Kalang River, Swan River, Maroochy River and Caboolture River.

As discussed in **Section 2** restrictions have been successful placed on towing activities to reduce the river bank erosion rates in the Williams River and the Wallamba River. Owing to the success the restricted area has been, or is planned to be, extended in order to try to reduce erosion in other affected areas of the rivers.

Vessel management options successfully implemented elsewhere could be considered for the Tweed River include:

- Implementing 'No Tow' zones where towing activities are not permitted
- Implementing 'No Slow Tow' zones which prevent slow towing activities such as wakeboarding but permit fast towing activities such as waterskiing
- Implementing 'No wash' zones in areas of high environmental value, where critical infrastructure is threatened or particularly narrow reaches

As discussed in **Section 6.1** , river banks between Chinderah and Bray Park have been shown to be susceptible to erosion due to vessel wake. The selection of areas (size and location) for vessel management should be prioritising on the following basis:

- environmental value of particular river reach
- adjacent public infrastructure at threat from erosion
- economic centres which rely on vessel visitation related income
- adjacent private properties at threat from erosion
- provision of infrastructure for recreational boating

The advantages and disadvantages of implementing an enhanced vessel management strategy for the Tweed River are outlined in **Table 14**.

Table 14 Advantages and Disadvantages of implementing an enhanced vessel management strategy for the Tweed River.

Advantages	Disadvantages
▪ Inexpensive ▪ Prevention option instead of remediation option ▪ Provides opportunities for bank rehabilitation with riparian vegetation (naturally and hand planted) ▪ Environmental benefits	▪ Social impacts (particular user groups) ▪ Loss of recreational activity ▪ Possible economic impact due to reduced recreational use ▪ May require 'policing'

8.2 Engineered Options

PBP (1998) provides a comprehensive commentary on engineered protection and adaption options for erosion management on the Tweed River. These options are still relevant as engineering solutions. However, attempts to enhance environmental benefits (and reduce any impacts) of structural erosion protection options has lead to the publication of the DECCW Guideline for Environmentally Friendly Seawalls (2009). The following section references this guideline in presenting additional generic management options for consideration.

Erosion and seawall management in considering the environment should follow the guideline flow chart below (**Figure 26**).

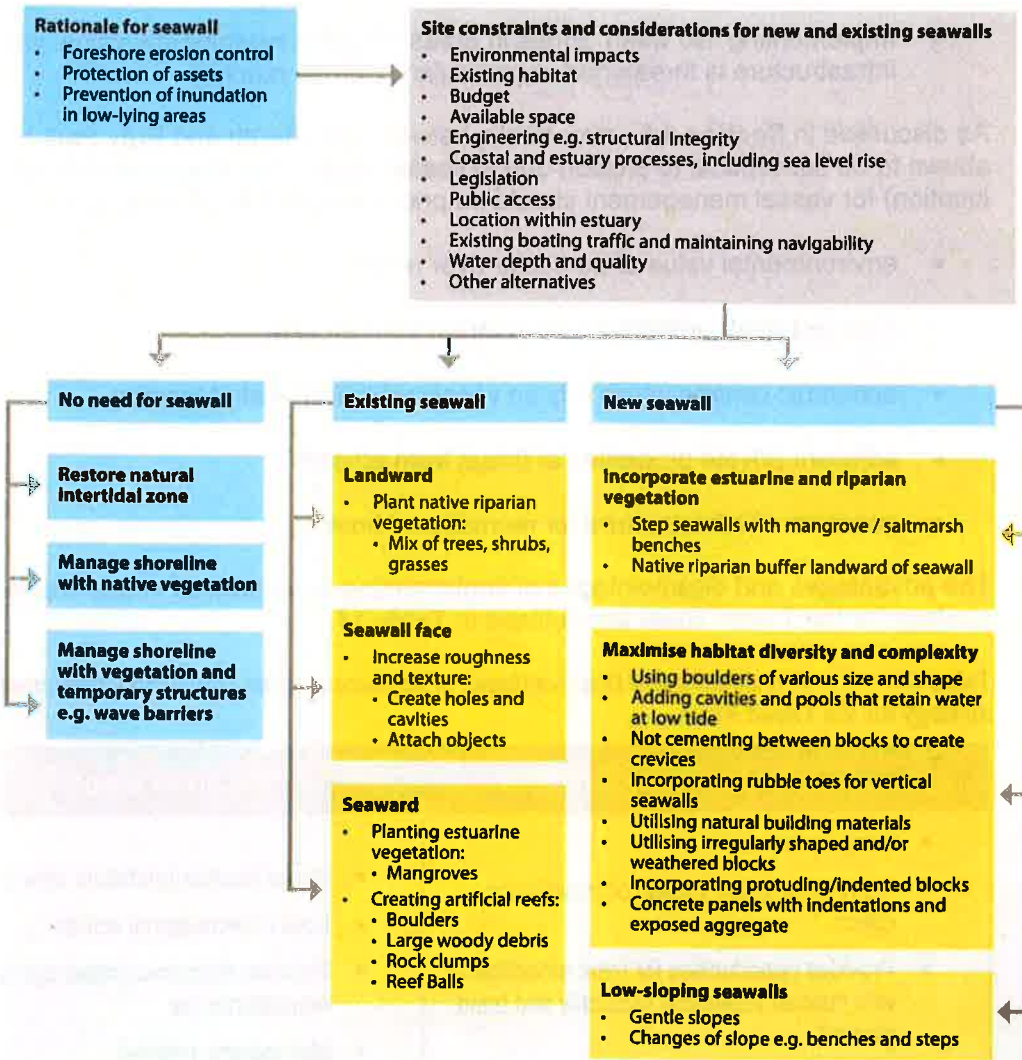

Figure 26 Summary guide for building new seawalls or modifying existing seawalls (DECCW, 2009)

8.2.1 Erosion Management

The required response to erosion issues depends on the severity of the erosion, the height of the embankment and the land use directly behind the eroded area. A series of management options to address areas with active bank erosion are provided below and a series of options where degraded seawalls exist are provided in **Section 8.2.2** .

Erosion Management Option E1

*Note: This option would only be feasible in conjunction with vessel management (refer to **Section 8.1**) to reduce vessel wash impacts, enabling vegetation establishment.*

In areas of significant erosion and where the bank is high and steep, the bank can be re-profiled to reach a stable slope. The slope of the bank is dependent on the type of sediment and soils present along the slope. Following the re-profiling of the bank, native riparian vegetation should be planted to help stabilise the new equilibrium slope. Vegetation not only helps to hold the bank material together through its roots, any branches or leaves in the water reduces any wave or tidal energy reaching the banks. This management option is illustrated in

Figure 27. This solution is possible where the water is not too deep, otherwise placing erosion protection on the slope would be more sustainable. Where the water is deep and battering back the bank is not possible due to the presence of infrastructure or other constraint, a rock revetment should be considered.

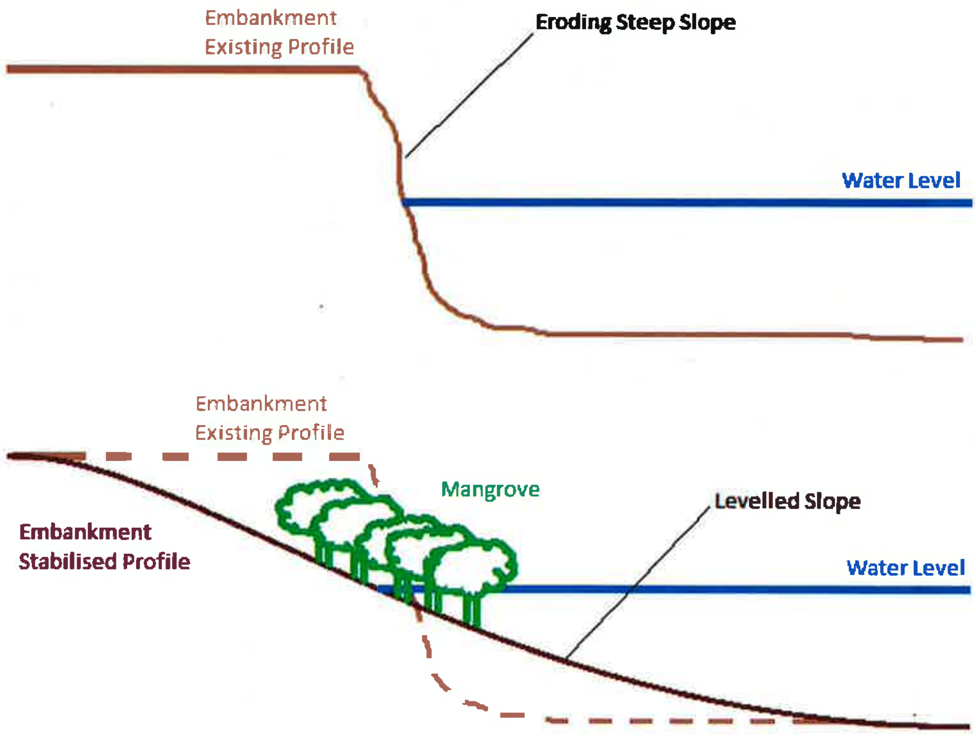

Figure 27 ***Re-profiling of the bank and vegetation planting***

Table 15 ***Advantages and Disadvantages of Erosion Management Option E1.***

Advantages	Disadvantages
▪ Inexpensive ▪ Levelling of the slope allows new areas for vegetation planting and increased habitat ▪ Avoid continual slumping of steep embankment	▪ Requires a buffer area at the back of the existing embankment to allow for levelling ▪ Landward movement of the top of the embankment may create damage to local vegetation and temporary loss of habitat, or, may impact on adjancetn public or private land use ▪ Protection relies on effective vegetation establishment and continued health (difficult where continual wake impacts exist)

Erosion Management Option E2

In areas of erosion at the toe of a steep slope, construction of a low crested rock revetment at the bottom of the bank can be an effective option. Designs can be to allow mangrove seedlings to grow amongst the gaps between the rocks (**Figure 28** and

Figure *29*).

Figure 28 ***Undercutting at Tweed River (left) and possible solution** from DECCW, 2009 (right)***

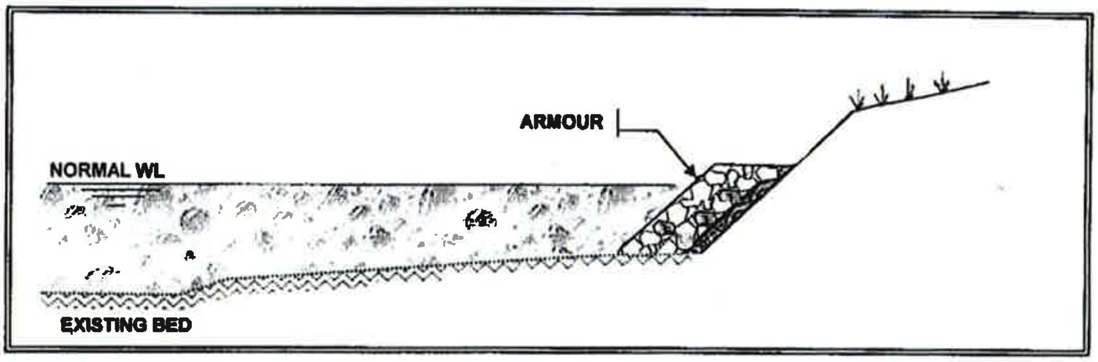

Figure 29 ***Low Crested Rock Revetment.***

A variation on this concept is the construction of rock fillets (low crested breakwater) offshore of the eroded bank (**Figure 30**). The reduced wave intertidal environment behind the wall encourages the recruitment of mangrove seedlings. This can be enhanced by planting.

