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2015 Riverbank Vulnerability Assessment using a Decision Support System: Seaham Weir Pool and Lower Williams River

WRL Technical Report 2015/02
May 2016

By W C Glamore, I R Coghlan and J E Ruprecht

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Project Details

Report Title	2015 Riverbank Vulnerability Assessment using a Decision Support System: Seaham Weir Pool and Lower Williams River
Report Author(s)	W C Glamore, I R Coghlan and J E Ruprecht
Report No.	2015/02
Report Status	Final
Date of Issue	May 2016
WRL Project No.	2014039.01 and 2015039.01
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Document Status

Version	Reviewed By	Approved By	Date Issued
Preliminary Draft V1.0	I R Coghlan	W C Glamore	04 June 2015
Draft V2.1	W C Glamore	G P Smith	04 November 2015
Final Draft V1.0	I R Coghlan	G P Smith	04 March 2016
Final	W C Glamore	G P Smith	26 May 2016

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Executive Summary

Key Summary Points:

- Riverbank erosion and boating management on the Williams River has been a highly controversial issue for many years.
- A Decision Support System (DSS) was used to objectively assess and rank a 38 km section of the Williams River to improve river management.
- The assessment was completed for two (2) management areas on the Williams River, including the Seaham Weir Pool from Seaham Weir to upstream of Clarence Town, and the Lower Williams River from Seaham Weir downstream to the Hunter River confluence at Raymond Terrace.
- The study findings suggest that a range of factors, including boating activities, poor land management practices, and flooding, have degraded the condition of the riverbanks along the Williams River study area, rendering the riverbanks more susceptible to erosion.
- The riverbank conditions were shown to deteriorate as a direct result of the largest flood on record on the Williams River in April 2015. Typical flood impacts on the riverbanks included:
    - Damage was generally observed on the outside banks compared to the inside banks;
    - Loss of sub-aquatic vegetation, reeds, and phragmites in the wave zone;
    - Reduction in upper riverbank ground-cover vegetation, including exotic weeds and vines;
    - Riverbank erosion and slumping; and
    - Tree up-rooting.
- Land and water-based management options, including a Management Action Plan have been outlined at sites with the highest vulnerability to erosion.
- Combined land and water-based management interventions are recommended to ensure successful, long-term outcomes. The implementation of temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) are recommended in conjunction with remedial riverbank works.
- A staged approach is recommended for implementing the Management Action Plan. Successful implementation of the Management Action Plan will require detailed site investigation and costing, and inclusive community and stakeholder consultation.
- The management actions for the Seaham Weir Pool should be prioritised over the Lower Williams River, due to the public health concerns associated with the long-term decline in water quality.

Following implementation and evaluation of the riverbank remediation activities, boating restrictions should be reassessed once riverbank vegetation is re-established.

BACKGROUND

This study details a riverbank vulnerability assessment of a 38 km section of the Williams River, NSW using a Decision Support System (DSS). The assessment was completed for two (2) management areas on the Williams River, including the Seaham Weir Pool from Seaham Weir to upstream of Clarence Town, and the Lower Williams River from Seaham Weir downstream to the Hunter River confluence at Raymond Terrace. The study outcomes quantify the current riverbank condition and provide evidence-based management recommendations for the Seaham Weir Pool and Lower Williams River. Information from the report can be used to inform an updated regional boating plan for the Williams River. The study was jointly funded by the Hunter Water Corporation and Transport for NSW.

Numerous projects have been completed over the past three decades to assess riverbank erosion and boat wake wave impacts on the Williams River. In 2012, a scientific study was undertaken by Glamore and Davey (2012), detailing the riverbank vulnerability to erosion on the Seaham Weir Pool (SWP Stage 1). For the current study, the riverbank condition in two (2) areas on the Williams River was assessed in March 2015, including the:

i) Lower Williams River, which was initially assessed (LWR Stage 1); and
ii) Seaham Weir Pool, which was reassessed (SWP Stage 2).

The March 2015 assessment had two (2) purposes:

i) Applying the DSS methodology to the Lower Williams River (Baseline Assessment); and
ii) Identifying whether the riverbanks of the Seaham Weir Pool were becoming more or less vulnerable to erosion.

A major flood occurred in April 2015 on the Williams River, immediately following the March 2015 DSS assessment. The April 2015 flood was the largest recorded flood event on the Williams River and resulted in major changes to the riverbank condition data previously collected. As such, a follow-up field assessment was conducted in August 2015 to re-assess the erosion potential of the riverbanks on the Seaham Weir Pool (SWP Stage 3) and Lower Williams River (LWR Stage 2). This dataset provided up-to-date information on the riverbank condition and the opportunity to scientifically document the impacts of a significant flooding event on the riverbanks of the Williams River.

STUDY APPROACH

A DSS, as outlined by Glamore and Badenhop (2006), was used to objectively assess and rank the vulnerability of the riverbanks to erosion based on a variety of environmental factors. The DSS is structured around three (3) major components:

(i) Calculating the natural background wind-wave energy at a site;
(ii) Quantifying the vessel generated wave energy and the operating frequency of boats (i.e. number of boat passes); and
(iii) Assessing the susceptibility of a shoreline to erosion due to the vessel generated waves.

The DSS comprises a database with a range of vessel generated wave energies from recreational boating activities, including wakeboarding, waterskiing, and wakesurfing. In this study, the DSS ranking system was used to assess:

- The current condition of the riverbanks;
- The dynamic nature of the riverbanks over time;
- The vulnerability of the riverbanks to erosion;
- The effect of natural wind waves, boat wake waves and other contributing factors to riverbank erosion along key reaches of the river; and
- Potential management actions for highly vulnerable riverbank sections.

As per the DSS methodology, the river between Raymond Terrace and upstream of Clarence Town was divided into 79, 500 m long sections. Field campaigns assessed the erosion potential at three (3) representative transects on the left and right riverbanks within each 500 m section.

An erosion potential score and erosion potential rating were determined for each site in the study area. In assessing the erosion potential of the riverbanks (i.e. the current condition), key criteria and weighting factors were combined to form an erosion potential rating. These criteria included river type, native vegetation cover, erosion descriptors, adjacent land-use, and channel features. Sites with highly negative erosion potential scores have a low resistance to erosion, whereas sites with highly positive erosion potential scores have a high resistance to erosion.

The riverbank erosion potential, wind waves, and boat waves at each section were assessed within the DSS to produce a final boat management recommendation of either 'Allow' (Permit), 'Monitor' (Permit with Monitoring) or 'Manage' (Manage Activities). When wave attenuation (i.e. as calculated by the distance of a boat from the shore) was a limiting factor in the final outcome, and the maximum wave would result in a different management category, sites were presented as 'Allow*' or 'Monitor*'.

STUDY FINDINGS

Key findings from this study are summarised below:

Seaham Weir Pool

- Riverbank conditions along the study area generally deteriorated over the assessment period from March 2012 to August 2015.
- The riverbanks in the study area became more erosive over the assessment period from March 2012 to August 2015, with the majority of the erosive sites located in the wakeboard zone of the Seaham Weir Pool. In 2012, 55% of the riverbank sites assessed were erosive and 45% were resistant to erosion. In March 2015, 59% of the riverbank sites assessed were erosive and 41% were resistant to erosion, while in August 2015, 77% of the riverbank sites assessed were erosive and 23% were resistant to erosion.
- The DSS results for the assessment period from March 2012 to August 2015 indicated that the number of sites requiring management had increased, with the majority of the 'Manage' sites located in the wakeboard zone, while the number of 'Monitor' and 'Allow' sites had correspondingly decreased. In 2012, 13% of sites were 'Manage', 81% were 'Monitor', and 6% were 'Allow'. In March 2015, 24% of sites were 'Manage', 71% were 'Monitor', and 5% were 'Allow', while in August 2015, 28% of sites were 'Manage', 68% were 'Monitor', and 4% were 'Allow'.
- The maintenance of a quasi-static operational water level upstream of Seaham Weir appears to exacerbate erosion. Although raising the existing operational water level of Seaham Weir by approximately 300 mm was shown to modestly improve the ability of the riverbanks upstream of the weir to resist erosion, it was acknowledged that the response of riverbank vegetation to an ongoing raised operational water level was likely to be detrimental. On this basis, WRL does not recommend altering the Seaham Weir operational water level to combat riverbank erosion.
- Riverbank cross-sectional survey profiles (including undercutting) were repeated at 17 locations along a straight stretch of the Seaham Weir Pool to quantify the impact of the April 2015 flood event. The results of the land survey showed that there has been a net loss (erosion) of between 250 to 750 m^3 of riverbank soil into the Seaham Weir Pool across the 17 monitoring sites (a 1 km stretch on one side of the river) between December 2012 and February 2016.
- While the land survey and the DSS assessments are different measures of riverbank condition, the land survey results independently verify the DSS riverbank condition trajectory in this area. However, the measures diverged for Sites 10-17 between April 2014

and February 2016 where significant net accretion was recorded, whereas the DSS ratings either further deteriorated or did not change.

- Monitoring of the 17 riverbank survey locations is considered to be an important part of ongoing management of water quality in the Seaham Weir Pool.

Lower Williams River

- Riverbank conditions along the study area generally deteriorated over the assessment period from March 2015 to August 2015.
- The riverbanks in the study area became more erosive over the assessment period from March 2015 to August 2015, with the majority of the erosive sites located in the wakeboard and waterski zones of the Lower Williams River. In March 2015, 43% of the riverbank sites assessed were erosive, while 57% were resistant to erosion. While in August 2015, 57% of the riverbank sites assessed were erosive and 43% were resistant to erosion.
- The DSS results for the assessment period from March 2015 to August 2015 indicated that the number of sites requiring management had increased, with the majority of the 'Manage' sites located in the wakeboard and waterski zones, whereas the number of 'Monitor' and 'Allow' sites had correspondingly decreased. In March 2015, 43% of sites were 'Manage', 47% were 'Monitor', and 10% were 'Allow', while in August 2015, 52% of sites were 'Manage', 42% were 'Monitor', and 6% were 'Allow'.
- At high tide on the Lower Williams River, wave action was slightly less likely to cause riverbank erosion than at mid – low tide, but the difference was not considered sufficient to develop water-based management actions linked to the tidal stage of the river.

Entire Study Area

All five (5) erosion potential ratings in the DSS ('Highly Resistant', 'Moderately Resistant', 'Mildly Resistant', 'Moderately Erosive', and 'Highly Erosive') were observed in the study area. Figures ES-1 and ES-2 provide the distribution of the erosion potential categories across the study area following the April 2015 flood.

As per Table ES-1, the majority (57%) of the sites within the study area were identified as requiring ongoing monitoring to observe if the riverbanks become more or less vulnerable to erosion with time. Approximately 25% of all sites assessed in August 2015 were categorised as 'Manage' and are recommended for immediate action to prevent further erosion. A further 11% of sites are recommended for immediate action to prevent ongoing erosion by encouraging boating activities towards the centre of the river (i.e. 'Monitor*' sites), where sufficient river width is available. Figures ES-3 and ES-4 provide the overall DSS management outcomes to assist in developing erosion mitigation measures.

Table ES-1: Number of Stretches Determined in each DSS Management Category (August 2015)

Study Area	Stretch	River Section	Management Option				
			Allow	Allow*	Monitor	Monitor*	Manage
Seaham Weir Pool	31-45	U/S of the 4 knot Section	2	0	26	0	2
	27-30	4 knot Section (U/S)	0	0	5	1	2
	23-26	Waterskiing Section (U/S)	0	0	4	2	2
	18-22	Wakeboarding Section	1	0	2	1	6
	10-17	Waterskiing Section (D/S)	0	0	10	1	5
	7-9	4 knot Section (D/S)	0	0	6	0	0
	1-6	Restricted Area Near Weir	1	0	8	0	3
Lower Williams River	79	No Boats Permitted (U/S)	1	0	1	0	0
	78	4 knot Zone	2	0	0	0	0
	71-77	Wakeboarding Zone (U/S)	0	0	6	3	5
	59-70	Waterskiing Zone	0	1	10	6	7
	50-58	Wakeboarding Zone (D/S)	0	0	8	3	7
1-79		***TOTAL***	**7**	**1**	**86**	**17**	**39**

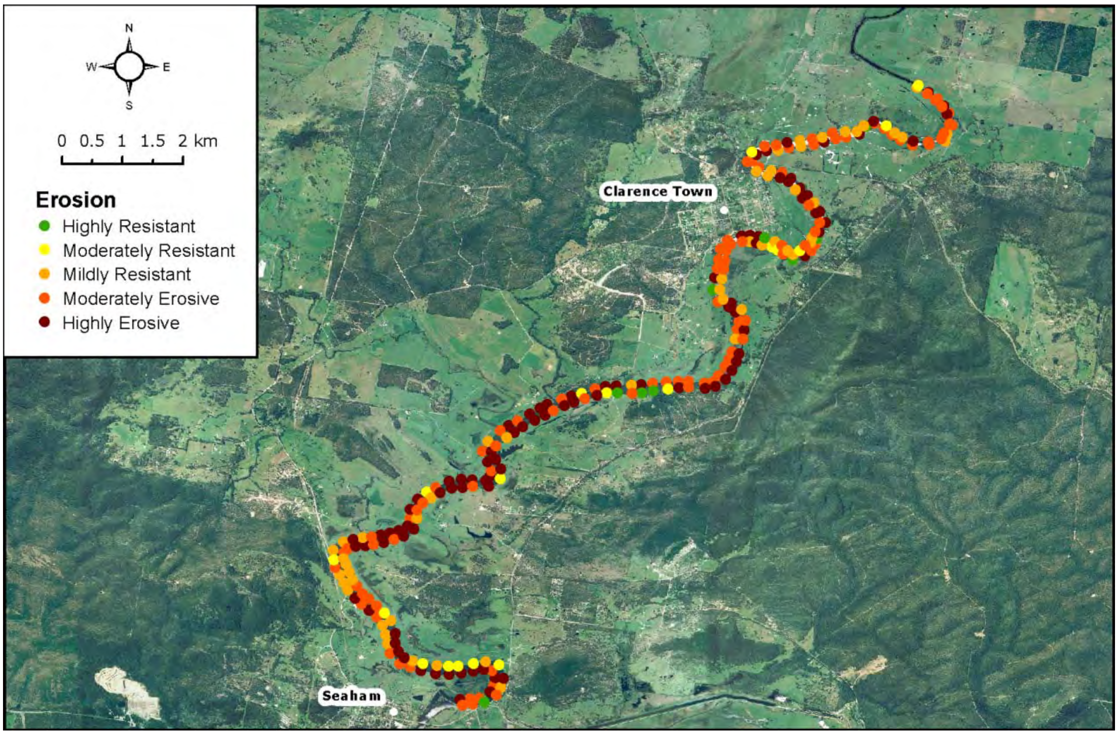

Figure ES-1: Erosion Potential for Each Transect on the Seaham Weir Pool (Existing Operational Water Level)

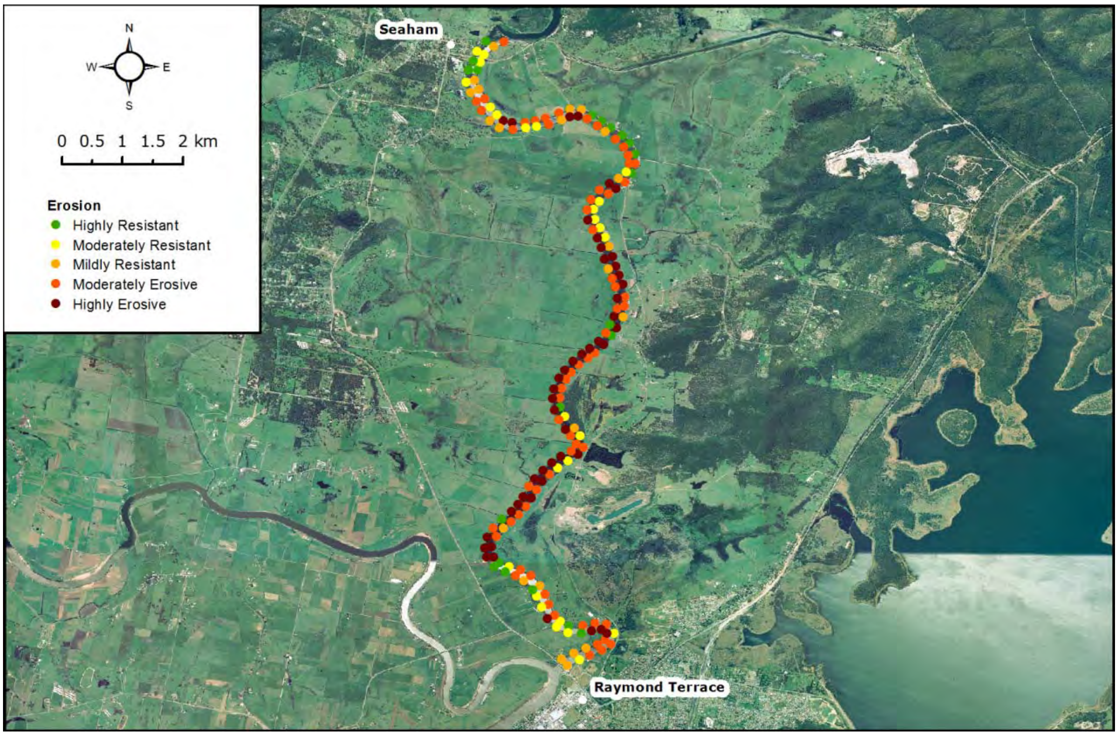

Figure ES-2: Erosion Potential for Each Transect on the Lower Williams River (Mid - Low Tide Conditions)

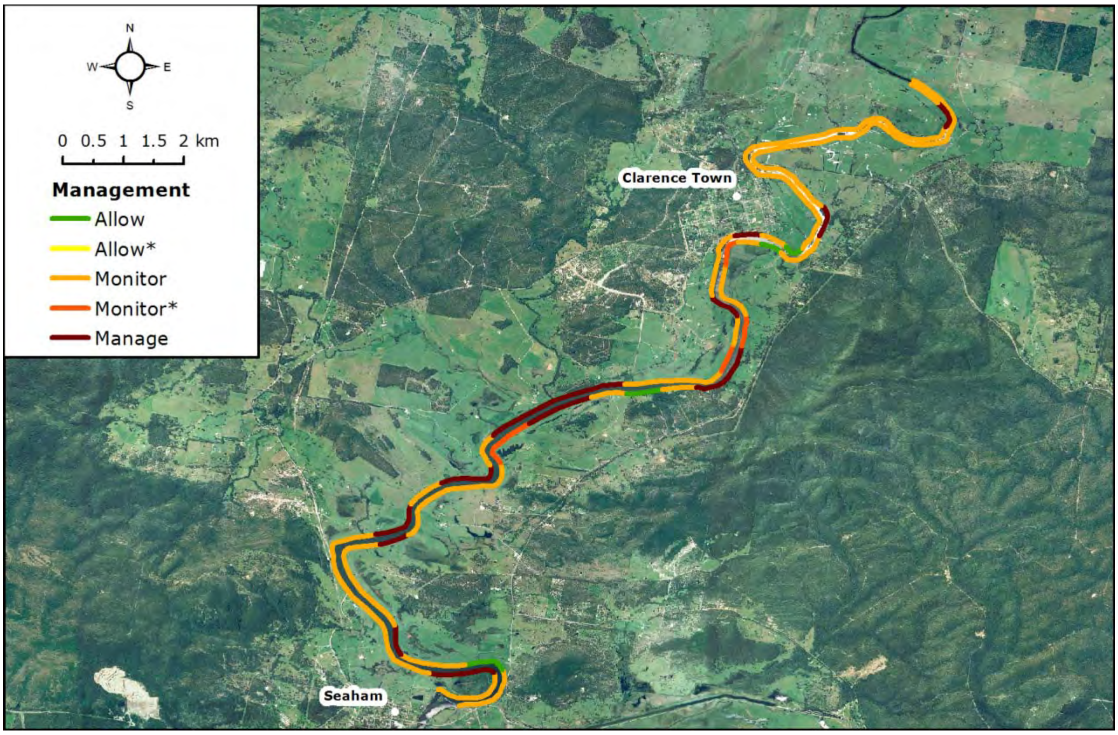

Figure ES-3: 2015 Final DSS Management Recommendations for Seaham Weir Pool

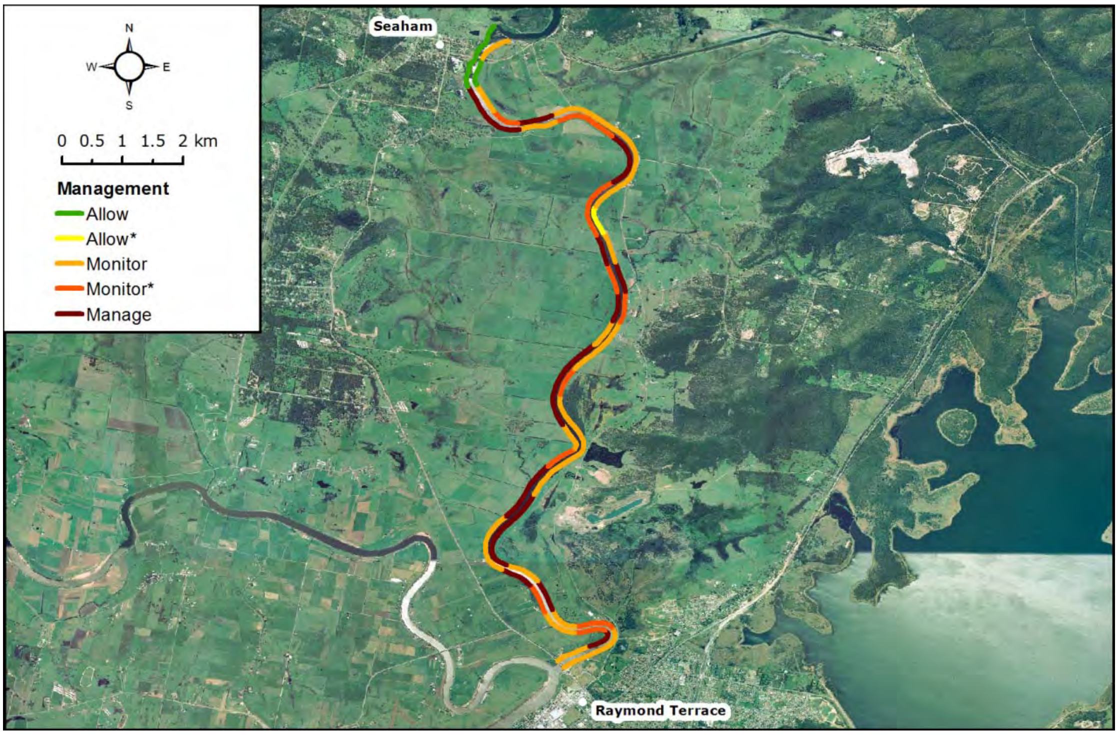

Figure ES-4: 2015 Final DSS Management Recommendations for Lower Williams River

RECOMMENDATIONS

Land and water-based management options have been outlined to improve the DSS management outcomes (i.e. from 'Manage' or 'Monitor*' to 'Monitor') at sites with the highest vulnerability. The recommended onsite strategies for the two (2) site classification types across the study region consider both immediate and programmed management outcomes. Note that the management recommendations provided are not intended or designed to 'flood proof' the riverbank sections across the study region from natural river flooding. The management recommendations are as follows:

1. **Stage 1 Management Action Plan** (to commence following community and stakeholder consultation, detailed site investigation and costing, and approvals) involves riverbank remediation, including weed removal, native vegetation regeneration, and stock exclusion, combined with temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones to comply with Clause 9:2(c) of the Marine Safety (General) Regulation (2009), which states that "the operator of a vessel must not cause wash that damages or impacts unreasonably on… any bank, shore or waterside structure") as shown in Figures ES-5 and ES-6. Sites that require additional remediation effort, such as eco-engineering structures (e.g. rock fillets) and battering to reduce erosion and to improve their management rating to 'Monitor', are also highlighted in the preliminary land management options provided in Figures ES-5 and ES-6. Note that eco-engineering structures and battering could be considered for all sites if an 'Allow' management rating is preferred (and resources are available). Note also that rock fillets are not recommended for outside banks due to the potential maintenance cost to rectify damage post-floods.

2. **Stage 2 Management Action Plan (or *Riverbank Management Program*)** involves ongoing monitoring and evaluation of the areas addressed by the *Stage 1 Management Action Plan* for a period of up to 36 months from the completion of the riverbank remediation activities. Ongoing management activities would include:

    a. Enforcing temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) until riverbank vegetation is re-established;
    b. Monitoring of revegetation and structural works post flood to identify maintenance needs;
    c. Maintenance of fencing installed for the control of stock movements and access to the river;
    d. Maintenance of revegetation works, including providing water, repair of bioengineered structures/installations, and ongoing weed management, such as controlling grass and weed growth around seedlings etc. Note that 'pulse grazing' to control particular weed species is not recommended; and
    e. Ongoing monitoring of the 17 riverbank locations on the Seaham Weir Pool where cross-sectional survey profiles have been measured. WRL recommends that these sites are re-surveyed every 24 months after the *Stage 1 Management Action Plan* is implemented to assist with the development of a conceptual sediment budget for the Seaham Weir Pool.

The *Stage 1 Management Action Plan* was formulated on the most recent DSS riverbank vulnerability assessment of the Seaham Weir Pool and Lower Williams River, and provides a sustainable outcome for the study region. The *Stage 1 Management Action Plan* provides immediate management recommendations for approximately 25% of all sites on the Seaham Weir Pool included in the August 2015 DSS assessment, and greater than 50% of all sites on the

Lower Williams River included in the August 2015 DSS assessment, which had a DSS management rating of 'Manage' or 'Monitor*'. On the Seaham Weir Pool, it is recommended that 25 transects have riverbank regeneration, whereas one (1) site has eco-engineering structures and battering to achieve a management rating of 'Monitor' or better. On the Lower Williams River, it is recommended that 31 transects have riverbank regeneration, two (2) sites have eco-engineering structures, and two (2) sites have eco-engineering structures and battering to achieve a management rating of 'Monitor' or better. Note that on a single stretch on the outside bend of the Lower Williams, R76, eco-engineering structures such as rock fillets are not recommended, and accordingly the management rating after immediate actions are implemented is 'Monitor*'.

Prior to implementing the *Stage 1 Management Action Plan*, a comprehensive program should be confirmed to provide the best environmental outcomes for the entire study region. This approach should aim to minimise the edge effects of the riverbank remediation works and, where possible, integrate into the works program other sites adjacent to the stretches identified, while equipment and personnel are mobilised onsite.

As part of the *Stage 1 Management Action Plan*, a combination of land and water-based management interventions is recommended to ensure successful, long-term outcomes. The implementation of temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) is required in some parts of the river in conjunction with riverbank works, as it is difficult to establish riverbank vegetation and wave zone cover using natural techniques with ongoing boat wash.

If it is necessary to manage boating numbers across the study region, and recognising the potential cost of implementing the *Riverbank Management Program,* it is recommended that the *Stage 1 Management Action Plan* is implemented via a staged-approach. If this approach is undertaken, the Management Action Plan for the Seaham Weir Pool should be prioritised over the Lower Williams River, due to the public health concerns associated with the long-term decline in water quality within a critical drinking water source for the Lower Hunter region, and the exacerbated erosion issues associated with having a static water level on the Seaham Weir Pool.

In the interim on the Lower Williams River, alternative bioengineering techniques, such as fish balls, coir log walls, silt fences or other geotextile products (e.g. Flow Net), or brushing (i.e. logs of various sizes and other debris secured to the riverbank or wave zone), may be implemented to reduce wave action reaching the riverbank, hence encouraging vegetation regrowth and sediment deposition. It is acknowledged that the risk of failure for these 'soft', but more economical (initial installation costs only), structures is greater than rock fillets, as they can be severely damaged by high magnitude floods, and may require regular maintenance.

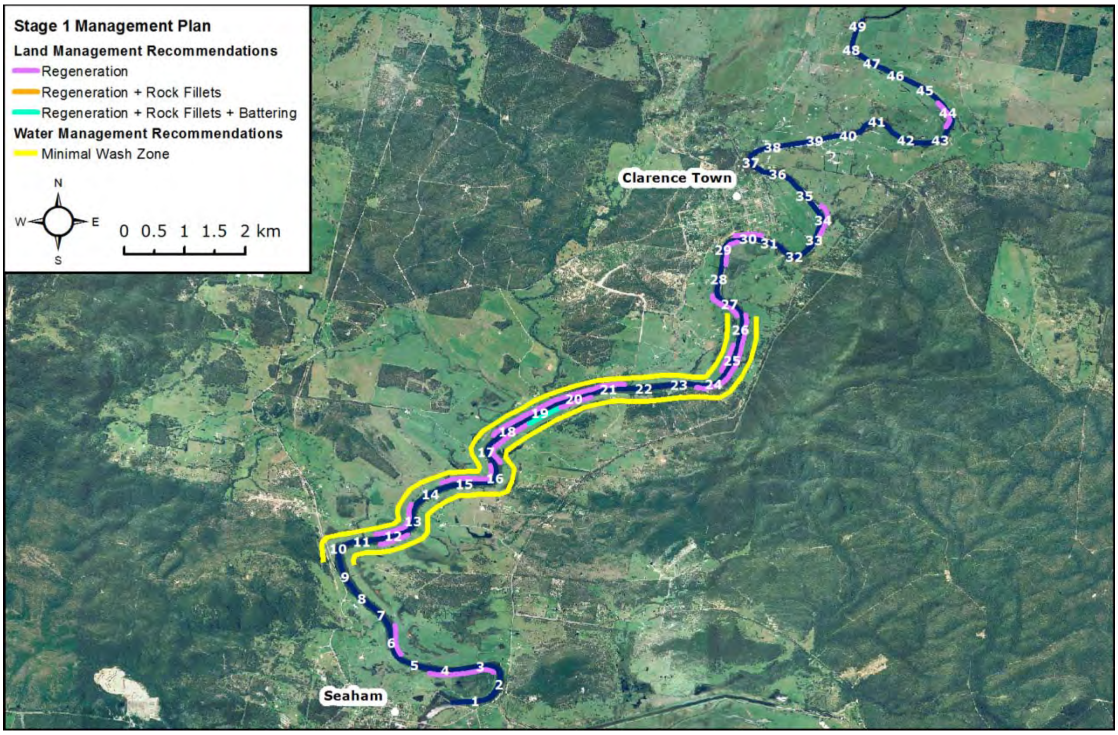

Figure ES-5: Final Management Recommendations for the Seaham Weir Pool

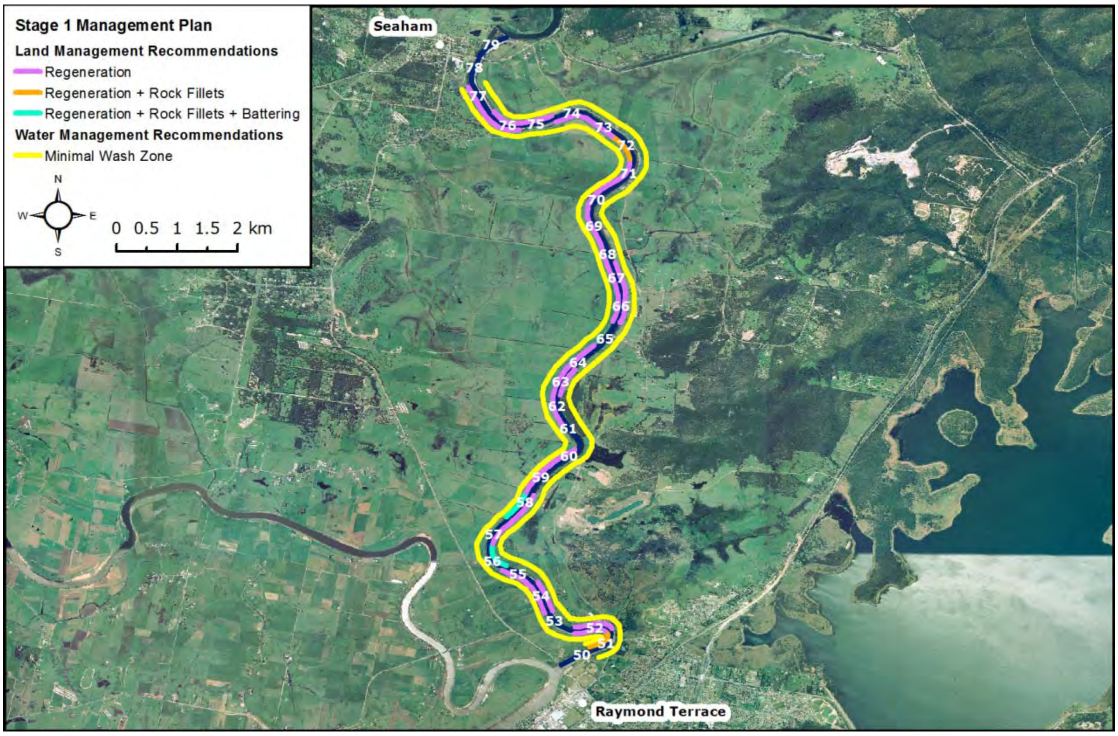

Figure ES-6: Final Management Recommendations for the Lower Williams River

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1. Introduction

The Williams River is the eastern-most, major tributary of the Hunter River and has its confluence with the Hunter River at Raymond Terrace. Flows within the Williams River have been regulated with the construction of Chichester Dam and Seaham Weir (Hunter Water, 2015a). The Seaham Weir Pool lies between the Seaham Weir and the upstream limit of navigation on the Williams River, some 5 km north of Clarence Town (Figure 1-1). The Seaham Weir Pool is approximately 23 km in length and is regulated around a quasi-static level, except for small tidal inflows through the fishway on high tides (Hunter Water, 2006). The Lower Williams River, between Raymond Terrace (Hunter River confluence) and Seaham Weir, is approximately 15 km in length and is tidally influenced. Hunter Water Corporation (hereafter, "Hunter Water") extracts water from the Williams River immediately upstream of the Seaham Weir transferring the water to Grahamstown Dam via the Balickera Canal (Hunter Water, 2015b).

The Williams River has a long history of recreational boating and has been the focus of many studies assessing the impact of boat wake waves on the river environment (Gibson and Ness, 1992; Umwelt, 1995; Patterson Britton & Partners, 1996; Cowell, 1996; Healthy Rivers Commission of NSW, 1996; Cox et al., 1999; Harper Somers, 2001; Cox and Dorairaj, 2002; Roberts and Cummins, 2002; Cox, 2003a; Cox, 2003b; GHD, 2006; Spearpoint, 2008; Gilligan, 2008; Cameron and Hill, 2009; WorleyParsons, 2010; Glamore and Davey, 2012; WorleyParsons, 2012). The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia has also been actively involved in applied research projects on the Williams River dating back to 1995.

Hunter Water, NSW Roads and Maritime Services (NSW RMS), and other government agencies working with private landholders, farmers, industry, community groups and volunteers, have made significant contributions to maintain and improve the Williams River over the past twenty years. Despite these efforts, various sections of the Williams River have degraded riverbanks requiring improved management.

In 2012, WRL established a baseline (Stage 1) for evidence-based management of riverbank erosion on the Seaham Weir Pool. A Decision Support System (DSS), developed by WRL, was used to objectively assess the susceptibility of the riverbanks on the Seaham Weir Pool to erosion based on a variety of environmental factors. Specifically, the DSS's robust and repeatable ranking system was used to assess:

- The current condition of the riverbanks;
- The effect of natural wind waves and boat wake waves and other contributing causes to riverbank erosion along key reaches of the river; and
- The vulnerability of the riverbanks to erosion.

In March 2015, the riverbank vulnerability assessment was repeated on the Seaham Weir Pool (Stage 2) to assess the trajectory of riverbank condition and extended to include the Lower Williams River. Accordingly, a baseline for management on the Lower Williams River (Stage 1) was established.

On April 20 2015, a significant flooding event commenced on the Williams River. Significant changes to the erosion potential of the riverbanks in the study area were observed following this event. As such, a follow-up field assessment campaign was undertaken in August 2015 to re-assess the erosion potential of the riverbanks on the Seaham Weir Pool (Stage 3) and Lower

Williams River (Stage 2). This data provided a unique opportunity to scientifically document the impacts of a significant flooding event on the riverbanks in isolation of other factors (i.e. limited wind-wave exposure and boating activity).

Many land and water-based factors can contribute to riverbank erosion (Glamore and Badenhop, 2006). Land-based factors include the clearing of native vegetation on riverbanks and hard hoofed stock grazing on riverbanks. Water-based factors include periodic flooding (which both erodes and deposits material), tidal flows causing natural scour and waves (generated by either the wind or boats) breaking against riverbanks. Wave impacts are the focus of this study, with consideration given to land-based factors that influence the vulnerability of the riverbank to wave attack.

At the core of the DSS assessment process is a field-based evaluation of the erosion potential of the riverbank. Key criteria and weighting factors are combined to form an erosion potential rating for each assessed site (Glamore and Badenhop, 2006). These criteria include river type, vegetation coverage and extent, erosion descriptors, adjacent land use and channel features (see example DSS field sheet in **Appendix G**). For the purpose of informing specific management actions, the DSS highlights riverbank sections potentially impacted by boat wave energy. Note that the left and right riverbanks are defined relative to an observer looking downstream.

Following this introduction, the report is composed of the following sections:

- **Section 2** includes information about the April 2015 flooding event on the Williams River, history of Seaham Weir, and existing boating management on the Williams River;
- **Section 3** provides an overview of the DSS assessment methodology;
- **Section 4** presents the details of the Williams River DSS assessment;
- **Section 5** provides the results of the DSS analysis for a range of different scenarios;
- **Section 6** discusses the results of the DSS and recommendations for management interventions; and
- **Section 7** details the references used throughout the completion of this study.

This report has been structured to highlight the key findings of the study. Significant tasks that do not form the core of the riverbank vulnerability assessment have been documented in appendices, rather than in the main body of the report. Specifically, literature relevant to this project was reviewed by WRL and summarised in **Appendix A**. Readers unfamiliar with the background theory of wind waves and boat wake waves are directed to **Appendix B**. A detailed overview of the DSS methodology is provided in **Appendix C**.

Additional appendices to this report include:

- **Appendix D** provides Williams River wind and wake wave data;
- **Appendix E** provides wind rose and frequency data from the Williamtown RAAF station;
- **Appendix F** compares winds at Williamtown RAAF Base with Australian Standard winds;
- **Appendix G** provides an example DSS field sheet;
- **Appendix H** provides information on water levels during the DSS field assessments;
- **Appendix I** provides field examples of erosion potential categories;
- **Appendix J** provides an example wind waves versus boat waves comparison;
- **Appendix K** provides Equivalent Wind/Boat Wave ARI Ratings for the study area;
- **Appendix L** provides the baseline DSS results for the Lower Williams River;
- **Appendix M** provides DSS sensitivity tests for elevated water levels (Williams River);
- **Appendix N** provides DSS sensitivity tests for high boat passes (Lower Williams River);
- **Appendix O** provides DSS sensitivity tests for AS1170.2 winds (Lower Williams River);
- **Appendix P** provides DSS boat wave attenuation sensitivity tests (Lower Williams River);
- **Appendix Q** provides a discussion on the updates incorporated into the DSS since the 2012 assessment; and
- **Appendix R** provides a discussion on a series of cross-sectional riverbank survey profiles on the Seaham Weir Pool.