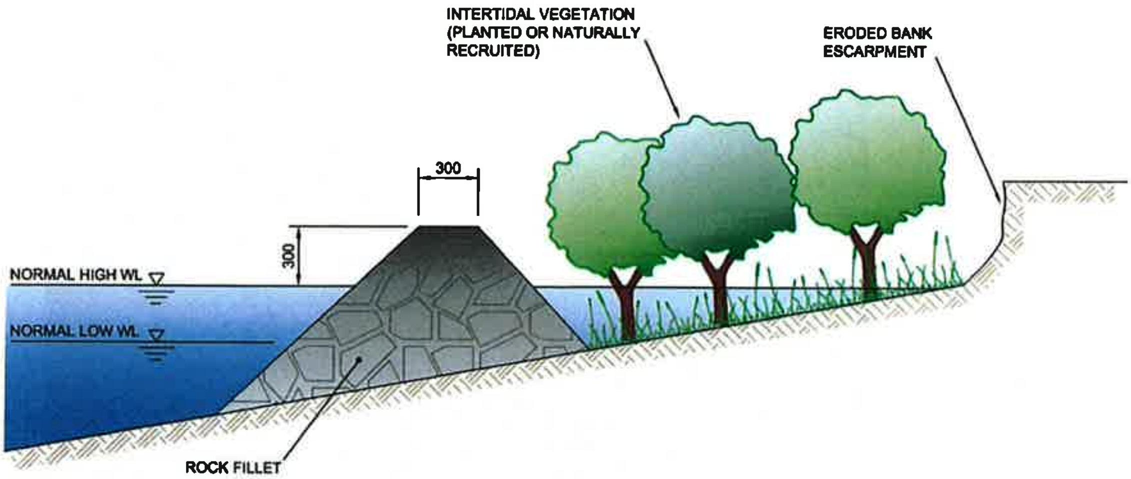

Figure 30 ***Low Crested Rock Breakwater.***

Table 16 ***Advantages and Disadvantages of Erosion Management Option E2.***

Advantages	Disadvantages
▪ Provides long-term structural protection to the embankment toe preventing bank slumping ▪ Creates new habitats and areas for vegetation such as mangrove to grow which assists in bank stabilisation ▪ Rock protection allows vegetation establishment even where continual wake impacts exist (more so for rock fillet variant)	▪ Slope should not be too steep ▪ Hard protection if not properly designed, may generate edge effect and further erosion around the structure ▪ Not feasible if the adjacent waterway is deep, where a full rock revetment would be a better solution

Erosion Management Option E3

Note: This option would only be feasible in conjunction with vessel management (refer to ***Section 8.1*** *) to reduce vessel wash impacts, enabling vegetation establishment.*

Where erosion occurs in gaps of vegetation (**Figure 31**), native vegetation can be planted, closing the gap and preventing further erosion. Furthermore, these areas have also been shown to reduce surface runoff of pollutants entering the waterway. Riparian vegetation provides increased protection to the bank through the following:

- Low growing foliage dissipating tidal and wave energy and thereby reducing the erosive flow along the riverbank
- Deep roots can reinforce the soil, helping to prevent deep-seated geotechnical failures and also providing an effective path for drainage reducing risk of slumping
- Riverbank soil moisture can be reduced by extensive tree planting, this reduces the risk of excessive pore pressure in wet conditions and reduces the likelihood of soil shrinkage and cracking during extended dry conditions

Figure 31 Erosion at gap of vegetation in Tweed River

Table 17 Advantages and Disadvantages of Erosion Management Option E3.

Advantages	Disadvantages
▪ Stabilises embankment ▪ Reduced runoff ▪ Simple and inexpensive ▪ Aesthetic aspect	▪ Native species have to be selected carefully ▪ Maintenance during establishment of the vegetation ▪ May obscure views of the waterway ▪ Could be damaged by storm event, bushfire or floods ▪ Difficult to establish vegetation where continual wake impacts exist ▪ Only suitable in conjunction with vessel management to enhance bank rehabilitation

Erosion Management Option E4

In areas of moderate erosion in low embankment height e.g. along parks and open space areas, a step seawalls with mangrove or saltmarsh benches can be an effective solution (**Figure 32**).

Figure 32 Moderate erosion along low bank (left) and possible solution* e.g. Claydon Reserve at Kogarah bay from DECCW, 2009 (right)

**Vegetation should be site specifically chosen to suit the location, exposure of the site and the wave climate*

Table 18 Advantages and Disadvantages of Erosion Management Option E4.

Advantages	Disadvantages
▪ Provides long-term protection against erosion ▪ Creates new habitats and vegetation areas ▪ Aesthetic aspect	▪ Requires buffer area at the back of the embankment ▪ Relatively expensive ▪ Embankment should not be too steep

Erosion Management Option E5

Where erosion is significant, a properly designed rock revetment could be constructed along the river bank (**Figure 34** and **Figure 35**). This effectively covers the bank with an erosion resistant surface. The revetment can be designed with a toe apron to protect against toe scour, this can either be self launching (placed directly on the current bed level) or buried (to minimise impacts on stream conveyance).

Figure 33 Well designed rock revetment (Tweed River)

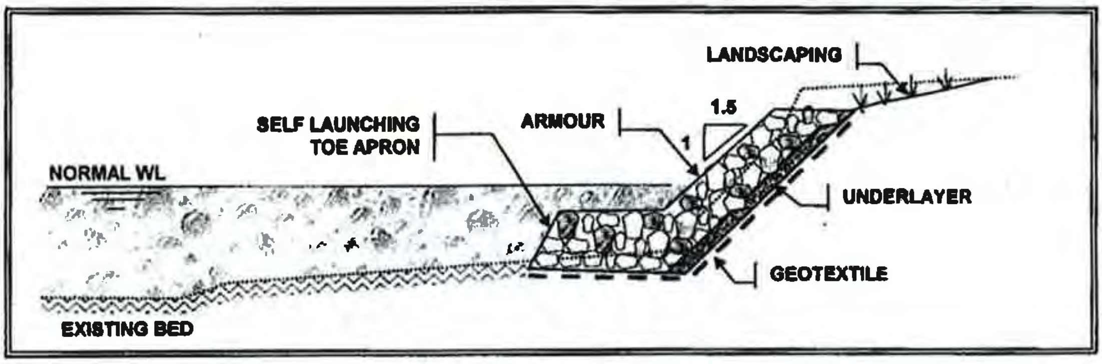

Figure 34 *Rock Revetment with Self-Launching Toe Apron (PBP, 1998).*

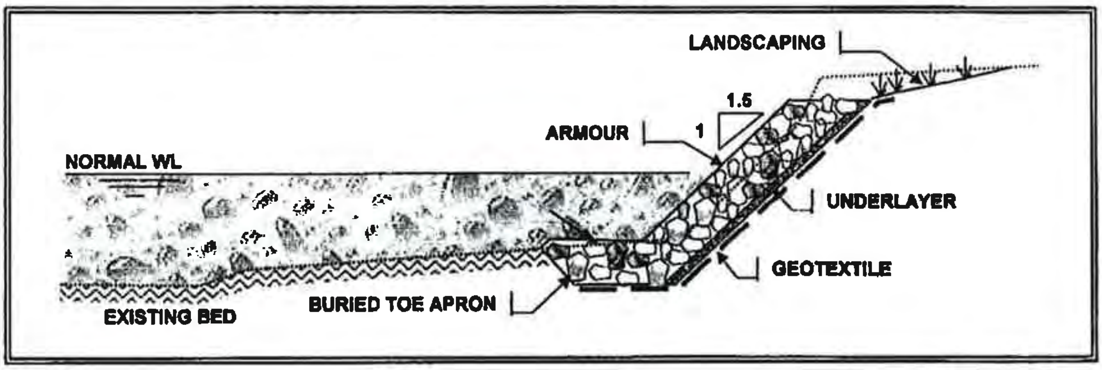

Figure 35 *Rock Revetment with Buried Toe Apron (PBP, 1998).*

Table 19 *Advantages and Disadvantages of Erosion Management Option E5.*

Advantages	Disadvantages
▪ Provides long-term protection against erosion ▪ Provides some new habitat ▪ Further vegetation can be planted at the back of the seawall ▪ Where possible could be combined with Option E4 (inclusion of vegetation bench)	▪ High capital cost ▪ Aesthetic aspect ▪ Impact on natural environment, vegetation and habitats ▪ Decreases access to water ▪ May generate edge effect ▪ Limits bank rehabilitation opportunities ▪ Ongoing maintenance requirements (cost)

8.2.2 Existing Protection Management

Existing seawalls along the Tweed River, could be upgraded and improved to incorporate environmental improvements.

Seawall Management Option S1

In areas where various building material have been dumped, these materials could be replaced by sloped rock revetments allowing mangrove seedlings to establish amongst the gaps between the rocks (**Figure 36**). This will improve the visual aspect and the level of protection against erosion.

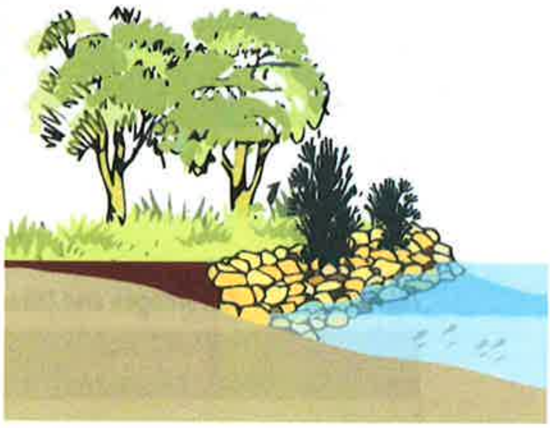

Figure 36 Dumped materials at Tweed River (left) and possible solution from DECCW, 2009 (right)

Table 20 Advantages and Disadvantages of Erosion Management Option S1.

Advantages	Disadvantages
▪ Provides long-term protection against bank erosion ▪ Aesthetic aspect ▪ Allows for mangrove to grow between gaps of rocks	▪ High cost ▪ Impact on natural environment, vegetation and habitats

Seawall Management Option S2

In front of vertical seawalls such as concrete or brick walls, a sloped rock revetment could be constructed to created more habitat for marine organisms and to reduce wave reflections (**Figure 37**).

Figure 37 *Vertical seawall (left) and possible improvement from DECCW, 2009 (right)*

Table 21 *Advantages and Disadvantages of Erosion Management Option S2.*

Advantages	Disadvantages
▪ Reduces risk of failure of poor condition revetment ▪ Cheaper than replacing poor-condition seawall by new rock revetment ▪ Allows for mangrove to grow between gaps of rocks ▪ Reduces wave reflections (and subsequent toe scour)	▪ Seawall ideally should be vertical ▪ Vertical seawall should not be too high ▪ Relatively expensive ▪ Impact on existing environment and habitat ▪ Relies to some extent on the structural integrity of existing wall ▪ Difficulty in obtaining certification by design engineer due to previous design being "inherited"

Seawall Management Option S3

Informal protection (not properly designed) needing minimal maintenance can be repaired instead of being replaced. This could be realised by reusing existing rocks or capping existing seawall with new rocks. The former option is to be used where the seawall is not designed to proper engineering standards while the latter option can be used where seawall is adequate but is not high enough or requires more material to improve effectiveness.

Furthermore, maintenance can improve the environmentally-friendly aspect of the seawall by modifying the design to allow vegetation to grow between gaps of rock.

Table 22 Advantages and Disadvantages of Erosion Management Option S3.

Advantages	Disadvantages
▪ Provides long-term protection against erosion ▪ Reduces risk of failure of poor condition rock revetment ▪ Could be less expensive than replacing poor-condition revetment by new rock revetment ▪ Could allow for mangrove to grow between gaps of rocks	▪ Not feasible for high crested structures ▪ Relatively expensive ▪ Unknown underlying geotechnical condition can compromise design (and safety) ▪ Difficulty in obtaining certification by design engineer due to previous design being "inherited"

8.3 Assessment of Existing Management Measures

A visual condition assessment of existing erosion protection measures undertaken within the Tweed Estuary was carried out, through a field assessment of various bank revetment projects carried out between 2003 and 2011.

The bank protection sites assessed are shown in **Figure 38**. The sites were visited over a period of two days, from 13 – 14 September 2011. The visual assessment comprised a thorough site walk-over and a photographic record of each site undertaken using a digital GPS camera.

Table 23 provides a summary of the findings of this assessment for the sites visited. A full report is provided in **Appendix B**.