The project was jointly funded by Hunter Water and Transport for NSW (TfNSW), with support from Port Stephens Council (PSC). These groups have an interest in activities on the Williams River, including boating and its potential impact on water quality and erosion. The outcomes of this study can be used to inform an updated regional boating plan for the Williams River.

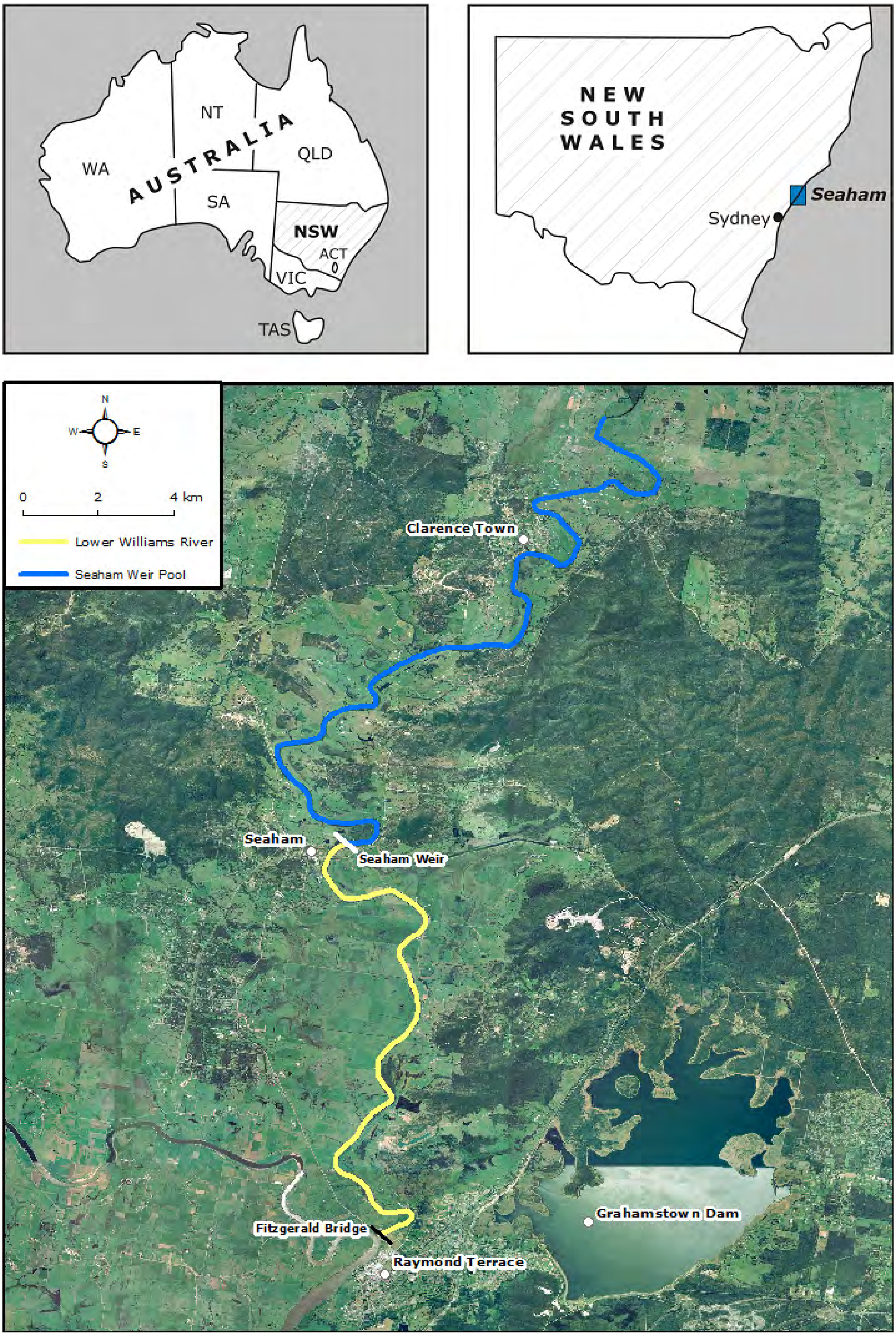

Figure 1-1: The Study Area

2. Background Information

2.1 Preamble

This chapter provides background information on the influence of the Seaham Weir on riverbank erosion in the Williams River, existing boating restrictions within the study area and the April 2015 flood event on the Williams River.

2.2 Seaham Weir

Seaham Weir was constructed in 1967 to separate the downstream tidal estuarine salt water from the upstream fresh water (NSW DPI, 2006). This structure facilitates the transfer of fresh water from the Williams River to Grahamstown Dam via the Balickera pump station and canal.

The presence of Seaham Weir:

- Is likely preventing bed-load sediment influx and reducing suspended sediment influx into the Lower Williams River (possible contributor to erosion) (Cameron and Hill, 2009);
- Is likely increasing sediment deposition in the area immediately upstream of the weir (possible contributor to accretion);
- Would have a variable influence on flood induced erosion immediately downstream of the weir depending upon the magnitude of the flood event (possible erosion mitigation or enhancement);
- Is likely reducing flood induced erosion immediately upstream of the weir due to reduced flood velocities (possible erosion mitigation);
- Is likely having a negligible effect on non-flood induced erosion immediately downstream of the weir due to wind-wave and boat wave attack (negligible change in tidal levels, but change to tidal phase and reduced tidal velocities); and
- Is likely increasing non-flood induced erosion immediately upstream of the weir due to wind-wave and boat wave attack at a quasi-static, regulated water level (possible erosion enhancement) (Spearpoint, 2008).

Due to significant differences in the nature of the Williams River upstream and downstream of the Seaham Weir, this report separates the riverbank analysis into the Seaham Weir Pool (upstream) and the Lower Williams River (downstream).

2.3 Existing Management

2.3.1 Overview

Existing boating management zones on the Seaham Weir Pool and the Lower Williams River are summarised in Sections 2.3.2 and 2.3.3, respectively. These are based on Upper and Lower Williams Boating Traffic Management Plans that exist to protect the environment of the Williams River. The conditions of the plans are enforceable under NSW Roads and Maritime Services (NSW RMS) regulations.

2.3.2 Seaham Weir Pool

The Upper Williams River Boating Traffic Management Plan (NSW RMS, n.d.) sets out existing boating restrictions between the Seaham Weir (Stretch 1) and the upstream limit of navigation on the Williams River (Stretch 49) (Figure 2-1). Each zone within the Seaham Weir Pool has been aligned with the corresponding DSS sites (see Section 4.2) in Table 2-1 and reproduced in Figure 2-2.

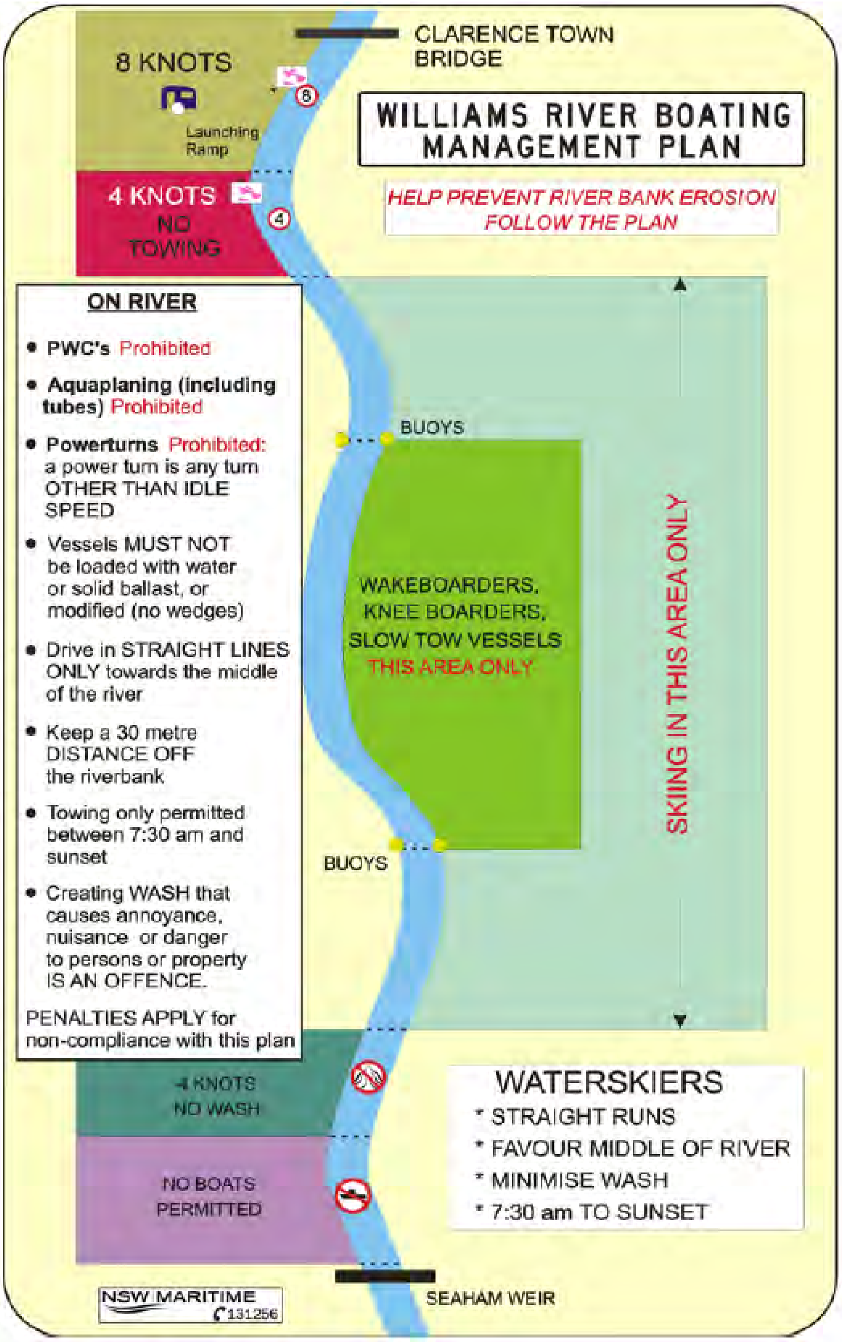

Figure 2-1: Upper Williams River (Seaham Weir Pool) Boating Traffic Management Plan (NSW RMS, n.d.)

Table 2-1: Seaham Weir Pool Boating Management Zones

Stretch	River Section	Scenario	# Passes
1-6	Restricted Area Near Weir	Waterski 4 knots	1
7-9	4 knot Section (D/S)	Waterski 4 knots	10
10-17	Waterskiing Section (D/S)	Waterski Operating	50
18-22	Wakeboarding Section	Wakeboard Operating	50
23-26	Waterskiing Section (U/S)	Waterski Operating	50
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50
31-49	U/S of the 4 knot Section	Waterski 8 knots	1

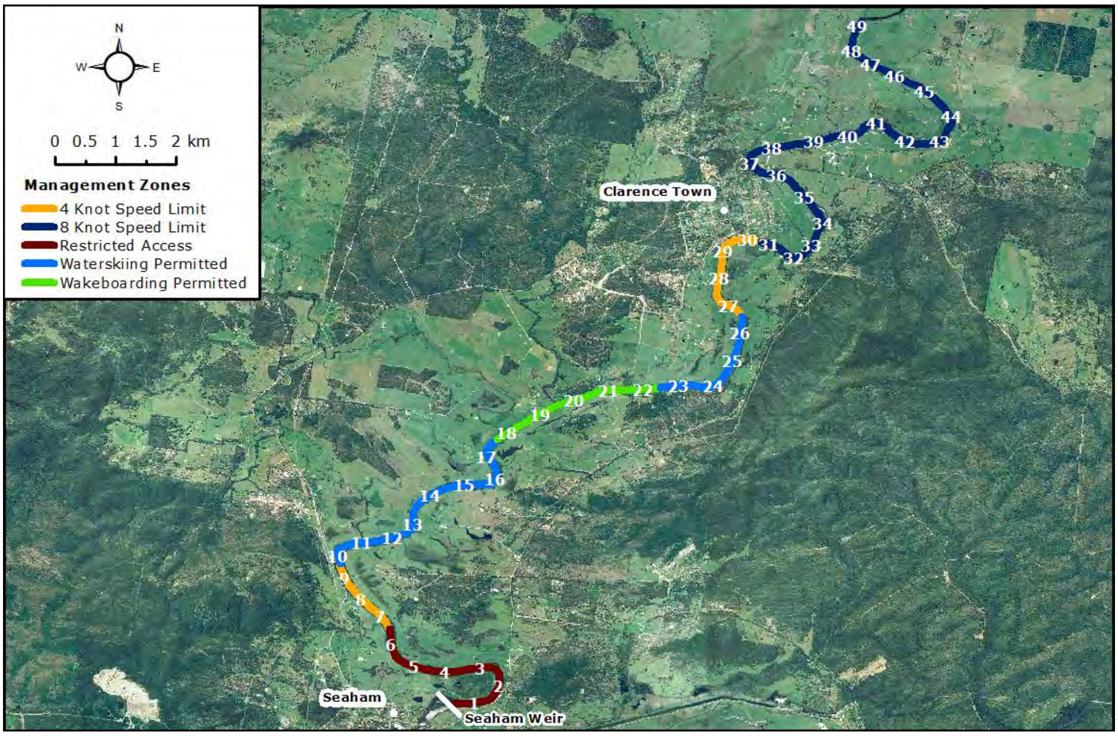

Figure 2-2: Existing Boating Management Zones for the Seaham Weir Pool Between Seaham Weir (Stretch 1) and the Limit of Navigation (Stretch 49)

The Plan includes the following restrictions:

- Restricted zone immediately upstream of Seaham Weir (Stretches 1-6).
- 4 knot speed limit at upstream of the restricted zone (Stretches 7-9);
- Waterskiing allowed from the start of the 4 knot zone south of Clarence Town to the start of the 4 knot zone north of Seaham (Stretches 10-26);
- Wakeboarding and other slow tow activities may take place only in the middle of the Seaham Weir Pool (Stretches 18 – 22);
- 4 knot speed limit at downstream of the 8 knot zone (Stretches 27-30); and
- 8 knot speed limit at Clarence Town (Stretches 31-49).

2.3.3 Lower Williams River

The Lower Williams River Boating Traffic Management Plan (NSW RMS, n.d.) sets out existing boating restrictions between Fitzgerald Bridge at Raymond Terrace (Stretch 50) and the Seaham Weir at Seaham (Stretch 79) (Figure 2-3). Each zone within the Lower Williams River is aligned to the corresponding DSS sites (see Section 4.2) in Table 2-2 and reproduced in Figure 2-4.

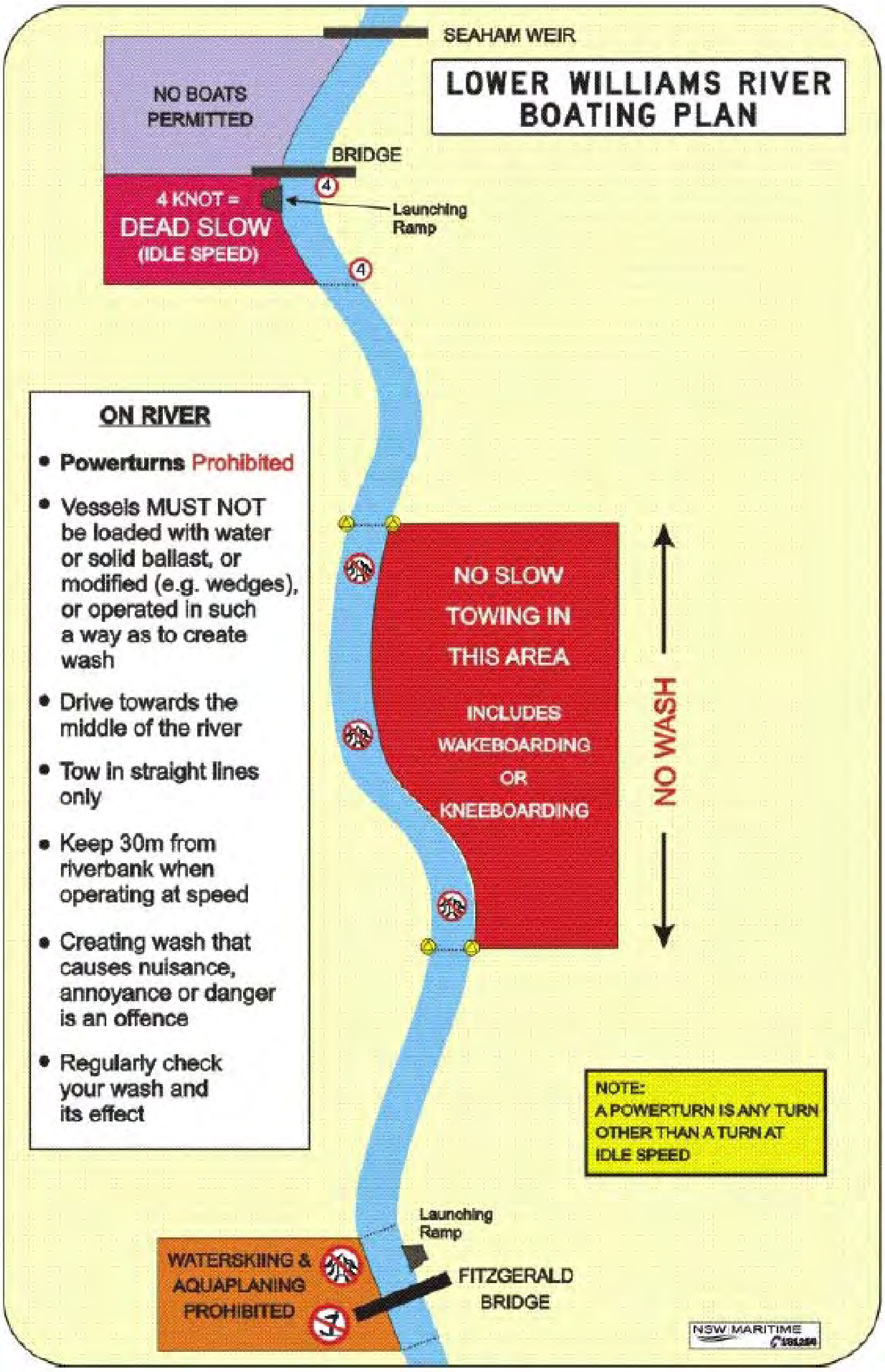

Figure 2-3: Lower Williams River Boating Traffic Management Plan (NSW RMS, n.d.)

Table 2-2: Lower Williams River Boating Management Zones

Stretch	River Section	Scenario	No. Boat Passes
50-58	Wakeboarding Zone (D/S)	Wakeboard Operating	50
59-70	Waterskiing Zone	Waterski Operating	50
71-77	Wakeboarding Zone (U/S)	Wakeboard Operating	50
78	4 knot Zone	Waterski 4 knot	50
79	No Boats Permitted (U/S)	Waterski 4 knot	1

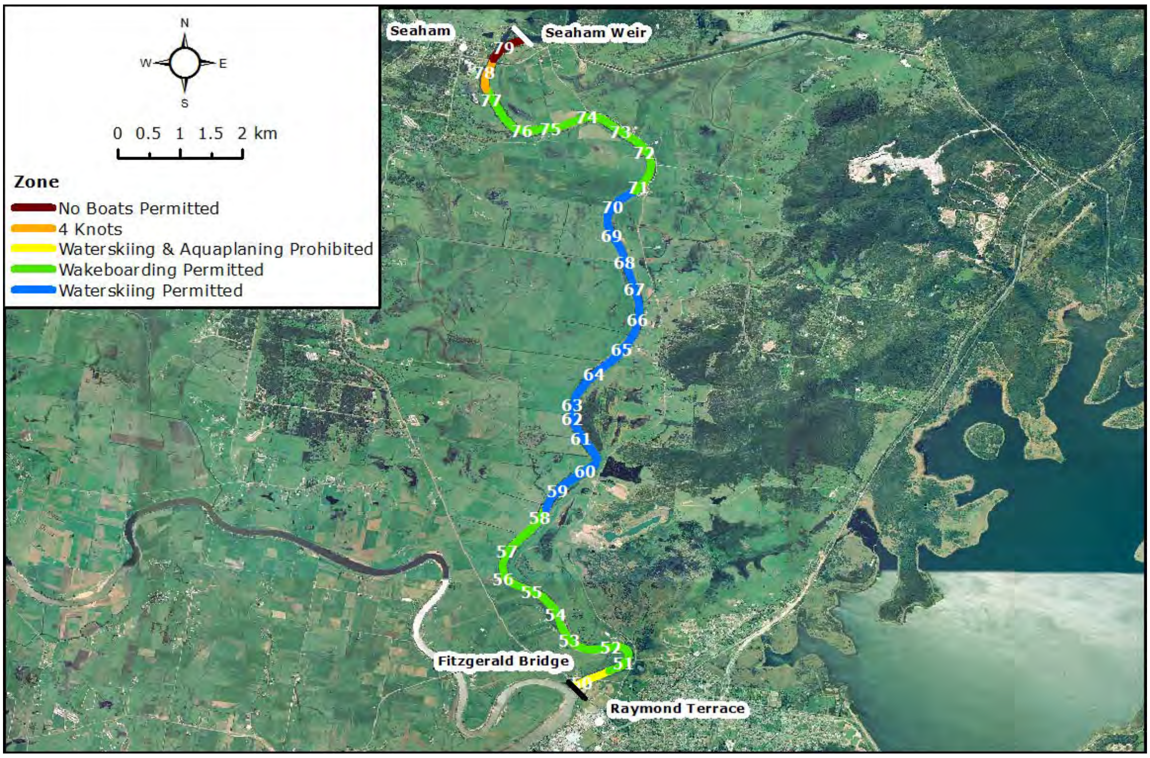

Figure 2-4: Existing Boating Management Zones for the Lower Williams River Between Fitzgerald Bridge (Raymond Terrace) (Stretch 50) and Seaham Weir (Stretch 79)

The Plan includes the following restrictions:

- A 'No tow' zone under the Fitzgerald Bridge at Raymond Terrace (Stretch (50);
- Waterskiing permitted from the edge of the 'No tow' zone just upstream of Raymond Terrace boat ramp to the start of the 4 knot zone at Seaham (Stretches 51-77);
- Wakeboarding and other slow tow activities permitted on the top and bottom ends of the river but not in the 'No slow towing' (waterskiing permitted) area between Stretches 59 – 70;
- 4 knot speed limit at Seaham Boat Ramp (Stretch 78); and
- Restricted zone between Jim Scott Bridge and Seaham Weir (Stretch 79).

2.4 April 2015 Flood Event

In April 2015, an intense low pressure system (also known as an East Coast Low) caused severe storm conditions and flash flooding in the Hunter region. Manly Hydraulics Laboratory (MHL) reported on this event by providing water level, wave and rainfall hydrometric data collected from the 20 April to 5 May 2015 flood event in the Hunter and Central Coast regions (MHL, 2015). The report also provided water level and rainfall data from Bureau of Meteorology (BoM), NSW Office of Water (NOW), and Hunter Water.

During the flood period from 20 April to 5 May 2015, flooding on the Williams River ranged in classification from minor to major, as provided in Table 2-3. In the Upper Hunter Region, the Williams River at Dungog experienced major flooding reaching a peak water level of 8.68 m AHD at 10:30 AM on 21 April 2015, and the rainfall at Dungog recorded a peak intensity of 180 mm/h, which is an annual exceedance probability (AEP) of less than 1%. In the Lower Hunter Region, the Williams River at Glen Martin (alternatively, Mill Dam Falls) also experienced major flooding with a recorded peak water level of 12.13 m AHD. The BOM flood classification at Raymond Terrace was minor, with peak water levels reaching 3.06 m AHD. Observed water levels on the Williams River at Mill Dam Falls, Seaham Weir (downstream) and Raymond Terrace from 20 April to 5 May 2015 are provided in Figure 2-5. Figure 2-6 displays a wind rose from Williamtown Station for the month of April where the majority of the winds blew from the south, with a maximum wind gust of 113 km/h recorded on 21 April 2015. Images captured from the flood on Seaham Weir Pool are provided in Figure 2-7.

Table 2-3: Peak Observed Water Levels at Key Locations on the Williams River for the Period 1 April to 5 May 2015 (Source: MHL Report 2364, 2015)

Station Name	Station Number	Site Owner	Peak Level (m AHD)	BOM Flood Classification
Williams River at Dungog	210903	NOW	8.68	Major
Williams River at Glen Martin (Mill Dam Falls)	210010	NOW	12.13	Major
Seaham Weir (Downstream)	210462	MHL	3.90	Unknown
Raymond Terrace	210452	MHL	3.06	Minor

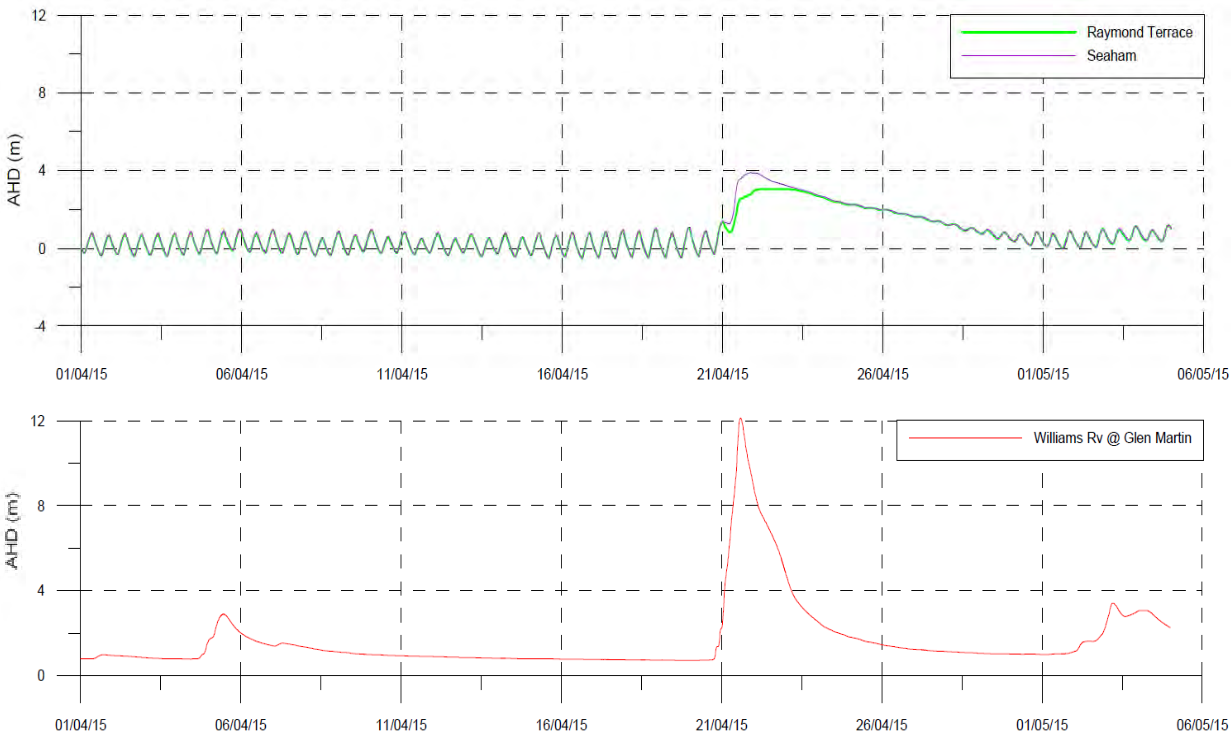

Figure 2-5: Observed Water Levels on the Williams River Recorded within the DSS Study Area (Source: MHL Report 2364, 2015)

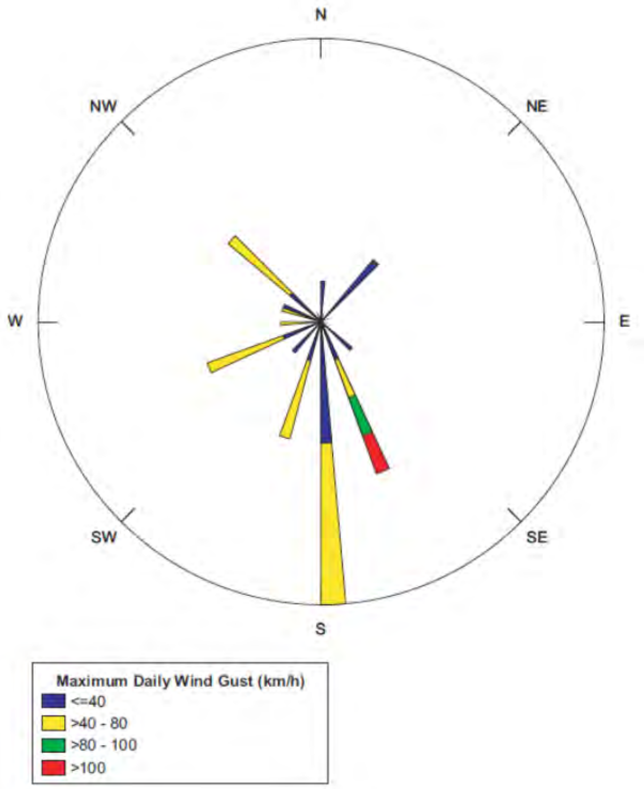

Figure 2-6: Wind Rose from Williamtown Station for April 2015 (Source: MHL Report 2364, 2015)

Figure 2-7: Images of April 2015 Flood on Seaham Weir Pool (Source: Mr John Spearpoint, 2015)

3. Decision Support System Methodology Overview

A Decision Support System (DSS) is used to determine if boats should be permitted on a waterway based on whether the waves generated by passing vessels are likely to cause erosion at selected sites along the shoreline (Glamore and Badenhop, 2006). The DSS is structured around three (3) major components: (i) the natural background wind-wave energy at a site, (ii) the vessel generated wave energy and the operating frequency of boats (i.e. number of boat passes), and (iii) the susceptibility of a shoreline to erode due to the vessel generated wave energy.

In brief, the DSS method includes the following steps:

1. Wind waves are generated by wind blowing across a fetch of river. The energy of the waves may be limited by either the duration of the wind blowing or the length of the fetch. The first step of the DSS assessment calculates the natural wind-wave energy at a site using standard methods. Wind data is presented as a percentage occurrence for different wind speed intervals and is typically divided into eight (8) inter-cardinal wind directions (i.e. N, NE, E, SE, S, SW, W, NW). The calculated wind-wave energy is converted to an Average Recurrence Interval (ARI) to provide the likelihood of a wave occurring at a site.
2. The energy of a passing boat wave is then determined based on previous field experiments from several recreational and commercial vessels at various speeds. As a boat travels through the water, it generates a series of waves (or a wave train). The height and period of these waves vary depending on several factors including boat speed and type. While it is important to calculate the maximum energy, it is possible that wave attenuation may reduce the impact of the boat waves on the shoreline. Previous studies show that the boat wave trains become fully developed at 22 m from the sailing line. At this distance, the wave height is approximately 36% of the original wave height. Beyond 22 m from the sailing line, further wave attenuation occurs.
3. The third step is to assess the potential for the riverbank to erode based on a series of weighted factors that incorporate physical and ecological features of the riverbank. The area to be assessed will be predetermined by the overall extent of the waterway feasible for recreational boating. The waterway length is then divided into 500 m stretches on each side of the river. Each stretch is then divided into three (3) sections and a 10 m wide transect at the midpoint of each section is assessed. The vegetation scores attributed to each transect are rated from ‘Highly Resistant’ to ‘Highly Erosive’. The riverbank erosion potential of the three (3) transects is averaged for each stretch.
4. Once the initial three (3) steps have been undertaken, the wake wave energy is compared to the ARI of the wind-wave energy. This comparison is undertaken for both the maximum generated wake wave and the total wave energy generated in a typical day (i.e. eight (8) daylight hours) involving multiple boat passes. The comparison of these wake wave energies with the ARI of the wind-wave energy provides an indication of the likely impact of the boat waves on the shoreline. Where the energy of the boat wake waves is of similar magnitude to the energy of the natural wind wave environment, it is unlikely that the boat wake waves will cause significant damage. If, however, boat wake wave energy greatly exceeds the wind wave energy of the site, erosion is anticipated.
5. The results of the previous step (Step 4) are then compared with the bank erosion potential (Step 3) to determine the most appropriate boat management strategy for each site: ‘Allow’ (Permit), ‘Monitor’ (Permit with Monitoring) and ‘Manage’ (Manage Activities).

Detailed descriptions of the DSS methodology are provided in Glamore and Badenhop (2006; 2007) and in Appendices B and C.

4. Overview of Field Assessment Details

4.1 Preamble

This section discusses the specific aspects of the Williams River field assessments. Initially, the site selection requirements are discussed in Section 4.2, followed by a brief description of the 2015 field assessments in Sections 4.3 and 4.4. Note that a full description of the DSS methodology is provided in Appendix C. The wind data and locations used for the 2015 assessments, along with the rationale behind the selection of boat numbers and conditions within the study area, is provided in Appendix D.

4.2 Site Selection

Sites were selected within the study area using aerial photography and GIS mapping. Note that the previous stretches used on the Seaham Weir Pool (Stretches 1-49) for the inaugural assessment in 2012 (SWP Stage 1) were maintained for consistency in reporting and are provided in Figure 4-1. The Lower Williams River was segmented into the required stretches at 500 m intervals from the Hunter – Williams River confluence at Raymond Terrace to Seaham Weir (Stretches 50-79) and are depicted in Figure 4-2.

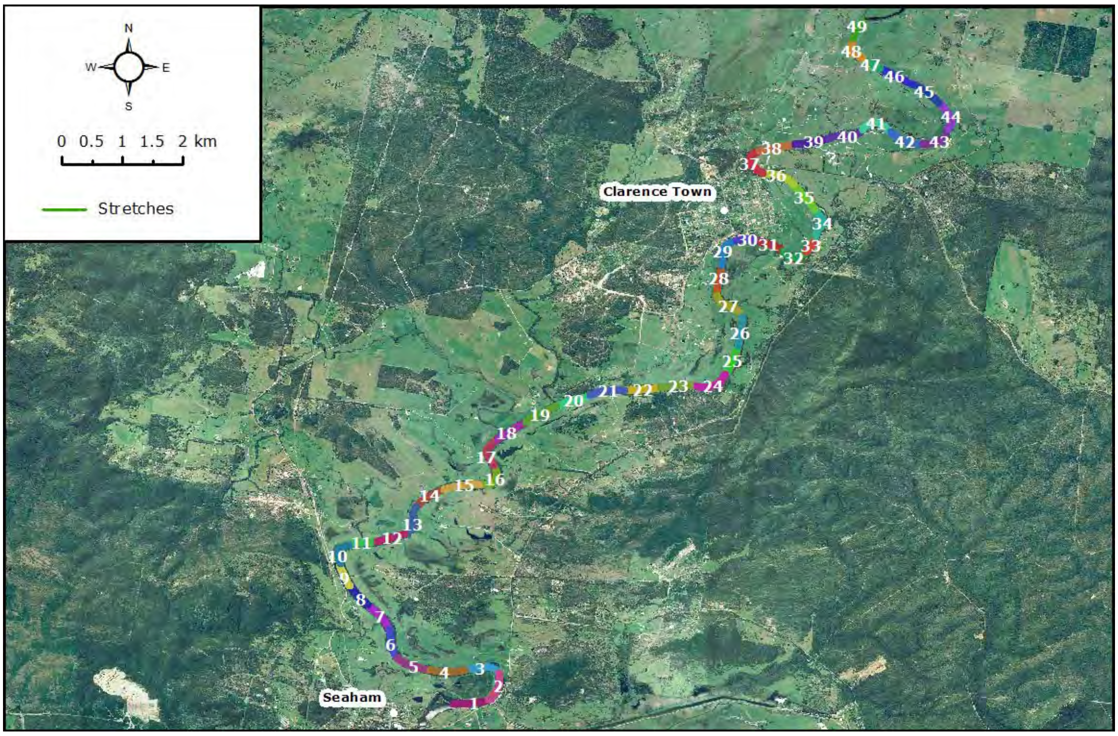

Figure 4-1: Numbered Stretches for the Seaham Weir Pool (Stretches 1 – 49)

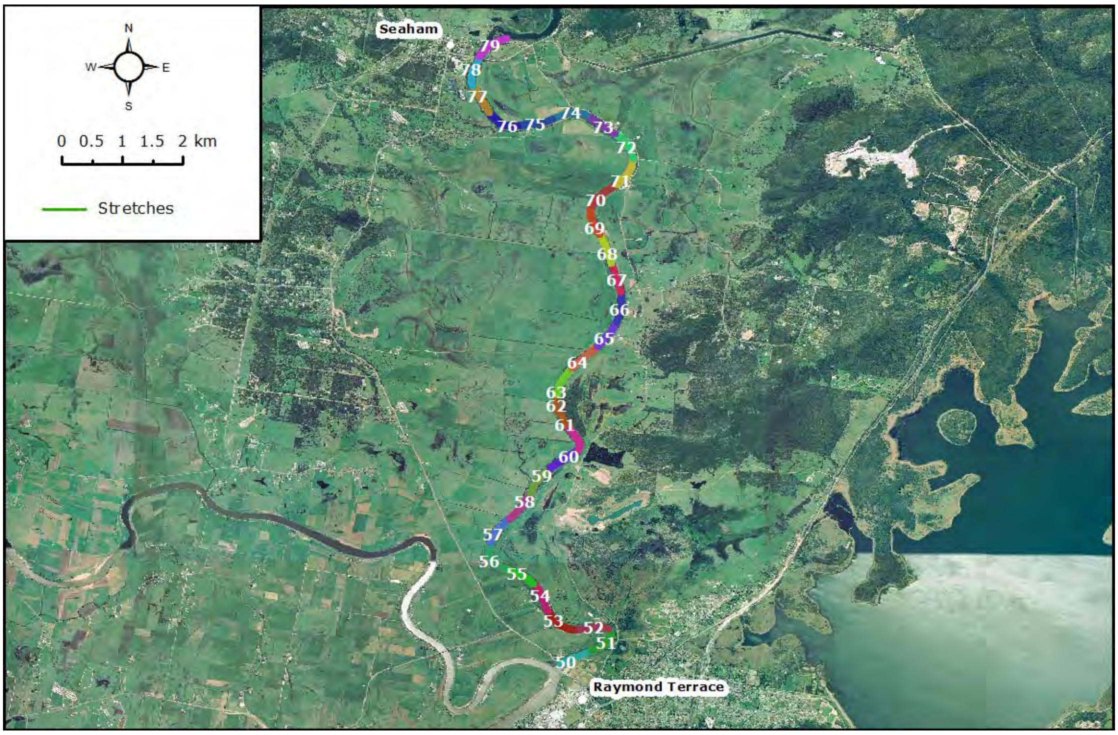

Figure 4-2: Numbered Stretches for the Lower Williams River (Stretches 50 – 79)

4.3 Williams River 2015 Field Assessments

Six (6) consecutive days (11 – 16 March, 2015) were allocated for the March 2015 field assessment of the Seaham Weir Pool (Stage 2) and Lower Williams River (Inaugural Assessment, Stage 1). WRL undertook a second field assessment campaign in August 2015 to re-assess the riverbanks on the Seaham Weir Pool (Stage 3) and Lower Williams River (Stage 2), following the flooding event in April 2015. Details of the field assessment dates and locations are provided in Table 4-1 and Table 4-2, respectively. Water levels during the 2015 field assessments are provided in Appendix H. Photos of the Hunter Water boat and NSW RMS boat are provided in Figure 4-3 and Figure 4-4, respectively.

Table 4-1: March 2015 Field Assessment Dates and Locations

Date	Tasks	Boat and Driver
Wednesday 11 March 2015	Seaham Weir Pool Field Day 1 of 4	Hunter Water
Thursday 12 March 2015	Seaham Weir Pool Field Day 2 of 4	Hunter Water
Friday 13 March 2015	Lower Williams River Field Day 1 of 2	NSW RMS
Saturday 14 March 2015	Lower Williams River Field Day 2 of 2	NSW RMS
Sunday 15 March 2015	Seaham Weir Pool Field Day 3 of 4	Hunter Water
Monday 16 March 2015	Seaham Weir Pool Field Day 4 of 4	Hunter Water

Table 4-2: August 2015 Field Assessment Dates and Locations

Date	Tasks	Boat and Driver
Friday 22 August 2015	Seaham Weir Pool Field Day 1 of 4	Hunter Water
Saturday 23 August 2015	Seaham Weir Pool Field Day 2 of 4	Hunter Water
Tuesday 26 August 2015	Lower Williams River Field Day 1 of 2	NSW RMS
Wednesday 27 August 2015	Lower Williams River Field Day 2 of 2	NSW RMS
Thursday 28 August 2015	Seaham Weir Pool Field Day 3 of 4	Hunter Water
Friday 29 August 2015	Seaham Weir Pool Field Day 4 of 4	Hunter Water

Figure 4-3: Boat Provided by Hunter Water for the Field Assessment of Seaham Weir Pool

Figure 4-4: Boat Provided by NSW RMS for the Field Assessment of Lower Williams River

Site inspection locations were predetermined to eliminate bias (Section 3.2) and were identified in the field through a combination of aerial photography and GPS co-ordinates (in MGA 56). Three (3) transects on each riverbank from Stretches 1–47 (Seaham Weir Pool) and 50–79 (Lower Williams River) were observed in March 2015, totalling 462 site inspections. The same sites were surveyed again in August 2015, except for Stretches 46 and 47 on the Seaham Weir Pool, totalling 450 site inspections. Note that Stretches 48–49 (Figure 4-1) were excluded from the March 2015 assessment, and Stretches 46–49 were excluded from the August 2015 assessment, because the sites were inaccessible due to low water levels.

4.4 Site Identification and Erosion Indicators

A combination of aerial photography and GPS co-ordinates was used to locate each pre-selected field transect. Prior to the field assessments, the exact transect extent was determined to ensure assessors were documenting the same riverbank locations. Two (2) assessors completed the field work. An independent assessor was used to undertake several quality assurance checks to ensure the repeatability of the analysis. During the field assessments, a DSS field sheet was completed (Appendix G), a GPS waymark obtained, and two (2) photographs were taken at each transect location. The width of the river was measured using a laser rangefinder, and the vertical and horizontal extent of any undercutting was measured with a surveyors staff.

Note that the erosion potential for each site was based on its current condition when inspected in the field. That is, no assessment was made of the cause (i.e. flooding, tidal scour, wind waves or boat wake waves) of erosion observed or the condition of the riverbank prior to undertaking the field assessments. However, during the August 2015 field assessment, obvious shoreline examples of flood damage were recorded for a qualitative assessment analysis of the riverbank condition. During the 2015 field assessments, several erosion indicators were constant for the entire 38 km study region, including:

- Stage variability was recorded as ‘regulated’ on the Seaham Weir Pool and ‘tidal’ on the Lower Williams River due to the nature of the two (2) systems;
- The lateral stability was recorded as ‘high’ for all stretches due to channel migration analysis;
- Sinuosity (the degree of meandering across the river valley is equal to the channel length of the river divided by the valley length) was greater than 1.3 (i.e. very little meandering across the floodplain);
- Hunter Water and RMS staff confirmed that no de-snagging had taken place in the river prior to the assessment; and
- Water extraction for irrigation was noted in the study area.

5. Decision Support System Results

5.1 Preamble

This section summarises the results for the riverbank assessments of the Seaham Weir Pool and Lower Williams River in March 2015 (pre-flood) and August 2015 (post-flood). The erosion potential assessments of the study area are discussed in Section 5.2. The management recommendations from the DSS are then presented in Section 5.3 for the Seaham Weir Pool and Section 5.4 for the Lower Williams River. The equivalent Average Recurrence Interval (ARI) ratings for each boat pass scenario on the Seaham Weir Pool and Lower Williams River are provided in Appendix K.

Note that for each riverbank stretch, one (1) of three (3) management recommendations is assigned: Permit ('Allow'); Permit with Monitoring ('Monitor'); or Manage ('Manage'). The final rating is a function of the riverbank erosion potential and the relative magnitude of natural wind wave energy versus boat wake wave energy (see Appendix C). 'Allow' sites have positive riverbank erosion potential scores and limited differences between the wind and wake energies. 'Monitor' sites have neutral riverbank erosion potential scores and moderate differences between the wind and wake energies. 'Manage' sites have negative riverbank erosion potential scores and significant differences between the wind and wake energies.

In most cases, the DSS assessment adopts the 'distance of boat from shore' as half the width of the river at each stretch. However, in some sections of the study area, recreational boaters are likely to be closer to the riverbank than half the width of the river. For the boat wave attenuation sensitivity test on the Lower Williams River (Appendix P), a 'distance off' value of 30 m was selected for all scenarios. This distance is consistent with boating management plans found elsewhere in NSW. Finally, when wave attenuation is a limiting factor in the management recommendation, and the maximum wave would result in a different management category, sites are presented as 'Allow*' or 'Monitor*' in this assessment.

5.2 Riverbank Erosion Potential Assessment

All five (5) erosion potential categories (refer to Appendix Section C.5) in the DSS were observed at transects in the study area during the 2015 field assessments. All transects documented during the field assessments were averaged for the left and right riverbank of each stretch to produce a representative erosion potential for each riverbank. Field examples of the erosion potential categories are provided in Appendix I. WRL sub-contracted Delfs Lascelles Consulting Surveyors to re-survey riverbank cross-sectional survey profiles (including undercutting) at 17 locations along a straight stretch of the Seaham Weir Pool to quantify the impact of the April 2015 flood event. The results of the assessment are provided in Appendix R.

5.2.1 March 2015 (Pre-Flood) Assessment – Seaham Weir Pool

In March 2015, the riverbank vulnerability assessment was conducted at the existing operational water level for the Seaham Weir Pool. The maintenance of a quasi-static operational water level (i.e. regulated rather than tidal) for the Seaham Weir Pool appears to exacerbate the erosive effects of wind and boat wake waves, resulting in significant undercutting of the riparian vegetation along the majority of the study area. In some areas, vegetation undercutting of more than 1 m (vertical and horizontal) was observed and appeared to be directly linked to bank destabilisation effects, such as fallen trees. An example staff measurement of undercutting taken in March 2015 at Site R03B is provided in Figure 5-1.

Table 5-1 and Figure 5-2 provide the distribution of riverbank erosion potential categories at the existing operational water level for the Seaham Weir Pool based on the March 2015 assessment. The March 2015 erosion potential results for the Seaham Weir Pool show that 43% of all transects observed were 'Mildly Resistant' to erosion or better, while approximately 57% of sites were 'Moderately Erosive' or worse at the existing operational water level. These results indicate that the riverbank condition of the study area had generally worsened since the 2012 assessment (Glamore and Davey, 2012). However, no assessment was made of the cause (i.e. flooding, tidal scour, wind waves or boat wake waves) of any erosion observed.

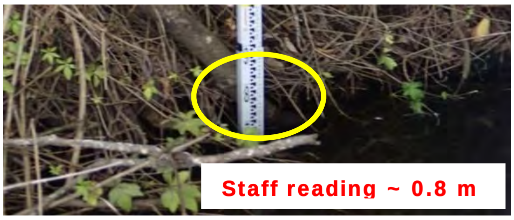

Figure 5-1: Undercutting of approximately 0.8 m (Vertical) at Site R03B (March 2015)

Table 5-1: Erosion Potential of the Seaham Weir Pool at Operational Water Level in March 2015

Erosion Potential (Existing Operational Water Level)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	10	0
Moderately Resistant	32	6
Mildly Resistant	79	33
Moderately Erosive	89	43
Highly Erosive	72	12
Total	**282**	**94**

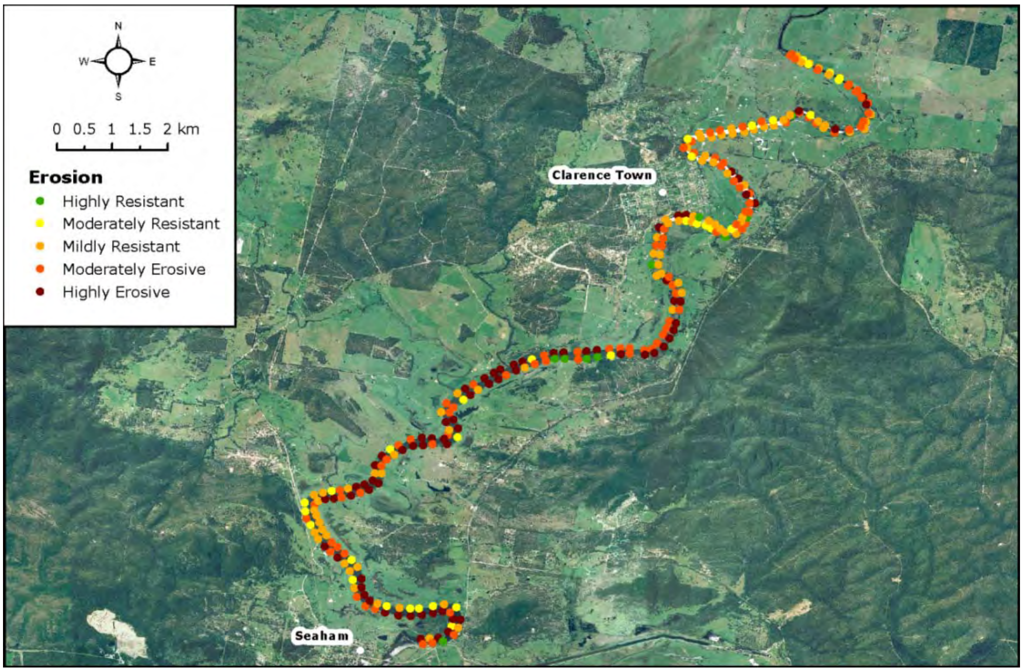

Figure 5-2: Erosion Potential of the Seaham Weir Pool at Operational Water Level in March 2015

During the March 2015 field assessment it was noted that the erosion potential of the riverbanks may be slightly reduced if the operational water level is raised by approximately 300 mm in the short-term. For these cases the wave zone would alter from bare vertical and undercut tree roots to the bottom level of the vegetation. A field example comparing the existing versus a raised operational water level for the Seaham Weir Pool is provided in Figure 5-3.

Results of a raised operational water level assessment for the Seaham Weir Pool are provided in Appendix M. A comparison between the existing and raised operational water level assessments highlighted minimal difference between the number of occurrences for each erosion potential category. Note it was acknowledged that the response of riverbank vegetation to an ongoing raised operational water level is unknown and may result in the long-term root migration up the riverbank. On this basis, altering the Seaham Weir Pool operational water level to mitigate erosion is not recommended.

Figure 5-3: Comparison Between Existing vs Raised Operational Water Levels for Seaham Weir Pool at Site R03C

5.2.2 August 2015 (Post-Flood) Assessment – Seaham Weir Pool

The April 2015 flood event (discussed in Section 2.4) caused significant changes to the erosion potential of the riverbanks along the Seaham Weir Pool study area. Figure 5-4 provides an example where significant undercutting has led to riverbank failure at Site L11A following the flood event. Table 5-2 and Figure 5-5 provide the distribution of erosion potential categories for the existing operational water level on the Seaham Weir Pool based on the August 2015 assessment. A comparison between the March 2015 (pre-flood) and August 2015 (post-flood) DSS assessments indicated that flooding has directly increased the number of sites identified as erosive in the study area. Considering only transects within the Seaham Weir Pool (Stretches 1-45), the number of sites in the 'Moderately Erosive' or 'Highly Erosive' categories increased from 157 occurrences before the April 2015 flood to 191 occurrences after the flood, a 13% increase in erosive sites. These changes corresponded to an equivalent reduction in the number of sites identified as resistant to erosion in the March 2015 assessment.

Figure 5-4: Comparison of March 2015 (Pre-Flood) and August 2015 (Post-Flood) at Site L11A

Table 5-2: Erosion Potential of the Seaham Weir Pool Study Area in August 2015

Erosion Potential (Existing Operational Water Level)	Number of Occurrences[1] (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	9	0
Moderately Resistant	18	4
Mildly Resistant	52	17
Moderately Erosive	98	50
Highly Erosive	93	19
Total	**270**	**90**

[1] Number of occurrences based on field assessment of Stretches 1-45 only.

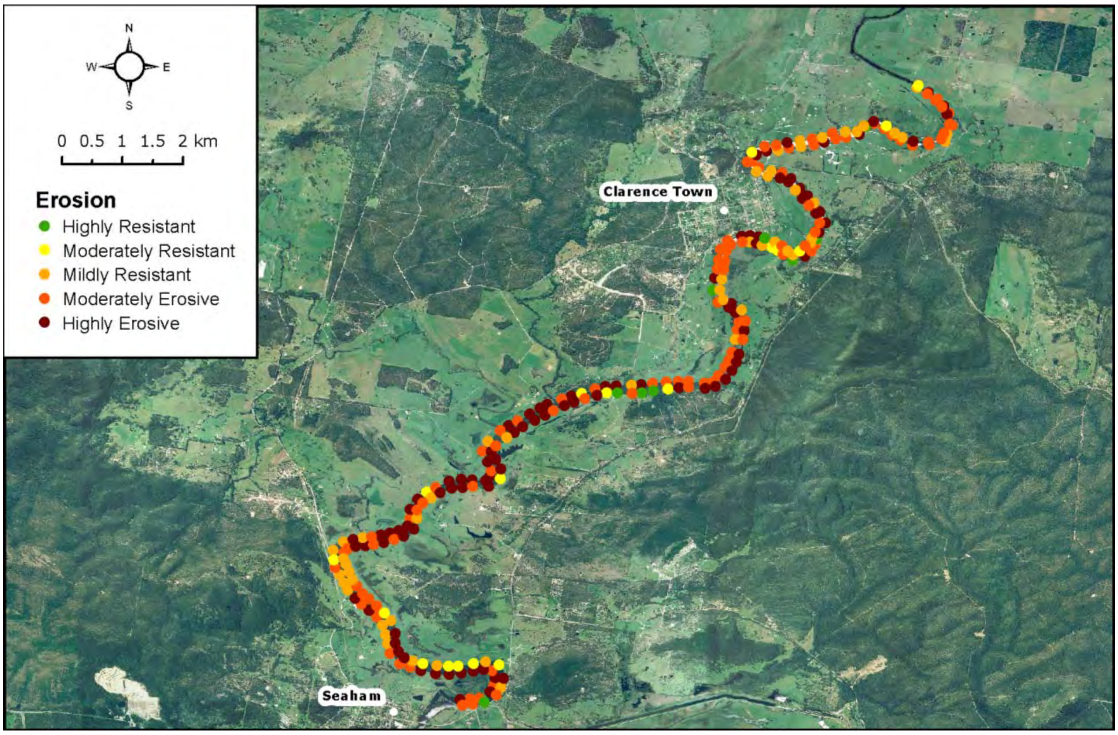

Figure 5-5: Erosion Potential of the Seaham Weir Pool Study Area in August 2015

5.2.3 March 2015 (Pre-Flood) Assessment – Lower Williams River

The riverbank vulnerability assessments on the Lower Williams River were conducted at mid – low tide to accurately observe the wave zone. Table 5-3 and Figure 5-6 provide the distribution of the erosion potential categories across the Lower Williams River study area at mid - low tide in March 2015. The March 2015 erosion potential results for the Lower Williams River show approximately 53% of all transects observed were 'Mildly Resistant' to erosion, while the remaining sites were identified as 'Moderately Erosive' or worse. These results indicated that the riverbanks of the Seaham Weir Pool were generally in a worse condition than the riverbanks of the Lower Williams River at the time of the assessment.

Table 5-3: Erosion Potential of the Lower Williams River Study Area in March 2015

Erosion Potential (Mid – Low Tide)	Number of Occurrences[1] (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	24	4
Moderately Resistant	28	7
Mildly Resistant	44	23
Moderately Erosive	50	22
Highly Erosive	33	4
Total	**179**	**60**

[1] Number of occurrences exclude transect R79C as the site was not accessible due to low water levels.

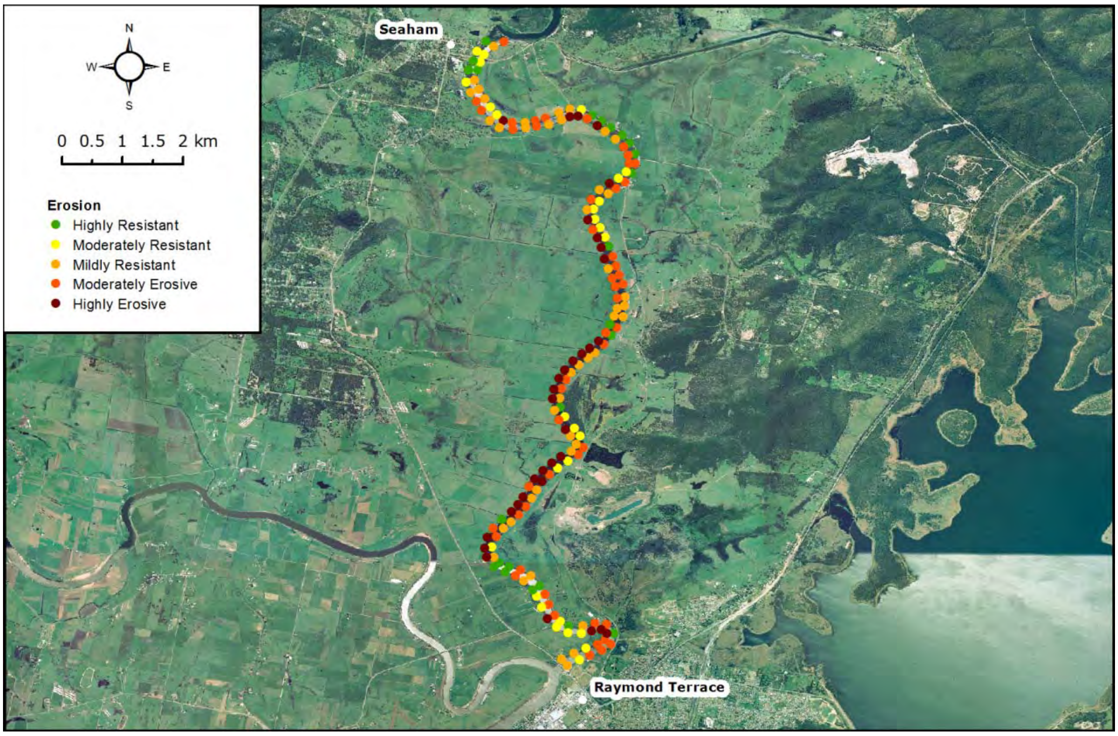

Figure 5-6: Erosion Potential for Each Transect on the Lower Williams River in March 2015

As with the Seaham Weir Pool, during the March 2015 field assessment it was noted that the erosion potential is slightly reduced around the top of high tide. For these cases on the Lower Williams River, the wave zone would alter from a gently sloping tidal beach to the bottom level of the vegetation or bedrock/armouring. This was shown to reduce riverbank susceptibility to wave attack. Figure 5-7 provides a representative transect in the study region showing the effect of water level on the erosion potential assessment between mid – low and high tide.

Results of the high tide assessment on the Lower Williams River are provided in Appendix M. The difference in erosion resistance between mid – low tide and high tide was not considered sufficient to develop water-based management actions linked to the tidal stage of the river (i.e. encouraging recreational boaters through education to limit boating activity in the lower half of the tidal cycle).

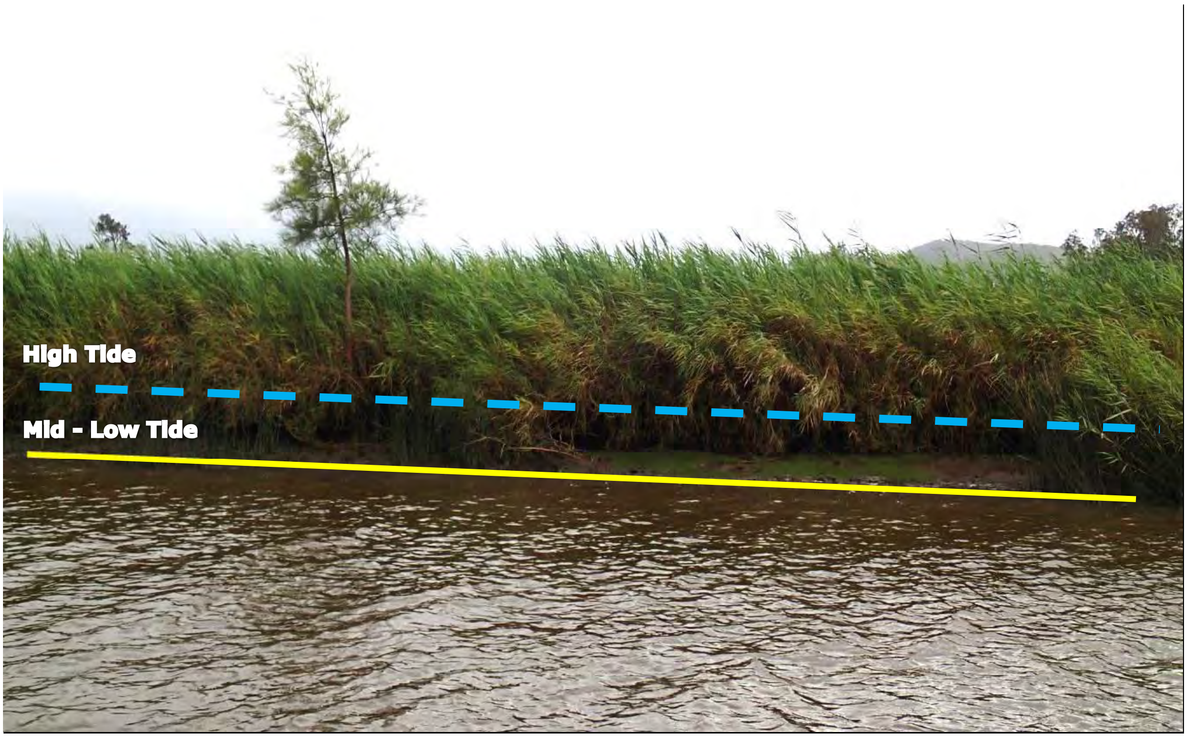

Figure 5-7: Effect of Water Level on Erosion Potential Assessment at Transect L63B (March 2015)

5.2.4 August 2015 (Post-Flood) Assessment – Lower Williams River

Changes to the riverbank condition following the April 2015 flood were also observed on the Lower Williams River. Table 5-4 and Figure 5-8 provide the distribution of erosion potential categories for mid – low tide conditions on the Williams River during the August 2015 assessment. A comparison between the March 2015 (pre-flood) and August 2015 (post-flood) DSS assessments indicated that flooding has directly increased the number of sites identified as erosive in the study area. Excluding transect R79C, as the site was not accessible due to low water levels at the time of the field assessments, the number of sites in the 'Moderately Erosive' or 'Highly Erosive' categories increased from 83 occurrences before the April 2015 flood to 110 occurrences after the flood, a 15% increase in erosive sites. These changes are consistent with the results on the Seaham Weir Pool with an equivalent reduction in the percentage of sites identified as resistant between the March and August 2015 assessments.

Table 5-4: Erosion Potential of the Lower Williams River Study Area in August 2015

Erosion Potential (Mid – Low Tide)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	21	4
Moderately Resistant	26	4
Mildly Resistant	22	18
Moderately Erosive	63	26
Highly Erosive	47	8
Total	**179**	**60**

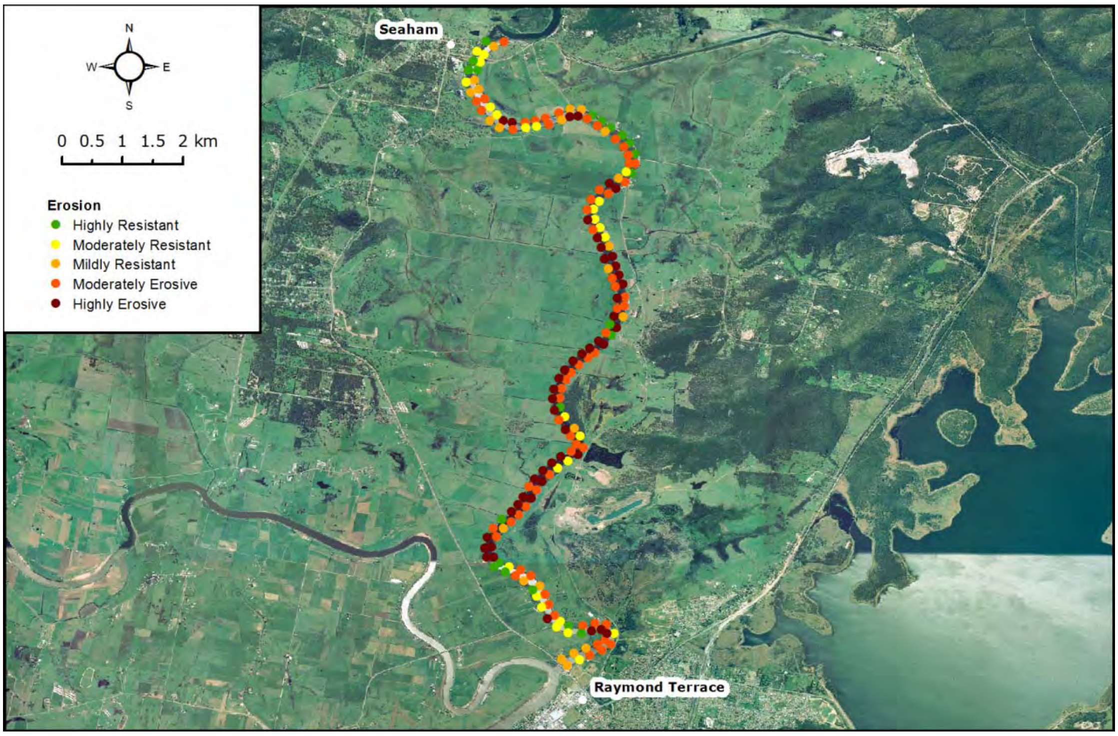

Figure 5-8: Erosion Potential of the Lower Williams River Study Area in August 2015

5.2.5 Factors Influencing Riverbank Erosion Potential

The DSS assessment of the Seaham Weir Pool and Lower Williams River found that sites with low resistance to erosion were influenced by a range of factors. Many reaches are laterally unconfined by alluvial floodplains on one (1) or both sides. These floodplains were typically observed to be laterally unconfined farmlands cleared of native riparian vegetation (Figure 5-9). At many sites there was also obvious uncontrolled stock access to the riverbanks (Figure 5-10 and Figure 5-11). In fact, during the 2015 field assessments stock access was observed at approximately 25% of all sites on the Seaham Weir Pool and approximately 40% of all sites on the Lower Williams River. The combination of these factors increases the risk of bank destabilisation including erosion, slumping and undercutting (Figure 5-12).

Armouring of the riverbank is a major influencing factor in the assessment of riverbank erosion potential. Very few reaches of the study area are naturally armoured by large rock ledges or cliffs (Figure 5-13), while other reaches have been artificially armoured (Figure 5-14 and Figure

5-15). This armouring, whether it is natural or artificial, generally provides 'Highly Resistant' erosion potential ratings.

The DSS assessment has also found that significant flooding on the Williams River has resulted in substantial changes to the erosion potential of the riverbanks in the study region. Flooding was generally observed to exacerbate the impacts of erosion, slumping, and undercutting, through further riverbank destabilisation or failure. Flooding was also effective at removing exotic weeds and vegetation on the riverbanks in the study area, exposing a bare wave zone or upper bank, which is subject to further erosion. Photographic field examples pre and post-flood are provided in Figure 5-17.

Figure 5-9: Cleared Floodplain and Cattle Access at Stretch R66 on the Lower Williams River (March 2015)

Figure 5-10: Cattle Access on Riverbanks and Erosion Present at Stretch L02 on Seaham Weir Pool (March 2015)

Figure 5-11: Cattle Access on Riverbanks and Erosion Present at Stretch L57 on Lower Williams River (March 2015)

Figure 5-12: Undercutting at Stretch L79 on Lower Williams River (March 2015)

Figure 5-13: Natural Rock Armouring (Also Note Undercutting) at Stretch R75 on the Lower Williams River (March 2015)

Figure 5-14: Armouring at Stretch L21 on Seaham Weir Pool (March 2015)

Figure 5-15: Armouring at Stretches L72 and L73 on the Lower Williams River (March 2015)

Figure 5-16: Rock Fillets at Transect R55C on the Lower Williams River (August 2015)

Figure 5-17: Flooding Impacts at Stretches L19A, L24A, L67B and L74C (Top to Bottom)

5.2.6 Influence of Riverine Geomorphology

In addition to the site specific erosion potential assessments, consideration was also given to the influence of natural processes, such as riverine geomorphology, on riverbank stability. Each river stretch was assigned one (1) of three (3) geomorphic zones: inside bank, outside bank or straight, to incorporate the complexities associated with riverine geomorphology in the study region. Figure 5-18 and Figure 5-19 provide geomorphic classifications on the Seaham Weir Pool and Lower Williams River, respectively, for comparison with the DSS erosion potential values provided in Figure 5-5 and Figure 5-8.

The results of the erosion potential assessments show that there were isolated locations where riverine geomorphology could be linked with expected flooding events, such as increased erosion on outside banks, and reduced erosion on inside banks and straights. However, the overall response of the riverbanks to the April 2015 flood was not directly correlated with these geomorphic zone classifications. This substantiated the hypothesis that there are additional factors to consider in a riverbank assessment beyond riverine geomorphology.

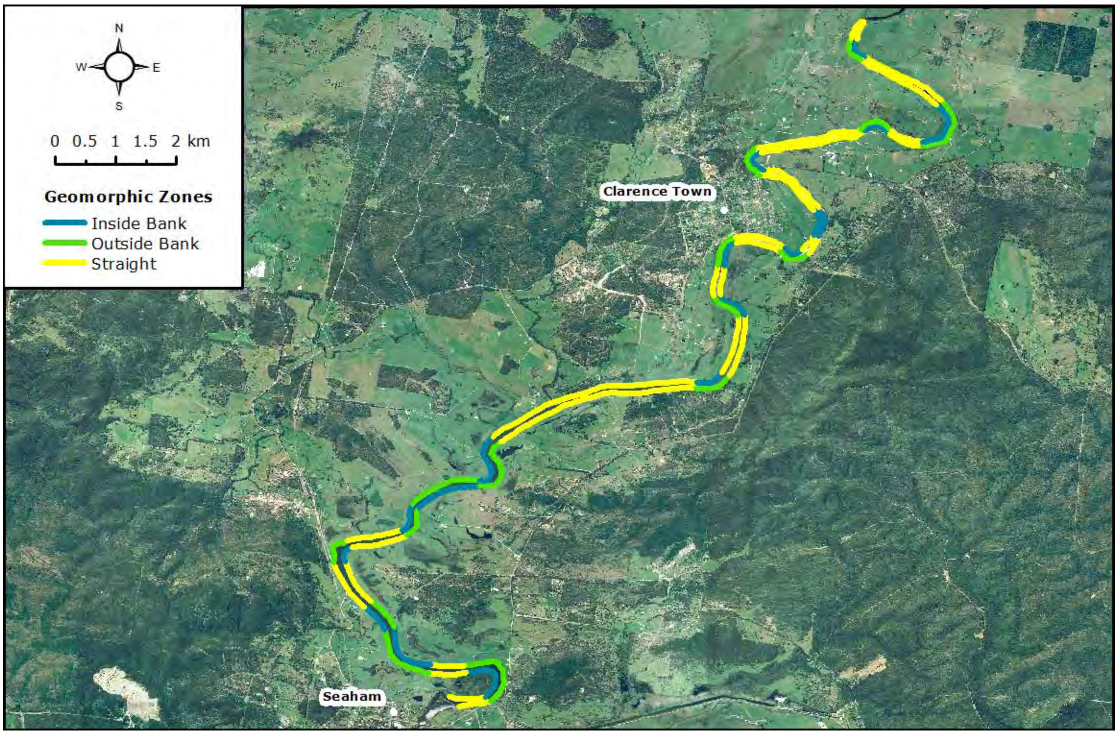

Figure 5-18: Geomorphic Zones of the Seaham Weir Pool

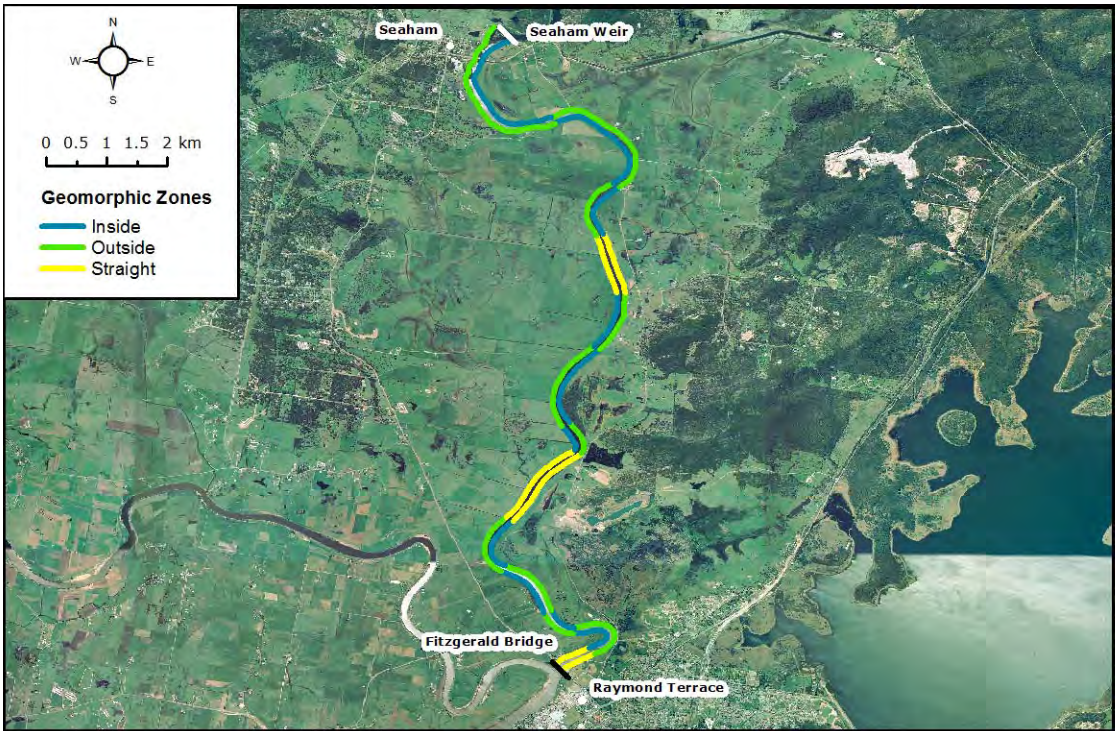

Figure 5-19: Geomorphic Zones of the Lower Williams River

5.3 DSS Management Recommendations – Seaham Weir Pool

5.3.1 Overview

Following the results of the erosion potential assessment in Section 5.2, this section provides an overview of the DSS management recommendations from the March 2015 (pre-flood) and August 2015 (post-flood) assessment of the Seaham Weir Pool at the existing operational water level. The management recommendations presented in this section are based on scaled Williamtown RAAF Base wind data with the medium boat pass scenario in river sections 10 to 30 and low boat pass scenarios for the remaining boating management zones. Management outcomes at a potentially raised (+300 mm) water level on the Seaham Weir Pool are provided in Appendix M. Note that no alternative boat pass scenarios or wind sources have been considered in the 2015 assessments.

5.3.2 March 2015 (Pre-Flood) Assessment

Table 5-5 and Figure 5-20 provide the DSS management outcomes from March 2015 for the Seaham Weir Pool assessment under existing operational water level conditions. This assessment resulted in 70% of all sites assessed being assigned a 'Monitor' recommendation, followed by 16% 'Manage', 9% 'Monitor*', and 6% 'Allow' sites. While every river section in the study area received at least one (1) 'Monitor' rating, the highest number of 'Monitor' ratings, being 31 out of a total of 66 occurrences, were located between stretches 31-47, upstream of the 4 knot section. The same river section also received three (3) 'Allow' ratings.

Table 5-5: Number of Stretches Determined in Each DSS Management Category in March 2015

Stretch	River Section	# Passes	Management Option				
			Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	1	1	0	8	0	3
7-9	4 knot Section (D/S)	10	0	0	6	0	0
10-17	Waterskiing Section (D/S)	50	0	0	10	2	4
18-22	Wakeboarding Section	50	1	0	1	3	5
23-26	Waterskiing Section (U/S)	50	0	0	4	2	2
27-30	4 knot Section (U/S)	50	0	0	7	1	0
31-47	U/S of the 4 knot Section	1	3	0	31	0	0
1-47*	***TOTAL***		**5**	**0**	**67**	**8**	**14**

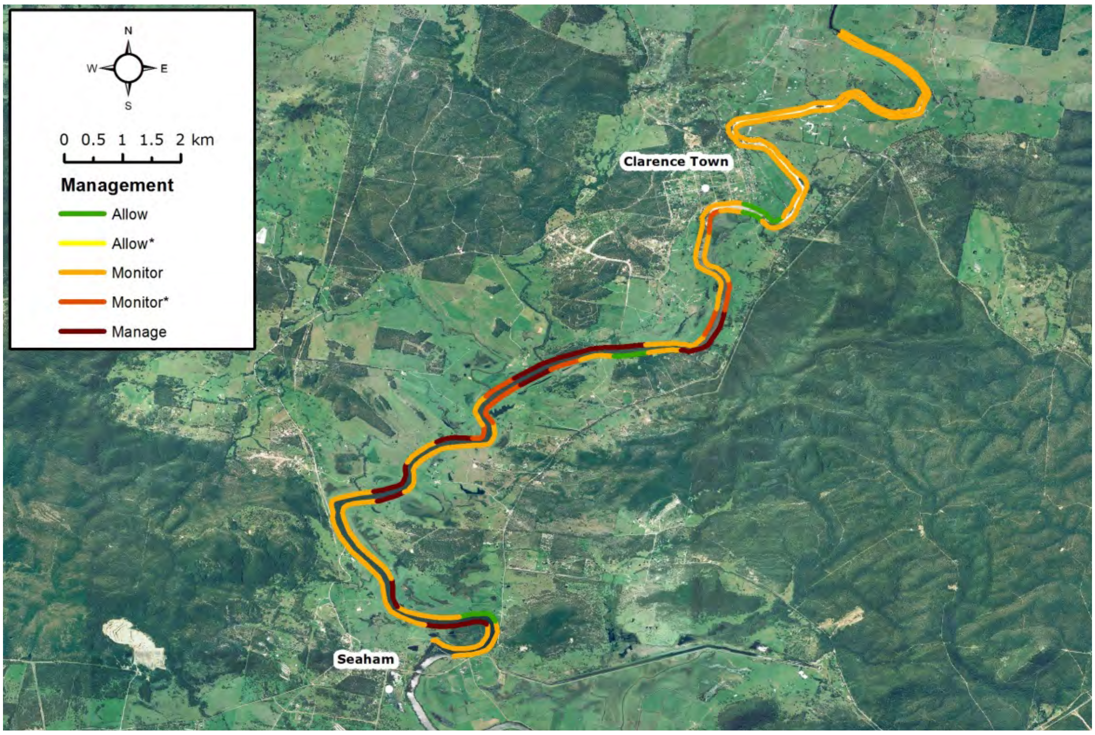

Figure 5-20: March 2015 (Pre-Flood) DSS Management Outcomes for Seaham Weir Pool - Scaled Williamtown RAAF Base Wind Data - Existing Operational Water Level

5.3.3 Final DSS Management Recommendations – August 2015 (Post-Flood) Assessment

Table 5-6 and Figure 5-21 provide the DSS management recommendations from August 2015 for the Seaham Weir Pool study area under the existing operational water level conditions. This combined management approach yielded a 68% majority of 'Monitor' recommendations for the study area, followed by 22% 'Manage', 6% 'Monitor*' and 4% 'Allow' sites. That is, less than 5% of the sites assessed in the Seaham Weir Pool study area are permissive for boating without further investigation or long-term monitoring.