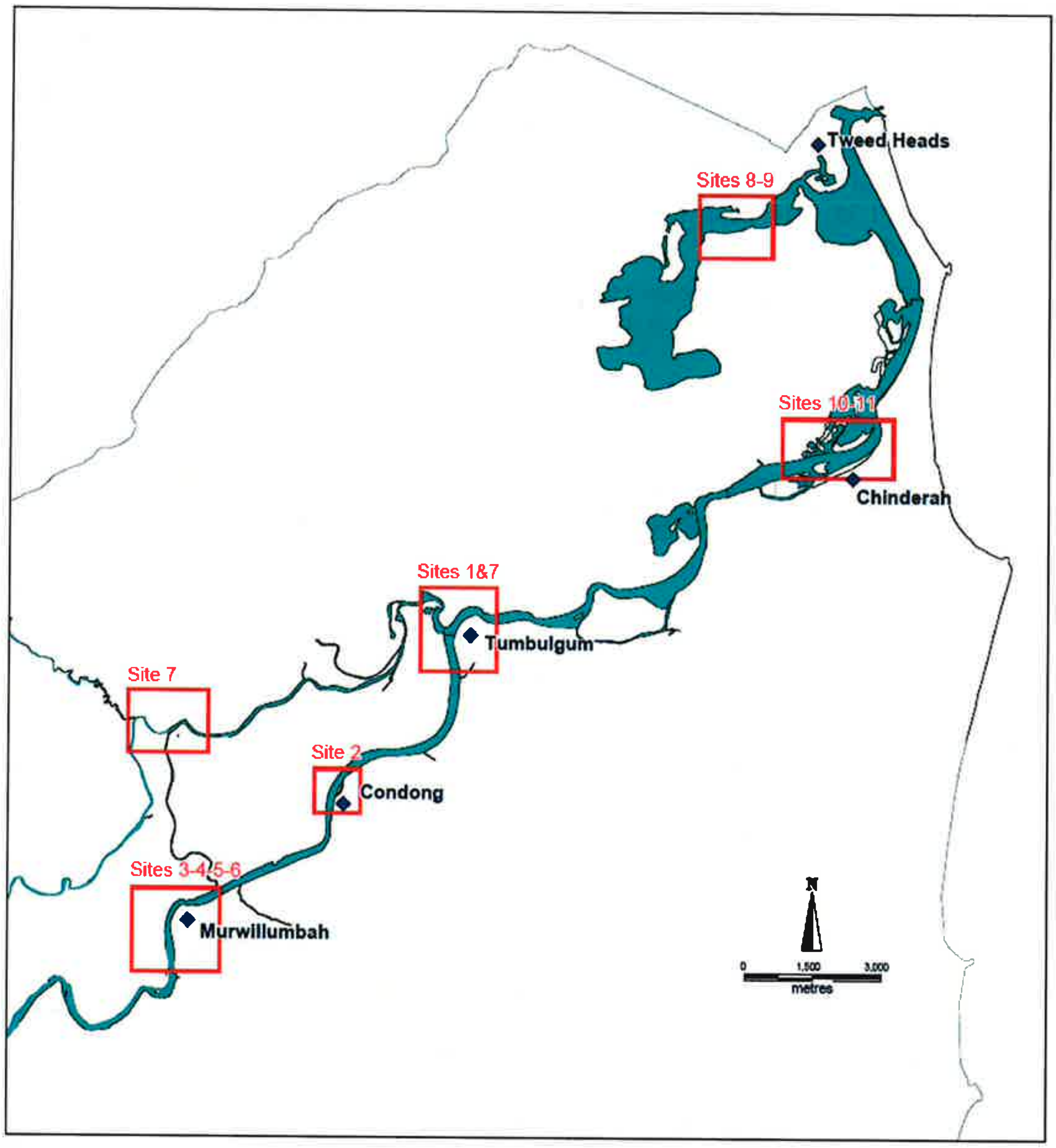

Figure 38 Overview of sites assessed as part of the existing erosion prevention measures assessment.

Table 23 Bank Erosion Improvement Works and Observations

Site No.	Site Name	Priority/Erosion Severity	Observations/Recommendations
1	Tumbulgum	Low/Medium	This site requires maintenance of sections of revetment which have been damaged and completion of revetment where there are gaps in the foreshore protection. Effort should be made to restore foreshore vegetation
2	Condong	Low/Medium	Banks adjacent to the revetment at the boat ramp are suffering from erosion. These should be battered back to a gentler slope and planted with native vegetation and phragmites to protect the toe of the slope
3	Budd Park	High	Severe erosion is occurring at this location. A foreshore revetment is recommended here and a building appears to be at potential risk due to bank erosion
4	South Murwillumbah Levee	Low	The revetments here appear to be in good condition. However, will require ongoing monitoring
5	Commercial Road	Low	This area is not experiencing severe erosion at present but should be monitored to assess existing protection works and the need for toe protection works for the existing steep embankment
6	Heritage Wharf	Low	This area has an existing revetment which is in reasonable condition but should be monitored for continuing performance and maintained if required in the future
7	Rous River	Medium	The existing revetments should be monitored and a revetment constructed for the unprotected embankment at Dulguigan Road
8	Philp Parade	Medium	Sections of revetment which have failed due to overtopping and lack of geotextile should be reconstructed as funds allow.
9	Dry Dock Road	Medium	Sections of revetment which are redundant could be removed and planted with natural vegetation
10	Oxley Cove	Medium	Revetment construction is needed on the eastern peninsula and revetment reconstruction is needed at the western side of Old Ferry Road
11	Chinderah	Low/Medium	The existing environmentally friendly seawalls including soft foreshore protection measures should be monitored to assess their relative effectiveness in protecting the bank and restoring environmental values. Maintenance is recommended for a short section of seawall which is suffering damage due to wave overtopping.

8.4 Cost - Benefit Assessment

A number of hypothetical options have been considered as part of a broad cost-benefit assessment; these options are considered for discussion purposes only. They should not be considered as definitive management options but for relative order of magnitude comparison. The three options considered are:

Option 1: Maintain the status quo with minimal new bank protection

Option 2: Implementation of a No-Towing Policy

Option 3: Restrict towing activities to a designated area (s) and protect banks

Each option is discussed in terms of preliminary estimated costs, both tangible (quantified where possible) and intangible, in the following sections and a summary of the costs and benefits of these options is summarised in **Table 25.**

Note that the highly conceptual nature of the options inhibits accurate costing and estimates should be considered as indicative of the relative order of magnitude only. Consistency in costing assumptions has been maintained across the different options such that a comparative assessment is possible.

8.4.1 Option 1 – Maintain the status quo with minimal new protection

Option 1 represents an option allowing towing activities to continue as currently permitted and the maintenance of existing bank protection and installation of additional protection works (for 'visible erosion areas'). This would allow for the continued use of most of the waterway (with the exception of currently restricted waters) for water-skiing and wakeboarding activities. These recreational boating activities will continue to attract the local boating community and visitors to the area. Accordingly, there will be continued contribution to the local economy through expenditure on associated activities such as food and beverages, supplies, equipment, entertainment etc.

Constructing new bank protection in the foreshore locations nominated in the recent foreshore condition survey as 'visible erosion areas', would mitigate erosion in the most critical areas. Bank erosion would still occur in areas currently nominated as 'exposed' and areas of 'minimal or sparse vegetation'. There would be a need for progressive protection of these areas as they become degraded.

Vessel registrations have been increasing by approximately 5% per year for the Tweed River area while the average annual growth rate for boat licenses was 6.4% (based on 1998 to 2003 NSW Maritime data). Option 1 would allow for the accommodation of this continued increase in boating traffic and usage by utilising the majority of the waterway for the recreational boating activities including water skiing and wake boarding. At present boating facilities such as boat ramps, access jetties, pontoons and parking, rather than the waterway area, limit the capacity of the waterway. Theoretically, limited facilities could be an effective means of managing vessel use so that wake impacts do not increase.

NSW Maritime initiatives to educate the boating community through campaigns regarding boat wake induced erosion and responsible towing techniques would continue to be supported.

Costs for construction of new bank protection have been estimated as $2000/m. This rate represents an average cost of the various bank treatments that might be appropriate for the different areas of foreshore. Costs for maintenance of new and existing bank protection has been estimated as $250/m based on an upgrade of some $1250/m being required every 5 years.

8.4.2 Option 2 – Implementation of a No-Towing Policy

Option 2 represents an option of removal of towing activities on the Tweed River. This would be achieved through regulatory controls, signage, monitoring and enforcement (through fiscal penalties). This option would have minimal capital costs as there are no physical works required. A likely reduction in erosion would be achieved through removal of a significant contributing mechanism. Costs to maintain existing bank protection structures would be reduced as the intensity of wave activity is reduced. Costs for maintenance of existing bank protection has been estimated as $200/m based on an upgrade of some $1000/m being required every 5 years.

Boating usage of the waterway would be reduced and would have a flow-on effect on the local economy. The boating community currently invests into associated services whilst spending time on the waterway, contributing to the local economy. This contribution would be significantly reduced.

Estimates of the financial contributions to the local economy from visitor spending have been calculated on the basis of visitor and spending statistics presented for the Tweed Shire in Tourism Profiles for Local Government Areas in Regional Australia, New South Wales (TRA, 2008), and boating statistics for the Tweed River presented in NSW Maritime Tweed Estuary Boating Plan 2006-2010. The following assumptions were made in the determination of the potential cost (loss) to the local economy of a no towing policy in the estuary:

- There would be a 20% reduction in vessels visiting the Tweed. This is based on the findings of the review of boating activity levels during January 2004, with a concentrated review over the Australia Day long weekend, 24-26. This review found that 22% of vessels on the waterway were undertaking towing activities (water-skiing or wakeboarding). It is assumed that a proportion of these vessels (2%) would continue to visit the area for other recreational boating purposes.

- An average of 3.5 people would be aboard each vessel. It is noted that a minimum of 3 people are required for towing activities to allow for a dedicated driver and spotter.

- The seasonal daily visitation rates were estimated from the summer peak rate of 277 adopted in NSW Maritime Tweed Estuary Boating Plan 2006-2010 (**Table 24**):

Table 24 Estimated seasonal daily visitation rates.

Season	Estimated daily no. vessels (average)
Summer weekend	250
Summer midweek	75
Spring and autumn weekend	150
Spring and autumn midweek	40
Winter weekend	50
Winter midweek	10

The total loss to the local economy from implementing a no-towing policy on the Tweed was estimated to be $2.8 million per year (in 2011 dollars). The potential loss of local income would be expected to increase annually at a rate in the order of 5% in line with the historical increase in vessel registrations and boat licences.

8.4.3 Option 3 – Restrict towing activities to designated area and protect banks

Option 3 represents an option involving restriction of towing activities to a purpose built section of estuary (with protected banks). For example, the area from the Cane Rd (Condong) Bridge to upstream of Stotts Island Nature Reserve (east of Tumbulgum) has been considered for the purposes of this comparative assessment. This approximately 7km stretch of waterway is popular for towing activities as it has reaches that are sheltered from the different prevailing wind directions providing a good flat water surface for water skiing and wakeboarding in most conditions. This option would aim to consolidate towing activities to an existing popular area with suitable facilities. Subsequently, the remainder of the estuary would be relieved from the bank erosion potential of towing boat wakes.

Currently the boat ramp at Tumbulgum is heavily utilised and under significant pressure during peak periods. The attraction of the Tumbulgum boat ramp facility is the associated services available in the nearby township and the general character of the town as a visitor destination. In an attempt to relieve the pressure on the Tumbulgum facility an upgraded boat ramp and pontoon facility has recently been constructed upstream at Condong. There is plenty of scope to enhance the facilities in this designated area, as suggested in previous studies such as the Tweed River Estuary Recreational Boating Study (PBP, 2008). Concepts such as new sandy beaches along the foreshore, a clubhouse style facility at Condong and increased pontoon area for casual tie-up of vessels at Tumbulgum. However, for the purposes of this economic assessment improvements have been limited to bank protection in 'visible erosion areas' and construction of car (and trailer) parking areas at each boat ramp. A user pays system has been considered whereby payment needs to be made to enter the car park areas and access the ramp to offset high capital costs of constructed bank protection.

Costs for construction of new bank protection have been estimated as $2000/m. This rate represents an average cost of the various bank treatments that might be appropriate for the different areas of foreshore. It was assumed for costing purposes that all public and private 'visible erosion areas' would be protected. Costs for maintenance of new and existing bank protection has been estimated as $250/m based on an upgrade of some $1250/m being required every 5 years.