The final management recommendations (Table 5-6) for the DSS assessment on the Seaham Weir Pool vary significantly across each river section. A comparison between the March 2015 (Table 5-6) and August 2015 (Table 5-5) DSS assessments indicated that flooding has directly increased the number of sites assigned with a 'Manage' recommendation in the Seaham Weir Pool study area. Considering only transects surveyed within the Seaham Weir Pool (Stretches 1-45), the number of sites with a 'Manage' recommendation increased from 14 sites before the April 2015 flood to 20 sites after the flood, an overall 7% increase across the study area. For all sites assessed between Stretches 10-26, where either waterskiing or wakeboarding activities are currently permitted, 14% of the sites were assigned a 'Manage' recommendation (up 2% from March 2015), while 18% of the sites were assigned a 'Monitor' recommendation (up 1% from March 2015). While every river section in the study area received at least two (2) 'Monitor' ratings, the highest number of 'Monitor' ratings, being 26 out of a total of 61 occurrences, were located between stretches 31-45, upstream of the 4 knot section. The same river section also received two (2) 'Manage' ratings and two (2) 'Allow' ratings.

Table 5-6: Number of Stretches Determined in Each DSS Management Category in August 2015

Stretch	River Section	# Passes	Management Option				
			Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	1	1	0	8	0	3
7-9	4 knot Section (D/S)	10	0	0	6	0	0
10-17	Waterskiing Section (D/S)	50	0	0	10	1	5
18-22	Wakeboarding Section	50	1	0	2	1	6
23-26	Waterskiing Section (U/S)	50	0	0	4	2	2
27-30	4 knot Section (U/S)	50	0	0	5	1	2
31-45	U/S of the 4 knot Section	1	2	0	26	0	2
1-45*	***TOTAL***		**4**	**0**	**61**	**5**	**20**

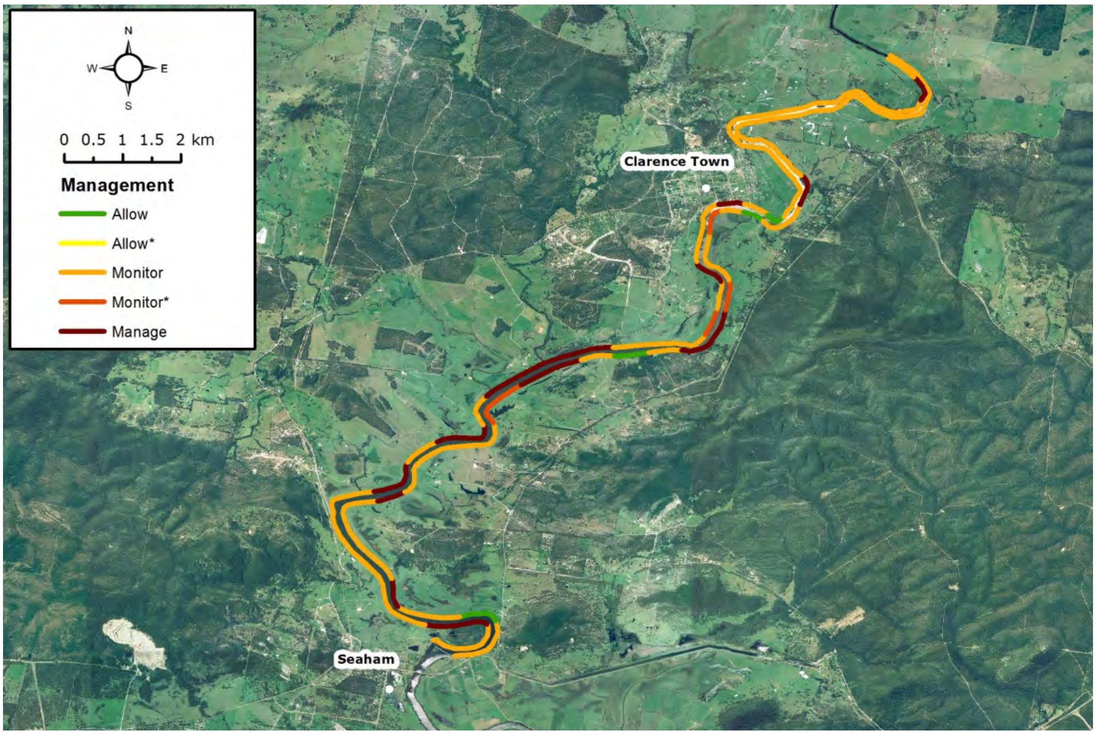

Figure 5-21: August 2015 DSS Management Recommendations for Seaham Weir Pool - Scaled Williamtown RAAF Base Wind Data - Existing Operational Water Level

5.4 DSS Management Recommendations – Lower Williams River

5.4.1 Overview

This section provides an overview of the management recommendations for the Lower Williams River produced using the DSS. DSS results are provided for both the March 2015 (pre-flood) and August 2015 (post-flood) field assessments. The March 2015 assessment was a baseline assessment of the Lower Williams River study area at mid – low tide (assessed for nine (9) different boat pass scenarios) and several sensitivity tests, including high tide, high boat passes, Australian Standard wind conditions and boat wave attenuation assessed for six (6) different boat pass scenarios. Maps of the March 2015 baseline scenarios and four (4) sensitivity tests are provided in Appendices L to P, respectively.

A summary of the March 2015 scenarios, includes:

- A Baseline Assessment:
  - Wakeboarding 'operating' conditions for 10, 50, and 150 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds;
  - Waterskiing 'operating' conditions for 10, 50, and 150 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds; and
  - Wakesurfing 'operating' conditions for 10, 50, and 150 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds.
- A Sensitivity Test for High Tide Conditions (same as Baseline Assessment, but at high tide).
- A Sensitivity Test for High Boat Passes:
  - Wakeboarding 'operating' conditions for 300 and 500 boat passes (12 hour duration) and 'maximum wave' condition for 50 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds;
  - Waterskiing 'operating' conditions for 300 and 500 boat passes (12 hour duration) and 'maximum wave' condition for 50 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds; and
  - Wakesurfing 'operating' conditions for 300 and 500 boat passes (12 hour duration) and 'maximum wave' condition for 50 boat passes (8 hour duration) at mid – low tide, applying scaled Williamtown RAAF winds.
- A Sensitivity Test with Australian Standard Winds (same as Baseline Assessment, but with wind speed values based on 1170.2).
- A Sensitivity Test with Boat Wave Attenuation (same as Baseline Assessment, but with 30 m 'distance of boat from shore' value which, where possible, is equivalent to the minimum required distance for a boat travelling past a shoreline at more than 10 knots (RMS, 2016)).

Note that the updated field assessment information from August 2015 was used to develop the final management recommendations for the Lower Williams River study area. Only the final wind/boat pass scenario was investigated with the August 2015 (post-flood) information.

5.4.2 March 2015 (Pre-Flood) Assessment

The combined management approach for the March 2015 field assessment on the Lower Williams River at mid to low tide yielded a 47% majority of 'Monitor' recommendations, followed by 25% 'Monitor*', 18% 'Manage', 5% 'Allow*', and 5% 'Allow', across all other sites. While every river section (except Stretch 78) received at least one (1) 'Monitor' rating, 25% were located in the two (2) wakeboarding sections (17% downstream and 8% upstream), and 20% were located in the waterski zone. The two (2) wakeboarding sections combined had approximately three (3) times the number of 'Manage' sites (14%) compared to the waterski zone (5%). Those sites rated as 'Allow' are located within two (2) sections (Section 78 and 79) downstream of Seaham Weir, with existing boating restrictions. There are 18 sites (3 'Allow*' and 15 'Monitor*') where wave attenuation was a limiting factor in the management recommendations.

Table 5-7: Lower Williams River March 2015 (Pre-Flood) Assessment for Mid – Low Tide Conditions

Stretch	River Section	Scenario	# Passes	Management Option				
				Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboarding Zone (D/S)	Wakeboard Operating	50	0	0	10	4	4
59-70	Waterskiing Zone	Waterski Operating	50	0	2	12	7	3
71-77	Wakeboarding Zone (U/S)	Wakeboard Operating	50	0	1	5	4	4
78	4 knot Zone	Waterski 4 knots	50	2	0	0	0	0
79	No Boats Permitted (U/S)	Waterski 4 knots	1	1	0	1	0	0
50-79	***TOTAL***			**3**	**3**	**28**	**15**	**11**

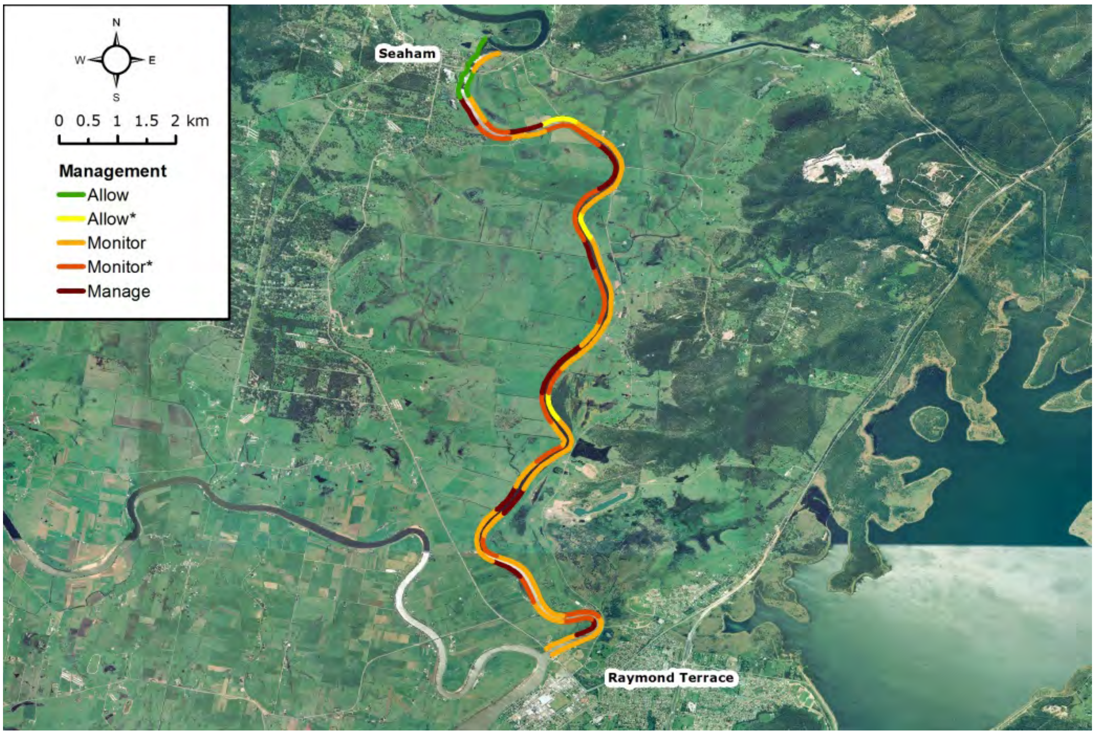

Figure 5-22: Lower Williams River March 2015 (Pre-Flood) Assessment (Scaled Williamtown RAAF Base Wind Data, Mid – Low Tide Conditions, 8 hour Duration)

5.4.3 *Final DSS Management Recommendations – August 2015 (Post-Flood) Assessment*

As with the Seaham Weir Pool, the final DSS management recommendations for the Lower Williams River (Table 5-8 and Figure 5-23) were developed by combining the results of the boating scenarios presented in Section 4.5.2 and are consistent with existing management zones. This included two additional DSS cases for the 4 knot zone at Seaham Boat Ramp and the restricted zone between Jim Scott Bridge and Seaham Weir.

A comparison between the March 2015 (Table 5-8) and August 2015 (Table 5-7) DSS assessments at mid to low tide on the Lower Williams River showed that flooding directly increased by 14% the number of sites assigned with a 'Manage' recommendation. The increase in the number of 'Manage' sites corresponded to an equivalent decrease in the number of recommendations across all other categories. For the August 2015 field assessment, the combined management approach on the Lower Williams River resulted in 42% of all sites being assigned 'Monitor', followed by 32% 'Manage', 20% 'Monitor*', 5% 'Allow', and 2% 'Allow*'. While every river section (except Stretch 78) received at least one (1) 'Monitor' recommendation, 26% were located in the two (2) wakeboarding sections (13% downstream and 10% upstream) and 17% were located in the waterski zone. The two (2) wakeboarding sections combined had almost twice the number of 'Manage' sites (20%) as the waterski zone (12%). Those sites rated as 'Allow' are located within the two (2) sections (Section 78 and 79) downstream of Seaham Weir, with existing boating restrictions. There were 13 sites (one (1) 'Allow*' and 12 'Monitor*') where wave attenuation was a limiting factor in the final management recommendations. Proportionally, this was a greater number of sites influenced by wave attenuation than on the Seaham Weir Pool, due to the modest increase in river width on the Lower Williams River.

Table 5-8: Final Management Recommendations for Lower Williams River in August 2015

Stretch	River Section	Scenario	# Passes	Management Option				
				Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboarding Zone (D/S)	Wakeboard Operating	50	0	0	8	3	7
59-70	Waterskiing Zone	Waterski Operating	50	0	1	10	6	7
71-77	Wakeboarding Zone (U/S)	Wakeboard Operating	50	0	0	6	3	5
78	4 knot Zone	Waterski 4 knots	50	2	0	0	0	0
79	No Boats Permitted (U/S)	Waterski 4 knots	1	1	0	1	0	0
50-79	***TOTAL***			**3**	**1**	**25**	**12**	**19**

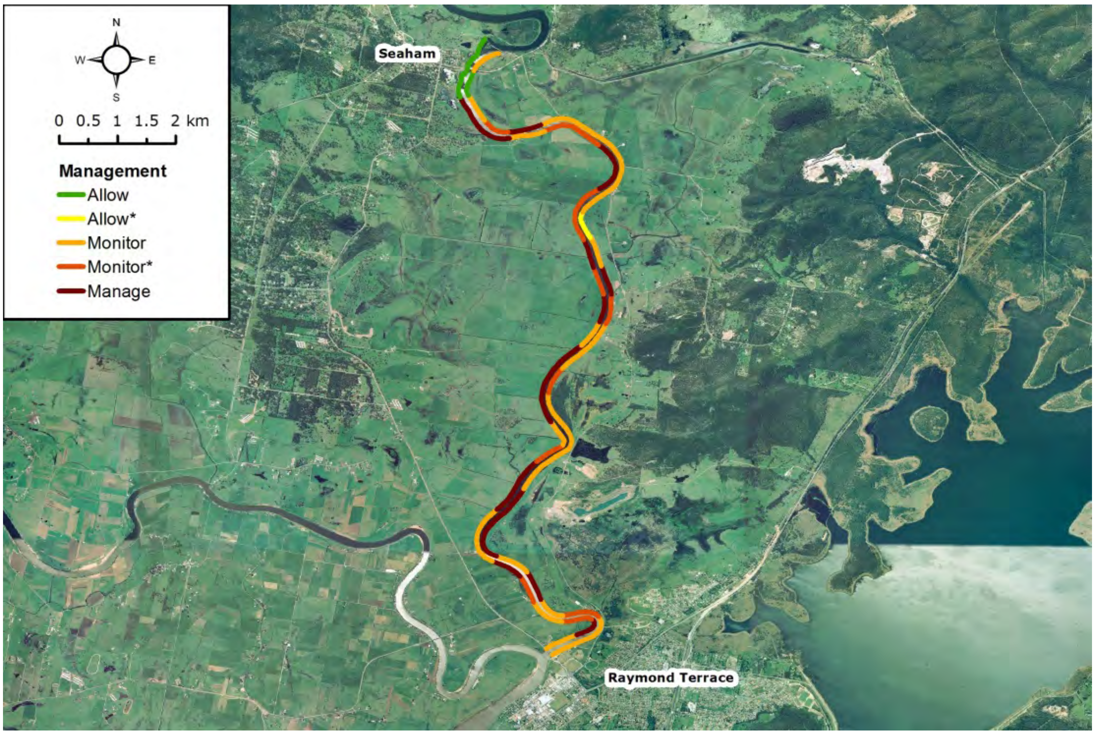

Figure 5-23: August 2015 DSS Management Recommendations for Lower Williams River (Scaled Williamtown RAAF Base Wind Data, Mid – Low Tide Conditions, 8 hour Duration)

6. Management Actions

6.1 Preamble

This section discusses the results presented in Sections 5.4 and 5.5, comparing the management recommendations of the inaugural assessment on the Seaham Weir Pool (2012), as well as the March 2015 (pre-flood) and August 2015 (post-flood) field assessments on the Seaham Weir Pool and Lower Williams River.

6.2 DSS Management Discussion

6.2.1 Seaham Weir Pool

Since the previous DSS assessment on the Seaham Weir Pool (Glamore and Davey, 2012), the DSS has been updated following revisions to the algorithm used to calculate the erosion potential and subsequent management recommendation at each site. Several updates that were incorporated into the DSS methodology, included:

- Adjustments to the application of erosion potential criteria;
- An improved method used for calculating approximate ARIs (refer to the method for calculating ARIs outlined in Appendix section B.3.4);
- The inclusion of additional field data from three (3) wakeboarding vessels to the DSS vessel database based on recent field testing (Glamore *et al.*, 2014); and
- The addition of wakesurf "operating" conditions as a new vessel activity.

As these changes to the DSS may alter the DSS results at each site, data from the 2012 assessment of the Seaham Weir Pool was re-processed using the current DSS version (DSS v2.4) to allow direct comparison with the March 2015 assessment (see Appendix Q for more details). The analysis showed that there were minimal differences in the DSS results between the previous version (DSS v1.6) and updated version (DSS v2.4) for the 2012 assessment on the Seaham Weir Pool.

As per the previous assessment (Glamore and Davey, 2012), the final management recommendations for the Seaham Weir Pool were based on a medium boat pass scenario for river stretches 10 to 30 and the low boat pass scenario for the remaining boating management zones. A summary of the March 2015 field assessment results for the Seaham Weir Pool is reproduced in Table 6-2 from Section 5.3.3. Note that low water levels during the March 2015 assessment exposed a rock bar across the channel making the remaining sites upstream of Stretch 47 inaccessible by boat. As an assessment of the change in erosion potential at these sites was not undertaken they have not been included in the comparison between the 2012 and 2015 assessments (Table 6-3). In any case, discussions with Hunter Water and NSW RMS suggest that these sites are rarely subject to boat waves.

Table 6-3 provides a direct comparison between the March 2015 field assessment of the Seaham Weir Pool (Table 6-2) and the adjusted 2012 baseline (Table 6-1). It was evident that riverbank erosion conditions across the study area had generally deteriorated over the assessment period. An example of this is shown in Figure 6-1 where riverbank conditions have significantly worsened at R04C from 'Mildly Resistant' in 2012 (left) to 'Highly Erosive' in 2015 (right). The DSS results showed an overall 7% increase in 'Highly Erosive' sites, with the majority of the sites located in the wakeboarding section of the Seaham Weir Pool, and an overall decrease in 'Moderately Erosive' and 'Mildly Resistant' sites (by 7% and 4%, respectively). However, it was also evident during the March 2015 field assessment that the riverbank conditions at several sites across the study area were unchanged (Figure 6-2) or had improved (Figure 6-3) since the inaugural 2012 field assessment.

In reviewing the results provided in Table 6-3, it was evident that the erosion potential of the riverbanks was one of the most important factors influencing the management outcomes. The DSS results showed modest increases in the number of reaches observed in the 'Manage' and 'Monitor*' categories (9% and 2%, respectively), and comparative decreases in the 'Monitor' and 'Allow*' categories (14% and 1%, respectively). Following the erosion potential assessment, there was a 4% increase in the number of sites rated as 'Manage' in the wakeboarding section. As such, the March 2015 study results suggested that the riverbank condition trajectory was in a negative eroding state.

A review was undertaken to identify the likely causal mechanisms influencing the riverbanks on the Seaham Weir Pool over the three (3) year period between the inaugural assessment and March 2015 assessment. Notably, boat usage information on the Seaham Weir Pool (including boating types, boat passes and boating activities) during this period was unavailable. While riverbank fencing information was provided to Hunter Water in 2014 (Appendix A, Section A.2.1), changes to riverbank fencing (installation or removal), and corresponding changes to stock access over this period were also unknown. Similarly, it was difficult to distinguish between natural riverbank vegetation re-growth and man-made intervention (i.e. planting of native riparian vegetation and/or removal of weeds). No new man-made riverbank armour protection was noted in the March 2015 DSS field assessment.

Figure 6-4 provides water levels recorded on the Seaham Weir Pool between March 2012 and August 2015. During this period there were three (3) separate flooding events on the Williams River, including floods in March 2013 and November 2013, which exceeded the Moderate Flood Level (7.6 m AHD). More recently, in April 2015, an intense low pressure system resulted in a Major Flood Level (greater than 9.10 m AHD) in the Williams River with an annual exceedance probability (AEP) of less than 1% (MHL, 2015).

A summary of the results from the August 2015 field assessment of the Seaham Weir Pool is reproduced in Table 6-4 (see also Section 5.4.2). The DSS results provided in Table 6-5 show that the condition of the riverbank across the study area has generally deteriorated further since the March 2015 field assessment. Photographic field examples showing the trajectory of the riverbank condition from 2012 to August 2015 is provided in Figure 6-5 and Figure 6-7, where riverbank conditions have significantly worsened at R04C and R18B, respectively. Typical flood impacts on the riverbanks observed during the August 2015 field assessment, included:

- Loss of sub-aquatic vegetation, reeds, and phragmites in the wave zone (Figure 6-6);
- Reduction in upper riverbank ground-cover vegetation, including exotic weeds and vines;
- Riverbank erosion and slumping; and
- Tree up-rooting.

Table 6-5 shows that the number of stretches identified as 'Moderately Erosive' or 'Highly Erosive' has increased from 55 occurrences in March 2015 (pre-flood) to 69 occurrences in August 2015 (post-flood), a 16% increase in erosive sites. Furthermore there was a 7% increase in the number of stretches assigned a 'Manage' recommendation. These changes also corresponded to an equivalent reduction in the number of sites identified as resistant to erosion in the March 2015 assessment. No sites in the study area improved between the March 2015 assessment and the August 2015 assessment, except for Stretch R22. Overall, the riverbank conditions are significantly worse compared to the 2012 assessment (Figure 6-8). Due to the relatively short timeframe between assessments, and the limited boat activity over winter, the increased erosive state of the riverbanks was considered to be a direct result of the flooding that occurred in April 2015. It is worth noting that while the erosion appears to be directly linked to the floods, the vulnerability of the riverbank to erode was likely due to a range of pre-existing factors, as measured in the DSS analysis.

Figure 6-1: Riverbank Conditions Worsened at R04C From 'Mildly Resistant' in 2012 (Left) to 'Highly Erosive' in March 2015 (Right)

Figure 6-2: Riverbank Conditions Unchanged at L22B From 'Highly Resistant' in 2012 (Left) to 'Highly Resistant' in March 2015 (Right)

Figure 6-3: Riverbank Conditions Improved Slightly at L14A From 'Highly Erosive' in 2012 (Left) to 'Moderately Erosive' in March 2015 (Right)

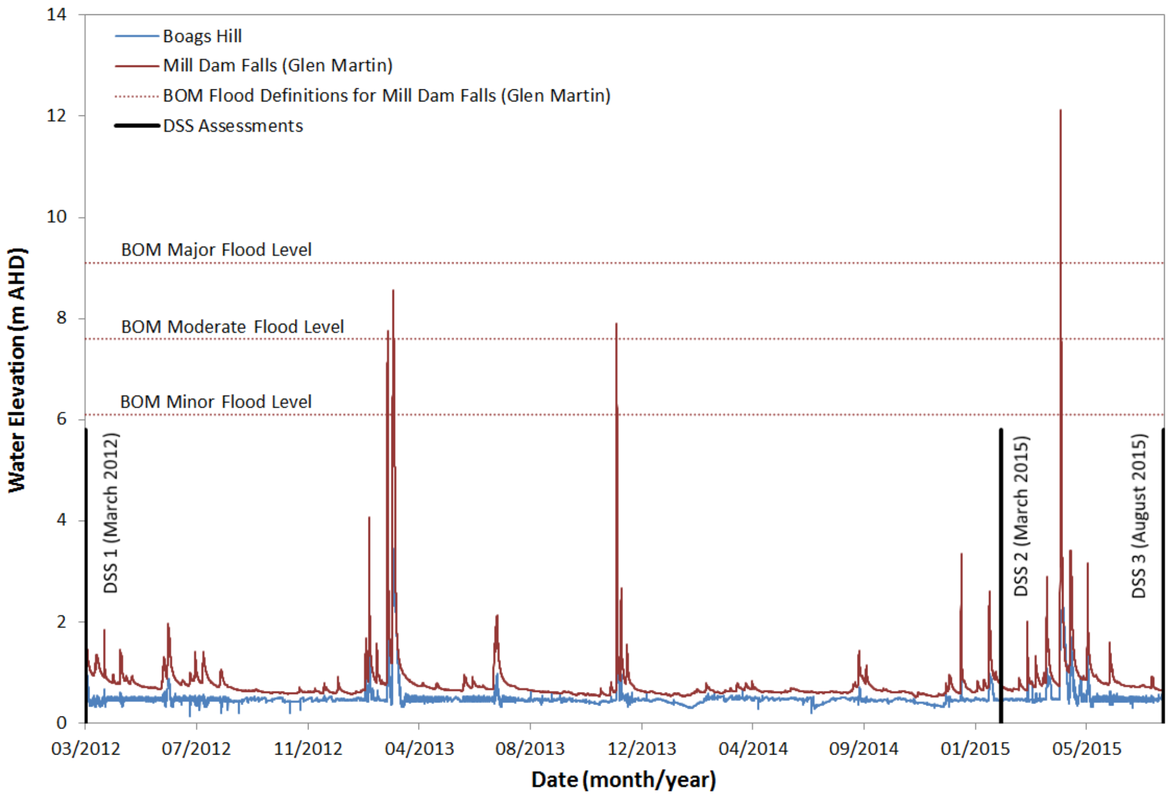

Figure 6-4: Water Levels on the Seaham Weir Pool between 2012 and 2015 DSS Assessments

Due to the narrow width of the river in the upper reaches of the Seaham Weir Pool, there were very few 'Monitor*' ratings (<10%) and no 'Allow* ratings in the final management recommendations (Table 6-5). Between Stretches 1 – 49 on the Seaham Weir Pool, the mid-river width ranges between 15 – 70 m, with a typical mid-river width of approximately 50 m. Upstream of Stretches 27 – 49, the mid-river width is less than 50 m, and upstream of Stretches 41 – 49, the mid-river width is less than 30 m. While boat speeds are presently limited to 8 knots for the narrow Stretches 41-49, this speed limit directly corresponds to the 'maximum wave' conditions of waterskiing vessels. **To prevent further damage to riverbanks in the upper reaches of the Seaham Weir Pool, WRL recommends that boating restrictions are introduced in Stretches 41-49 (and possibly Stretches 31-40) to minimise boat wash due to inadequate river width for wave attenuation.**

Figure 6-5: Riverbank Conditions Worsened at R04C From 'Mildly Resistant' in 2012 (Top) to 'Highly Erosive' in March 2015 (Middle), and 'Highly Erosive' in August 2015 (Bottom)

Figure 6-6: Example Loss of Sub-Aquatic Vegetation and Tree Uprooting from April 2015 Flood Event at Stretch R24 - 9 August 2014 (Top) 4 October 2015 (Bottom) (Source: NearMap)

Figure 6-7: Riverbank Conditions Worsened at R18B From 'Moderately Erosive' in 2012 (Top) to 'Highly Erosive' in March 2015 (Middle), and 'Highly Erosive' in August 2015 (Bottom)

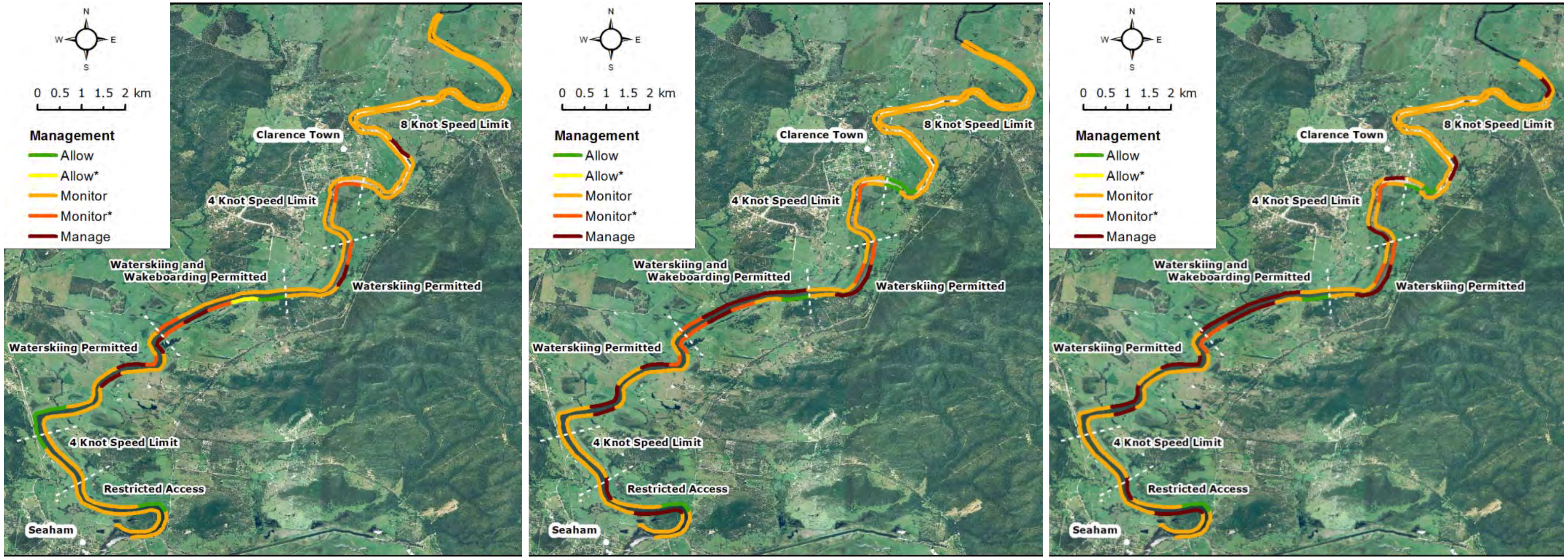

Figure 6-8: Comparison of DSS Management Recommendations from Field Assessments in March 2012 (Left), March 2015 (Middle) and August 2015 (Right)

Table 6-1: 2012 Adjusted Baseline Summary (DSS v2.4) for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0	1	8	3	0	1	0	11	0	0
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0	1	5	0	0	1	0	5	0	0
10-17	Waterski Section (D/S)	Waterski Operating	50	0	2	5	6	3	2	0	10	1	3
18-22	Wakeboard Section	Wakeboard Operating	50	0	2	1	7	0	1	1	4	3	1
23-26	Waterski Section (U/S)	Waterski Operating	50	0	0	1	6	1	0	0	6	1	1
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0	0	2	6	0	0	0	6	2	0
31-49	U/S of the 4 knot Section	Waterski 8 knots	1	0	0	16	21	1	0	0	37	0	1
1-49	***TOTAL***			**0**	**6**	**38**	**49**	**5**	**5**	**1**	**79**	**7**	**6**

Table 6-2: March 2015 (Pre-Flood) Assessment (DSS v2.4) for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0	1	4	4	3	1	0	8	0	3
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0	0	3	3	0	0	0	6	0	0
10-17	Waterski Section (D/S)	Waterski Operating	50	0	0	3	9	4	0	0	10	2	4
18-22	Wakeboard Section	Wakeboard Operating	50	0	2	0	5	3	1	0	1	3	5
23-26	Waterski Section (U/S)	Waterski Operating	50	0	0	0	6	2	0	0	4	2	2
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0	0	4	4	0	0	0	7	1	0
31-47	U/S of the 4 knot Section	Waterski 8 knots	1	0	3	19	12	0	3	0	31	0	0
1-47	***TOTAL***			**0**	**6**	**33**	**43**	**12**	**5**	**0**	**67**	**8**	**14**

Table 6-3: Comparison of 2012 and March 2015 Assessments for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0%	0%	-4%	1%	3%	0%	0%	-3%	0%	3%
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0%	-1%	-2%	3%	0%	-1%	0%	1%	0%	0%
10-17	Waterski Section (D/S)	Waterski Operating	50	0%	-2%	-2%	3%	1%	-2%	0%	0%	1%	1%
18-22	Wakeboard Section	Wakeboard Operating	50	0%	0%	-1%	-2%	3%	0%	-1%	-3%	0%	4%
23-26	Waterski Section (U/S)	Waterski Operating	50	0%	0%	-1%	0%	1%	0%	0%	-2%	1%	1%
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0%	0%	2%	-2%	0%	0%	0%	1%	-1%	0%
31-47	U/S of the 4 knot Section	Waterski 8 knots	1	0%	3%	6%	-9%	-1%	3%	0%	-2%	0%	-1%
1-47	***TOTAL***			**0%**	**0%**	**-2%**	**-5%**	**7%**	**0%**	**-1%**	**-9%**	**1%**	**9%**

Table 6-4: August 2015 (Post-Flood) Assessment (DSS v2.41) for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0	1	4	4	3	1	0	8	0	3
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0	0	3	3	0	0	0	6	0	0
10-17	Waterski Section (D/S)	Waterski Operating	50	0	0	1	10	5	0	0	10	1	5
18-22	Wakeboard Section	Wakeboard Operating	50	0	1	1	3	5	1	0	2	1	6
23-26	Waterski Section (U/S)	Waterski Operating	50	0	0	0	6	2	0	0	4	2	2
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0	0	2	4	2	0	0	5	1	2
31-45	U/S of the 4 knot Section	Waterski 8 knots	1	0	2	6	20	2	2	0	26	0	2
1-45	***TOTAL***			**0**	**4**	**17**	**50**	**19**	**4**	**0**	**61**	**5**	**20**

Table 6-5: Comparison of March 2015 and August 2015 Assessments for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10-17	Waterski Section (D/S)	Waterski Operating	50	0%	0%	-2%	1%	1%	0%	0%	0%	-1%	1%
18-22	Wakeboard Section	Wakeboard Operating	50	0%	-1%	1%	-2%	2%	0%	0%	1%	-2%	1%
23-26	Waterski Section (U/S)	Waterski Operating	50	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0%	0%	-2%	0%	2%	0%	0%	-2%	0%	2%
31-45	U/S of the 4 knot Section	Waterski 8 knots	1	0%	-1%	-10%	9%	2%	-1%	0%	-1%	0%	2%
1-45	***TOTAL***			**0%**	**-2%**	**-13%**	**8%**	**8%**	**-1%**	**0%**	**-2%**	**-3%**	**7%**

6.2.2 *Lower Williams River*

A summary of the erosion potential and management ratings from the March 2015 field assessment on the Lower Williams River is provided in Table 6-6. The DSS results showed overall that approximately 57% of the study area was ‘Mildly Resistant’ to erosion or better. Of this allocation, 33% of the sites were located in the wakeboarding permitted zones, 17% of the sites were located in ‘No slow towing’ area, and the remaining sites were located in the restricted zones. The remaining sites in the study area were ‘Moderately Erosive’, except for approximately 7% which were deemed ‘Highly Erosive’. The distribution of ‘Moderately’ to ‘Highly Erosive’ sites were evenly spread across the wakeboard and waterski zones.

The erosion potential results from the March 2015 field assessment were indicative of the management ratings assigned to sites along the study area. The majority of the sites (>47%) were identified as requiring further monitoring to calculate the riverbank condition trajectory. Whereas, approximately 18% of all sites assessed in March 2015 were assigned a ‘Manage’ rating and required immediate action to prevent further erosion. The remaining sites across the study area were identified as being relatively stable in terms of erosion, or potentially could have been managed by restricting boat traffic to river areas where sufficient width was available to reduce wake wave energies at the shoreline.

As with the Seaham Weir Pool assessment, Table 6-8 provides a comparison between the March 2015 (pre-flood) (Table 6-6) and August 2015 (post-flood) (Table 6-7) field assessments on the Lower Williams River. It was evident from the August 2015 study results that riverbank erosion conditions across the Lower Williams River had generally deteriorated over the assessment period. An example of this is shown in Figure 5-17 where riverbank conditions worsened at L67B from ‘Moderately Erosive’ in March 2015 to ‘Highly Erosive’ in August 2015. As a result of similar conditions along the length of Stretch L67, the management rating changed from ‘Monitor’ (pre-flood) to ‘Manage’ (post-flood). Overall, the DSS results showed a 14% increase in erosive sites, with these sites located in the wakeboard and waterski sections on the Lower Williams River. There was also a 13% increase in the number of sites assigned with a ‘Manage’ recommendation following the August 2015 assessment. No sites in the study area improved between the March and August 2015 assessment, as shown in Figure 6-9.

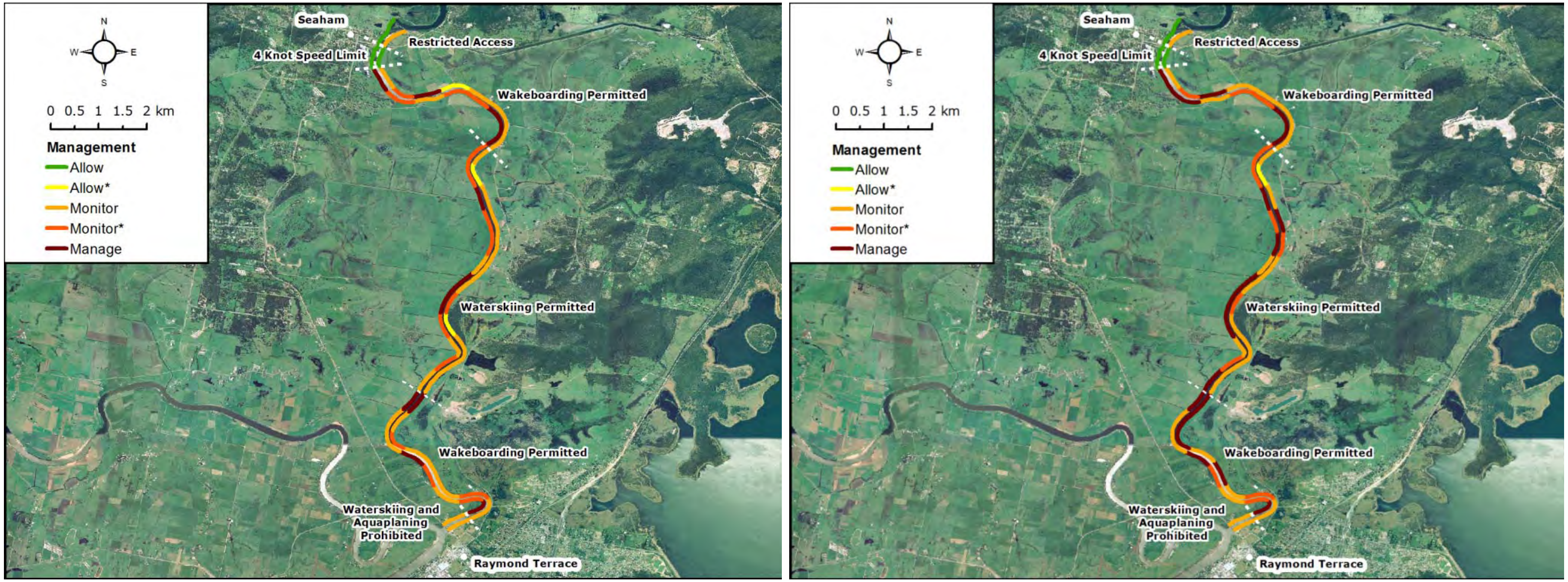

Figure 6-9: Comparison of DSS Management Recommendations from Field Assessments in March 2015 (Left) and August 2015 (Right)

Table 6-6: March 2015 (Pre-Flood) Assessment for Lower Williams River

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboard Zone (D/S)	Wakeboard Operating	50	0	3	9	5	1	0	0	10	4	4
59-70	Waterski Zone	Waterski Operating	50	0	2	8	11	3	0	2	12	7	3
71-77	Wakeboard Zone (U/S)	Wakeboard Operating	50	2	1	5	6	0	0	1	5	4	4
78	4 knot Zone	Waterski 4 knots	50	1	1	0	0	0	2	0	0	0	0
79	No Boats Permitted (U/S)	Waterski 4 knots	1	1	0	1	0	0	1	0	1	0	0
50-79	***TOTAL***			**4**	**7**	**23**	**22**	**4**	**3**	**3**	**28**	**15**	**11**

Table 6-7: August 2015 (Post-Flood) Assessment for Lower Williams River

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboard Zone (D/S)	Wakeboard Operating	50	0	2	7	8	1	0	0	8	3	7
59-70	Waterski Zone	Waterski Operating	50	0	1	5	11	7	0	1	10	6	7
71-77	Wakeboard Zone (U/S)	Wakeboard Operating	50	2	0	5	7	0	0	0	6	3	5
78	4 knot Zone	Waterski 4 knots	50	1	1	0	0	0	2	0	0	0	0
79	No Boats Permitted (U/S)	Waterski 4 knots	1	1	0	1	0	0	1	0	1	0	0
50-79	***TOTAL***			**4**	**4**	**18**	**26**	**8**	**3**	**1**	**25**	**12**	**19**

Table 6-8: Comparison of March 2015 and August 2015 Assessments for Lower Williams River

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboard Zone (D/S)	Wakeboard Operating	50	0%	-2%	-3%	5%	0%	0%	0%	-3%	-2%	5%
59-70	Waterski Zone	Waterski Operating	50	0%	-2%	-5%	0%	7%	0%	-2%	-3%	-2%	7%
71-77	Wakeboard Zone (U/S)	Wakeboard Operating	50	0%	-2%	0%	2%	0%	0%	-2%	2%	-2%	2%
78	4 knot Zone	Waterski 4 knots	50	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
79	No Boats Permitted (U/S)	Waterski 4 knots	1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
50-79	***TOTAL***			**0%**	**-5%**	**-8%**	**7%**	**7%**	**0%**	**-3%**	**-5%**	**-5%**	**13%**

6.3 Forensic Examination of Key Riverbank Vulnerability Factors

A forensic examination was undertaken to identify the key factors producing low erosion potential scores across the study region, and to provide practical intervention tools to improve the physical and biological condition of degraded riverbanks on the Seaham Weir Pool and Lower Williams River. The objectives to achieve this, include:

- Mitigation of active erosion;
- Improvement of riparian corridors to enhance bed and riverbank stability, as well as providing a corridor for native flora and fauna;
- Improvement of the aquatic environment to encourage a greater quantity and diversity of aquatic flora and fauna; and
- Improvement of water quality through the mitigation of erosion, and the removal of nutrients via improved vegetation “buffers” in the riparian zone.

The forensic examination was based on the analysis of three (3), 10 m wide transects within a given 500 m stretch across the study region. Forensics were considered for two (2) site classification types only, including:

1. Sites that were prescribed a ‘Manage’ rating in the August 2015 (post-flood) DSS assessment for the boating management conditions as provided in Table 2-1 at the existing operational water level on the Seaham Weir Pool, and Table 2-2 at mid – low tide on the Lower Williams River; and
2. Sites that were prescribed a ‘Monitor*’ rating for the same boating management conditions as described in site classification type 1, that changed to a ‘Manage’ rating in a boat wave attenuation sensitivity test (i.e. boating at 30 m off the shoreline).

6.3.1 Rehabilitation Guidelines for Australian Streams

The forensic examination was undertaken in accordance with the principles of the *Rehabilitation Guidelines for Australian Streams* (Rutherford *et al.*, 2000) published by the Land and Water Resources Research and Development Corporation (LWRRDC) and the Cooperative Research Centre for Catchment Hydrology (CRCCH) at Monash University. The manual has two (2) volumes and is designed to provide guidance and tools to rehabilitate the biological and physical values of Australia’s streams.

Volume 1 of the manual provides rehabilitation concepts and a summary of the rehabilitation planning procedure. This is essentially broken down into four (4) key stages, as follows:

1. Planning (problem identification);
2. Identifying solutions (preliminary design);
3. Detailed design; and
4. Monitoring and Evaluation.

This forensic investigation fulfils stages 1 and 2 of this process.

A further detailed design stage is required onsite. Rutherford *et al.* (2000) Volume 2 provides detailed information about the broad intervention tools that can be used for rehabilitation of degraded Australian streams. These are separated into two (2) categories, including:

1. Intervention in the channel:

   - Full-width structures;
   - Partial-width bank erosion control structures;
   - Longitudinal bank protection;
   - Bed replenishment;
   - Re-instating cut-off meanders;
   - Fish cover;
   - Boulders;
   - Overcoming barriers to fish passage;
   - Management of large woody debris; and
   - Sand and gravel extraction as a rehabilitation tool.

2. Intervention in the Riparian Zone:

   - Vegetation management (banks and in-channel revegetation);
   - Streams infested by exotic weeds;
   - Willow-infested streams; and
   - Managing stock access to streams (fencing the riparian corridor).

It is important to note that the manual emphasises that rehabilitation does not imply absolute stability. On the contrary, it implies that stream systems rely on a certain level of disturbance by flooding, erosion and variable water quality, to maintain their diversity. To that point, the management recommendations are not intended or designed to 'flood proof' the riverbank sections across the study region from natural river flooding.

6.3.2 Management Strategies

For the purpose of undertaking the forensic examination, the intervention tools identified in the *Rehabilitation Guidelines for Australian Streams* (2000) have been considered and grouped into practical water and land management options, and are discussed under the following categories, including:

1. Temporary water management strategies:

   - Boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones or enforced mid-river boating).

2. Land management strategies:

   - Battering;
   - Bioengineering;
   - Exotic weed management;
   - Fencing (i.e. stock exclusion);
   - Reshaping;
   - Revegetation; and
   - Eco-engineering structures (i.e. rock fillets).

Definitions are provided for the aforementioned water and land management strategies as follows:

Battering involves removing vertical sections of eroded riverbank by reducing the slope to 1H:3V or less where possible.

Bioengineering typically involves using vegetation, wood and biodegradable products to reduce surface erosion and provide toe protection while revegetation is established.

Exotic weed management requires weed species to be controlled selectively to maintain the valuable functions of the native stream vegetation. Selective application of approved herbicides, manual removal, or sometimes-biological methods can be used.

Fencing involves erecting a structure to remove stock access from the riverbank.

Reshaping involves smoothing eroded riverbanks without cutting material or disturbing existing native vegetation.

Revegetation involves re-establishing local native vegetation in the riparian zone, including native canopy on the verge, shrubs and ground cover on the upper bank, and reeds and river mangroves in the wave zone, to stabilise bank sediments by generating a network of roots and partially absorbing wave and current forces.

Eco-engineering Structures (i.e. rock fillets) are a bioengineered approach to riverbank stabilisation. These structures dissipate wave energy, capture sediment, and create sheltered environments that are colonised by native vegetation (Figure 6-10).

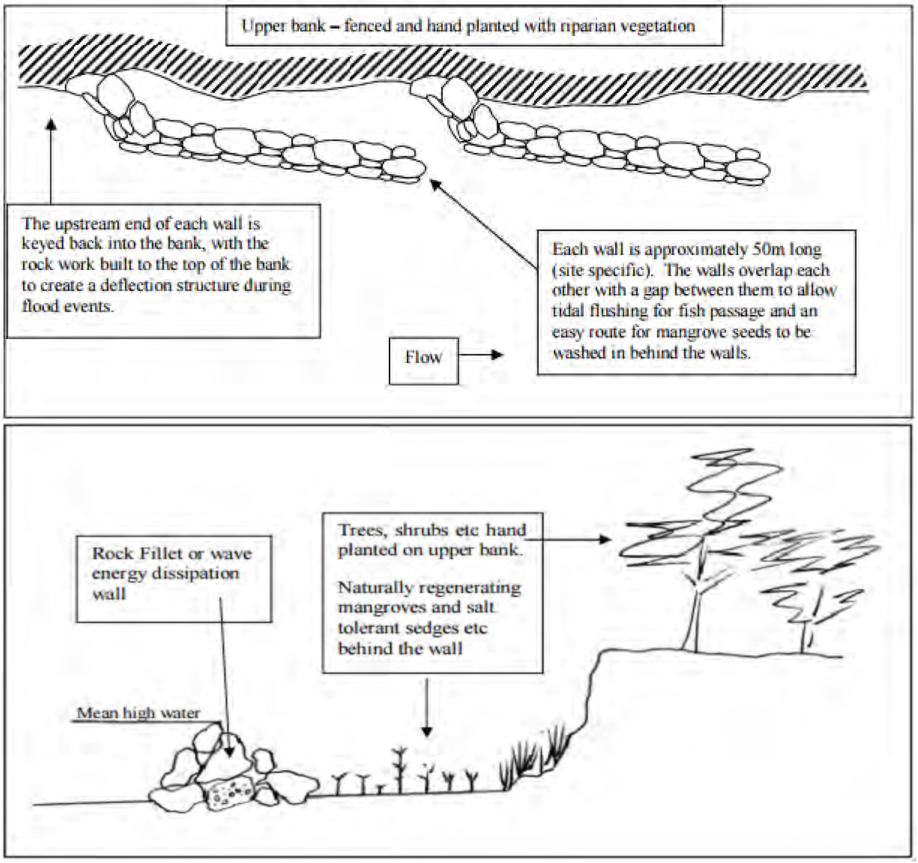

Figure 6-10: Schematic Plan View (Top) and Cross-Section (Bottom) of Rock Fillets used to Rehabilitate an Eroding Riverbank (after Skelton & Great Lakes Council, 2003)

Note that WRL has considered two (2) boat restriction types to minimise riverbank erosion in preparing the recommendations for this report as follows:

Minimal wash zones refer to areas where wash from vessels can cause damage, injury or annoyance to other vessels, the shoreline or people. The implementation of temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) should be enforced in accordance with Clause 9:2(c) of the Marine Safety (General) Regulation (2009), which states that "the operator of a vessel must not cause wash that damages or impacts unreasonably on… any bank, shore or waterside structure".

Encouraging boating activities towards the centre of the river is applicable to areas within the study region where safety is a concern due to narrow river widths and submerged rock bars.

Encouraging mid-river boating had a limited capacity to reduce erosion due to the relatively narrow width of the Williams River. As a result, temporary buoy deployment at mid-river widths was not included in WRL's management recommendations.

These onsite actions can be used to improve the rating of a site from 'Manage' to at least 'Monitor' as simulated using the DSS. It is important to note that this section of the report provides preliminary recommendations based on a desktop forensic examination at individual transects and does not remove the need for site-specific detailed engineering design. Detailed planning is recommended, including site inspections, to assess the management recommendation across the entire riverbank stretch.

6.3.3 Management Recommendations

Land and water-based management options have been outlined to improve the DSS management outcomes (i.e. from 'Manage' or 'Monitor*' to 'Monitor') at sites with the highest vulnerability. The recommended onsite strategies for the two (2) site classification types across the study region consider both immediate and programmed management outcomes. Note that the management recommendations provided are not intended or designed to 'flood proof' the riverbank sections across the study region from natural river flooding. The management recommendations are as follows:

1. **Stage 1 Management Action Plan** (to commence following community and stakeholder consultation, detailed site investigation and costing, and approvals) involves riverbank remediation, including weed removal, native vegetation regeneration, and stock exclusion, combined with temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) in some parts of the river as shown in Figure 6-11 and Figure 6-12. Sites that require additional remediation effort, such as eco-engineering structures (i.e. rock fillets) and battering to reduce erosion and to improve their management rating to 'Monitor', are also highlighted in the preliminary land management options provided in Table 6-9 and Table 6-10. Note that eco-engineering structures and battering could be considered for all sites if an 'Allow' management rating is preferred (and resources are available). Note also that rock fillets are not recommended for outside banks due to the potential damage costs of maintenance post-flood.

2. **Stage 2 Management Action Plan (or *Riverbank Management Program*)** involves ongoing monitoring and evaluation of the areas addressed by the *Stage 1 Management Action Plan* for a period of up to 36 months from the completion of the riverbank remediation activities. Ongoing management activities would include:

    a. Enforcing temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) until riverbank vegetation is re-established;
    b. Monitoring of revegetation and structural works post flood to identify maintenance needs;
    c. Maintenance of fencing installed for the control of stock movements and access to the river;
    d. Maintenance of revegetation works, including providing water, repair of bioengineered structures/installations, and ongoing weed management, such as controlling grass and weed growth around seedlings etc. Note that 'pulse grazing' to control particular weed species is not recommended; and
    e. Ongoing monitoring of the 17 riverbank locations on the Seaham Weir Pool where cross-sectional survey profiles have been measured. WRL recommends that these sites are re-surveyed every 24 months after the *Stage 1 Management Action Plan* is implemented to assist with the development of a conceptual sediment budget for the Seaham Weir Pool.

The *Stage 1 Management Action Plan* was formulated on the most recent DSS riverbank vulnerability assessment of the Seaham Weir Pool and Lower Williams River, and provides a sustainable outcome for the study region. The *Stage 1 Management Action Plan* provides immediate management recommendations for approximately 25% of all sites on the Seaham

Weir Pool included in the August 2015 DSS assessment, and greater than 50% of all sites on the Lower Williams River included in the August 2015 DSS assessment, which had a DSS management rating of 'Manage' or 'Monitor*'. On the Seaham Weir Pool, it is recommended that 25 transects have riverbank regeneration, whereas one (1) site has eco-engineering structures and battering to achieve a management rating of 'Monitor' or better. On the Lower Williams River, it is recommended that 31 transects have riverbank regeneration, two (2) sites have eco-engineering structures, and two (2) sites have eco-engineering structures and battering to achieve a management rating of 'Monitor' or better. Note that on a single stretch on the outside bend of the Lower Williams, R76, eco-engineering structures such as rock fillets are not recommended, and accordingly the management rating after immediate actions are implemented is 'Monitor*'.

Prior to implementing the *Stage 1 Management Action Plan*, a comprehensive program should be confirmed to provide the best environmental outcomes for the entire study region. This approach should aim to minimise the edge effects of the riverbank remediation works and, where possible, integrate into the works program other sites adjacent to the stretches identified, while equipment and personnel are mobilised onsite.

As part of the *Stage 1 Management Action Plan*, it is recommended that land and water-based management interventions are combined to ensure successful, long-term outcomes. The implementation of temporary boating restrictions that prevent further damage to riverbanks (i.e. minimal wash zones) is required in some parts of the river in conjunction with riverbank works, as it is difficult to establish riverbank vegetation and wave zone cover using natural techniques with ongoing boat wash.

If it is necessary to manage boating numbers across the study region, and recognising the potential cost of implementing the *Riverbank Management Program,* it is recommended that the *Stage 1 Management Action Plan* is implemented via a staged-approach. If this approach is undertaken, the Management Action Plan for the Seaham Weir Pool should be prioritised over the Lower Williams River, due to the public health concerns associated with the long-term decline in water quality within a critical drinking water source for the Lower Hunter region, and the exacerbated erosion issues associated with having a static water level on the Seaham Weir Pool.

In the interim on the Lower Williams River, alternative bioengineering techniques, such as fish balls, coir log walls, silt fences or other geotextile products (e.g. Flow Net), or brushing (i.e. logs of various sizes and other debris secured to the riverbank or wave zone), may be implemented to reduce wave action reaching the riverbank, hence encouraging vegetation regrowth and sediment deposition. It is acknowledged that the risk of failure for these 'soft', but more economical (initial installation costs only), structures is greater than rock fillets, as they can be severely damaged by high magnitude floods, and may require regular maintenance.

Table 6-9: Recommended Riverbank Management Program for On-Ground Works Along the Seaham Weir Pool

Transect	Outside Bend?	August 2015 DSS Management Rating	Regeneration					Rock Fillets	Battering	Management Rating after Immediate Actions
			Fencing*	Exotic Weed Management	Reshaping (Where Possible)	Revegetation	Bioengineering (Where Possible)			
L06	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor
L12		Manage	✓	✓	✓	✓	✓			Allow
L17		Monitor*	Confirm status	✓	✓	✓	✓			Allow*
L18		Monitor*	✓	✓	✓	✓	✓			Allow*
L19		Manage	Confirm status	✓	✓	✓	✓	✓	✓	Allow*
L20		Manage	Confirm status	✓	✓	✓	✓			Monitor
L24	✓	Manage	✓	✓	✓	✓	✓			Monitor
L25		Manage	✓	✓	✓	✓	✓			Monitor
L26		Monitor*	Confirm status	✓	✓	✓	✓			Monitor
L29	✓	Monitor*	Confirm status	✓	✓	✓	✓			Monitor
L34	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor
R03		Manage	Confirm status	✓	✓	✓	✓			Allow
R04		Manage	✓	✓	✓	✓	✓			Allow
R12		Manage	✓	✓	✓	✓	✓			Allow
R13		Manage	✓	✓	✓	✓	✓			Monitor
R15		Manage	✓	✓	✓	✓	✓			Allow
R16		Manage	✓	✓	✓	✓	✓			Allow*
R18		Manage	Confirm status	✓	✓	✓	✓			Allow*
R19		Manage	Confirm status	✓	✓	✓	✓			Monitor
R20		Manage	Confirm status	✓	✓	✓	✓			Monitor
R21		Manage	Confirm status	✓	✓	✓	✓			Allow
R25		Monitor*	✓	✓	✓	✓	✓			Allow*
R27	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor
R30	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor
R44		Manage	✓	✓	✓	✓	✓			Allow

* The existence of fencing at sites marked "confirm status" was not verified during the field assessments. WRL conservatively assumed that stock access was present in its analysis at these transects.

Table 6-10: Recommended Riverbank Management Program for On-Ground Works Along the Lower Williams River

Transect	Outside Bend?	August 2015 DSS Management Rating	Regeneration					Rock Fillets	Battering	Management Rating after Immediate Actions
			Fencing*	Exotic Weed Management	Reshaping (Where Possible)	Revegetation	Bioengineering (Where Possible)			
L52	✓	Monitor*	Confirm status	✓	✓	✓	✓			Allow*
L54	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor
L56		Manage	✓	✓	✓	✓	✓	✓	✓	Monitor
L57		Manage	✓	✓	✓	✓	✓			Allow
L58		Manage	Confirm status	✓	✓	✓	✓			Monitor
L63		Monitor*	Confirm status	✓	✓	✓	✓			Allow*
L66	✓	Monitor*	Confirm status	✓	✓	✓	✓			Allow*
L67		Manage	Confirm status	✓	✓	✓	✓			Allow
L75		Manage	✓	✓	✓	✓	✓			Monitor
L76		Monitor*	✓	✓	✓	✓	✓			Allow*
R51		Manage	✓	✓	✓	✓	✓	✓		Monitor
R52		Monitor*	✓	✓	✓	✓	✓			Allow
R54		Monitor*	Confirm status	✓	✓	✓	✓			Monitor
R55		Manage	Confirm status	✓	✓	✓	✓			Monitor
R58		Manage	✓	✓	✓	✓	✓	✓	✓	Monitor
R59		Manage	Confirm status	✓	✓	✓	✓			Allow
R60		Monitor*	✓	✓	✓	✓	✓			Allow*
R62	✓	Manage	✓	✓	✓	✓	✓			Monitor
R63	✓	Manage	✓	✓	✓	✓	✓			Monitor
R64	✓	Manage	✓	✓	✓	✓	✓			Monitor
R66		Manage	✓	✓	✓	✓	✓			Allow*
R67		Monitor*	✓	✓	✓	✓	✓			Allow*
R68		Manage	✓	✓	✓	✓	✓			Allow*
R69	✓	Monitor*	✓	✓	✓	✓	✓			Monitor
R70	✓	Monitor*	✓	✓	✓	✓	✓			Allow*
R71		Manage	✓	✓	✓	✓	✓			Monitor
R72		Manage	✓	✓	✓	✓	✓	✓		Monitor
R73		Manage	✓	✓	✓	✓	✓			Allow*
R74		Monitor*	✓	✓	✓	✓	✓			Allow*
R76	✓	Manage	✓	✓	✓	✓	✓			Monitor*
R77	✓	Manage	Confirm status	✓	✓	✓	✓			Monitor

* The existence of fencing at sites marked “confirm status” was not verified during the field assessments. WRL conservatively assumed that stock access was present in its analysis at these transects.

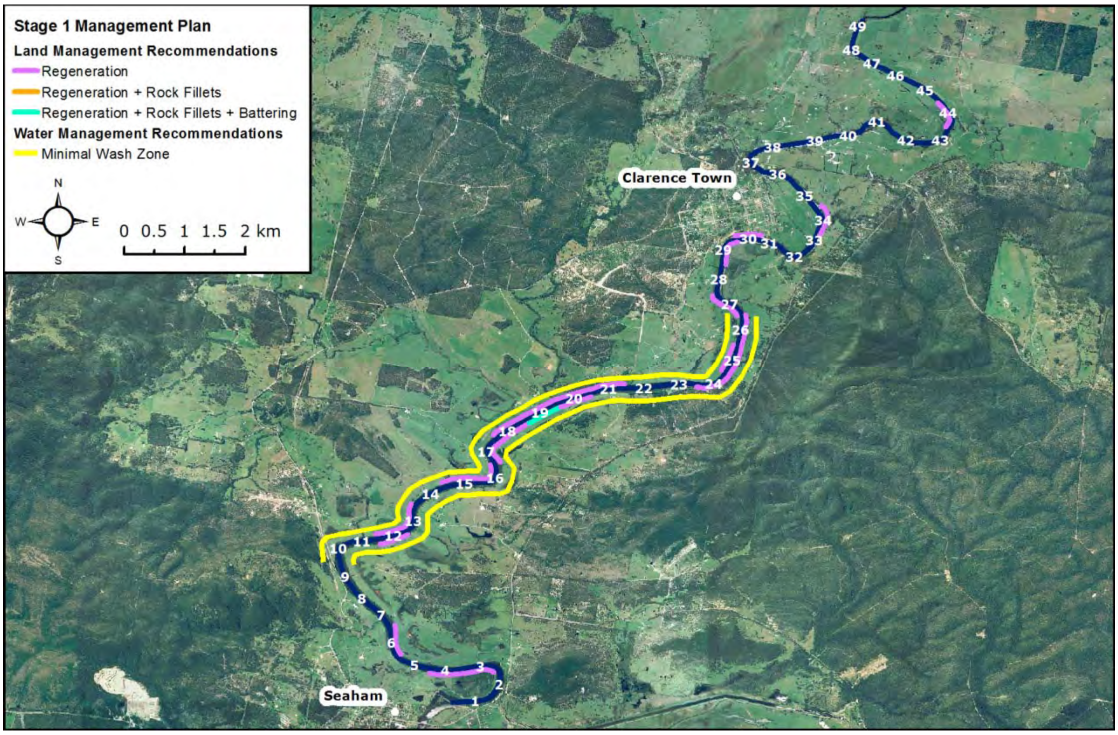

Figure 6-11: Final Management Recommendations for the Seaham Weir Pool

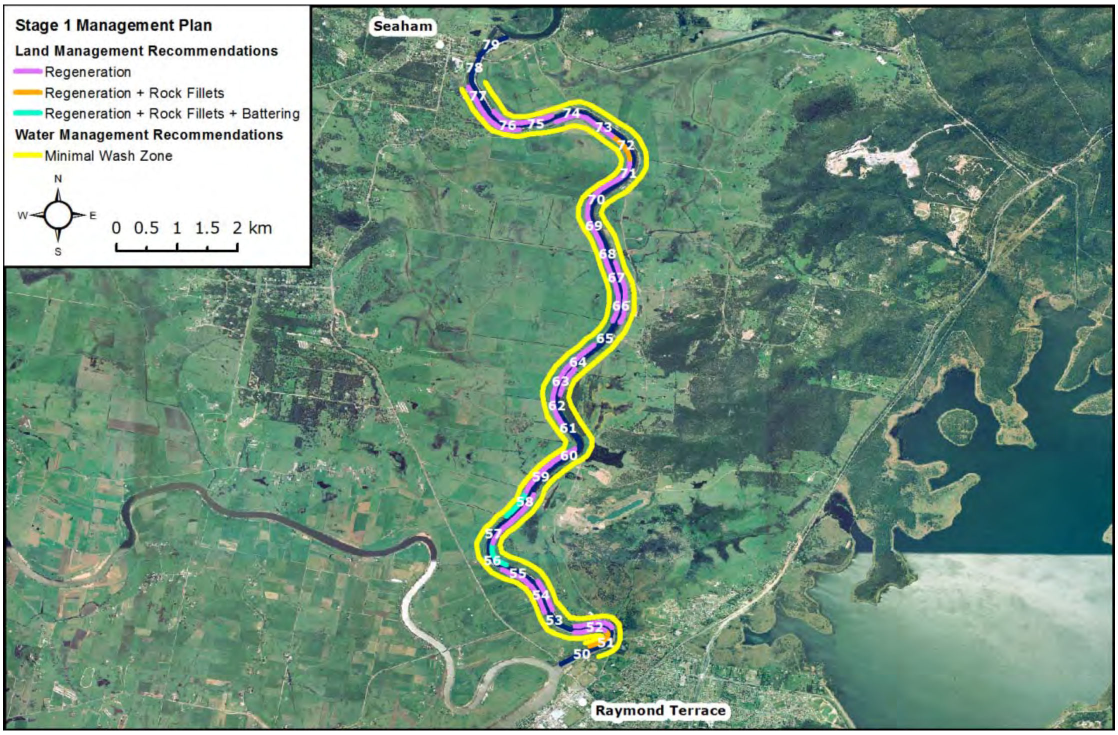

Figure 6-12: Final Management Recommendations for the Lower Williams River

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Appendix A – Literature Review

A.1 Preamble

WRL TR 2012/05 (Glamore and Davey, 2012) reviewed all literature available at the time of writing (2012) on recreational boating and riverbank erosion on both the Seaham Weir Pool and the Lower Williams River. For brevity, literature reviewed in WRL TR 2012/05 was omitted from this present report. Readers unfamiliar with this review are directed to Sections 2.3 and 2.4 of WRL TR 2012/05. However, references for literature reviewed in WRL TR 2012/05 are included below.

Seaham Weir Pool

- Measurements of Sediment and Phosphorous Re-suspension Caused by Boat Generated Waves on the Seaham Weir Pool (Gibson and Ness, 1992);
- Final Draft Williams River Environmental Study: Department of Planning (Umwelt (Australia), 1995);
- The Effects of Wave Action and Other Influences on the Water Quality and Ecology of Seaham Weir Pool (Patterson Britton & Partners, 1996);
- Letter to Brian Ness (Johnston, 1996);
- Wave Action and Bank Erosion behind Seaham Weir in the Williams River (Cowell, 1996);
- Independent Enquiry into the Williams River (Healthy Rivers Commission of NSW, 1996);
- Boating Management at Williams River - Seaham Weir Pool (Cox, et al., 1999);
- Monitoring Survey of Williams River from Seaham to Clarence Town (Harper Somers, 2001);
- Impact of Boating Management Plan on Boating Usage on the Williams River, NSW (Cox and Dorairaj, 2002);
- Re-vegetation Trials on the Williams River, NSW (Roberts and Cummins, 2002);
- Additional Monitoring of Boating Usage, Compliance with Boating Management Plan Williams River - Seaham Weir Pool, NSW (Cox, 2003a);
- Overview of Boating Management Plan Williams River - Seaham Weir Pool (Cox, 2003b);
- Letter to Charlie Dunkley - Re: Williams River Boating Management (Evans, 2004);
- Williams River Best Management Practice Demonstration Project: Riverbank Erosion Monitoring Survey, Williams River Weir Pool 2004-2008, Maitland, NSW (Spearpoint, 2008);
- Letter to Hunter Water Corporation: Williams River Survey Monitoring Project, Seaham to Clarence Town (Holmes, 2008); and
- Riverbank Erosion and Recreational Boating in the Williams River Weir Pool (Gilligan, 2008).

Lower Williams River

- Hunter Estuary Processes Study (MHL, 2003);
- Williams River Bank Erosion Study (GHD, 2006); and
- Assessing the Impact of Wake Boarding in the Williams Estuary, NSW, Australia: Challenges for Estuarine Health (Cameron and Hill, 2009).

Literature published following the release of WRL TR 2012/05 on recreational boating and riverbank erosion on both the Seaham Weir Pool and the Lower Williams River has been reviewed by WRL and is summarised in the following sections of Appendix A.

A.2 Seaham Weir Pool

A.2.1 Letter to Hunter Water Corporation: WRCA Fencing Study (Rayward, 2014)

Mr Digby Rayward, President of the Williams River Care Association (WRCA), wrote to Hunter Water on behalf of the WRCA to present the collation of fencing and cattle grazing information along riverfront properties on Seaham Weir Pool between the Weir and the area immediately upstream of the Clarence Town Boat Ramp (WRL Transects 1-31). The riverbanks were labelled as follows:

- Properties without cattle (30%);
- Properties with cattle and with fencing to restrict cattle access (55%); and
- Properties with cattle but without fencing to restrict cattle access (15%).

WRCA asserted that property owners of riverbank sections with cattle but without fencing were unlikely to introduce fencing in the future due to either:

- High, steep riverbanks which are inaccessible (or provided limited access) to cattle regardless of the presence of fencing; or
- Low, flat riverbanks where fencing is unlikely to survive flood events.

WRCA asserted that unrestricted cattle access is not the primary cause of riverbank erosion on the Seaham Weir Pool and suggested that future studies should focus on the impacts of boating activities on riverbank erosion instead.

A.2.2 River Bank Monitoring Survey for Part of the Williams River (Delfs Lascelles Consulting Surveyors, 2014)

Delfs Lascelles Consulting Surveyors (DLCS) prepared a report comparing riverbank cross-sectional survey profiles (including undercutting) measured at 17 locations along a straight stretch of the Seaham Weir Pool in December 2012 and April 2014. Note that the December 2012 survey was undertaken by RPS Group and the April 2014 survey was undertaken by DLCS. At the +0.6 m AHD contour, approximately equivalent to the median water level (Glamore and Davey, 2012), typical linear change in riverbank position across the 17 measurement locations was -0.4 m (erosion), with a range of -1.1 m (erosion) to +0.2 m (accretion). DLCS noted that there had been substantial changes in the position and profile of the riverbanks at almost all of the locations (but negligible accretion), with the greatest erosion occurring for DLCS measurements locations 12-17.

A.2.2 Regional Boating Plan: Port Stephens - Hunter Region (Transport for NSW, 2015)

The Maritime Management Centre within Transport for NSW prepared the Regional Boating Plan for the Port Stephens – Hunter Region. The plan includes boating restrictions on the Seaham Weir Pool to improve user behaviour, minimise possible environmental impacts and manage on water conflicts as illustrated in Figure A-1.

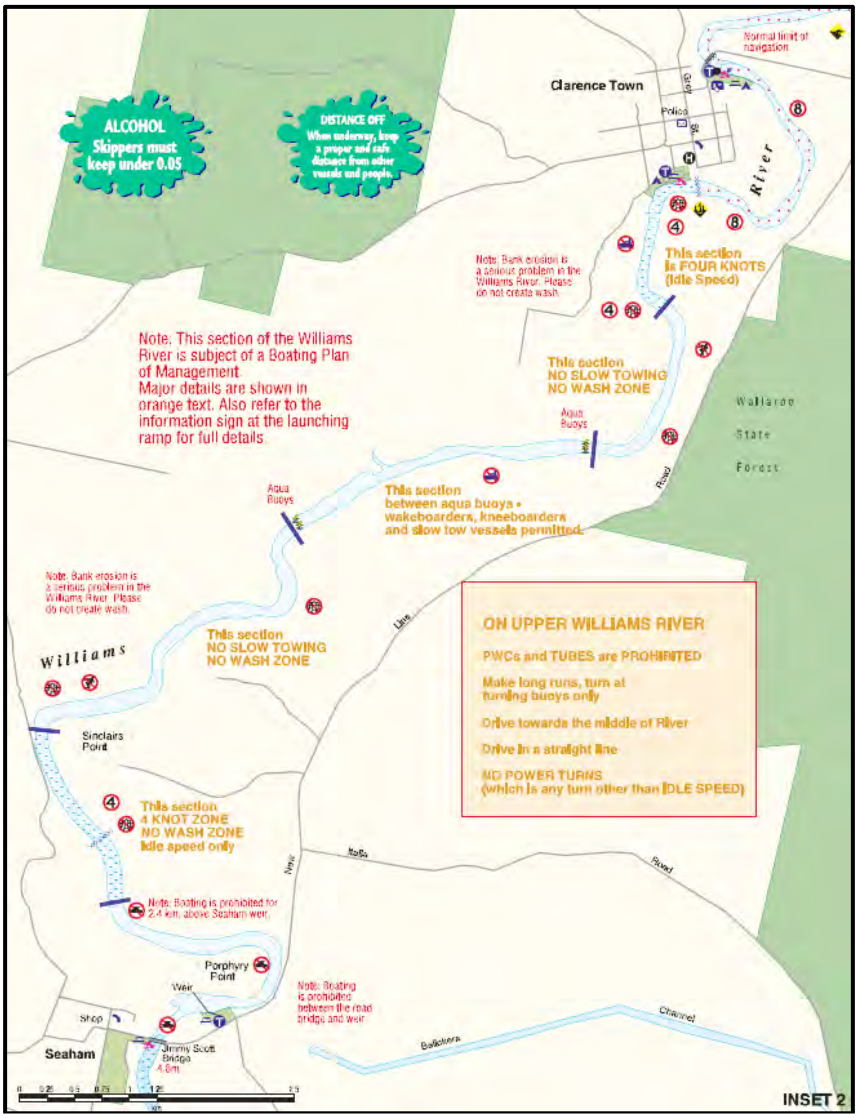


Figure A-1: Boating Safety Restrictions on Seaham Weir Pool (Source: NSW RMS, 2011)

The plan noted that there are two public boat ramps located on the Seaham Weir Pool at Clarence Town (downstream at Wharf Reserve and upstream at Bridge Reserve) and numerous private jetties. Regional projects prioritised in the plan included upgrading both boat ramps at Clarence Town.

In consulting with stakeholders and the general public on the development of the Regional Boating Plan, riverbank erosion (and boating activity's contribution to it) was determined to be the most contentious management issue. The plan notes that, by far, the largest number of submissions received related to boating activity and riverbank erosion on the Seaham Weir Pool.

A.3 Lower Williams River

A.3.1 Williams River Riverbank Erosion Study (WorleyParsons, 2010)

WorleyParsons prepared a report for Port Stephens Council examining the impact of a "No Slow Tow" zone in the middle of the Lower Williams River. This review assessed the influence of the restriction on riverbank erosion rates and riparian vegetation as recommended by GHD (2006). This zone, which prohibits wakeboarding but not Waterskiing, was introduced in conjunction with fencing off of part of the riverbanks on a three (3) year trial basis in May 2007. This study primarily examined riverbank cross-sectional survey profiles (including undercutting) measured at 14 monitoring locations (with corresponding photographs) by Port Stephens Council (PSC) between December 2004 and May 2010.

Table A.2 compares each of the PSC monitoring locations with the nearest WRL transect. The 14 PSC monitoring locations include areas both within and without (no boating restrictions) the "No Slow Tow" zone. Boating is prohibited at two sites located between the Jim Scott Bridge and Seaham Weir which were used as "control" sites. As the riverbanks at these sites are well vegetated and stock access is restricted; WorleyParsons considered that they were the closest representation of riverbanks free from anthropogenic activities within the Lower Williams River.

Table A.2: Comparison of PSC and WRL Riverbank Assessment Locations

PSC Monitoring Location	Nearest WRL Transect	Description
1	R51A	No Boating Restrictions
2	R56B	No Boating Restrictions
3	R63B	No Slow Tow Zone
4	R68B	No Slow Tow Zone
5	R73C	No Boating Restrictions
6	R77B	No Boating Restrictions
7	R79A	Boating Prohibited (Control Site)
8	L79A	Boating Prohibited (Control Site)
9	L75A	No Boating Restrictions
10	L67B	No Slow Tow Zone
11	L63A	No Slow Tow Zone
12	L56C	No Boating Restrictions
13	L54A	No Boating Restrictions
14	L50C	No Boating Restrictions

Riverbank erosion was primarily quantified as the change in position of the top of the riverbank. Prior to analysis of the influence of the introduction of "No Slow Tow" zone, cross-sectional profiles before and after the "Pasha Bulker" flood event in June 2007 were analysed to estimate the flood-induced erosion on the Lower Williams River.

WorleyParsons found that at almost all of the 14 sites, the top of the riverbank position had eroded as a result of the "Pasha Bulker" flood event (comparing February/March and August 2007 profiles). The average erosion measured at the top of the riverbank position was 1.2 m due to the "Pasha Bulker" flood event (range 0.0 to 2.5 m). WorleyParsons asserted that the extent of riverbank erosion during a flood event was influenced by pre-existing undercutting, slumping, vegetation (or lack thereof) and cattle access.

Following the introduction of the “No Slow Tow” zone (comparing August 2007 and May 2010 profiles), average erosion within the zone was 0.2 m (range -0.3 to 0.5 m). Outside the “No Slow Tow” zone, the average erosion was 0.6 m (range -0.1 to 1.8 m). While noting significant scatter in the data, WorleyParsons concluded that, on average, the monitoring locations outside of the “No Slow Tow” zone were more eroded than those locations within it. This conclusion was further supported by comparison of vegetation photographs with significant regrowth within the “No Slow Tow” zone but less (or no) regrowth outside of it during the three (3) year trial period. This increased erosion was partly attributed to boat wake wave attack. More generally, the trend for erosion at almost all of the 14 sites was considered most likely due to the presence of Seaham Weir preventing bed load sediment influx and reducing suspended sediment influx into the Lower Williams River. WorleyParsons also noted that anecdotal evidence existed that slow towing was still occurring within the restricted “No Slow Tow” zone (i.e. non-compliance).