Table 25 ***Cost Benefit Assessment Matrix***

Option	Cost	$ Cost (2011)	Benefit	$ Benefit (2011)	Environmental impacts	Socio economic impacts	Benefit-Cost Summary
Option 1: Maintain status quo (allowing towing activities as currently permitted) with maintenance of existing bank protection and installation of additional protection works (for 'visible erosion areas')	Capital cost of new bank protection works On-going maintenance of existing and new bank protection works	$10,000,000 $3,600,000 p.a.	Access to waterway encouraging visitation/tourism Scope to accommodate growth in no. of vessels on waterway Continued boating tourism contribution to the local economy	$2,800,000 p.a.	X Environmental cost – bank erosion may still occur in 'exposed' areas and areas of 'minimal or sparse vegetation'. X Visual impact of rock structures X Local loss of foreshore habitat	✓ Continued general support of boating tourism in Tweed area. ✓ More spatially distributed impacts	This option allows for continued towing activities and visitor contribution to the local economy whilst protecting the most critical eroded bank areas. Capital investment is significant.
Option 2: No towing activities policy on Tweed River	Minimal capital cost (signage, regulation, enforcement) On-going maintenance of existing bank protection works Reduction in boating tourism contribution to local economy	$1,800,000 p.a. $2,800,000 p.a.	Reduced capital cost for new bank protection works in future Reduced maintenance cost for existing bank protection	(no direct $ value)	✓ No further degradation or erosion of river banks with associated habitat benefits. ✓ Bank vegetation rehabilitation opportunities ✓ Improved visual amenity ✓ Protection of high environmental value areas	X Loss of boating tourism and visitor contribution to the local economy X loss of some water-based recreational opportunities ✓ Fewer conflicts between river users ✓ Reduced pressure on boating facilities	Though capital investment is minimal and environmental benefits are significant, there would be costs to the local economy from reduced visitation and dissatisfaction from the water-skiing and wakeboarding community.
Option 3: Provide purpose built (protected) section of estuary for towing activities from the Cane Rd (Condong) Bridge downstream to the Stotts Island Nature Reserve (east of Tumbulgum).	Capital cost of new bank protection works On-going maintenance of existing and new bank protection works	$7,700,000 $1,700,000 p.a.	Increased boating tourism economic contribution to the local communities of Condong and Tumbulgum Potential cost recovery through user pays system for access to carpark and boat ramp.	$2,800,000 p.a. $100,000 p.a.	X Visual impact of rock structures X Local loss of foreshore habitat ✓ No further degradation or erosion of river banks due to towing activities. ✓ Protection of high environmental value areas	✓ / X Increased visitation to the towns of Condong and Tumbulgum with the positive and negative impacts this entails for locals. Concentration of: ✓ economic prosperity ✓vibrancy X crowding X noise X conflict between locals and visitors X parking X safety	This option would accommodate towing activities and support boating tourism whilst confining adverse impacts to a designated section of the river. Managing access (trailer parking etc.) could provide opportunities to address some of the negative social impacts as well as provide a mechanism to contribute to the significant capital investment of this option

Note: The preliminary cost estimates are based on SMEC's experience and judgement as a firm of practising professional engineers, familiar with the construction industry and with reference to Rawlinsons (2011). The cost estimates can NOT be guaranteed as we have no control over contractor's prices, market forces and competitive tender bids. The cost estimates may exclude items which should be considered in a cost plan. Examples of such items are design fees, project management fees, authority approval fees, contractors risk and other project contingencies (e.g. to account for construction and site conditions, weather conditions, ground conditions and unknown services). If a reliable cost estimate is required, then an appropriately qualified Quantity Surveyor should be engaged following selection of the preferred concepts and detailed design of the works.

9 SUMMARY

This study was aimed at undertaking an assessment of the current state of the river banks in the Tweed River, quantifying the impacts of vessel wake on bank erosion and presenting possible management options for consideration. A field investigation was undertaken to update the state of the river banks since the last assessment by PBP in 1998. In addition, any bank revetment projects carried out from 2003 to 2011 were assessed. The upstream areas of the Tweed River were generally found to be prone to erosion, with river bank erosion being most common between Bray Weir and Tumbulgum. Throughout the study area, a range of existing structures designed to prevent riverbank erosion were identified. These ranged from being well designed rock armouring to assorted items (such as building waste) being placed along the river bank in an attempt to prevent erosion.

Assessment of bank erosion mechanisms has been carried out. This found that both naturally generated wind waves and waves resulting from boat wakes have the potential to result in erosion. Comparison between naturally generated wind wave climate and the waves generated by vessel wake was undertaken. It was identified that because of the repetitive nature of towing activities (i.e. undertaking numerous laps along the same stretch of the river) and the size of the wake waves which they generate when travelling at operational speeds, they are the most likely vessel activities to cause significant bank erosion. It was found that the influence of wind generated and vessel wake vary through the Tweed River depending on the exposure of the river to the dominant wind directions and the frequency that towing activities occur in the area.

The study has demonstrated that vessel wake has the potential to cause and increase erosion of river banks within the Tweed River. Based on current practices, the entire stretch of river between Chinderah and Bray Park has been shown to be susceptible to erosion as a result of towing vessel wake. This area generally experiences limited wind generated waves. Accordingly, vessel wake becomes the dominant wave erosion mechanism.

The stretch of river downstream of Chinderah is more exposed to the predominant wind directions and so is subject to larger wind generated waves. Furthermore, this area has been reported as being used less frequently than the upstream areas for towing activities (this is consistent with the exposure of the site to wind energy). Accordingly, wake generated waves from towing activities are not expected to significantly increase river bank erosion in these areas given current practices. This is not to say that bank erosion does not occur in these locations (where unprotected). However, based on the wave assessment, wake waves from towing activities are not considered the dominant mechanism. If towing activities were restricted in other areas of the river, an increase in towing boats could be expected in this stretch of river. This outcome has been shown to have the potential to result in wake waves becoming increasingly significant. Indicating, that even in these downstream areas, which experience a more energetic wind generated wave climate than the upstream areas, waves resulting from tow boat wakes can significantly alter the natural climate if towing activities occur frequently.

A number of management options have been identified for consideration in mitigating the accelerated rate of bank erosion based on the river characteristics and the physical mechanisms of the erosion mechanism. The possible erosion management options range from non-engineered preventative measures though to engineered hard structural protection.

To predict the recovery potential of the river banks a simplistic River Styles Framework assessment was undertaken. The assessment found that provided suitable management options are implemented to mitigate anthropogenic erosion impacts, the recovery potential of eroded river banks to become healthy river banks is moderate. Visible results for eroded riverbanks could be achieved within a decade, but the area will require a long term strategy involving increased riparian vegetation to ensure successful recovery.

Based on the findings of this assessment a series of hypothetical management options have been analysed to provide an indicative cost-benefit assessment. The options considered were to maintain the current practise, implement a 'No-towing activities" policy, or to restrict towing to a specific reach of the river. The assessment looks at relative costs and benefits (tangible and intangible) based on these conceptual scenarios to provide a rational basis for further discussion regarding the implementation of management measures to mitigate erosion caused by vessel wake on the Tweed River.

10 REFERENCES

Australian Maritime College (2009) *Investigation into the effect of wash of baots and wind waves on the Swan River*. Prepared for the Swan River Trust.

Australian Wetlands (2010) *Coastal Zone Management Plan for Cobaki Broadwater and Terranora Broadwater.*

Bellingen Shire Council (2010) *Bellinger River Health Plan.*

Bellingen Shire Council (2010) *Kalang River Health Plan.1*

Brierley, G., Fryirs, K., Outhet, D. & Massey, C. (2002) *Application of the River Styles framework as a basis for river management in New South Wales, Australia.* Applied Geography 22, 91-122.

Cameron, T, & Hill, P. (2010) *Assessing the impact of wake boarding in the Williams estuary, NSW, Australia: - changes for estuarine health.*

DECCW Guideline for Environmentally Friendly Seawalls (2009)

Department of Transport and Main Roads (2009) *Ship operations and activities on the Maroochy River: Discussion Paper.*

GHD (2006) *Williams River Bank Erosion Study.*

Glamore, W.C. (2008) *A Decision Support Tool for Assessing the Impact of Boat Wake Waves on inland Waterways.*

Glamore, W.C. & Hudson, R. (2005) *Field Investigation and Comparative Analysis of Boat Wash Waves.* WRL Technical Report 2005/10.

Great Lakes Council (2008) *Creek to Coast: Great lakes Environment News – Issue 4, Summer 08/09.*

Lampert, G., Ferguson, R. & Brierley, G.J. (1999) *River Styles™in the Tweed and Brunswick catchments, NorthCoast, NSW.* Macquarie Research Limited Report for NSW Department of Land and Water Conservation.*72 pp*

NSW Maritime (2006) *Tweed Estuary Boating Plan 2006 – 2010.*

NSW Public Works (1991) *Managing the Tweed - Feasibility Study: Technical Report No 3.2.1 - Tidal Hydraulics.* Prepared by Oceanics Australia, Report No 3886.1, November 1989.

Patterson Britton and Partners (1996) *Upper Tweed Estuary Management Plan.* Prepared for Tweed Shire Council.

Patterson Britton and Partners (1996) *Lower Tweed Boating Study.* Prepared for Tweed Shire Council.

Patterson Britton and Partners (1998) *Tweed River Estuary Bank Management Plan.* Prepared for Tweed River Management Plan Advisory Committee.

Patterson Britton and Partners (2008) *Tweed River Estuary Recreational Boating Facilities Study.* Prepared for Tweed Shire Council.

Tourism Research Australia (TRA) (2008) Tourism Profiles for Local Government Areas in Wallis Lake

Estuary Management Committee (2005) *Wallis Lake Estuary Management Plan.*

WorleyParsons (2010) *Williams River Riverbank Erosion Study.* Prepared for Port Stephens Council.

Websites

http://www.greatlakesadvocate.com.au/news/local/news/general/wakeboards-banned/2026264.aspx, 05/09/2011

APPENDIX A – TWEED RIVER BANK ASSESSMENT

Introduction

As part of this study the bank assessment of the Tweed River undertaken for the Tweed River Estuary Bank Management Plan (PBP, 1998) has been updated so that it represents the current state of the banks. An assessment of the banks was undertaken on the 13/09/2011, this was completed on boat to enable a thorough inspection of both banks.

Maps showing the current state of the Tweed River banks within the study area are shown in the main report in Figures 2 to 6. A series of numbered comments are included on the maps to provide further clarification, the details of what these comments relate to are shown in Table A1.

The maps show that the upstream areas of the Tweed River appear to be more prone to erosion, with erosion of the riverbank being most common between Bray Weir and Tumbulgum.

Table A1 Comments associated with the maps showing the current state of the Tweed River banks, see Figures 2 to 6 in the main report for comment locations.

Location Reference Number	Comments
1	Steep bank, possible erosion threatening this bank with roadway adjacent.
2	Partial protection from "historical" rock protection with other areas significantly exposed and eroding / slumping. Building waste dumped in front of public house for ad-hoc protection.
3	Bana grass along bank possibly masking bank undercutting in some areas.
4	Low profile "historical" rock protection.
5	Significant undercutting visible with large erosion scarp very close to adjacent road.
6	Visible erosion with bank alignment likely to be receding into "wide river terrace".
7	Private house with mixed protection work of various quality, slope and material. Isolated patches of erosion where bank not protected by private revetments.
8	Past sandy feature in the river has disappeared.
9	Erosion issues in this area seem to have been mitigated by formal protection works along this section.
10	Exposed area with isolated patches of erosion.
11	Isolated 20m patch of eroded bank.
12	Ancillary boat ramp at Condong.
13	Isolated 25m patch of erosion with reeds either side at Condong ramp and pontoon facility.
14	Exposed area with undercutting of large tree with roots system but showing signs of recovery with low juvenile mangroves on low tide terrace. Low profile small stone wall.
15	Bank erosion where vegetation is sparse.
16	Visible erosion east of Island.

Location Reference Number	Comments
17	Large recently constructed rock revetment protecting private property.
18	Active visible erosion.
19	Some patches of erosion occurring between reasonably effective protected sections.
20	Small isolated spots of very localised critical erosion threatening the adjacent road. Protection should be considered by Council.
21	This area can be "awash with vessel wake in summer due to large number of vessels" (P Miller 2011, pers. comm., 13 September).
22	Gradual erosion of the bank.
23	Significant erosion of the bank.
24	Bank vegetation relatively well established on convex curve of the bank.
25	Vegetation has re-established and some juvenile mangroves were observed as well as a few mature trees.
26	Ad-hoc historical protection.
27	Visible erosion appears slow and there is some remaining vegetation.
28	Very large pine tree fallen into river due to strong winds with the root system taking a portion of bank with it. Undercutting erosion contributed to demise of tree.
29	Visible erosion in part limited by the presence of small rock works.
30	Localised erosion.
31	Exposed area with some rocks placed within intertidal zone being effective at limiting further erosion.
32	Visible erosion where there is no bank vegetation.
33	Failed *ad-hoc* revetment with visible erosion on highwater line that could be also due to upstream/downstream end-effect of adjacent revetments.
34	Visible undercutting of areas where there is no vegetation.
35	Failed revetment and exposed geotextile likely due to flood/entrance effects.
36	High crested, recently constructed formal seawall predominantly in good condition protecting road section.
37	*Ad-hoc* protection with some old broken up concrete slabs mainly used in very informal manner.
38	Stable riverbank protection is present, the habitat could be enhanced by planting mangrove seedlings amongst rocks.
39	Bank is slowly receding as a result of longshore processes.
40	Sandy banks are receding with some undermining of the foreshore vegetation.

Recent Changes

Details of how the current state of the banks differ to those reported in 1998 (PBP, 1998) are provided in the sections below. Along some of the banks it was noted that some areas which were previously described as eroding also had some ad hoc defences in place which were either poor or failed, while other eroding area did not have any historical defences. Therefore, these areas have been split into two categories, 'eroding' and 'ad-hoc defences, poor or failed defences' to provide further clarity.

Map 1

On the north bank of the river, downstream of Wollumbin Street Bridge, the existing area of erosion downstream of the defences was previously described as being exposed but with no visible erosion. A photograph showing the erosion along this area is shown in Figure A1.

Map 2

The stretch of the north bank of the river, downstream of Cane Road Bridge and directly downstream of an area of light vegetation/sparse trees was previously described as eroding up to the next area of light vegetation/sparse trees. However, the first section of this previously eroding area and the section downstream of the seawall have now changed to become exposed areas without visible erosion. A photograph of a section of these areas is shown in Figure A2. In addition, opposite this exposed area there is a section on the south bank shown as having visible erosion, this area had previously been described as an exposed area (Figure A3). On the south bank around Barnetts Road there is also an area which was previously recorded as having visible areas of erosion, now the area still has some intermittent areas with visible erosion but the majority of the bank looks stable with the relic rock defences in place around the waterline.

Map 3

The existing areas of erosion shown on the north bank upstream and the south bank downstream of the bridge in Tumbulgum were previously both recorded as being almost twice the length. The previously eroding area on the north bank upstream of the bridge is still exposed but isn't showing any visible erosion. The area on the south bank is now partially defined as being light vegetation/sparse trees and partially as natural vegetation (Figure A4).

Map 4

There were no significant changes in the state of the banks between 1998 and the present day for this stretch of the river.

Map 5

The north bank of the river, located directly upstream from Oxley Cove, now has *ad-hoc,* defences along a stretch which had previously been just light vegetation/sparse trees (Figure A5). In addition, the areas of the south bank of the river upstream of the Chinderah Bridge which is now defended by a rock revetment for a section (Figure A6) and *ad-hoc* poor protection (Figure A7) had previously been recorded as eroding.

Additional Photographs

Photographs showing examples of the type of erosion experienced within the Tweed River are also shown in Figures A8 to A11. Examples of the type of river bank defence present within the Tweed River are shown in Figures A12 to A15; these range from well designed rock revetments to *ad-hoc* defences made up of a range of materials.

Summary

The changes recorded in the state of the riverbanks in the Tweed River since the initial Tweed River Estuary Bank Management Plan (PBP, 1998) are summarised below:

Murwillumbah to Condong – a slight increase in the areas of the riverbank subject to erosion has been recorded.

Condong to Tumbulgum – there has been a reduction in the areas of the riverbank showing signs of erosion, with these areas now being exposed but not showing signs of erosion.

Downstream area around Chinderah –new defences have been implemented in areas which were previously eroding. A section of well designed rock revetment has been added adjacent to Chinderah Bay Drive and some *ad-hoc* defences have been added in two locations.

Figure A1 Photograph of the new area of erosion in Map 1.

Figure A2 Photograph of a section within Map 2 which was previously recorded as eroding but is now exposed area without visible erosion.

Figure A3 Photograph of a section within Map 2 which was previously recorded as exposed but is now visibly eroding.

Figure A4 Photograph of a section within Map 3 which was previously recorded as eroding and is now lightly vegetated.

Figure A5 Photograph of a section within Map 5 which was previously recorded as having light vegetation and now has ad-hoc defences in place.

Figure A6 *Photograph of a section within Map 5 which was previously recorded as eroding and now has a rock revetment in place.*

Figure A7 *Photograph of a section within Map 5 which was previously recorded as eroding and now has ad-hoc poor defences in place.*

Figure A8 *Photograph of an example eroding section of river bank within the Tweed River.*

Figure A9 *Photograph of an example section of river bank experiencing undercutting within the Tweed River.*

Figure A10 Photograph of an example section of river bank experiencing undercutting within the Tweed River.

Figure A11 Photograph of an example section of river bank experiencing erosion resulting in a loss of riparian vegetation within the Tweed River.

Figure A12 Photograph of an example section of river bank with ad-hoc river bank defences in place in the Tweed River.

Figure A13 Photograph of an example section of river bank with ad-hoc river bank defences in place in the Tweed River.

Figure A14 Photograph of an example section of river bank with a well designed rock revetment in place along the Tweed River.

Figure A15 Photograph of an example section of river bank demonstrating the variable river bank defence structures implemented along private land, with a concrete seawall joining up to a tyre seawall.

APPENDIX B – STRUCTURAL ASSESSMENT

Management Options Assessment

A visual condition assessment of existing erosion protection measures within the Tweed Estuary was carried out through a field assessment of various bank revetment projects carried out between 2003 and 2011.

The bank protection sites were visited over a period of two days, from 13 – 14 September 2011. The visual assessment comprised a thorough site walk-over and a photographic record of each site undertaken using a digital GPS camera.

Table B1 provides a list of the sites visited. A map showing the site locations is provided in Figure B1.

Table B1 Sites which have undergone visual assessment

Site Number	Site Name	Description
1	Tumbulgum	Several revetment sections adjacent to stormwater pipe headwalls along Tumbulgum foreshore
2	Condong	Small revetment near boat launching area
3	Budd Park, Murwillumbah	Severe bank erosion along Tweed River southern bank, adjacent to Tourist Information Centre
4	South Murwillumbah Levee (River Street)	Several small sections of revetment along the riverbank, some fronting private property
5	Commercial Road, Murwillumbah	Revetment works adjacent to boat ramp
6	Heritage Wharf, Murwillumbah	Short section of revetment adjacent to wharf at Nicholl Park
7	Rous River	Three sites adjacent to road embankment where river meandering threatens roadway
8	Philp Parade	Revetment works along foreshore at Philp Parade to protect foreshore and significant trees from erosion
9	Dry Dock Road	Small vertical seawall adjacent to boat shed and boat launching area
10	Oxley Cove	Rock revetment along Old Ferry Road and Bosun Boulevard
11	Chinderah	Mixture of rock revetment, double seawall to encourage growth of mangroves, and soft armour composed of compost-filled mesh bags

A detailed description of the site observations including visual condition assessment, assessment of the success (or otherwise) of the management measure and narrative describing the reasons for success or failure of the management measure is provided in the following sections.

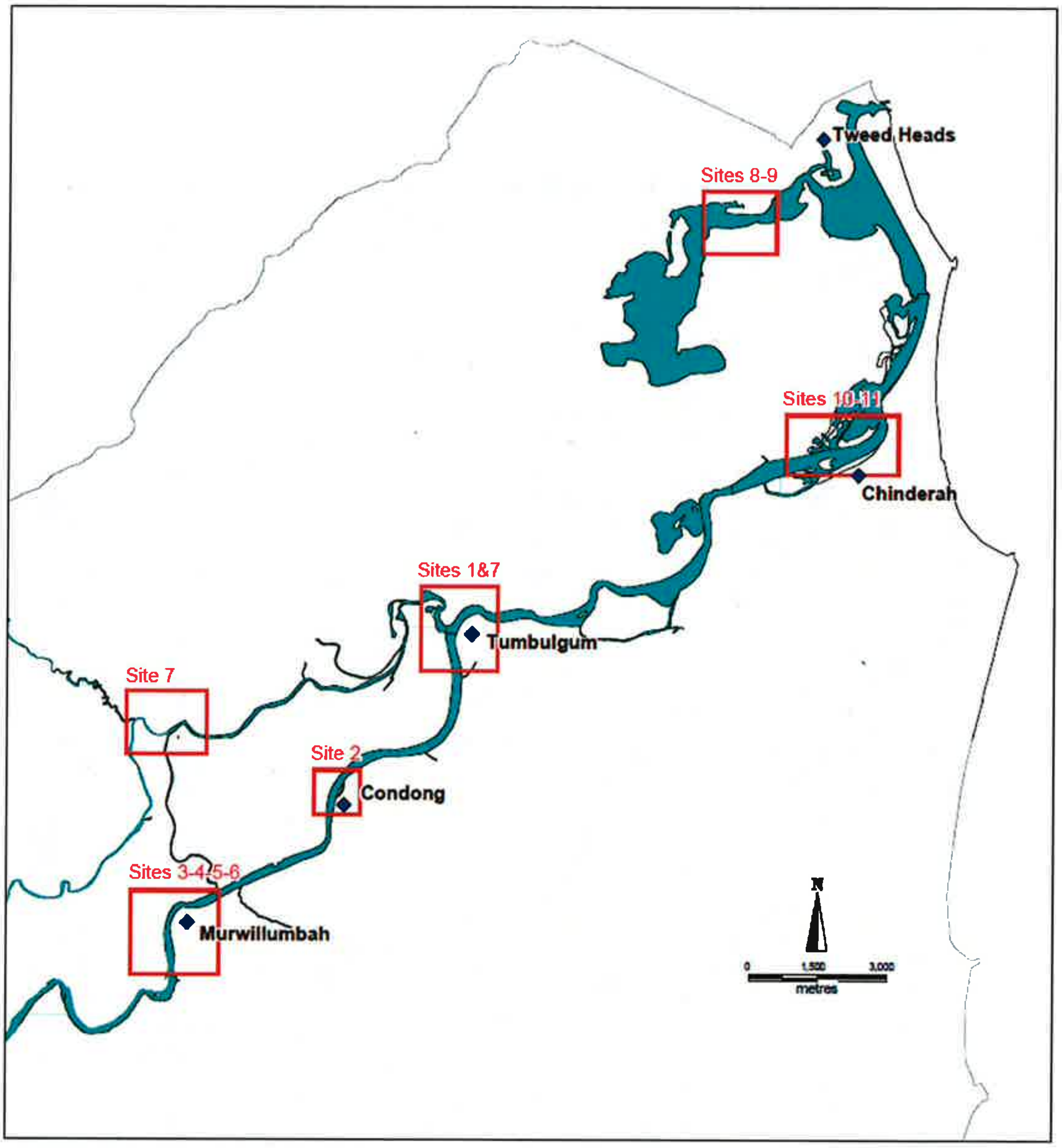

Figure B2 Overview of sites assessed

Site 1 – Tumbulgum

Overview

Tumbulgum is a small urban centre adjacent to the south bank of the Tweed River, opposite the Rous River confluence. The entire foreshore fronting the urban development area, between the Tumbulgum Bridge on the east and Government Road in the west, was inspected by foot. A site map is shown in Figure B2.

Most of the foreshore here was protected by some form of revetment or rock armour, though the protection was discontinuous and in varying condition. Some areas appeared to be newly constructed, backed by geofabric and retaining their original construction profile, with adequate toe support, good interlock between individual armour stones, and no signs of visible slumping. Other sections were constructed of very small armour, and there was some visible displacement of the smaller armour stones.

Some older sections of revetment had suffered erosion on their landward side, probably due to lack of geofabric and overtopping of the wall when the river level is high. Moderate riverbank erosion was evident in sections where the revetment was discontinuous.