It was more difficult to determine a trend in undercutting measurements, as compared to the top of the riverbank position. However, WorleyParsons noted that while undercutting is generally most evident under mature tree roots, undercutting is less pronounced on more rapidly eroding bare riverbanks without mature trees and other vegetation. That is, the absence or presence of undercutting alone on a riverbank is not directly related erosion resistance.

The study asserted that the full impact of the introduction of boating restrictions within the “No Slow Tow” zone may not be clear for a number of years and that the limited three (3) year time period was not sufficient to draw comprehensive conclusions. In the interim, WorleyParsons recommended that the “No Slow Tow” zone in the middle of the Lower Williams River be retained. If PSC sought to reduce the rate of non-flood induced erosion elsewhere, WorleyParsons recommend that the “No Slow Tow” zone be extended to the entirety of the Lower Williams River. It also recommended that an assessment of boating activity on the Lower Williams River (including boat pass numbers and user activities) would achieve a stronger correlation between these activities and their impacts on riverbank erosion.

A.2.2 Williams & Hunter Rivers Bank Erosion Monitoring Study 2009-2011 (WorleyParsons, 2012)

Following the review of riverbank erosion in 2010 (WorleyParsons, 2010), PSC extended the trial of the "No Slow Tow" zone in the middle of the Lower Williams River, by a further three (3) years to May 2013. In conjunction with this, WorleyParsons prepared a second report for PSC documenting the condition of riverbanks at the same 14 monitoring locations between October 2010 and June 2011.

In reviewing all available data since December 2004, the average erosion measured at the top of the riverbank position was 2.1 m (range -0.3 to 3.1 m). This was approximately equivalent to 25 mm/month. The study speculated on the importance of several factors contributing to erosion as follows:

- Average erosion rates from sites with unrestricted cattle access were marginally higher than for those sites where cattle access is restricted. However, the magnitude of the difference was not significant enough to be conclusive.
- Average erosion rates at meander bends were marginally higher than along straight reaches of the river. However, the magnitude of the difference was not significant enough to be conclusive.
- Over the entire December 2004 to June 2011 monitoring period; the most significant erosion between surveys was observed after the "Pasha Bulker" flood event in 2007 (comparing February/March and August 2007 profiles). The extent of this episodic erosion was equivalent to that measured in the remaining 6.5 year monitoring period.
- Average erosion rates for sites within the "No Slow Tow" zone were lower than for those sites without restrictions. On this basis, WorleyParsons cautiously noted (but not conclusively) that the establishment of the "No Slow Tow" zone had made a positive contribution to slowing the rate of erosion within the zone and should continue to be retained. In addition, vegetation had noticeably recovered within the "No Slow Tow" zone. However, it was stated that a single monitoring site within the "No Slow Tow" zone continued to record the highest erosion rate for any site in the Lower Williams River. No explanation was put forward to support this observation.

For those sites without restrictions, the rate of erosion had increased since the introduction of the "No Slow Tow" zone. In particular, one (1) site 2.4 km upstream of the "No Slow Tow" zone recorded the second highest erosion rate in the Lower Williams River. WorleyParsons speculated that this may be due to the introduction of the "No Slow Tow" zone "pushing" recreational boat activities further upstream resulting in more intense boating at this location. On this basis, it was recommended that the "No Slow Tow" zone be extended approximately 2.4 km further upstream. The study also recommended that the bathymetry cross-sections be surveyed at the northern end of the "No Slow Tow" zone and at the site 2.4 km upstream to determine whether riverbed erosion was linked with riverbank instability in the area.

As with the previous WorleyParsons report, it was recommended that an assessment of boating activity on the Lower Williams River (including boat pass numbers, user activities and locations) be undertaken. A new recommendation was also set out that the location and frequency of cattle access be included in future monitoring programs.

The report also documents Lower Williams River areas where rock fillets and timber retaining works have been undertaken to stabilise the riverbank. The areas where major bank stabilisation works have been undertaken are identified in Figure A-2.

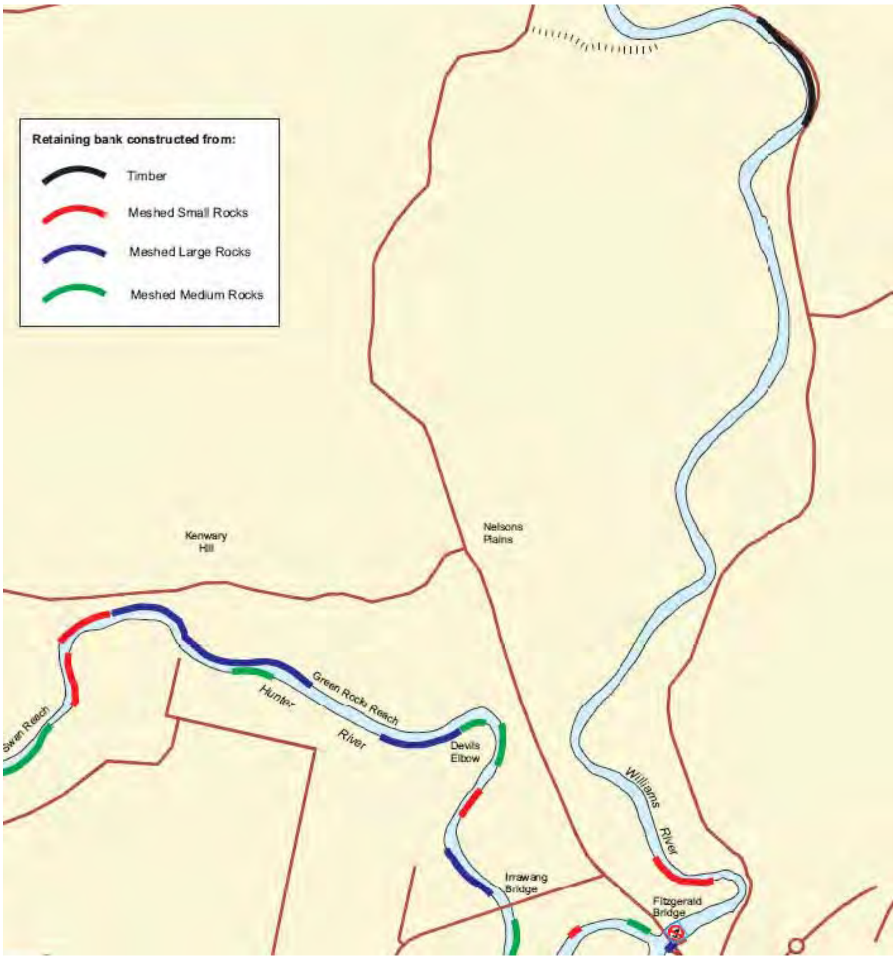


Figure A-2: Sites of Major Bank Stabilisation Works Along the Williams River (Source: RMS, 2009)

A.2.3 Regional Boating Plan: Port Stephens - Hunter Region (Transport for NSW, 2015)

The Maritime Management Centre within Transport for NSW prepared the Regional Boating Plan for the Port Stephens – Hunter Region. The plan includes boating restrictions on the Lower Williams River to improve user behaviour, minimise possible environmental impacts and manage on water conflicts as illustrated in Figure A-3.

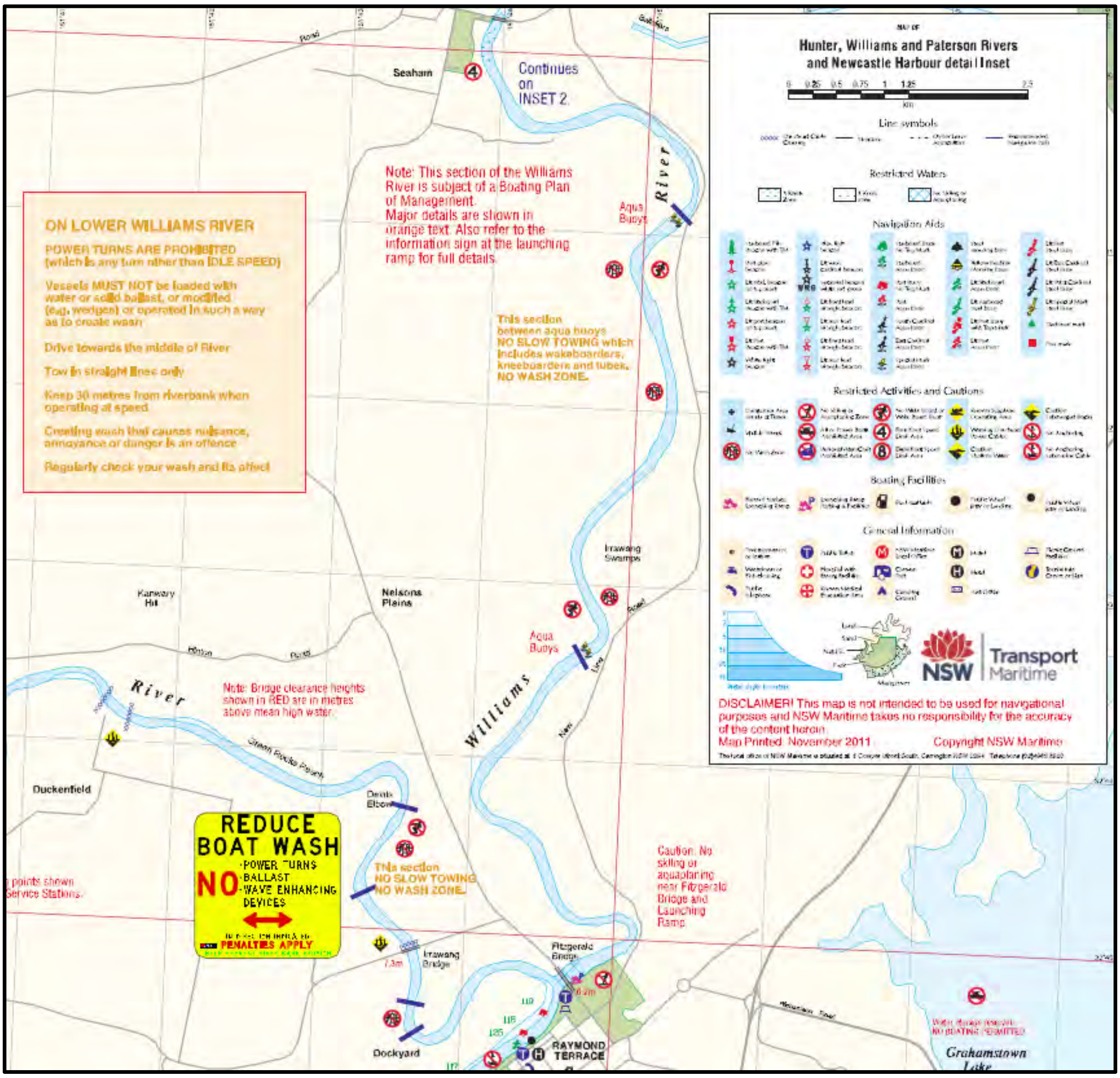


Figure A-3: Boating Safety Restrictions on Lower Williams River (Source: NSW RMS, 2011)

The plan noted that there are two public boat ramps located on the Lower Williams River (Raymond Terrace and Seaham) and numerous private jetties. A regional project prioritised in the plan included upgrading the boat ramp at Seaham.

The plan notes that a noticeable number of safety complaints (including irregular riding of personal watercraft, vessels not observing distances off and generation of wash) were received from within the Raymond Terrace area.

Appendix B – Wave Theory

B.1 Preamble

Wave theory is a large and complex discipline which ranges in scale from micro-sized waves to tsunamis. Furthermore, even first-order wave theory can contain intricate and advanced calculations. This review of basic wave theory focuses primarily on the theory directly applicable to this study. Only the most pertinent equations have been provided and the majority of the mathematics has been withheld from the text. Fundamental wave components are provided in Section B.2, with wind wave generation and propagation detailed in Section B.3 and boat wake wave generation and propagation discussed in Section B.4.

B.2 Fundamental Wave Components

The primary components characterising individual waves are wave period and wave height. The wave period (T) is defined as the time it takes for two successive wave crests or troughs to pass a given point. The vertical distance between a wave trough and crest is the wave height (H) (Figure B-1). Other useful variables include wavelength (L), the distance between consecutive wave crests or troughs, and celerity (C), the speed of the wave defined as the quotient of the wave length and wave period ($C = L/T$).

The wave components listed above can be used to describe either a single wave or a series of waves within a group, commonly referred to as a wave train. Throughout international literature for boat wake waves, both the largest wave height recorded within the wave train (H_{max}) and the wave with the largest period in the train (T_{peak}) are used to characterise the wave train. This difference is important, as sometimes the wave with the maximum height may not have the longest period (or vice versa) (Glamore and Hudson, 2005).

The energy within a wave is calculated using the wave height and period, as shown in Equation B-1. To calculate the total energy of waves within a wave train the individual wave energies are summed (Maynord, 2001). When measured under similar conditions, the total wave energy can be used to compare waves from multiple sources.

$$E = \frac{\rho g^2 H^2 T^2}{16\pi} \qquad \text{(B-1)}$$

where

- E = wave energy (per unit width of wave crest) (J/m)
- ρ = water density (kg/m^3)
- g = gravitational constant (m/s^2)
- H = wave height (m)
- T = wave period (s)
- π = constant (≈ 3.14)

Water depth (d) can have a significant influence on wave characteristics. As water depth decreases towards the shoreline, shoaling processes reshape the wave, potentially causing wave breaking. This shape is largely a function of water depth and wavelength, as waves begin to ‘feel’ the bottom when the ratio of depth/wavelength (d/L_w) is less than 0.5. For this type of assessment, waves can only be compared when the waves maintain a linear, sinusoidal wave shape (Parnell and Kofoed-Hansen, 2001).

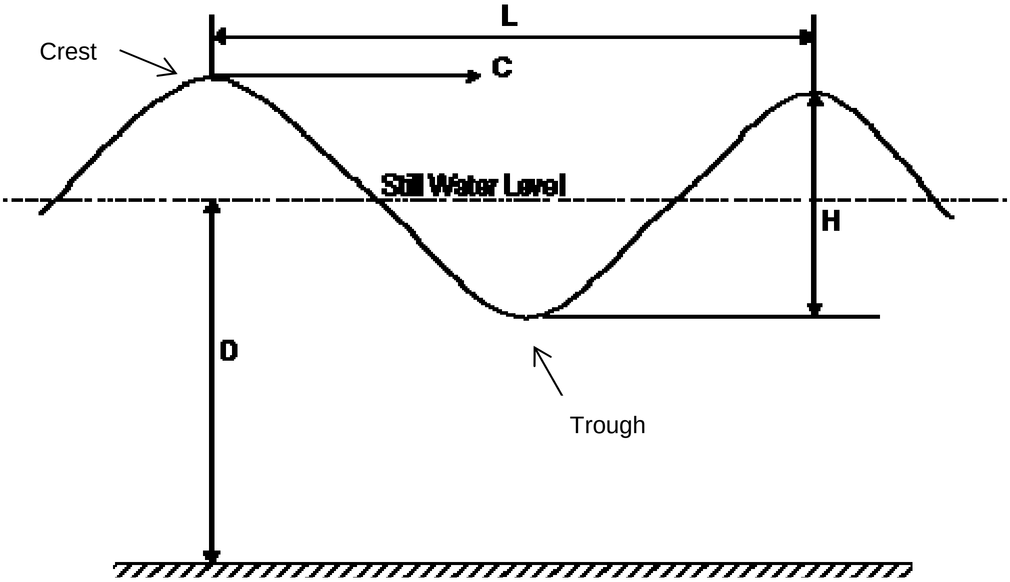


Figure B-1: Wave Characteristics

B.3 Wind Wave Generation and Propagation

The natural wind wave environment along a reach of a river is one of the shaping factors of the waterway. Wind waves are generated by wind blowing across a stretch of water. The available length of water for the wind to blow across is called the 'fetch'. The size of the waves may be limited by either the duration of the wind blowing or the length of the fetch. It is assumed that a waterway subjected to a certain wind-wave environment will establish equilibrium with that environment. For this reason, within the DSS the natural wind wave climate should be assessed for each site. The energy of wind waves can then be compared with the energy of boat wake waves. *Where the energy of the boat wake waves is of similar magnitude to the energy of the natural wind wave environment, it is unlikely that the boat wake waves will cause additional damage. If, however, boat wake wave energy greatly exceeds the prevailing wind wave energy of the site, accelerated erosion is more likely to result.* This section describes the method used to calculate wind wave energy at a site.

It is important to note that the factors which determine whether a wave will erode a riverbank are complex and not fully understood. The erosion potential depends on many factors including, but not limited to, both the maximum wave energy of a single wave and the combined impact of several waves over a longer duration. For this reason, the wind wave energy of a location is characterised in two ways. Firstly, the maximum fetch-limited wave energy is determined based on different wind speeds. Secondly, the cumulative wind wave energy for an extended duration is calculated to determine cumulative energy effects. Eight hours has been selected as an appropriate duration for calculating cumulative energy as it approximates the hours during which boats are likely to be travelling on an average day. However, when considering a more extreme case for the Williams River, 500 boat passes per day, a duration of twelve hours has been used as it is estimated this would only take place in summer when daylight hours are maximised.

Wind wave generation in deep water is governed by the wind speed, wind fetch and wind duration. If the development of the wave is hindered by the length of the fetch, the wind waves are termed fetch-limited, whereas if development is hindered by the duration of the wind, the waves are duration-limited. The current industry standard for coastal engineering works is the US Army Corps of Engineers Coastal Engineering Manual (CEM), (2006) which outlines a method for predicting wind waves for a selected site. The methodology used within the DSS utilises equations outlined in CEM.

B.3.1 Single Short Duration Maximum Fetch-Limited Waves

The following steps are used to calculate the maximum fetch-limited waves at a site. These values are used to compare the single maximum energy wind waves at a site with the maximum boat wake waves.

1. Determine the fetch length in compass directions at the location of interest (i.e. the distance over water for which the waves can develop).

2. Using the fetch length for each direction and the matrix of wind speeds for the location, calculate the time ($t_{x,u}$) in seconds for the waves to become fetch limited using Equation B-2. The wind speed used is the upper limit of each interval.

$$t_{x,u} = 77.23 \frac{X^{2/3}}{u^{1/3} g^{1/3}} \quad \text{(B-2)}$$

where

X = fetch length (m)
u = wind velocity (m/s)
g = acceleration due to gravity (9.81 m/s^2)

3. If the time, $t_{x,u}$ is less than the wind duration, the wave is duration limited. To maximise the waves generated by the wind, the waves can be converted to fetch limited waves by increasing the wind duration to the time for the waves to become fetch limited $t_{x,u}$. To calculate the wind speed at varying durations, the wind speed is firstly converted to a one hour wind speed u_{3600} before being converted to the wind speed u_i for the appropriate duration using the following equations:

$$\frac{u_i}{u_{3600}} = 1.277 + 0.296 \tanh\left(0.9 \log \frac{45}{t_i}\right) \quad (1<t_i<3600) \quad \text{(B-3)}$$

$$\frac{u_i}{u_{3600}} = -0.15 \log t_i + 1.5334 \quad (t_i>3600) \quad \text{(B-4)}$$

4. Wave growth with fetch can then be calculated using the following equations:

$$H_{m,0} = 4.13 \times 10^{-2} \left(\frac{u_*^2}{g}\right)\left(\frac{gX}{u_*^2}\right)^{\frac{1}{2}} \quad \text{(B-5)}$$

$$T_p = 0.651 \left(\frac{u_*}{g}\right)\left(\frac{gX}{u_*^2}\right)^{\frac{1}{3}} \quad \text{(B-6)}$$

where

$H_{m,0}$	= energy-based significant wave height (m)
T_p	= wave period (s)
u_*	= friction velocity
	= $(u^2 C_D)^{1/2}$
C_D	= drag coefficient
	= $0.001(1.1 + 0.035u)$

The product of these calculations is a matrix of wind waves that occur for a percentage of time based on the percentage of time the wind is observed to blow for a certain combination of direction and speed.

B.3.2 Extended Duration Wind Waves

While the previous section details how to determine the height and period of a wind wave at a specific site, it does not include a duration or time period over which this event is assumed to be occurring. The steps used to calculate the cumulative waves generated at a site over an extended duration (8 - 12 hours) are the same as those in Section B.3.1 with the following minor modifications:

1. Equations B-3 and B-4 are used to convert the 10 minute wind speeds to 8 hour duration wind speeds;
2. Wave growth with fetch is then calculated according to Equations B-5 and B-6 using the duration adjusted wind speeds; and
3. The number of waves calculated over the extended duration is calculated by dividing the duration by the wave period.

The output of these calculations is a second matrix of wind waves that occur for a percentage of time based on the percentage of time the wind has been blowing in a certain direction at a certain speed.

B.3.3 Wind Wave Energy

Wave energy (E) is a function of both wave height and wave period, and can be calculated according to Equation B-1. For each wind speed, the energy associated with the wave generated can now be calculated. Wind wave energy generated over the extended duration is simply the product of the energy of a single wave and the number of waves generated over the duration.

B.3.4 Average Recurrence Interval

The Average Recurrence Interval (ARI) provides the likelihood of a wave occurring within the selected time period. In this methodology, the ARI represents the probability of a wave occurring at a site based on the available wind data. Calculating the wind wave ARI's for both individual waves and waves over a period of time is important for comparing these waves against boat generated waves.

Using the record length of the wind data, the ARI of the wind wave energies can then be approximated using the following steps:

1. Sort the wind wave energies from least to greatest, where the greatest is rank 1;
2. Calculate the cumulative per cent occurrence for each of the records; and

3. Assign an approximate ARI for the greatest wind energy equal to the record length (n).
4. Calculate an approximate ARI for each of the remaining records (i) by dividing the record length (n) by the cumulative per cent occurrence for the previous energy record (i-1), then multiplying it by the total number of wind observations including calms (w_{obs}) plus 1. This is equivalent to the record length (n) divided by the rank of each energy record ($rank_i$).

$$ARI_i = \frac{n}{(Cumulative\ \%_{i-1} \times w_{obs}) + 1} = \frac{n}{rank_i} \qquad \text{(B-7)}$$

This needs to be completed for the energy of the single short-duration maximum fetch-limited waves and the cumulative energy of the extended duration wind waves, thereby generating two sets of values.

B.4 Wake Wave Generation and Propagation

Every vessel that moves through the water generates wake waves. Most boats generate at least two sets of waves; divergent waves which move out from the bow at an angle and transverse waves that move out from the stern (Macfarlane and Cox, 2003). The height and period of the waves in the wave train are largely associated with factors relating to the vessel and its operation including hull design, displacement, trim, loading, speed, method of propulsion, course, rate of change in course, etc. Other than at critical speeds, the energy of transverse waves from recreational vessels is negligible (Macfarlane and Cox, 2003). The propagation of divergent waves is a function of the hull form (Prismatic Coefficient), angle of entry, vessel speed, and speed-length ratio, and can take up to 5 boat lengths to fully develop (Maynord, 2001).

Boat speed has a significant influence on whether a boat is in displacement or planing mode (Figure B-2). When in displacement, or sub-critical, mode (i.e. lower speeds) short-crested divergent waves and transverse waves are present. When travelling in planing, or super-critical, mode (i.e. faster speeds) the divergent waves become long-crested and transverse waves fade away.

Johnson (1958) proposed the use of Froude numbers which relate the length of a vessel to boat velocity. These numbers can be used to indicate the conditions under which maximum wave height and length are produced. The length-based Froude number (F_L) defines that each vessel of a specific length will generate its maximum wave length when F_L is between 0.39 and 0.50 (Johnson, 1958) as calculated by:

$$F_L = v_s / \sqrt{g L_w} \qquad \text{(B-8)}$$

where

v_s = vessel speed (m/s)
L_w = vessel length at the water line (m)
g = gravitational constant (m^2/s)

The maximum wave height is produced when a boat is travelling at the same speed as the propagating wave train and is calculated using the depth-based Froude number (F_d) (Johnson, 1958). This wave height occurs when F_d = 1:

$$F_d = v_s / \sqrt{g h} \qquad \text{(B-9)}$$

where

h = water depth (m)

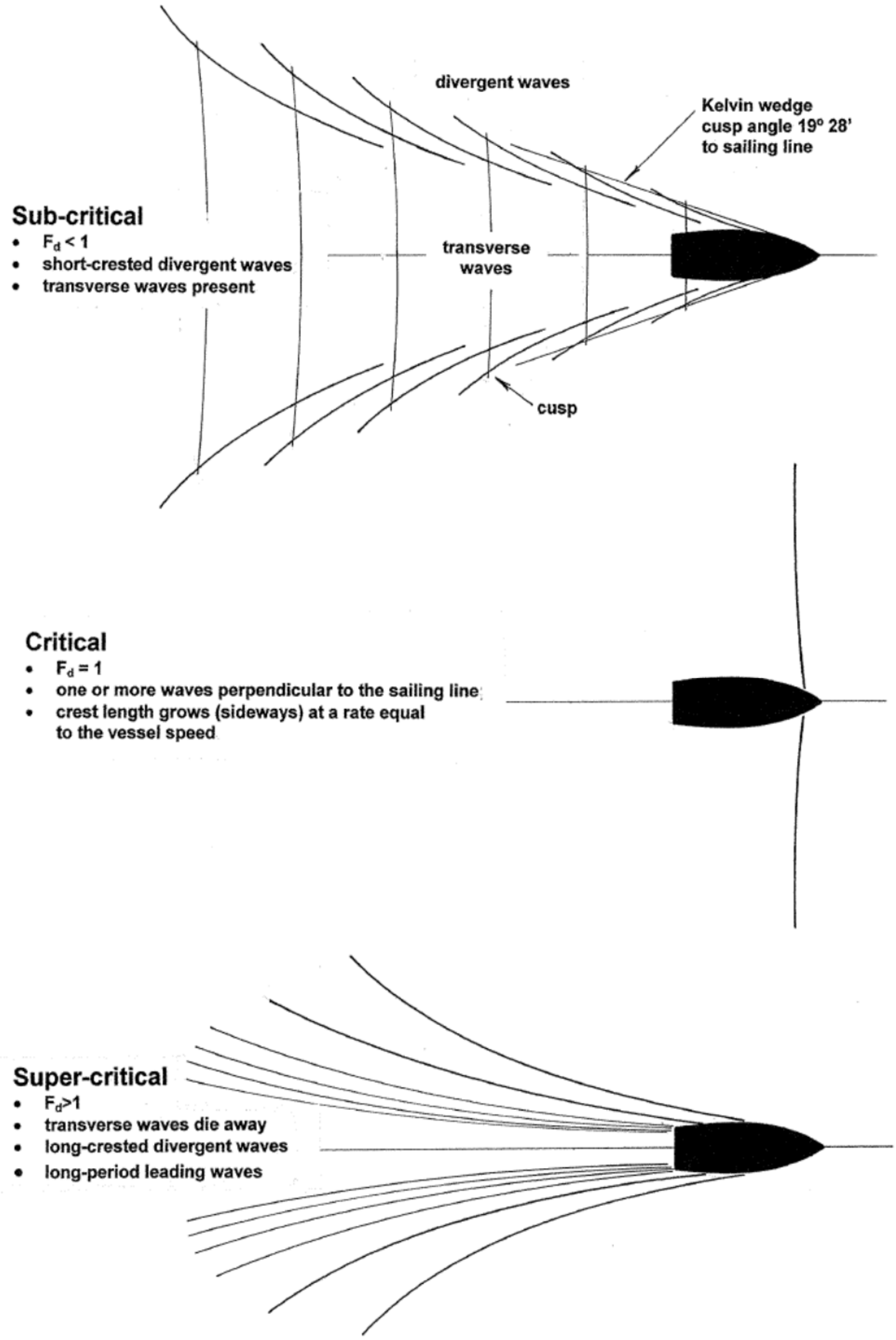


Figure B-2: Wake Wave Patterns (Source: Macfarlane and Cox, 2003)

The aforementioned Froude numbers can be used to determine when a theoretical vessel travelling at a given speed and depth would produce its maximum wave condition (Maynord, 2005). For instance, the majority of vessels used for waterskiing and wakeboarding have a length of approximately 6.0 m, which equates to a maximum transverse wavelength ($F_L = 0.5$) at a speed of approximately 7.5 knots (Glamore and Hudson, 2005). Furthermore, in water with an average depth of 10 m, these vessels would have to travel faster than 20 knots to maintain super-critical divergent wave patterns ($F_D > 1.0$) (Glamore and Hudson, 2005).

While this information is useful in gaining a fundamental understanding of the wave conditions based on vessel length, speed and water depth, it is important to note that a very small change in displacement (loading) or trim can have a major impact on wake height. Stumbo et al. (1999) indicated that a change in dynamic trim of as little as one degree can double the wash energy of a given vessel at a given speed. This is important because the vast majority of wakeboarding vessels have the capacity to alter loading and trim to optimise wake generation through ballasting (Glamore, 2011).

Once the boat waves are generated, the resultant wave train is influenced by a range of environmental factors including wind, water depth, riverbed characteristics, natural waves, tidal currents and other vessels. In a typical wave train, the wave height of the divergent waves attenuates due to diffraction as shown in Equation B-4 (Macfarlane and Cox, 2003). In contrast, as the wave train moves away from the vessel the waves disperse and the wave period increases. This spreading of the wave train continues for 2 - 5 boat lengths, after which the wave period remains relatively unchanged in deep water.

$$H = \gamma y^{-1/3} \quad \text{(B-10)}$$

where

H = wave height (m)

γ = variable dependent on the vessel and its speed

y = lateral distance from the sailing line (m)

If the wave travels into shallow water where it 'feels' the bottom, the wave will cease dispersing and become depth-limited. Within a wave train, waves with a longer wave period will become depth-limited prior to waves with a shorter wave period. If the wave continues to propagate into shallower waters, the wave height will increase while the wavelength and phase velocity decrease until the wave shoals and break (Glamore and Hudson, 2005). The impact of the breaking wave on the riverbank is an important component of the DSS used and discussed in Appendix C.

Appendix C – The Decision Support System (DSS) Method

C.1 Preamble

The need for a comprehensive, field tested methodology to determine the vulnerability of a riverbank to erode due to boat waves has been highlighted in several studies and via comparative techniques on waterways in Australia and around the world (e.g. Cowell, 1996; Johnston, 1996; Glamore and Hudson, 2005). The DSS developed by Glamore and Badenhop (2006; 2007) provides a standard methodology for assessing the erosional vulnerability of a riverbank, providing recommendations on the likely impact of recreational boat wake waves along a waterway using an evidence-based approach.

This section describes the DSS methodology. Specifics of the DSS application to the study area are found in Section 4 of the main body of the report and the results of the study in Section 5, with accompanying discussion and recommendations in Sections 6 and 6.3, respectively.

To accurately assess the range of processes involved, the DSS comprises several components. It combines the energy of the wake wave generated from the passing vessel and number of boat passes, the background wind energy and the erosive potential of the riverbank (Figure C-1). The DSS incorporates wake data from several types of boats operating at a range of speeds as measured in controlled field conditions. The wake wave energy is compared to the average recurrence interval (ARI) of the wind wave energy onsite. This comparison is undertaken for both the maximum generated wake wave and the total wave energy generated from a selected day involving multiple boat passes.

The DSS addresses previous inadequacies (e.g. Cowell, 1996; Johnston, 1996) by comparing wind wave energy with wake waves in a comprehensive manner. Previous comparison methods either addressed the energy of the maximum wave, or the cumulative energy of a series of waves. In the DSS, the probable impact of boat wake waves is assessed using both the energy of the maximum wave and the cumulative energy of multiple waves over a specified time period. The inclusion of both of these mechanisms is important as boat wake waves may cause damage to a riverbank via a solitary wave or the cumulative effect of multiple wake waves over an extended period of time.

Within the DSS, the wind/boat wave assessment is combined with a field assessment of bank erosion potential, specific to each location, to produce a management recommendation. The end result is one of three management categories: Permit (‘Allow’), Permit with Monitoring (‘Monitor’) and Manage (‘Manage’). These outcomes are discussed in more detail in Section C.6.

Results from the DSS can be used to quantitatively assess riverbank sections or provide overall waterway management. It has been trialled at various locations in NSW to ensure that it provides robust and scientific results (Glamore and Badenhop, 2007). These trials allowed for calibration and adaptation of the DSS to a wider range of conditions. *A fundamental assumption of the DSS is that it assumes that in an ideal environment, the riverbank has the potential to be in a dynamic equilibrium with the wind environment, and subsequently that boat wave energy exceeding the wind environment, depending on the relative magnitude and the riverbank vulnerability, has the potential to negatively impact the riverbank.*

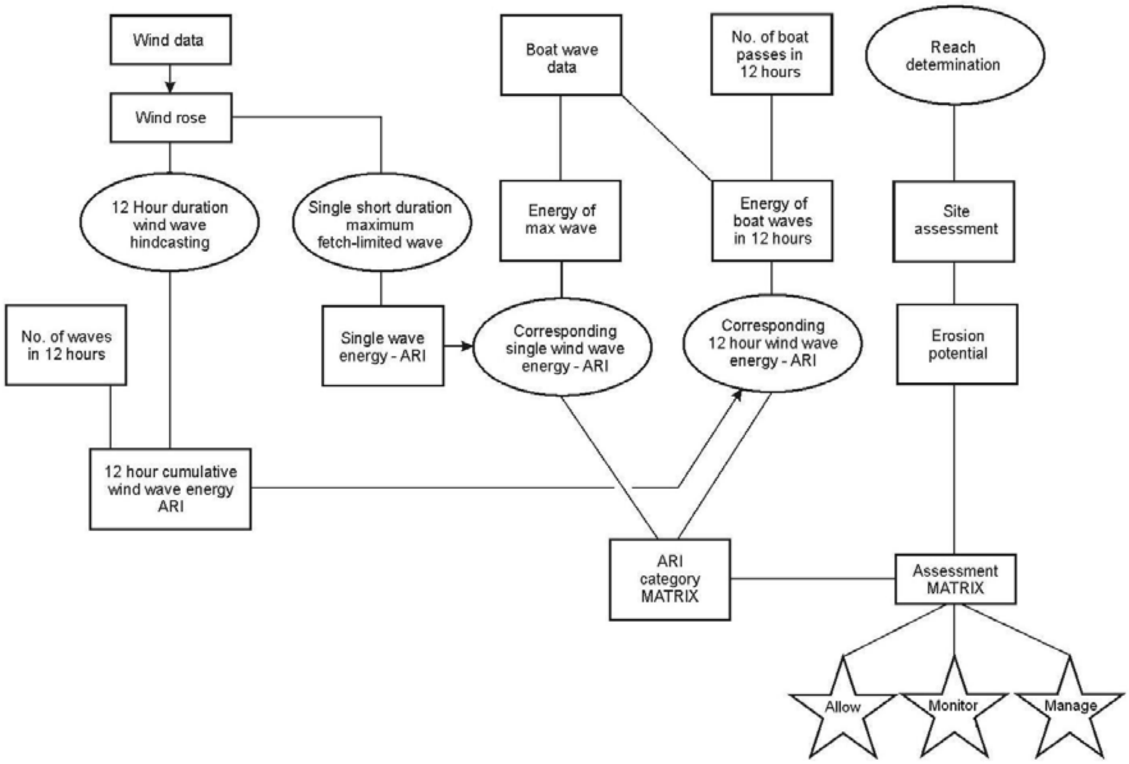


Figure C-1: Flow Diagram of the Decision Support System

C.2 Site Selection

The study area must be determined prior to undertaking any aspects of the field assessment. The entire study area is initially divided into stretches. These sections should generally be no greater than 500 m. As part of the process each riverbank is identified by one of the following geomorphic conditions: straight; inner-bank; or outer-bank. The length of each section should be chosen to ensure continuity in geomorphic condition. The DSS recommends at least 30 % (randomly chosen) of the stretches be observed to gain an adequate understanding of the state of the river. Each of the stretches selected for analysis is then divided into three sections and a 10 m wide transect at the midpoint of each section is assessed (Figure C-2). The erosion potential of the three (3) transects is averaged for each stretch. Note that for this study 100 % of all stretches selected were assessed.

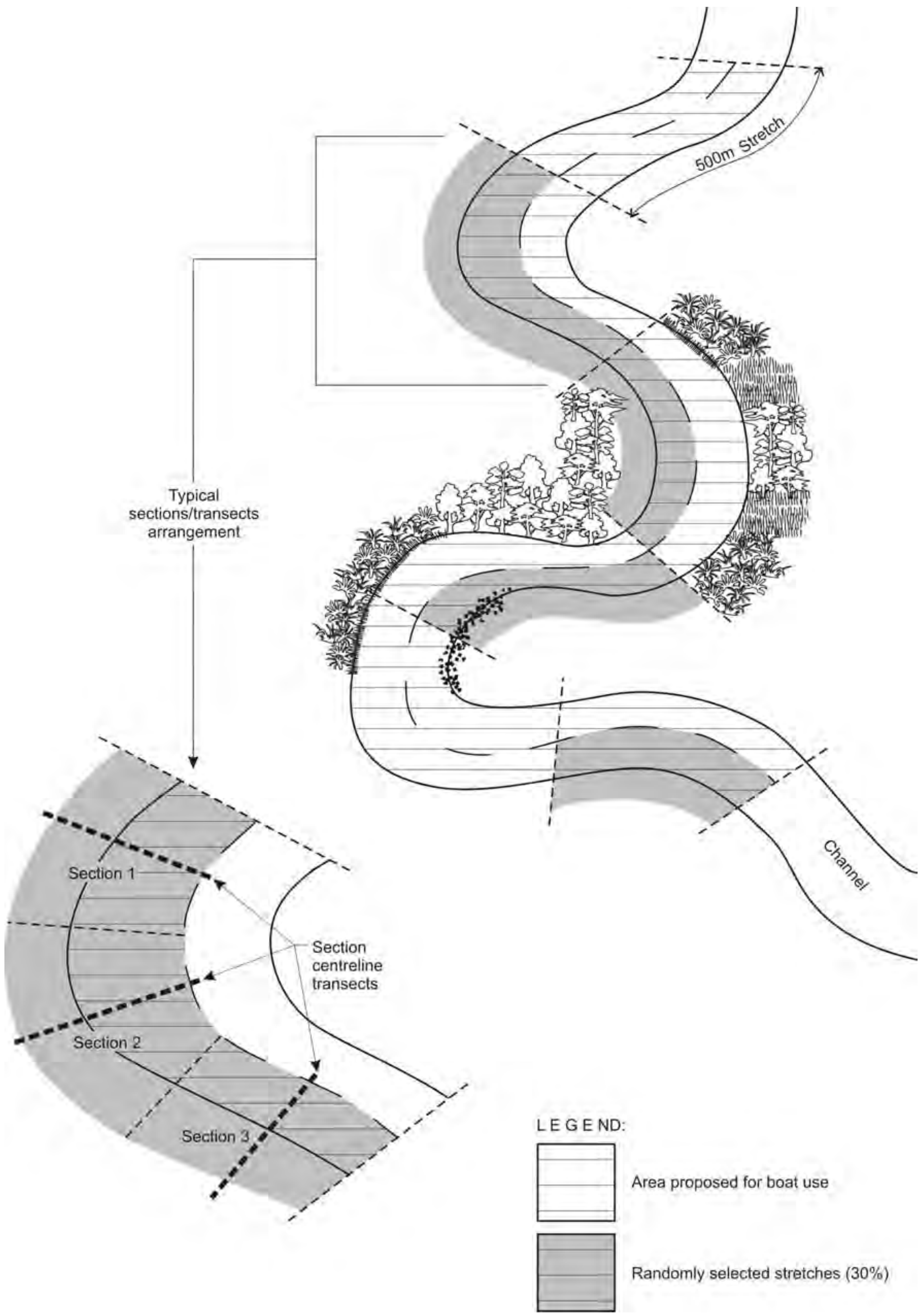


Figure C-2: Transect Locations

C.3 Wind Waves

The natural wind-wave environment is a shaping factor of any waterway. Wind waves are generated by wind blowing across a distance of water, also known as a 'fetch'. The size of the waves may be limited by the duration of the wind or the length of the fetch. It is assumed that in an ideal environment, a waterway subjected to a particular wind-wave climate has the potential to establish a dynamic equilibrium with that wind environment. In the DSS the natural wind wave climate is assessed for each site, with fetch lengths determined from the middle of each stretch. The natural energy of the wind waves can then be compared with the energy of boat wake waves.