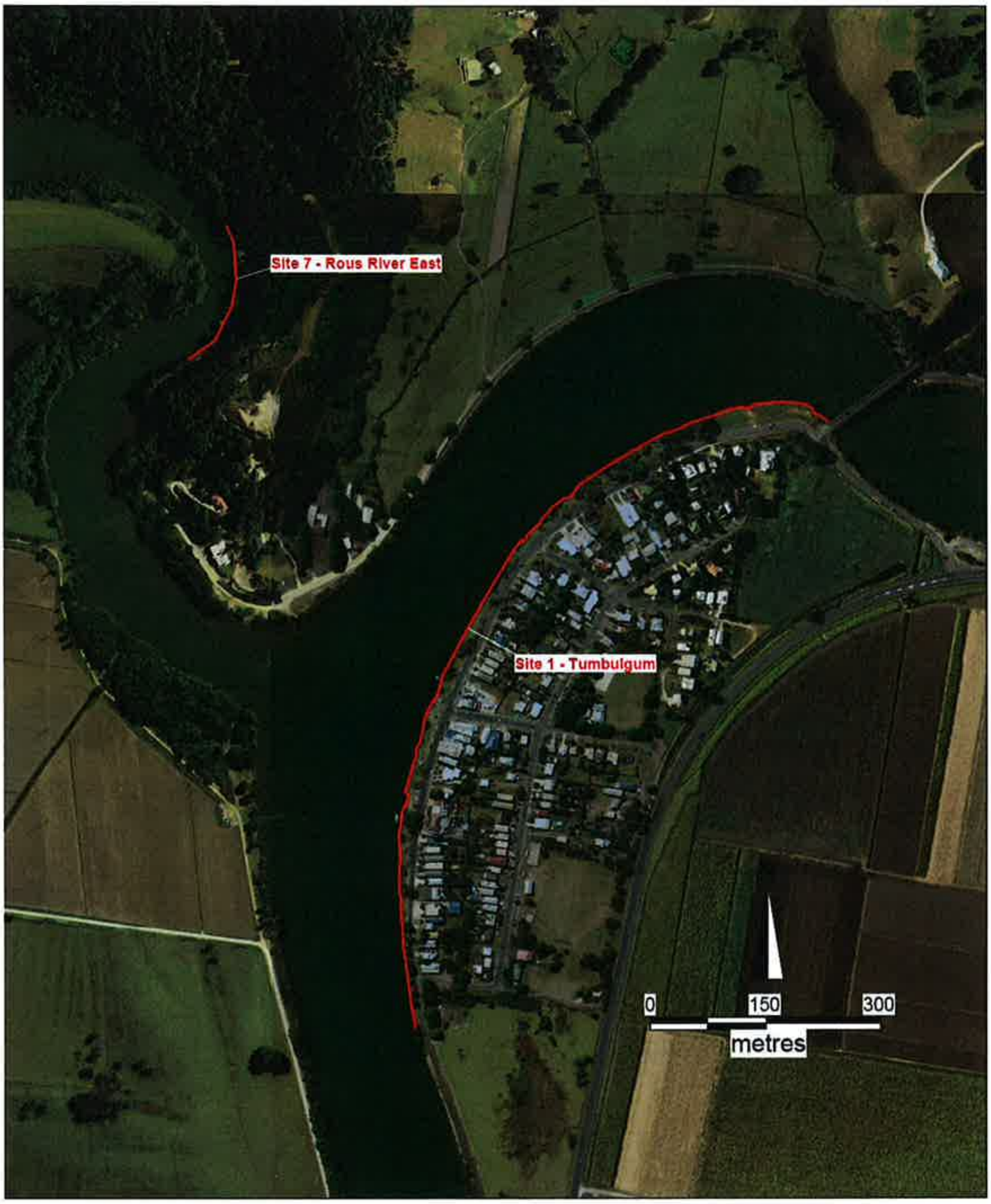

Figure B3 Site map – Tumbulgum and Rous River

Condition Assessment

The newly constructed sections were intact and well constructed, though discontinuous. Geofabric was present behind the revetment in the newly constructed sections. These sections showed no sign of slumping, armour dislodgement, overtopping or deformation. However, smaller armour rocks were scattered over the revetment, as shown in Figure B3. Severe bank erosion was evident immediately adjacent to the revetment.

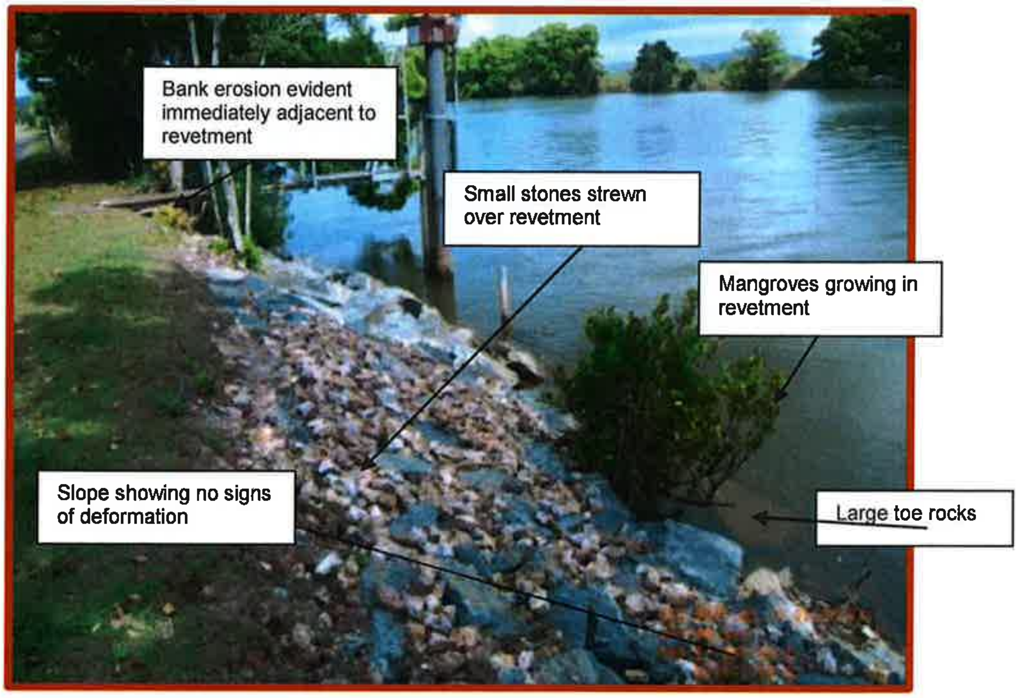

Figure B4 Revetment at Tumbulgum foreshore, looking west

Some sections of revetment were fronted by phragmites or mangroves, to help dissipate wave energy – these sections used smaller armour stones than the sections with no fronting vegetation. These sections were also generally well constructed and had not suffered any damage due to overtopping or deformation due to wave action.

Sections of foreshore where there was a gap in the revetment had undergone significant erosion, as illustrated in Figure B4. This erosion is threatening foreshore vegetation in some locations. Phragmites in front of these sections appeared to not be effective in reducing the erosion.

Figure B5 Eroded unprotected section at Tumbulgum foreshore

Sections of revetment further east along the foreshore, near the boat ramp, were inspected and found also to be generally in good condition. However, as these areas consisted of older construction, the armour stones had become rounded due to weathering and no longer provided sufficient interlock. Some slumping of the revetment protection had occurred, with some erosion at the top of the slope due to a low crest level and overtopping of the crest when the river levels are high. The older construction also appeared to lack geotextile or rock underlay, and this appears to be contributing to erosion of the slope, as loss of material was occurring through the larger voids in the armour. Typical affected sections are shown in Figures B5 and B6.

Figure B6 Erosion occurring at top of slope due to overtopping at a low-crested section

Figure B7 Detached section of revetment due to continuing erosion caused by lack of geofabric

Overall Assessment

The revetments in Tumbulgum are mostly in good condition, with the newer construction very effective in protecting the foreshore from erosion. There are some gaps in the seawall where erosion is more severe, and some areas of older construction which have suffered damage due to overtopping of low sections, slumping due to weathering of armour stones and loss of armour interlock, and erosion of the underlying soil due to lack of geofabric. It was noted that where the bank slopes were gentle, unprotected bank areas were not suffering from erosion.

Recommendations

It is recommended that the damaged revetment sections are maintained on an as-needs basis. Where there are gaps in the revetment and erosion is evident, the revetment should be extended to protect the bank in these areas. The construction should include geotextile and be laid at a slope of 1V:2H, and match the standard of the newer construction where possible. Median armour size should be around 300mm, with rough angular stones used in the construction, and larger toe rocks used to provide support to the overall structure.

Where the older revetment work is no longer being effective and erosion is evident behind the main armour layer, consideration should be given to reconstructing these sections by battering back the riverbank to a slope of 1V:2H, laying geofabric and relaying the revetment armour, with existing armour able to be reused in the construction. Where the revetments are in moderate condition, these areas should be monitored and maintained where necessary.

Planting phragmites in front of the revetments appears to be effective in reducing the wave energy sufficiently to allow the use of relatively small armour as bank protection. It also appears to reduce the toe scour impact caused by wave reflections and high velocity flood and tidal currents along the wall. However, such plantings are insufficient on their own to prevent erosion and undercutting of the banks, without the concurrent use of rock armour bank stabilisation. The revetment integrity does not appear to be greatly impacted by the colonisation of mangrove plants in the revetment face.

Site 2 – Condong

Overview

Condong is a small urban community upstream of Tumbulgum on the southern banks of the Tweed River. Most of the foreshore is adjacent to private development and could not be accessed from land. A relatively high short section of revetment was inspected adjacent to a boat ramp and a launching pad for larger craft. This revetment was observed to be in fair condition, though there was severe erosion evident adjacent to the revetment on either side.

The site plan is shown in Figure B7.

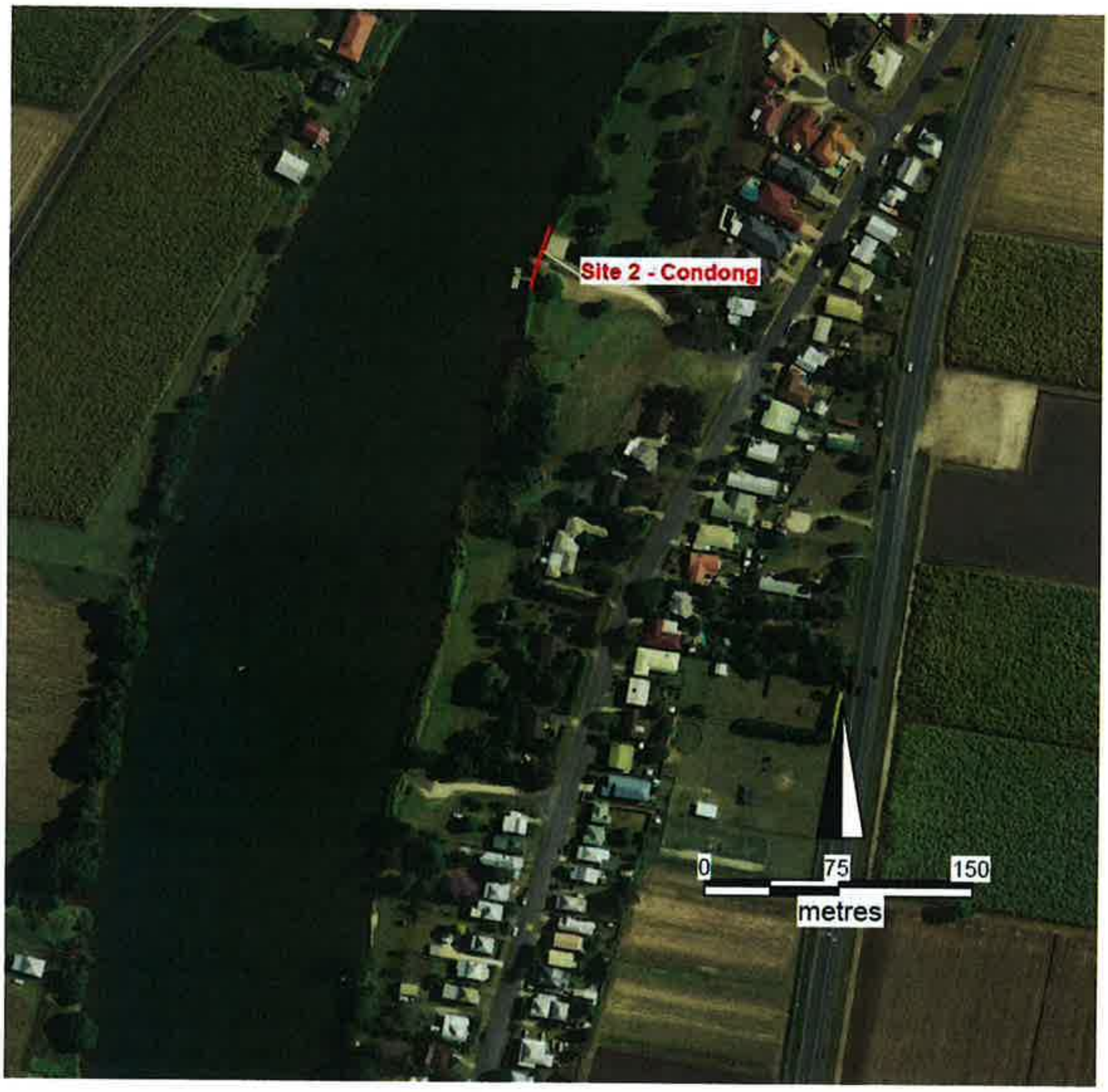

Figure B8 Site plan - Condong

Condition Assessment

The revetment adjacent to the boat ramp in Condong is shown in Figure B8. The revetment is in fair condition, with some displacement of individual armour stones as shown in Figure B8. However, severe bank erosion is occurring both upstream and downstream of the site. The revetment appears to have kept its profile shape and stones appear to be well interlocked.

Figure B8 Revetment adjacent to boat ramp at Condong

A revetment on the upstream side of the boat ramp is shown in Figure B9. This revetment consists of specially placed block-shaped armour stones, acting as a seawall placed at a near vertical angle. This seawall is in good condition.

Figure B9 Seawall on upstream side of boat ramp at Condong

Severe bank erosion is noted immediately adjacent to the seawall and revetment, as shown in Figure B10.

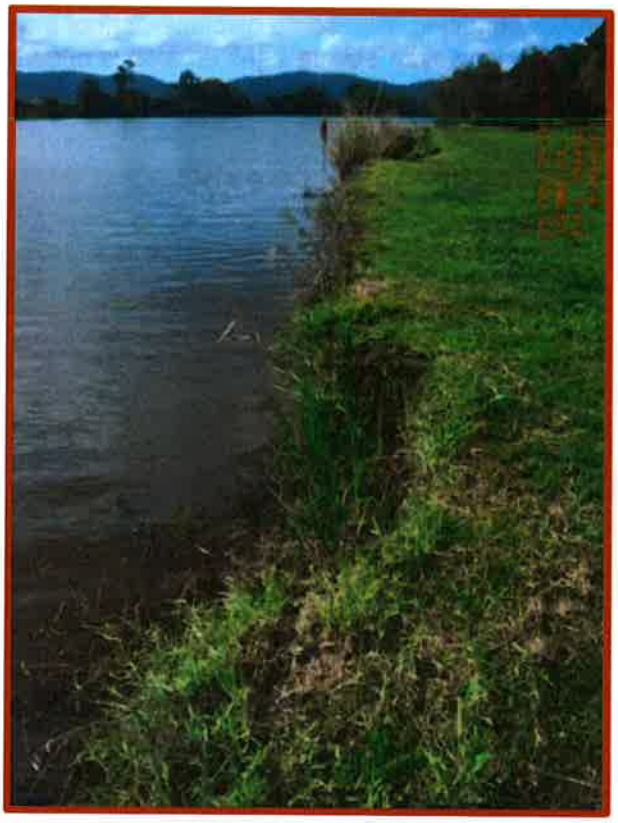

Figure B10 *Bank erosion immediately downstream of revetment at Condong boat ramp*

Recommendations

The seawalls at Condong are in good condition at present, though bank erosion is affecting the adjacent unprotected banks. It is recommended that the adjacent banks be battered back to a gentler slope and planted with native vegetation, with phragmites planted at the toe of the slope to reduce ongoing erosion of the banks adjacent to the existing rock protection.

Site 3 – Budd Park

Overview

Budd Park is located adjacent to the Tourist Information Centre at South Murwillumbah along the south bank of the Tweed River. A site plan is shown in Figure B11. This area is suffering from severe bank erosion which is threatening many large trees and creating a safety hazard for park users.

There is no revetment here at present, though it is understood that there is a revetment planned. Some rock bank protection has been placed adjacent to a small pontoon and stormwater outlet.

Figure B11 *Site map - Murwillumbah*

Figure B12 *Severe erosion at Budd Park*

Condition Assessment

Severe bank erosion is occurring at this site causing a safety hazard for park users. The existing rock protection at the stormwater outlet is laid at a very steep slope and it is assumed that this would form part of the proposed revetment to protect the banks at this location.

Severe erosion is occurring immediately downstream of the rock protection at the pontoon, as shown in Figure B13. The existing rock protection is working effectively to protect the bank from erosion, though the rocks have suffered from weathering and have become rounded over time, reducing the interlocking between individual armour stones. Failed rock protection was noted along the foreshore upstream of the Tourist Information Centre, with rock protection detached from the bank (Figure B14). This is likely due to lack of geofabric underlay, causing loss of fine material through the rock armour and continual erosion of the bank due to rainfall and high velocity flood flows. The revetment has also been laid at a relatively steep slope, leading to likely slip failure of the armour layer. Planting of saltmarsh vegetation at the toe of the eroded bank has been undertaken in an attempt to reduce the rate of erosion.

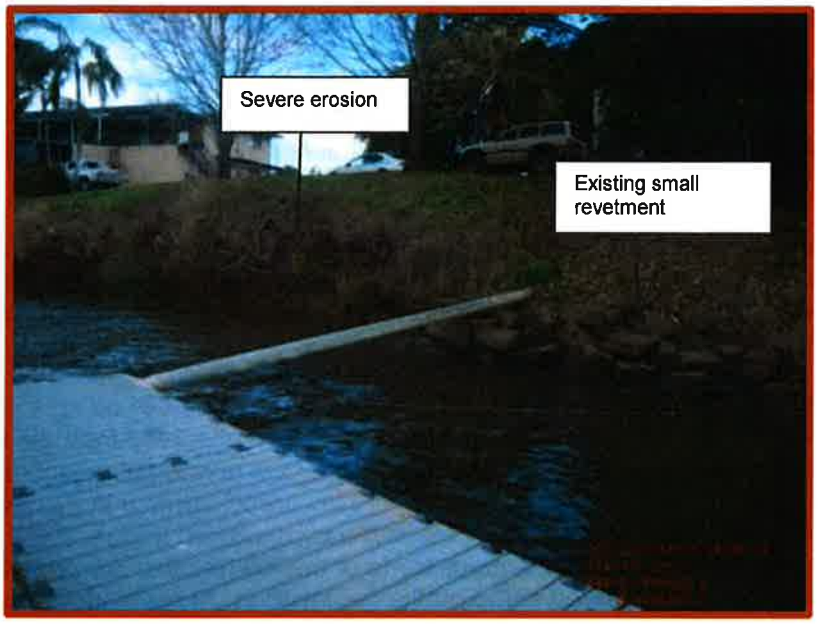

Figure B13 Existing revetment and adjacent erosion at Budd Park

Figure B14 Failed rock protection

Recommendations

It is recommended that rock protection be continued downstream of the pontoon and small jetty as an existing building is under threat due to bank erosion. Bank erosion protection should be installed after battering back the slope to 1V:2H, installation of geofabric and placement of armour stones. Areas where rock protection has failed should be reconstructed, by battering back the slope to 1V:2H, placement of geofabric underlay and reuse of the existing armour stones.

Site 4 – South Murwillumbah Levee (River Street)

Overview and Condition Assessment

This site is located along the southern bank of the Tweed River and is a levee protecting the township of South Murwillumbah from flooding.

There are several small revetments surrounding stormwater outlets at the foot of the levee, which is a grassed earthen embankment. These revetments are generally in good condition, despite being constructed of small armour with a median diameter of around 100mm.

Other revetments are located adjacent to private properties along the riverbank and could not be accessed by land. These revetments were observed from the opposite riverbank and appeared to be in fair to good condition. One revetment adjacent to Holland Street was in fair condition, with slumping of the lower rock armour in the revetment but this still serving its purpose of protecting the levee from erosion (Figure B15). The revetment here comprises relatively small armour stone at the toe (median diameter 200mm), and this appears to have suffered some profile deformation. At some locations the toe of the levee is planted with reeds which appears to have been effective against bank erosion in this locality.

Figure B15 Revetment at South Murwillumbah Levee with slumping of toe rock and deformation of profile

Recommendations

The revetments along the South Murwillumbah levee appear to be in reasonable condition. Ongoing monitoring of the revetment performance and bank erosion is required, with revetment maintenance likely to be required in the future.

Site 5 – Commercial Road

Overview and Condition Assessment

This site is located on the northern bank of the Tweed River, adjacent to the town of Murwillumbah. There appears to be moderate bank erosion in some locations along the Commercial Road foreshore, with small riprap armouring the toe of the slope. While some undercutting of the banks is occurring along this section at low tide, the banks appear to be relatively stable here.

Further upstream, some erosion was observed where fringing reeds had been planted along the banks, as seen in Figure B16.

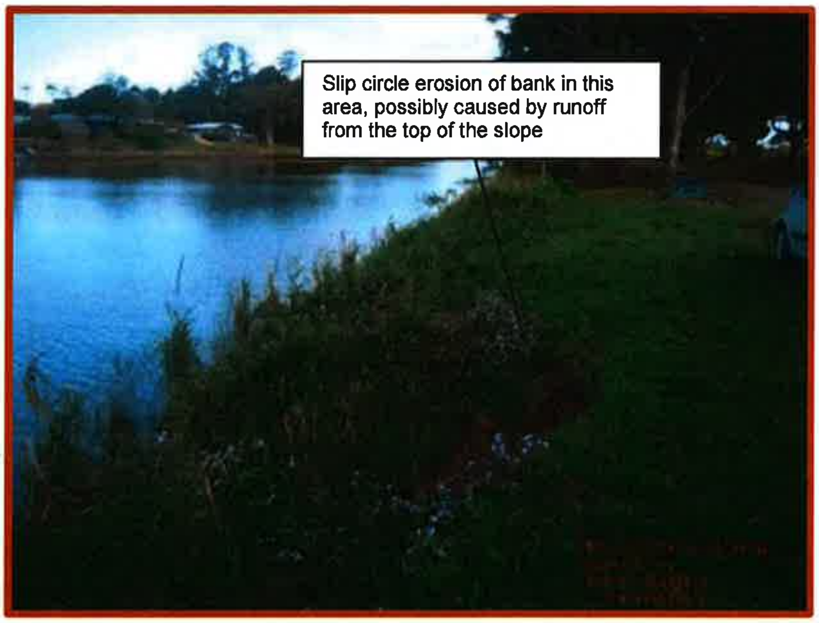

Figure B16 Erosion occurring upstream of Commercial Road area

A revetment adjacent to the boat ramp at the upstream end of Commercial Road (Figure B17) appeared to be recently constructed and in good condition, with the toe and revetment profile remaining intact. Large armour stones with a median diameter of around 600mm have been used in the revetment construction which appears to have been conservatively designed.

Recommendations

It is recommended that the foreshore along Commercial Road be monitored for signs of erosion. The downstream section of foreshore at Commercial Road is very steep but appears to be stable. This area should be monitored for undercutting of the banks. Should this occur, additional rock toe protection may be required. Areas experiencing erosion at present should be repaired and planted with fringing vegetation.

Figure B17 Revetment adjacent to boat ramp at upstream end of Commercial Road

Site 6 – Heritage Wharf

Overview and Condition Assessment

A revetment around 30m long is located adjacent to Skinner Lowes Wharf at Nicholl Park, on the northern bank of the Tweed River. This revetment is in reasonable condition.

The armour stones in this revetment have become rounded due to weathering and the lower stones have slumped due to poor interlock between individual armour stones. The revetment profile has become deformed into an S-shaped profile, possibly due to wave action and a bench has formed at the toe of the structure.

Despite the appearance of this structure, it is performing very well in protecting the foreshore against erosion. It is likely that the revetment has formed a dynamically stable profile, and the crest height is sufficient to prevent erosion due to overtopping. Geofabric underlay is present here.

Bank erosion was observed on both the upstream and downstream sides of the revetment.

The revetment is shown in Figure B18.

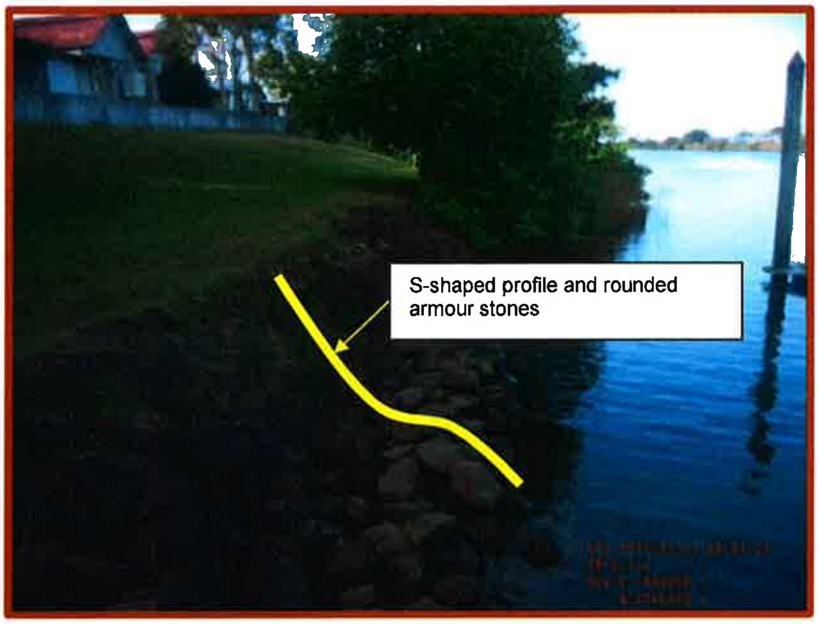

Figure B18 Revetment at Heritage Wharf

Recommendations

It is recommended that this structure be monitored to ensure its continuing effectiveness. While currently effective, the structure may require future maintenance should erosion occur at the site.