The Average Recurrence Interval (ARI) of the wind waves is used for this comparison. The ARI provides the likelihood of a wave occurring within the selected time period. In this methodology, the ARI represents the probability of a wave occurring at a site based on the available wind data. It is important to note that the factors determining whether a wave will erode a riverbank are complex and not fully understood. Erosion depends on many aspects including, but not limited to, the maximum energy of a single wave and the combined impact of many waves over a longer duration. Subsequently, the wind wave energy of a location is characterised in two ways in the DSS. First, the maximum fetch-limited wave energy is determined based on different wind speeds. Second, the cumulative wind wave energy for an extended duration is calculated to determine cumulative energy effects. Eight to twelve hour periods are recommended as an appropriate duration for calculating cumulative energy as it approximates the daylight hours during which boats are likely to be travelling. A more detailed example of wind wave calculations is provided in Appendix I.

C.4 Wake Waves

To enable comparison of boat waves with wind waves, the maximum wave is first extracted from collected field data of boat waves and the associated energy calculated. The wave energies included in the DSS are from controlled field tests on a range of vessels (Glamore and Badenhop, 2006). The wave characteristics can be selected for waterski or wakeboarding vessels performing under a range of conditions, including operational conditions, maximum wave generated and 4 knots. Subsequently, the maximum likely wave and the wave produced when travelling under the selected conditions are calculated. This information is then combined with the number of boat passes on the river in a given period. The user is also required to enter the minimum boat distance from shore.

The energy of the maximum wave is extrapolated to the energy of the entire wave train. The wave attenuation equation is applied to determine the likely energy of the wave when it reaches the riverbank. The energy of the entire wave train can then be multiplied by the number of boat passes over a specific time period to calculate the cumulative boat wake wave energy at the riverbank over the specified duration (8 - 12 hours). These two datasets are then compared to the previously calculated wind wave energy.

C.5 Riverbank Erosion

A detailed literature review on bank erosion was conducted to inform the development of the DSS. Key factors in the riverbank stability were found to include vegetation, stock access, sediment type and channel equilibrium. Additionally, bank instability may be caused by factors producing bed lowering, such as de-snagging, sand and gravel extraction, and construction of dams and weirs. Several different methods for assessing river condition were discussed and considered; their applicability for erosion potential assessment is detailed in Glamore and Badenhop (2006).

The bank erosion potential assessment included in the DSS estimates the susceptibility of riverbanks to erode due to boat wake waves. Key criteria and importance weightings are combined to form an erosion potential rating for the site. These criteria include river type, vegetation coverage and extent, erosion descriptors, adjacent land use and channel features. A full list and detailed description of the categories, indicators and weightings used within the DSS can be found in Glamore and Badenhop (2006).

The erosion potential is assessed at three transects along both banks of the river for each stretch (Assessment Sheet – Appendix F). A score is given for each transect (Table C-1) and these scores are averaged to obtain a final erosion potential category for the stretch of riverbank. Sites with highly negative erosion potential scores have a low resistance to erosion, whereas sites with strongly positive erosion potential scores should be well protected from bank erosion.

Table C-1: Erosion Potential Categories

Erosion Potential Score	Erosion Potential Category
≥ 40	Highly Resistant
20 to 40	Moderately Resistant
20 to 0	Mildly Resistant
0 to -25	Moderately Erosive
-25 to -97	Highly Erosive

C.6 Final Decision Support System Recommendations

Following the calculation of the boat wake wave energy, the wind wave energy and the erosion potential of the sites, the data is fed into a series of matrices determining the management recommendation. A rating must be completed for each stretch of the river to be analysed.

The first matrix (Table C-2) compares the ARI of the wind wave energy against the boat wave energy for both a single maximum boat wave train and an extended duration period (8 - 12 hours). The aim of this assessment is to determine the equivalent ARI of the boat wake wave energy. The outcome from Table C-2 is then compared to the calculated erosion potential for each stretch (Table C-3). The lower and upper bound recurrence intervals for each Wind ARI Rating Category are also shown in Table C-4 in readily understandable time intervals. An example of the wave comparison calculations are provided in Appendix I.

Depending on the management recommendation determined in Table C-3 varying general recommendations and suggestions for reassessment periods are provided. The permit (or 'Allow') recommendation occurs when the site has a low erosion potential and there is limited difference between wind and wake wave energies. In these circumstances the vessel in question should be permitted to operate. It is advised that after five (5) years the site be reassessed to determine if the boat wake waves have increased the erosion potential (Glamore and Badenhop, 2006).

Table C-2: Equivalent Wind ARI Rating

Equivalent Wind Wave ARI for Maximum Boat Wave Energy (years)	Equivalent Wind Wave ARI of Boat Pass Scenario for Extended Duration (years)					
	$<9.58\times10^{-3}$	9.58×10^{-3} – 1.92×10^{-2}	1.92×10^{-2} - 3.83×10^{-2}	3.83×10^{-2} - 1.53×10^{-1}	1.53×10^{-1} - 3.07×10^{-1}	$>3.07\times10^{-1}$
$<9.58\times10^{-3}$	A	A	B	C	C	C
9.58×10^{-3} – 1.92×10^{-2}	A	B	B	C	C	D
1.92×10^{-2} - 3.83×10^{-2}	A	B	C	C	D	D
3.83×10^{-2} - 1.53×10^{-1}	B	B	C	C	D	D
1.53×10^{-1} - 3.07×10^{-1}	B	C	C	D	D	E
$>3.07\times10^{-1}$	B	C	C	D	E	E

Table C-3: Final Management Recommendation

	Erosion Potential Category				
ARI Rating	**Highly Resistant**	**Moderately Resistant**	**Mildly Resistant**	**Moderately Erosive**	**Highly Erosive**
A	ALLOW	ALLOW	ALLOW	MONITOR	MANAGE
B	ALLOW	ALLOW	MONITOR	MONITOR	MANAGE
C	ALLOW	MONITOR	MONITOR	MANAGE	MANAGE
D	MONITOR	MONITOR	MONITOR	MANAGE	MANAGE
E	MONITOR	MANAGE	MANAGE	MANAGE	MANAGE

Table C-4: Lower and Upper Bound Recurrence Intervals for Wind ARI Rating Categories

ARI	Lower Bound Recurrence Interval	Upper Bound Recurrence Interval
<9.58×10^{-3} years		exceeded 2 times per week
9.58×10^{-3} – 1.92×10^{-2} years	exceeded 2 times per week	exceeded 1 time per week
1.92×10^{-2} - 3.83×10^{-2} years	exceeded 1 time per week	exceeded 1 time every 2 weeks
3.83×10^{-2} - 1.53×10^{-1} years	exceeded 1 time every 2 weeks	exceeded 1 time every 8 weeks
1.53×10^{-1} - 3.07×10^{-1} years	exceeded 1 time every 8 weeks	exceeded 1 time every 16 weeks
>3.07×10^{-1} years	exceeded 1 time every 16 weeks	

If the permit with monitoring recommendation (or 'Monitor') is prescribed then the vessel in question should be allowed on site, although monitoring is recommended and some erosion may still occur. If the 'Monitor' recommendation is prescribed and boats are already on the waterway then the site should be reassessed every two years. If boats are currently restricted from the waterway then the site should be assessed at six month intervals for the first two years and at two year intervals thereafter (Glamore and Badenhop, 2006).

The manage boating recommendation (or 'Manage') is given to sites where significant erosion is likely to occur from passing vessels. A range of restoration options should be considered for such sites. The DSS can be used to determine if reducing the boat numbers or implementing speed restrictions would improve its rating. The DSS can also be used to determine which of the characteristics investigated in the erosion potential assessment are having the most negative influence on the site and these can be prioritised for bank restoration works. A site classified as 'Manage' should be reassessed every two years (Glamore and Badenhop, 2006).

If the fully developed wave causes the score to be 'Monitor' or 'Manage' yet the attenuated wave rates 'Allow' or 'Monitor' the distance maintained from shore is critical to the management recommendation. Subsequently sites where this occurs are presented as 'Allow*' or 'Monitor*'.

Appendix D – Williams River Wind and Wake Wave Data

D.1 Wind Waves

D.1.1 Baseline DSS Assessment

An accurate representation of the wind climate is highly important for the DSS analysis. As per WRL's previous assessment (WRL TR 2012/05), the wind climate for the 2015 assessments of the Seaham Weir Pool and Lower Williams River was based on scaled Williamtown RAAF Base wind data. The scaling factors for the eight inter-cardinal directions were applied to the Williamtown RAAF Base wind data in the 2012 assessment on the Seaham Weir Pool, as per Cox *et al*. (1999) and are reproduced in Table D-1.

Cox *et al*. (1999) compared the recorded wind data from two anemometers installed adjacent to the Seaham Weir Pool with the Williamtown RAAF Base wind data from the same period, and used it to determine scaling relationships between the long-term Williamtown RAAF wind data and the conditions observed on the Seaham Weir Pool. In reviewing the scaling factors used in the 2012 assessment (SWP Stage 1), a calculation error was found in the scaling factor for the north direction. The correct scaling factor in the north direction should have been a 22% reduction, not a 34% reduction as reported in WRL TR 2012/15. In addition, while the correct scaling factor in the south west direction was determined in WRL TR 2012/15, a 15% decrease was used in the DSS analysis of the field data in the previous assessment. These errors led to an underestimation of the wind climate in the north and south-west direction in WRL TR 2012/15. As such, the correct scaling factors for the eight inter-cardinal directions applied to the Williamtown RAAF Base wind data in the 2015 assessments on the Seaham Weir Pool and Lower Williams River are also provided in Table D-1.

Table D-1: Scaling Factors Applied to Williamtown RAAF Base Wind Data

Cardinal Direction	Scaling Factors	
	2012 Assessment	2015 Assessment
North	34% reduction	22% reduction
North East	49% reduction	49% reduction
East	39% reduction	39% reduction
South East	32% reduction	32% reduction
South	64% reduction	64% reduction
South West	15% reduction	15% increase
West	40% reduction	40% reduction
North West	63% reduction	63% reduction

Wind rose frequency (count) data from the Williamtown RAAF Base station was obtained from the Bureau of Meteorology (BOM) for the 2012 and 2015 assessments. The scaled Williamtown RAAF Base wind rose data was used to complete wave hindcasting for both the single maximum wave and extended duration waves for each wind speed in each cardinal direction. A summary of the frequency (percentage) data used in the 2012 assessment (SWP Stage 1) for the period between 10/9/1942 and 30/9/2010 is provided in Table D-2. Table D-3 provides the updated frequency (percentage) data for the period between 10/9/1942 and 25/3/2015. A comparison between Table D-2 and Table D-3 shows only minor variations in the long-term wind rose frequency data from the Williamtown RAAF Base station with inclusion of data from 2010 to 2015. The updated frequency (percentage) data provided in Table D-3 was used in the 2015 assessments of the Seaham Weir Pool and Lower Williams River.

Table D-2: BOM Percentage Frequency of Wind Direction Vs Wind Speed at Williamtown RAAF (Period: 10/9/42 - 30/9/10, 166,235 Observations)

Wind Speed	Wind Bracket	Percentage Frequency								
		N	NE	E	SE	S	SW	W	NW	Total
1.39	1	0.84	0.99	0.79	0.51	0.46	0.38	1.27	1.57	6.81
4.17	2	2.52	4.81	3.82	4.07	3.11	2.19	5.93	6.98	33.42
6.94	3	0.30	2.22	2.79	3.89	3.58	1.44	3.88	2.71	20.80
9.72	4	0.05	0.73	1.23	1.58	2.51	0.75	2.58	1.77	11.20
11.11	5	0.01	0.06	0.11	0.17	0.49	0.15	0.71	0.56	2.27
12.50	6	0.01	0.02	0.02	0.15	0.44	0.12	1.04	0.84	2.64
									CALM	22.86
									Total	100.00

Table D-3: BOM Percentage Frequency of Wind Direction Vs Wind Speed at Williamtown RAAF (Period: 10/9/42 - 25/3/15, 180,409 Observations)

Wind Speed	Wind Bracket	Percentage Frequency								
		N	NE	E	SE	S	SW	W	NW	Total
1.39	1	0.81	0.95	0.75	0.48	0.43	0.36	1.19	1.49	6.47
4.17	2	2.69	5.16	3.88	4.01	3.08	2.20	5.90	7.31	34.22
6.94	3	0.31	2.39	2.81	3.98	3.57	1.48	3.86	2.81	21.21
9.72	4	0.05	0.73	1.24	1.66	2.54	0.76	2.52	1.77	11.28
11.11	5	0.01	0.06	0.11	0.18	0.50	0.15	0.68	0.56	2.26
12.50	6	0.01	0.02	0.02	0.14	0.42	0.12	0.98	0.82	2.53
									CALM	22.03
									Total	100.00

As per the DSS methodology (Appendix C), fetch lengths for each stretch were determined using the centre of each stretch as a reference point. Based on the length of the wind record, the average recurrence interval (ARI) of the wind wave energy was calculated for both the maximum wind wave and for an extended duration of wind waves of eight hours for all but two boat pass scenarios. Eight hours was selected for the extended duration wind analysis as it is a likely length of time for watersports on the river during daylight hours.

D.1.2 Lower Williams River DSS Sensitivity Test (Australian Standard for Winds)

Since anemometer data on the Lower Williams River is unavailable, a sensitivity test was undertaken to examine the assumption that the scaled Williamtown RAAF Base winds are a reasonable approximation of local winds. WRL re-assessed the wind wave energy based on wind conditions for the Williams River described by the Australian Wind Standard - AS 1170.2 (2011).

Design wind velocities (0.2 second gust, 10 m elevation, Terrain Category 2) in AS 1170.2 are given for average recurrence intervals of 1 to 10,000 years. Site wind speeds (V_{sit}), are calculated according to Equation D-1 using multipliers for direction (M_d), terrain ($M_{z,cat}$), shielding (M_s) and topography (M_t).

$$V_{sit} = V_R M_d (M_{z,cat} M_s M_t) \quad \text{(D-1)}$$

The study area falls within Region A2 (AS 1170.2, 2011) and corresponding wind speed multipliers were adopted. A Category 2 terrain multiplier is suggested for open terrain with well-scattered obstructions which is consistent with the topography of the riverbanks in the study area (AS1170.2:2011, S4.2.1). No further shielding or topography multipliers were applied. The site wind speeds (0.2 second) were adjusted to equivalent sustained 10 minute wind speeds using the approach set out in Figure II-2-1 of Part II of the USACE Coastal Engineering Manual (2006).

Sustained (10-minute) wind speeds for ARIs up to 10,000 years for each of the eight inter-cardinal directions at the Williamtown RAAF Base and AS 1170.2 are presented in Appendix F. Note that Williamtown RAAF Base wind data presented in Appendix E is unscaled. Since the shortest ARI given in AS 1170.2 is 1 year, the two datasets only overlap for ARI 1 to 73 years. The AS 1170.2 wind speeds are generally faster than the unscaled Williamtown RAAF Base wind speeds for all directions except from the north-west (approximately equivalent). Note that it is beyond the scope of this report to resolve the outlier with an ARI of 73 years for the west and north-west directions in the unscaled Williamtown RAAF Base wind dataset. On the basis of the overlap (ARI 1 to 73 years), the relative magnitude of the AS 1170.2 values compared to the unscaled Williamtown RAAF Base wind speeds are presented in Table D-4.

Table D-4: Australian Standard Wind Speeds relative to Unscaled Williamtown RAAF Base Data

Cardinal Direction	Wind Speed
North	45% higher
North East	50% higher
East	40% higher
South East	40% higher
South	15% higher
South West	30% higher
West	5% higher
North West	equivalent

Table D-5 compares the AS 1170.2 values (Table D-4) with the scaled Williamtown RAAF Base wind speeds (Table D-1) used in the baseline DSS assessment. Clearly, the Australian Standard design wind speeds described for the Williams River are significantly faster (1.13 – 3.19 times) than those used in the baseline DSS assessment. In the DSS, this will have the effect of increasing the natural wind wave energy across the study area and reducing the difference between the wind and wake wave energies. Accordingly, management ratings based for this sensitivity test will be more permissive of boating activities when compared to the baseline DSS assessment.

Table D-5: Australian Standard Wind Speeds relative to Scaled Williamtown RAAF Base Data

Cardinal Direction	Wind Speed
North	86% higher
North East	194% higher
East	130% higher
South East	106% higher
South	219% higher
South West	13% higher
West	75% higher
North West	170% higher

D.2 Wake Waves

D.2.1 Overview

The wake wave data already incorporated into the DSS provides quality controlled direct measurements of wake waves from various boats at pre-selected speeds. A required input, however, is the number of boat passes in the selected time period. Access to previous boat pass data on the Seaham Weir Pool and Lower Williams River was limited.

D.2.2 Seaham Weir Pool

Several boat pass monitoring studies have been conducted on the Seaham Weir Pool over the last 20 years. These include studies for the following periods:

- January 1995 (Patterson Britton and Partners, 1996);
- January 1998 (Cox and Dorairaj, 2002);
- April 1998 (Cox and Dorairaj, 2002);
- December 1999 – February 2000 (Cox and Dorairaj, 2002); and
- April – May 2003 (Cox, 2003a).

In 2012 (WRL TR 2012/05), WRL developed a range of daily boat pass numbers for the Seaham Weir Pool (Table D-6). Final management recommendations were based on the medium boat pass scenario in river sections 10 to 30 and the low boat pass scenario for the remaining boating management zones (shaded cells in Table D-6). Eight hours was selected as an appropriate duration for calculating cumulative energy as it approximates the hours during which boats are likely to be travelling on an average day. These same boat pass scenarios were used for the 2015 DSS assessments of the Seaham Weir Pool.

Table D-6: Adopted Daily Boat Passes for All Activities on the Seaham Weir Pool

Stretch	River Section	Scenario	No. Boat Passes		
			Low	Medium	High
1-6	Restricted Area Near Weir	Water Ski 4 knots	1	10	50
7-9	4 knot Section (D/S)	Water Ski 4 knots	10	50	150
10-17	Waterskiing Section (D/S)	Water Ski Operating	10	50	150
18-22	Wakeboarding Section	Wakeboard Operating	10	50	150
23-26	Waterskiing Section (U/S)	Water Ski Operating	10	50	150
27-30	4 knot Section (U/S)	Wakeboard 4 knots	10	50	150
31-49	U/S of the 4 knot Section	Water Ski 8 knots	1	10	50

Note: The final management recommendations were based on those cells shaded grey.

D.2.3 Lower Williams River

In the absence of any more recent detailed boat count information on the Lower Williams River, WRL has extended the daily boat pass numbers estimated for the Seaham Weir Pool to the Lower Williams River, and added the activity of wakesurfing (which is currently prohibited). These boat pass numbers (Table D-7) were considered satisfactory based on WRL's experience on the Lower Williams River, consultation with NSW RMS and results from detailed boat pass surveys for similar rivers. The wave type selected for each of these boat pass numbers was "operating conditions" (Glamore and Badenhop, 2006). This describes the waves generated when a vessel is towing a rider at operational speed (typically 10 knots for wakesurfing, 19 knots for wakeboarding and 30 knots for waterskiing). Eight hours was again selected as the duration for calculating cumulative energy.

Each of the nine scenarios in Table D-7 was examined for each stretch of the Lower Williams River to form the baseline DSS assessment. Two additional DSS cases were run for two stretches only:

- Waterski 4 knots – 50 Boat Passes - Stretch 78 (4 knot zone at Seaham Boat Ramp); and
- Waterski 4 knots – 1 Boat Pass - Stretch 79 (Restricted zone between Jim Scott Bridge and Seaham Weir).

Table D-7: Adopted Daily Boat Passes for All Activities on the Lower Williams River

Boat / Activity	Wave Type	No. Boat Passes	Duration (hours)
Wakeboard	Operating	10	8
		50	
		150	
Waterski	Operating	10	8
		50	
		150	
Wakesurf	Operating	10	8
		50	
		150	

Final management recommendations (Table D-8) were based on 50 boat passes at "operating conditions" in the wakeboarding (Stretches 50-58 and 71-77) and waterskiing zones (Stretch 59-70), 50 boat passes for waterskiing vessel at 4 knots at Seaham Boat Ramp (Stretch 78), and 1 boat pass for waterskiing vessel at 4 knots between Jim Scott Bridge and Seaham Weir (Stretch 79). Note that the adoption of a waterskiing vessel travelling at 4 knots for Stretches 78-79 is nominal. At this speed, the wake conditions generated are the same for both waterskiing and wakeboarding vessels. It is also noted that while towing is prohibited for Stretch 50 (under Fitzgerald Bridge), it is likely that wakeboarding vessels still travel through this area at "operating conditions" without a rider.

Table D-8: Boat Scenarios for Final Management Recommendations on the Lower Williams River

Stretch	River Section	Scenario	No. Boat Passes
50-58	Wakeboarding Zone (D/S)	Wakeboard Operating	50
59-70	Waterskiing Zone	Waterski Operating	50
71-77	Wakeboarding Zone (U/S)	Wakeboard Operating	50
78	4 knot Zone	Waterski 4 knots	50
79	No Boats Permitted (U/S)	Waterski 4 knots	1

D.2.3 Lower Williams River DSS Sensitivity Test (High Boat Passes)

A series of boat pass sensitivity tests were undertaken on the Lower Williams River with a second set of higher boat pass numbers (Table D-9). For these high boat passes, a duration of twelve hours was used as it was estimated this would only take place in summer with suitable daylight hours. "Maximum wave" conditions (for an 8 hour duration) were also included in this second boat pass set. Maximum wave energy is not produced when vessels (both wakeboarding and waterskiing) travel at "operating conditions", but rather at the slower velocity of approximately 8 knots. These conditions align with the length based Froude-number discussed in Appendix B, and are typically experienced when a boat is accelerating or slowing down.

Table D-9: Adopted Daily Boat Passes for High Boat Passes on the Lower Williams River

<table>
<tr><th>Boat / Activity</th><th>Wave Type</th><th>No. Boat Passes</th><th>Duration (hours)</th></tr>
<tr><td rowspan="3">Wakeboard</td><td>Maximum</td><td>50</td><td>8</td></tr>
<tr><td rowspan="2">Operating</td><td>300</td><td rowspan="2">12</td></tr>
<tr><td>500</td></tr>
<tr><td rowspan="3">Waterski</td><td>Maximum</td><td>50</td><td>8</td></tr>
<tr><td rowspan="2">Operating</td><td>300</td><td rowspan="2">12</td></tr>
<tr><td>500</td></tr>
<tr><td rowspan="2">Wakesurf</td><td rowspan="2">Operating</td><td>300</td><td rowspan="2">12</td></tr>
<tr><td>500</td></tr>
</table>

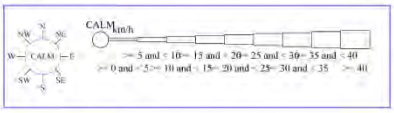
Appendix E – Wind Rose and Frequency Data

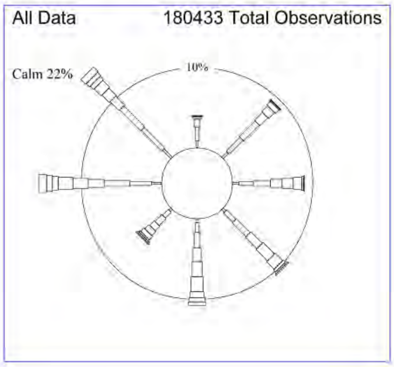
Roses of Wind direction versus Wind speed in km/h (10 Sep 1942 to 25 Mar 2015)

WILLIAMTOWN RAAF

Site No: 061078 • Opened Jan 1942 • Still Open • Latitude: -32.7932° • Longitude: 151.8359° • Elevation 9m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.





Frequency Analysis of Wind direction versus Wind speed in km/h (10 Sep 1942 to 25 Mar 2015)

Custom times selected, refer to attached note for details

WILLIAMTOWN RAAF

Site Number 061078 • Opened Jan 1942 • Still Open • Latitude: -32.7932° • Longitude: 151.8359° • Elevation 9m

Values are frequency totals.
Other important info about this analysis is available in the accompanying notes.

All Data **180433 Total Observations**

Wind speed in km/h	Wind direction									
	N	NE	E	SE	S	SW	W	NW	Calm	ALL
>= 0 and < 5	1460	1718	1359	874	783	653	2145	2687		**51433**
>= 5 and < 10	3065	4368	3220	2882	2157	1785	4944	6539		**28964**
>= 10 and < 15	1787	4934	3786	4344	3392	2179	5698	6652		**32773**
>= 15 and < 20	399	2506	2602	3607	3035	1425	3519	2764		**19860**
>= 20 and < 25	165	1803	2471	3578	3408	1239	3437	2306		**18410**
>= 25 and < 30	75	1110	1846	2386	3292	1026	3275	2198		**15210**
>= 30 and < 35	14	214	399	600	1294	350	1280	987		**5141**
>= 35 and < 40	15	106	205	325	910	270	1233	1014		**4082**
>= 40	10	29	40	259	754	216	1775	1475		**4560**
All	**6992**	**16792**	**15931**	**18858**	**19027**	**9145**	**27310**	**26624**	**39752**	**180433**