Site 7 – Rous River

Overview

Rous River is a tributary of the Tweed River, joining the Tweed River at Tumbulgum. Three sites were visited along the Rous River, where bank protection had been installed to prevent meandering of the river and undermining of the adjacent Dulguigan Road. A site plan for these sites is shown in Figures B2 and B19.

Figure B19 Road embankment protection at Rous River

Condition Assessment

A revetment has been constructed along the road embankment at the upstream section of Rous River, shown in Figure B20. This revetment appeared to be in good condition and was effective in protecting the road embankment against meandering of the river channel.

Figure B20 *Revetment along road embankment – Rous River (west)*

A further section (Rous River Centre) adjacent to Dulguigan Road consisted of an embankment close to the road edge, where the embankment has been battered back and sediment fencing installed. No bank protection has been installed here (Figure B21).

At the downstream end of Rous River, a revetment has been installed to act as road embankment protection and to protect some large trees and mangroves against erosion (Figure B22). This revetment is in good condition, having been constructed at a gentle slope, though the crest level appeared low, possibly due to slumping of the structure as a result of the soft underlying soils.

Recommendations

It is recommended that the existing revetments be monitored for continuing performance and structural integrity. It is recommended that rock protection be constructed for the unprotected section of embankment adjacent to Dulguigan Road at Rous River.

Figure B21 Unprotected embankment – Rous River (centre)

Figure B22 Revetment at downstream end of Rous River

Site 8 – Philp Parade

Overview

This site is located at Tweed Heads adjacent to Philp Parade. There are several sections of revetment here that have been recently rebuilt and are in good condition, with geotextile underlay and adequate toe protection. There are sections of older foreshore protection work that are in poor condition, with low crest levels, lack of geofabric underlay and erosion continuing on the landward side of the revetment. Other sections are devoid of protection and are suffering from erosion as a result, with several large trees threatened. Moderate boating traffic was observed at this area of the river on the day of the site visit.

The site location map is shown in Figure B23.

Figure B23 Site location map – Philp Parade and Dry Dock Road

Condition Assessment

The newly constructed sections were in good condition with no evidence of deformation, slumping or other damage. Rock armour size was around 400mm median diameter. These sections seemed to be successful in protecting the large trees along the foreshore (Figure B24).

Older sections had a lower crest level and were observed to have suffered damage, probably due to lack of geofabric underlay and overtopping due to high water levels. In some areas, the seawall had become detached from the embankment and concrete blocks had been dumped in an attempt to slow down the erosion (Figure B25). In these locations, some large trees were at threat of undermining.

Figure B24 Philp Parade, with newly constructed revetment

Figure B25 Severe erosion due to revetment overtopping and lack of geofabric underlay

Recommendations

The newly constructed revetments appear to be appropriate and are performing well. However, some of the older construction has suffered damage and is ineffective in preventing erosion of the bank. It is considered that the crest level of these older sections is too low to prevent overtopping of the bank, and that the lack of geofabric underlay is causing loss of fine bank material through the primary rock armour.

It is suggested that the damaged sections be reconstructed as per the newly constructed adjacent sections. The large armour stones from the older sections could be removed and replaced with smaller stones similar to those in the newer revetments, which would be adequate for the expected wave climate in this area. It is important that the revetment be underlain with geotextile to prevent continuing erosion through loss of fine material through the rock armour.

Site 9 – Dry Dock Road

Overview

This foreshore area consists of some sections of old revetment construction, with a new vertical seawall section adjacent to the boat sheds and wharf.

The older revetment sections have limited effectiveness in protecting the pedestrian pathway (west of the boat shed) and some significant trees east of the boat ramp.

Condition Assessment

The vertical seawall appeared to be newly constructed and in good condition, with a beach area located on the seaward side. This area was used as a boat launching area for recreational sailing. Some sinkholes have formed behind the seawall, possibly due to inundation of this area during abnormally high tides (Figure B26).

Figure B26 Vertical seawall adjacent to boat shed

The revetment works west of the boat shed and east of the boat ramp appeared to be largely ineffective, except for a section adjacent to a stormwater outlet. Minor erosion appeared to be occurring in some areas, due to overtopping of the revetments and lack of geofabric (Figure B27).

Figure B27 Rock protection for trees east of boat ramp at Dry Dock Road

Recommendations

It is recommended that the new seawall at Dry Dock Road be monitored and maintained as necessary.

Consideration should be given to removing the ineffective works at the beachfront area east of the boat ramp and within the mangrove areas. The embankment immediately downstream of the bridge is suffering from erosion – consideration should be given to reconstructing the existing revetment here by installing geofabric, or by removal of the seawall and establishing mangroves. Armour rocks recovered from seawall removal could be used in seawall construction elsewhere within the Tweed Council area. It is noted that the foreshore east of the bridge is not protected by rock and is not suffering from any significant erosion.

Site 10 – Oxley Cove

Overview and condition assessment

This site consists of a revetment constructed along the northern bank of the Tweed River (Figure B28). The revetment is approximately 600m long and provides protection to Old Ferry Road and an embankment sheltering the area of Oxley Cove, at Banora Point. This revetment was in good condition, with little evidence of damage due to rock armour displacement, structure deformation or overtopping (Figure B29). This reach of river experienced fairly heavy waterskiing boat traffic on the day of the site visit.

Moderate erosion has occurred on the unarmoured sheltered side of the embankment, possibly due to boat wake from resident boats within Oxley Cove. Severe erosion was evident immediately upstream of the revetment, adjacent to Old Ferry Road (Figure B30).

The embankment at the eastern side of Oxley Cove adjacent to Bosun Boulevard has suffered severe erosion, with most of this embankment unprotected from waves. An attempt to construct revetment protection to the most exposed section of the eastern side has failed, with slumping of rock armour due to the face of the revetment being too steep (Figure B31).

Figure B28 Oxley Cove and Chinderah revetment sites

Figure B29 Revetment at Oxley Cove (west)

Figure B30 Severe erosion at upstream side of revetment at old Ferry Road

Figure B31 Severe erosion and failed revetment at eastern side of Oxley Cove adjacent to Bosun Boulevard

Recommendations

Depending on the proposed use for the land on the eastern side of Oxley Cove, it is recommended that the revetment on the eastern side of Oxley Cove be repaired by battering back the slope to 1V:2H and reconstructing the revetment as per the existing revetment at Old Ferry Road. The embankment upstream of the main revetment is suffering from severe erosion and it is recommended that the existing revetment here be repaired.

Site 11 – Chinderah

Overview

The foreshore at Chinderah consists of a mixture of revetment, "double" seawall to encourage mangrove growth, and soft armouring consisting of geogrid mesh compost bags, to act as a "living" wall. The foreshore here is subject to heavy boat traffic, and a main access road is located immediately adjacent to the foreshore. This foreshore appears to have been used as an ideal location to trial various forms of bank protection, due to the heavy boat traffic experienced in the area and the long section of exposed foreshore.

Condition Assessment

The newly constructed revetment sections at the western end of the Chinderah foreshore were observed to be in good condition, with no evidence of damage (Figure B32). However, the presence of the rocks has made access to the foreshore difficult.

Figure B32 Typical new revetment section, Chinderah

The sections of "living wall" appeared to be performing well, with no signs of damage and much less visual impact compared with the rock revetment (Figure B33). An area of "double wall" had also been constructed to encourage the growth of mangroves, this appears to have been partly successful (Figure B34).

Immediately adjacent to the road embankment, a standard revetment with extensive crest width has been constructed. This revetment appears to be of older construction but is showing no signs of damage as it is well-constructed. Sufficient crest width to protect the road from wave overtopping is provided and there are no signs of damage or deformation to the revetment (Figure B35). Further east, a section of revetment had been constructed without adequate crest width and this section is beginning to suffer damage due to overtopping (Figure B36). This section is subject to a considerable northerly wind fetch.

A short section of embankment without adequate protection has suffered from severe erosion (Figure B37).

Figure B33 Soft armouring with geogrid and compost-filled mesh containers

Figure B34 "Double wall" at Banora Point to encourage growth of mangroves along bank

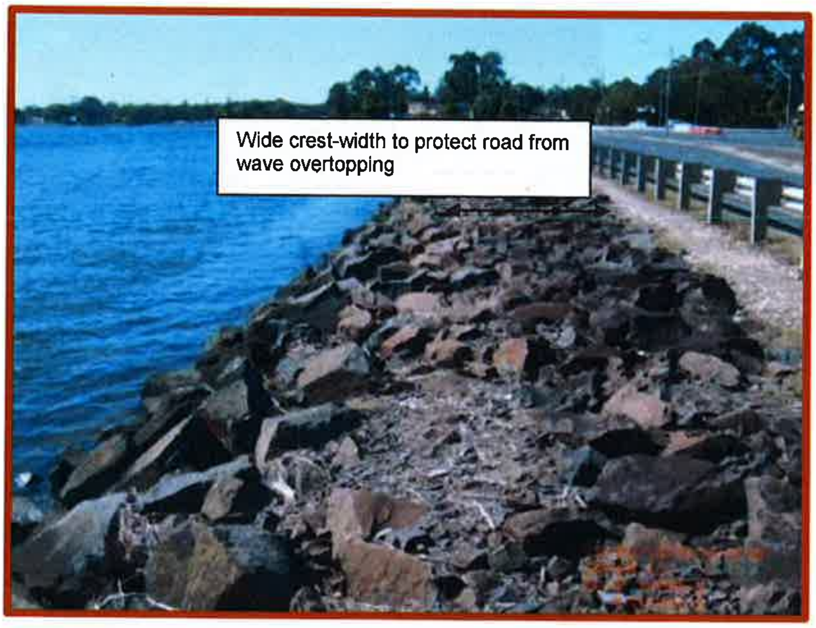

Figure B35 *Revetment providing effective protection from wave overtopping*

Figure B36 *Revetment with insufficient crest width showing some damage due to overtopping*

Figure B37 Section of embankment at Chinderah suffering erosion

Recommendations

It is recommended that the revetment trials along Chinderah be monitored over time to assess their effectiveness. Maintenance for the section of seawall shown in Figure B37 is recommended, by "topping up" of the crest with armour stone. It is recommended that the unprotected section of embankment shown in Figure B37 be armoured as per the adjacent construction.

Summary

It is noted that most of the revetments inspected are in good condition, especially those which have been recently constructed. The most common failure mechanism for rock bank protection appears to be overtopping of low-crested seawalls and loss of fine material through the primary armour layer due to lack of geotextile underlayer. The most successful of these constructions involved the use of a relatively gentle slope and geotextile underlayer.

The trials of soft armouring techniques being undertaken at Chinderah should be monitored closely as this technique has the potential to reduce visual impact and restore the natural values of the river banks. Rock protection at some locations is ineffective and erosion effects were commonly observed adjacent to the foreshore revetments.

The recommended priority for bank erosion improvement works is shown in Table B2.

Table B2 Bank Erosion Improvement Works and Observations

Site No.	Site Name	Priority/Erosion Severity	Observations/Recommendations
1	Tumbulgum	Low/Medium	This site requires maintenance of sections of revetment which have been damaged and completion of revetment where there are gaps in the foreshore protection. Effort should be made to restore foreshore vegetation
2	Condong	Low/Medium	Banks adjacent to the revetment at the boat ramp are suffering from erosion. These should be battered back to a gentler slope and planted with native vegetation and phragmites to protect the toe of the slope
3	Budd Park	High	Severe erosion is occurring at this location. A foreshore revetment is recommended here and a building appears to be at potential risk due to bank erosion
4	South Murwillumbah Levee	Low	The revetments here appear to be in good condition and require ongoing monitoring
5	Commercial Road	Low	This area is not experiencing severe erosion at present but should be monitored to assess existing protection works and the need for toe protection works for the existing steep embankment
6	Heritage Wharf	Low	This area has an existing revetment which is in reasonable condition but should be monitored for continuing performance and maintained if required in the future
7	Rous River	Medium	The existing revetments should be monitored and a revetment constructed for the existing unprotected embankment at Dulguigan Road
8	Philp Parade	Medium	Sections of revetment which have failed due to overtopping and lack of geotextile should be reconstructed as funds allow.
9	Dry Dock Road	Medium	Sections of revetment which are redundant could be removed and planted with natural vegetation
10	Oxley Cove	Medium	Revetment construction is needed on the eastern peninsula and revetment reconstruction is needed at the western side of Old Ferry Road
11	Chinderah	Low/Medium	Existing environmentally friendly seawalls including soft foreshore protection measures should be monitored to assess their relative effectiveness in protecting the bank and restoring environmental values. Maintenance is recommended for a short section of seawall which is suffering damage due to wave overtopping.