Appendix F – Williamtown RAAF Winds vs. AS 1170.2

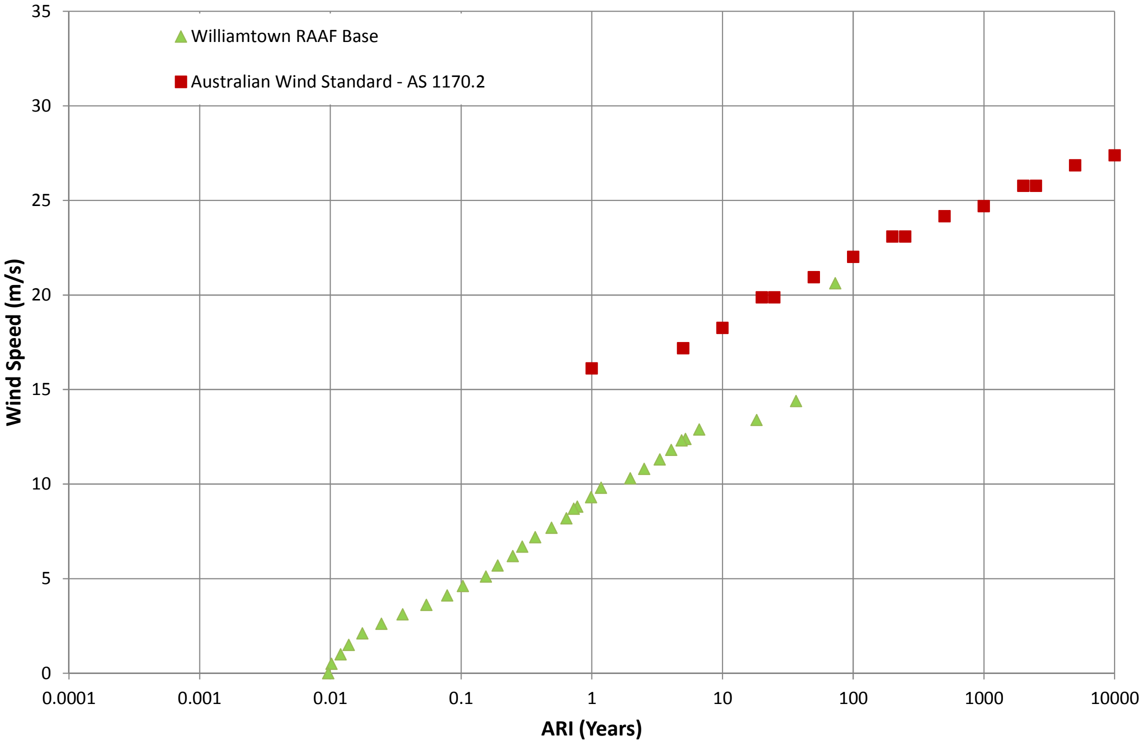


Figure E-1: Williamtown RAAF Base Winds vs. Australia Standard: North

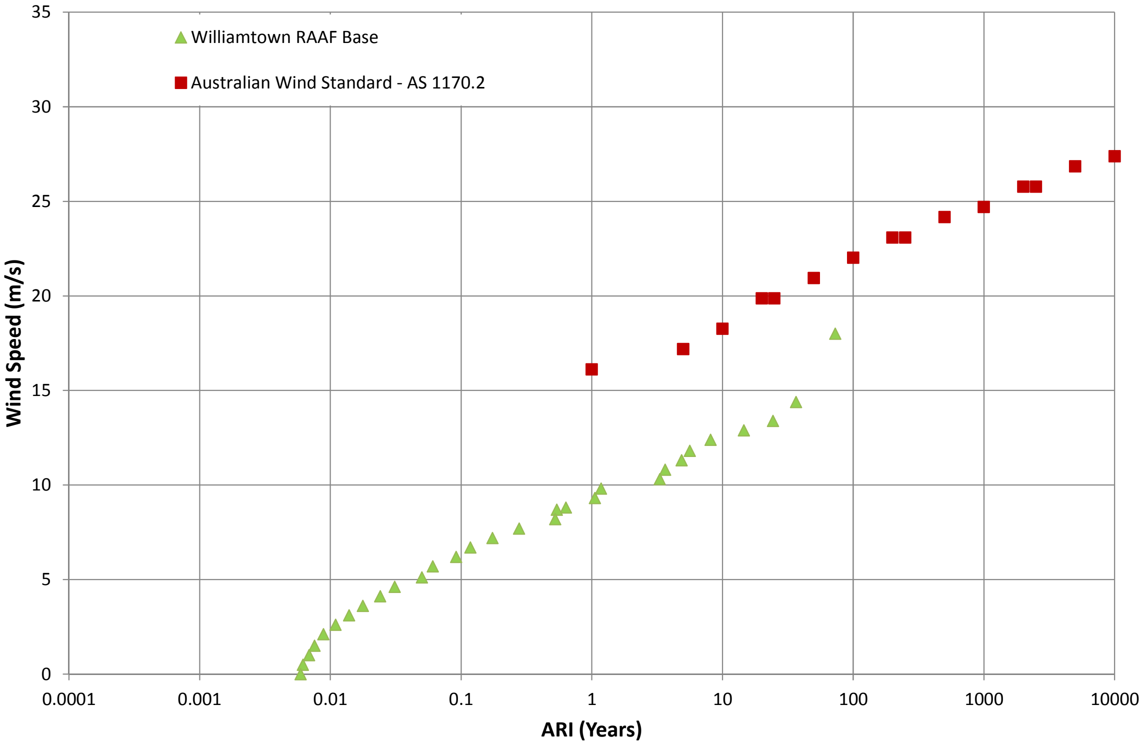


Figure E-2: Williamtown RAAF Base Winds vs. Australia Standard: North-East

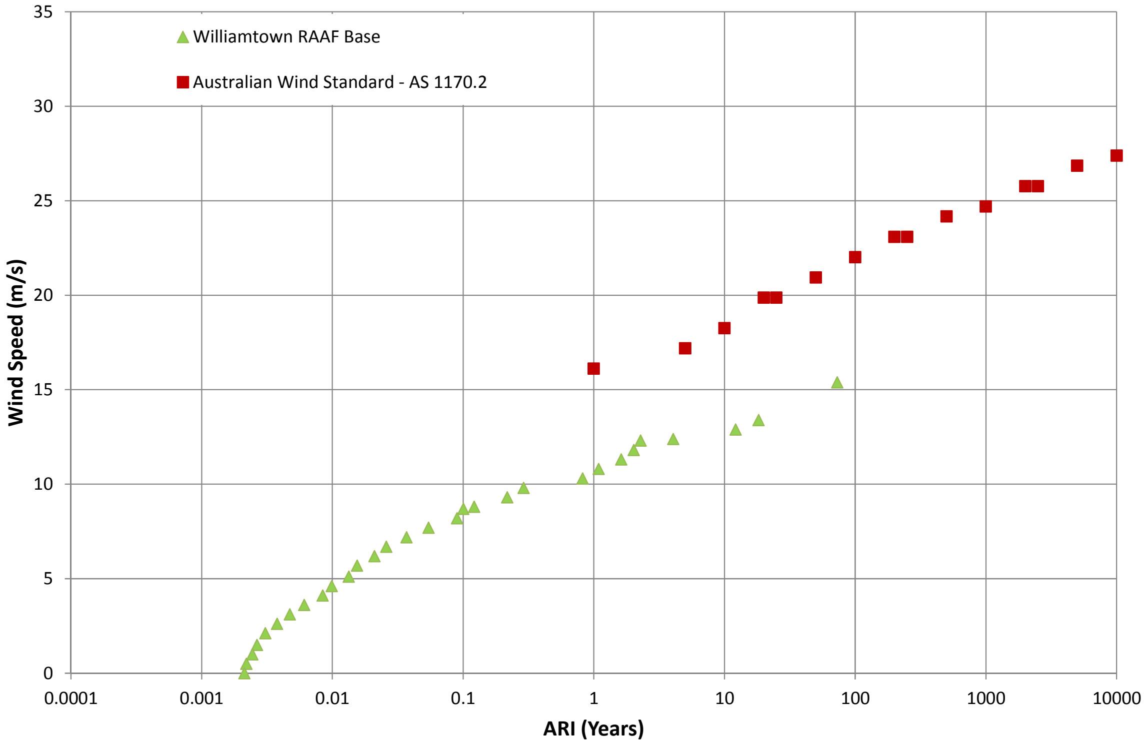


Figure E-3: Williamtown RAAF Base Winds vs. Australia Standard: East

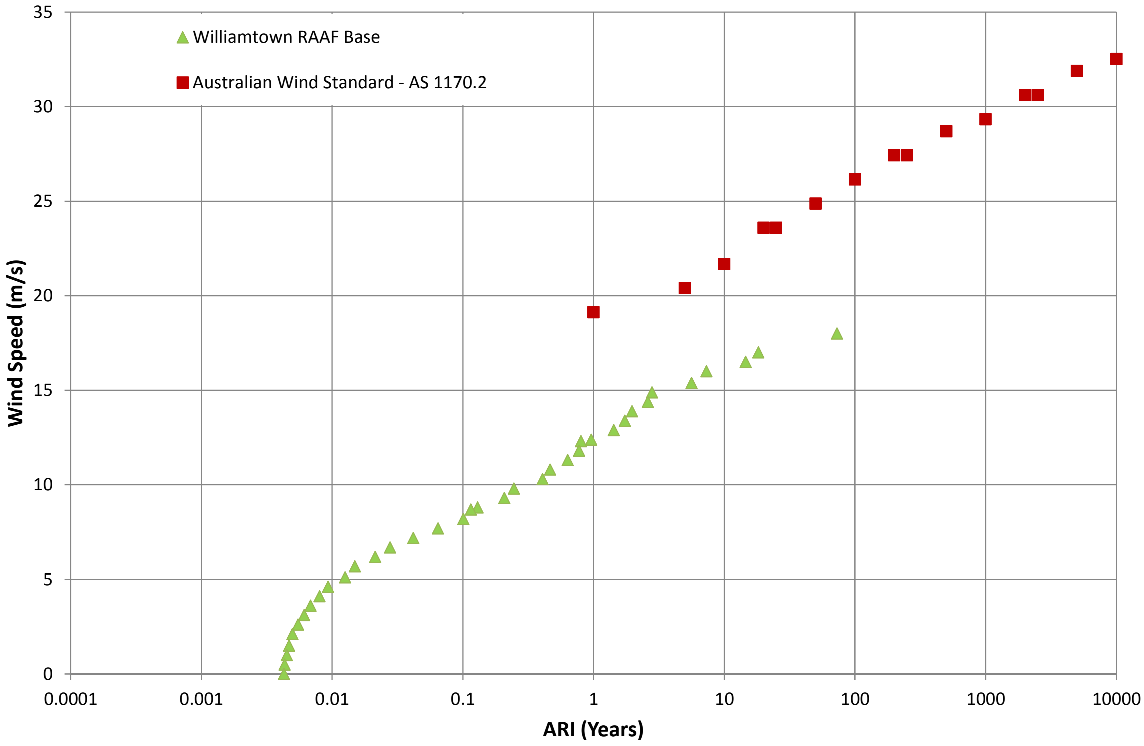


Figure E-4: Williamtown RAAF Base Winds vs. Australia Standard: South-East

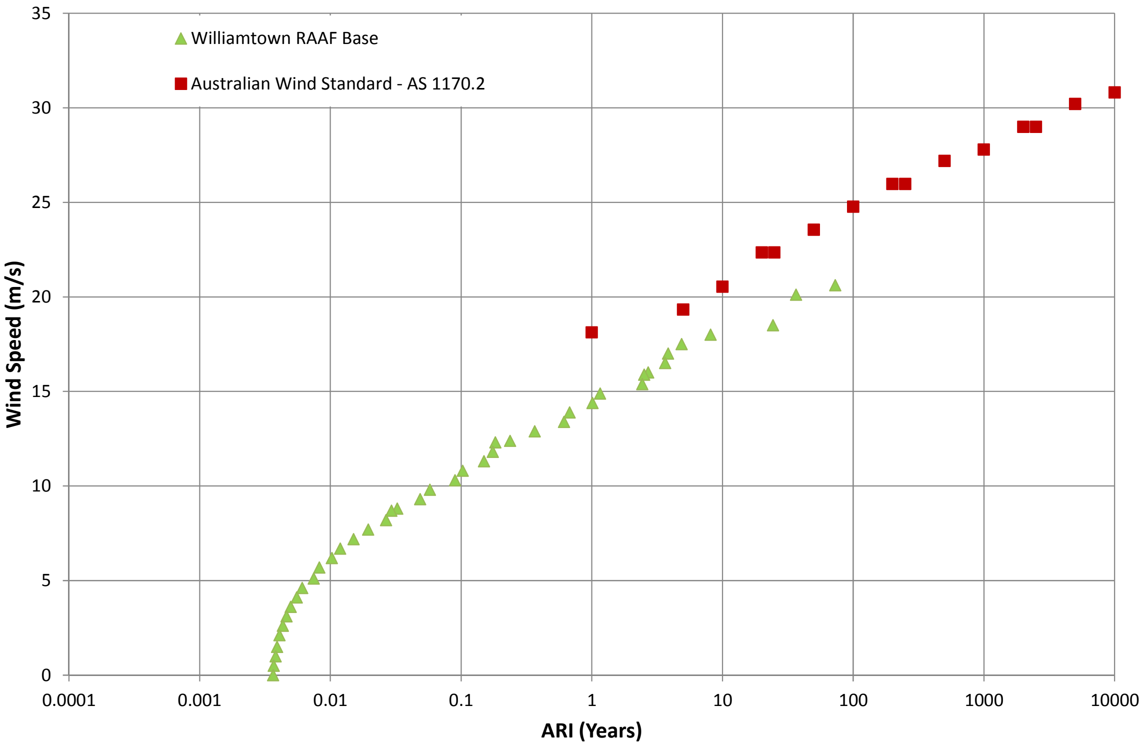


Figure E-5: Williamtown RAAF Base Winds vs. Australia Standard: South

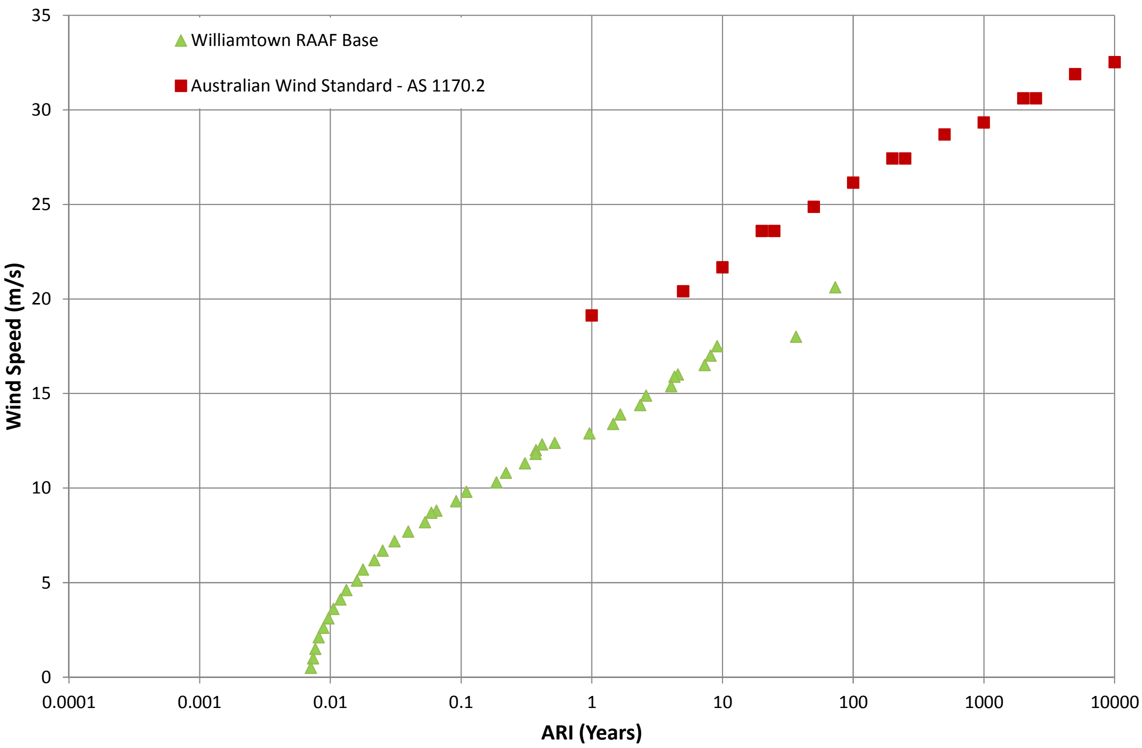


Figure E-6: Williamtown RAAF Base Winds vs. Australia Standard: South-West

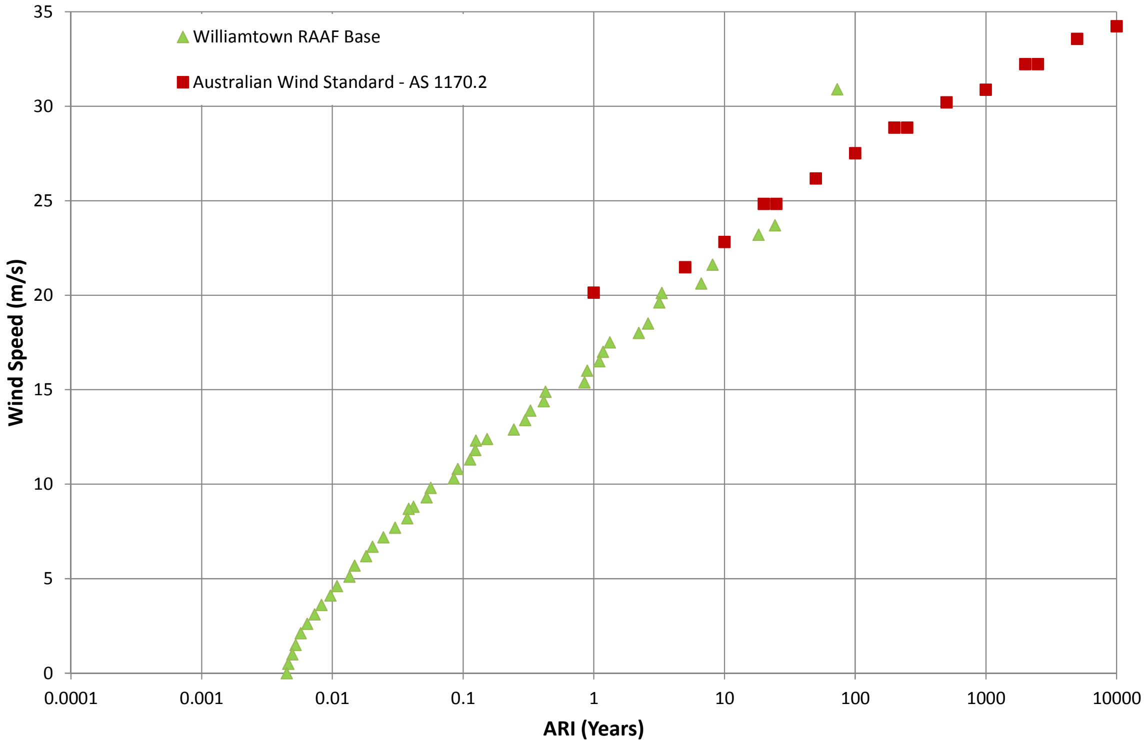


Figure E-7: Williamtown RAAF Base Winds vs. Australia Standard: West

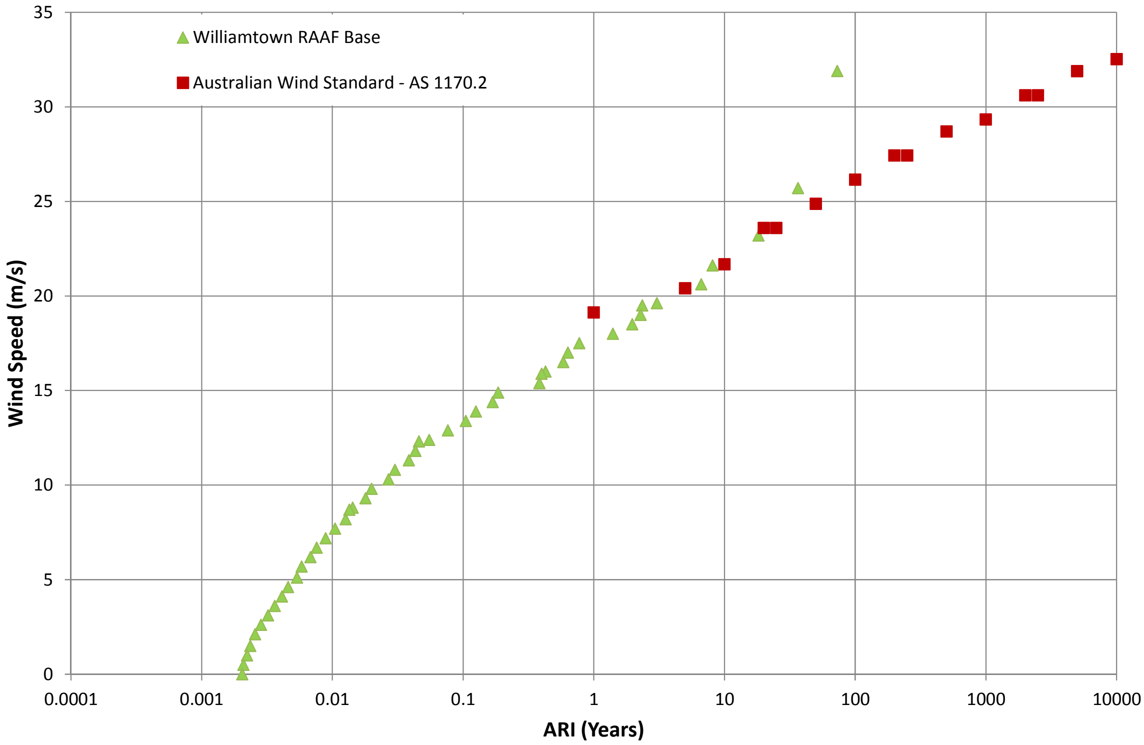


Figure E-8: Williamtown RAAF Base Winds vs. Australia Standard: North-West

Appendix G – Example DSS Field Sheet

Water Research Laboratory

Date:	**Stretch/Section:**
Time:	
Assessing Personnel:	**GPS Waypoint:** **or E:** **N:** AMG/MGA (circle correct one)
Photo Numbers:	

River Type

Valley Setting:	❑ Confined ❑ Partly confined ❑ Laterally unconfined	❑ Completely armoured ❑ Partially armoured
Longitudinal Continuity of Bank Vegetation Over Whole Stretch:	❑ < 10 % ❑ 10-30 %	❑ 31-60 % ❑ > 60 %

Vegetation (Not required if completely confined or armoured)

	Low Tide Assessment		High Tide Assessment	
Verge Cover (10 m from top of bank):	❑ < 10 % ❑ 10-30 %	❑ 31-60 % ❑ > 60 %		
Upper Bank Cover:	❑ < 10 % ❑ 10-30 %	❑ 31-60 % ❑ > 60 %		
Wave Zone Cover:	❑ < 10 % ❑ 10-30 %	❑ 31-60 % ❑ > 60 %	❑ < 10 % ❑ 10-30 %	❑ 31-60 % ❑ > 60 %
Native Canopy Species Regeneration (< 1 m tall):	❑ None	❑ Scattered ❑ Abundant		
Native Understorey Regeneration:	❑ None	❑ Scattered ❑ Abundant		
Dominant Wave Zone Cover Type:	❑ Bare (vertical slope) ❑ Bare (1:3 – 1:6 slope) ❑ Bare (≤1:7 slope) ❑ Rocks	❑ Grasses ❑ Reeds ❑ Trees/Tree roots ❑ Mangroves	❑ Bare (vertical slope) ❑ Bare (1:3 – 1:6 slope) ❑ Bare (≤1:7 slope) ❑ Rocks	❑ Grasses ❑ Reeds ❑ Trees/Tree roots ❑ Mangroves

Channel Features

Upper Bank Slope:	☐ Near Vertical ☐ ~1:3	☐ ~1:5 ☐ <1:7
Channel Width:	☐ <36 ☐ 36-120	☐ >120
Bank Height	☐ > 3 m ☐ 1-3 m	☐ < 1 m

Erosion

Bank Sediment Type:	☐ Bedrock/Boulders/Cobbles/ Armouring ☐ Cohesive	☐ Complex (sand & clay) ☐ Non-Cohesive
Erosion Above the Wave Zone:	☐ Absent ☐ < 10 % banks	☐ 10-30 % banks ☐ > 30 % banks
Slumping:	☐ Absent ☐ < 10 % banks	☐ 10-30 % banks ☐ > 30 % banks
Undercutting in the Wave Zone:	☐ Absent ☐ < 10 % banks	☐ 10-30 % banks ☐ > 30 % banks

Land use

Desnagging:	☐ None	☐ Conducted in last previous year
Excavation:	☐ Present	☐ Absent
Extraction:	☐ None	☐ Water ☐ Sediment
Stock Access:	☐ Absent	☐ Present

Brief Description of Site (include high tide and low tide markers)

Appendix H – Water Levels During Field Assessments

Glamore and Badenhop (2006) state that tidal river assessments should be conducted at mid to low tide to accurately assess the characteristics of the wave zone. Assessment dates on the Lower Williams River were selected to incorporate low tides during the middle of the assessment period. Water levels on the Lower Williams River are monitored by Manly Hydraulics Laboratory (MHL) on behalf of the NSW Office of Environment and Heritage (OEH) at Seaham Weir (Downstream) and Raymond Terrace (Figure H-1). Water levels on the Seaham Weir Pool are regulated and monitored at Glen Martin (also known as Mill Dam Falls) by NSW Office of Water (NOW) and at Boags Inlet by Hunter Water (Figure H-1). Figure H-2 (Seaham Weir Pool) and Figure H-3 (Lower Williams River) provide the water levels during the March 2015 field assessment. Figure H-4 (Seaham Weir Pool) and Figure H-5 (Lower Williams River) provide the water levels during the August 2015 field assessment. High water levels on the Seaham Weir Pool were measured on 13 - 14 March 2015, and again on 24 – 27 August 2015. Such levels would make it difficult to accurately assess the riverbanks. This was avoided as WRL assessed the Lower Williams River on these days until normal water levels returned on the Seaham Weir Pool.

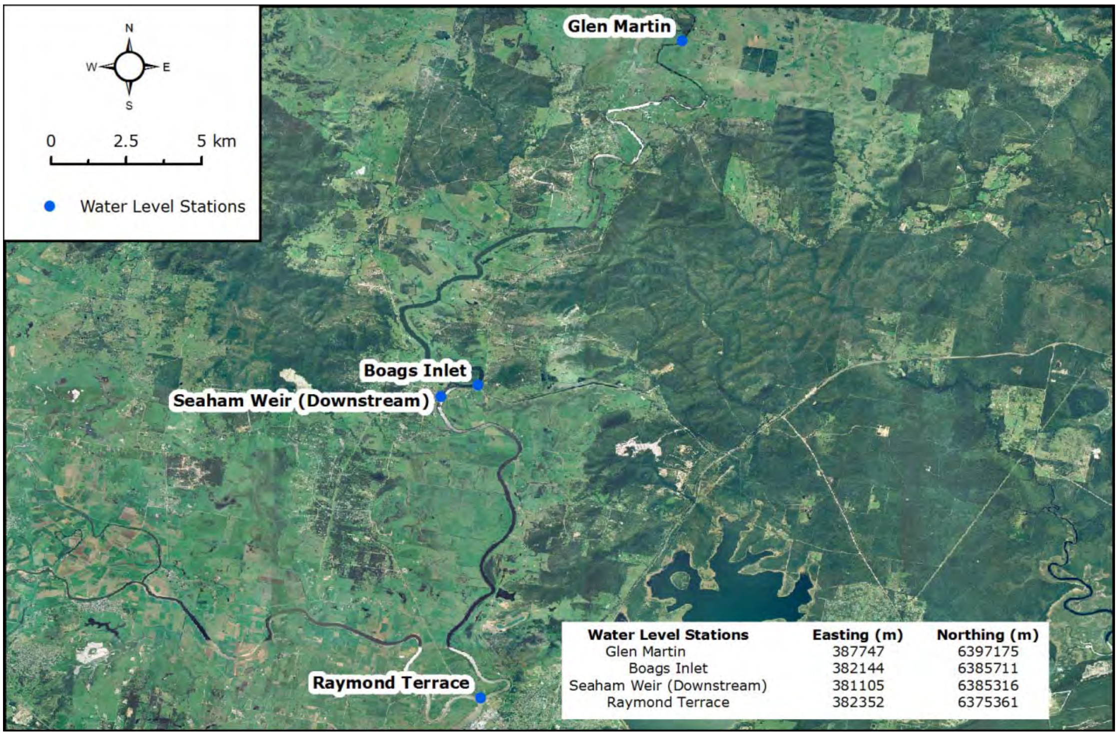


Figure H-1: Water Level Stations in the Study Area (Coordinate System in MGA 56)

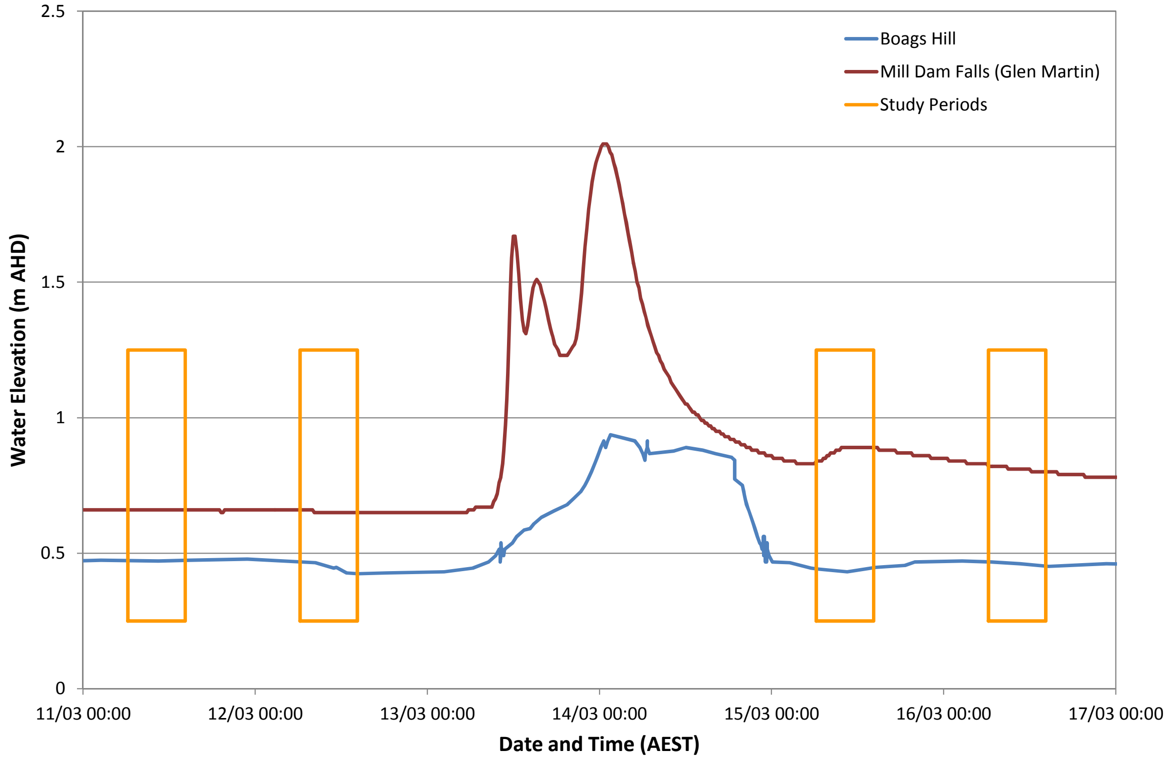


Figure H-2: Water Levels on the Seaham Weir Pool During the March 2015 Field Assessment

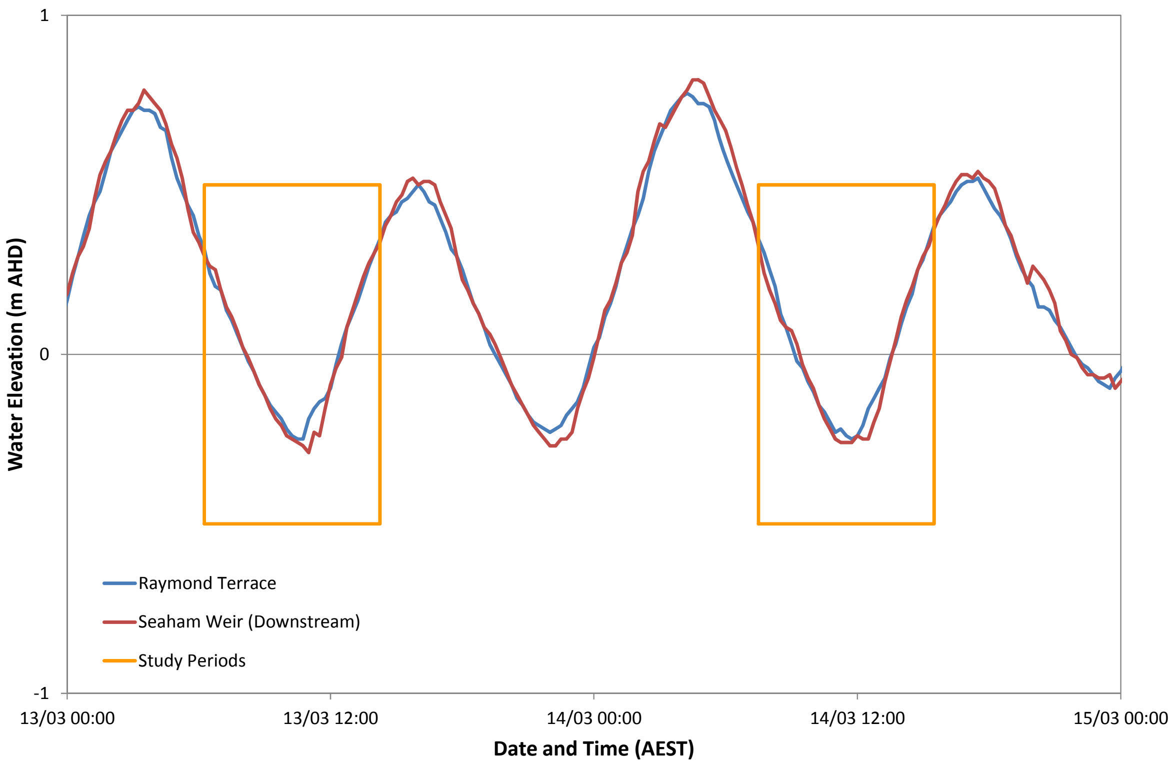


Figure H-3: Water Levels on the Lower Williams River During the March 2015 Field Assessment

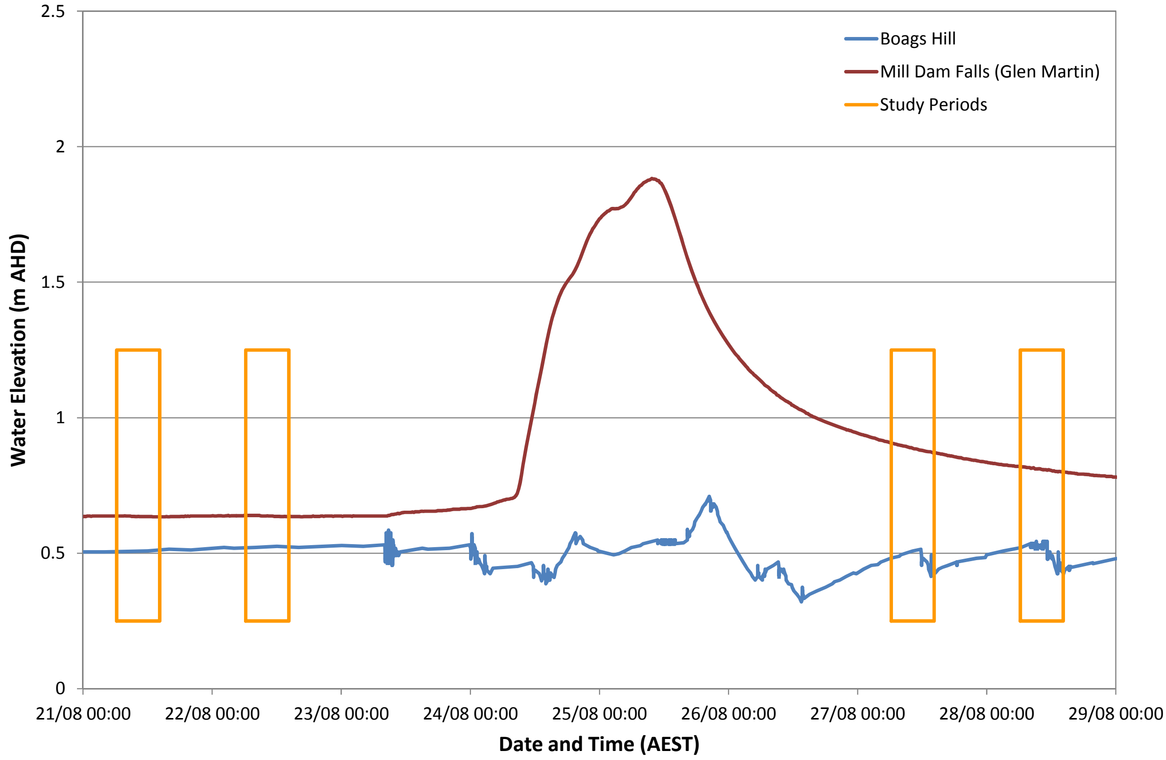


Figure H-4: Water Levels on the Seaham Weir Pool During the August 2015 Field Assessment

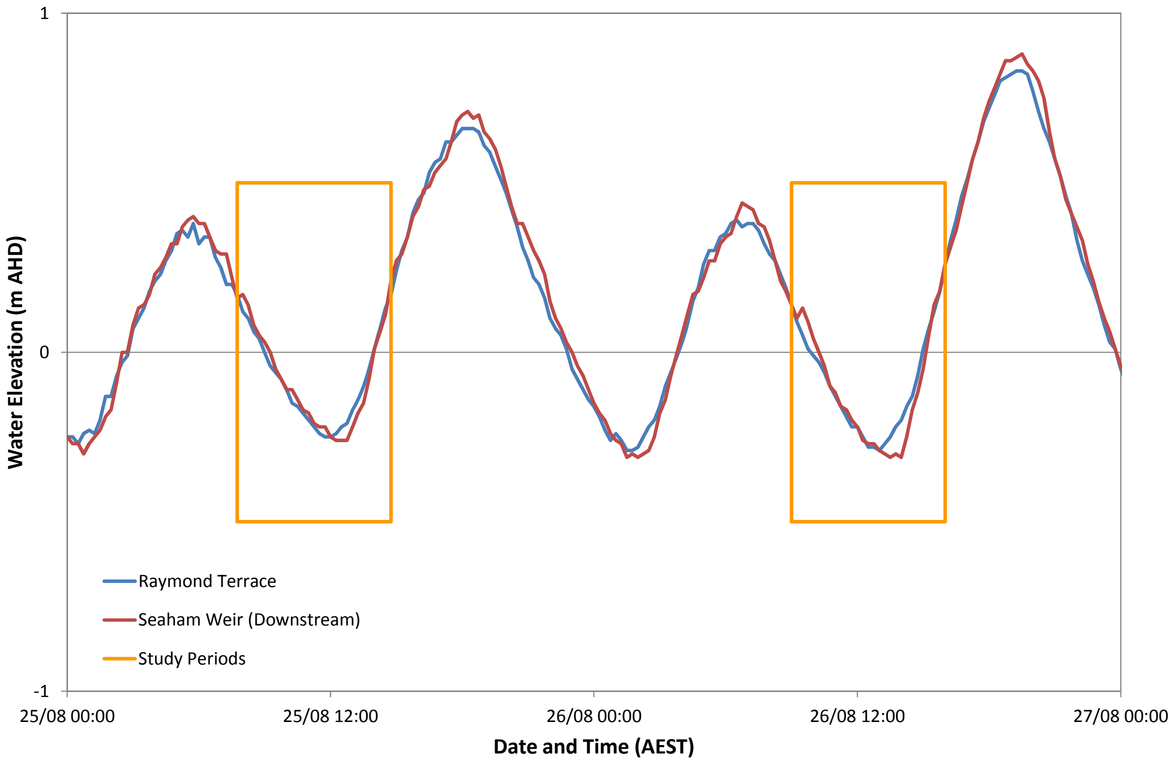
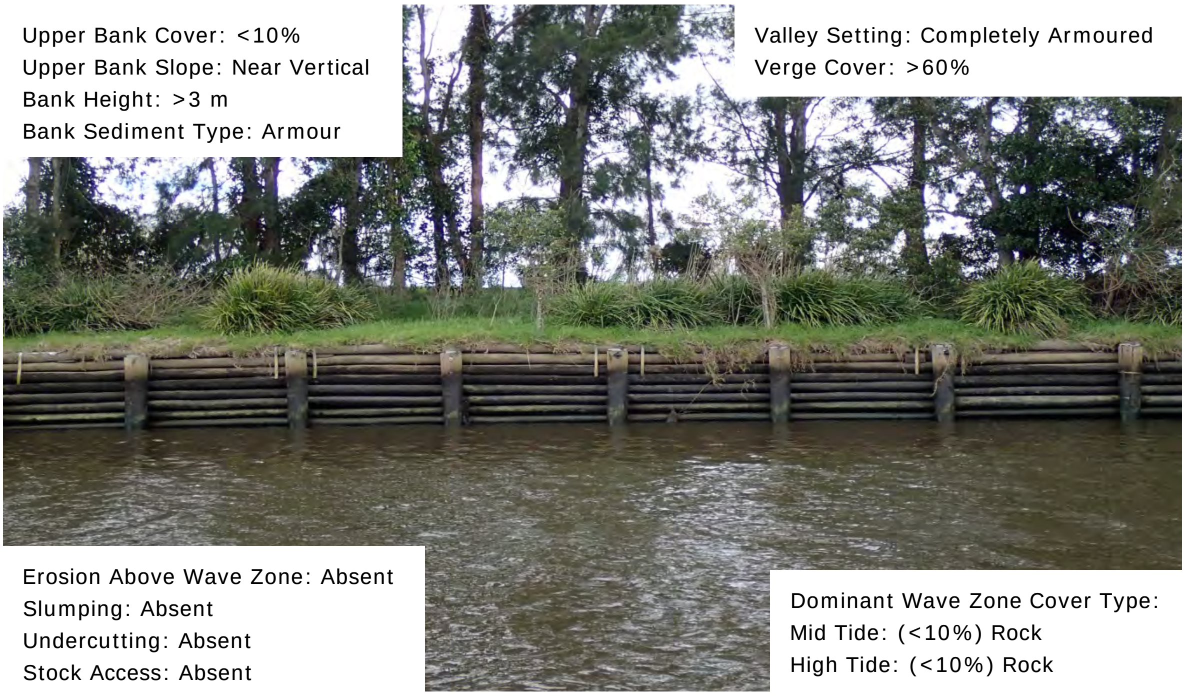


Figure H-5: Water Levels on the Lower Williams River During the August 2015 Field Assessment

Appendix I – Field Examples of Erosion Potential Categories



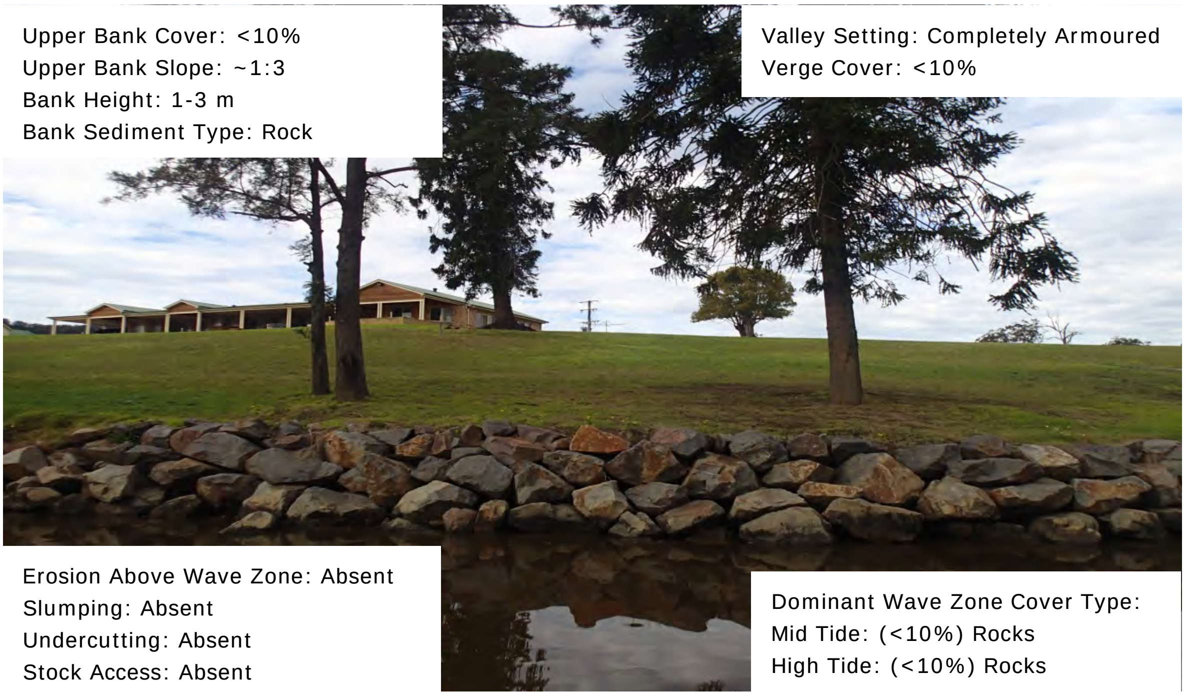
Upper Bank Cover: <10%
Upper Bank Slope: Near Vertical
Bank Height: >3 m
Bank Sediment Type: Armour

Valley Setting: Completely Armoured
Verge Cover: >60%

Erosion Above Wave Zone: Absent
Slumping: Absent
Undercutting: Absent
Stock Access: Absent

Dominant Wave Zone Cover Type:
Mid Tide: (<10%) Rock
High Tide: (<10%) Rock

Highly Resistant – L72B



Upper Bank Cover: <10%
Upper Bank Slope: ~1:3
Bank Height: 1-3 m
Bank Sediment Type: Rock

Valley Setting: Completely Armoured
Verge Cover: <10%

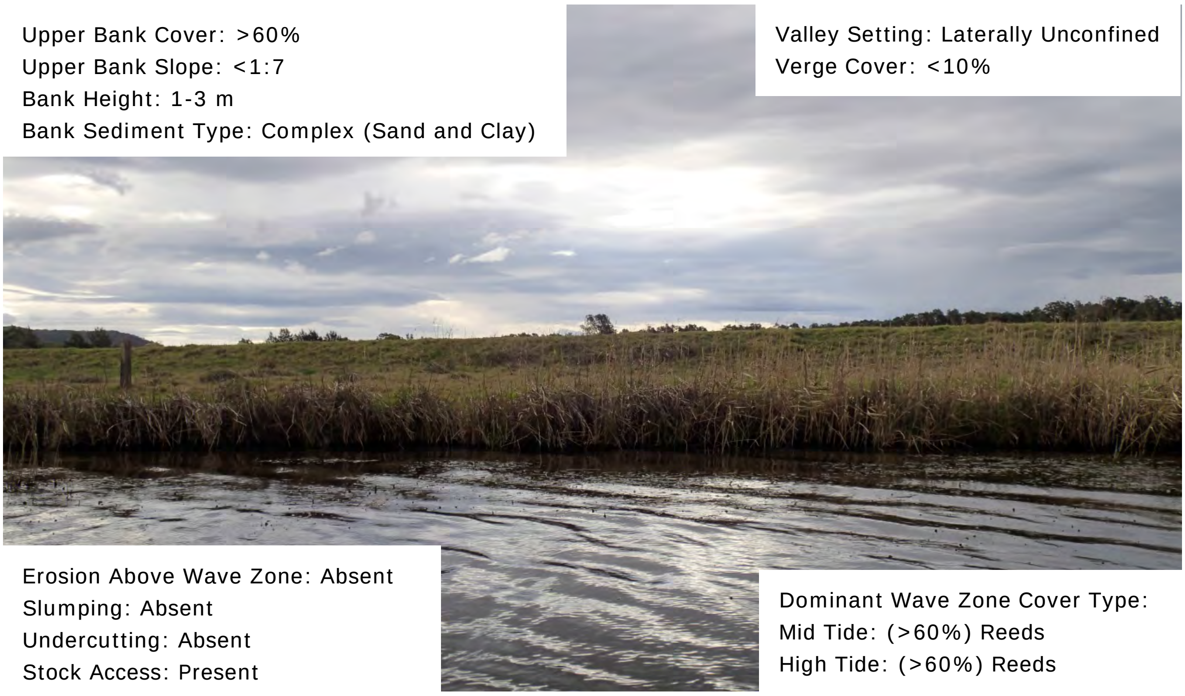
Erosion Above Wave Zone: Absent
Slumping: Absent
Undercutting: Absent
Stock Access: Absent

Dominant Wave Zone Cover Type:
Mid Tide: (<10%) Rocks
High Tide: (<10%) Rocks

Highly Resistant – L21B

Upper Bank Cover: >60%
Upper Bank Slope: <1:7
Bank Height: 1-3 m
Bank Sediment Type: Complex (Sand and Clay)

Valley Setting: Laterally Unconfined
Verge Cover: <10%



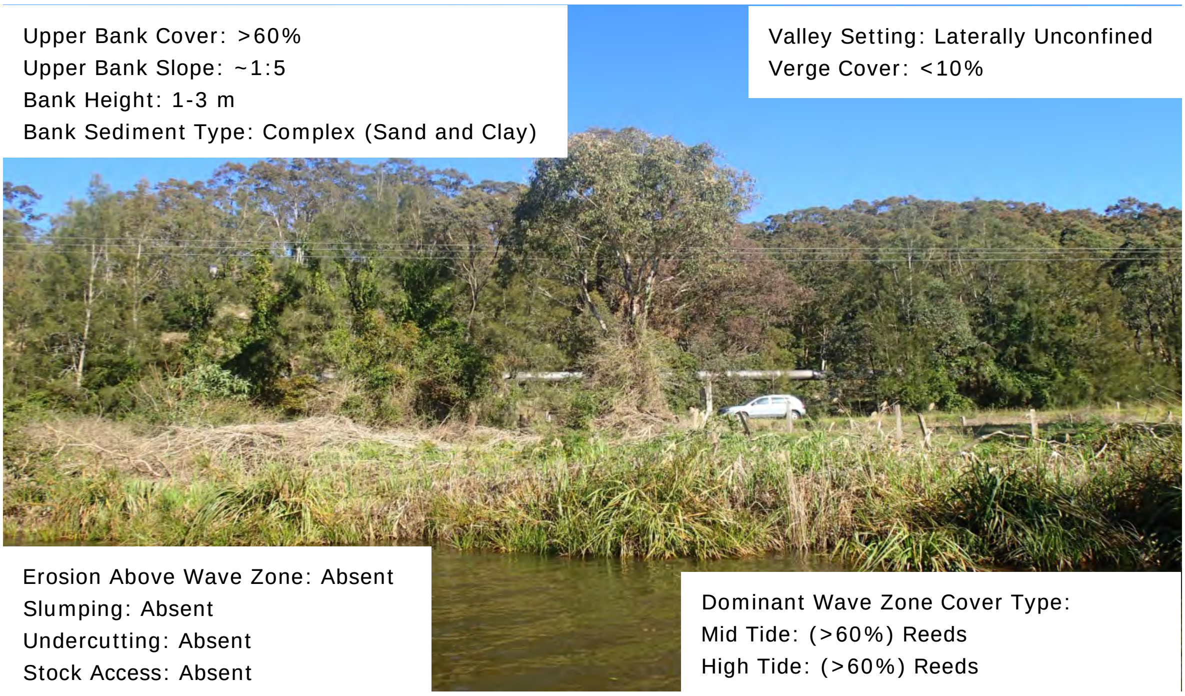
Erosion Above Wave Zone: Absent
Slumping: Absent
Undercutting: Absent
Stock Access: Present

Dominant Wave Zone Cover Type:
Mid Tide: (>60%) Reeds
High Tide: (>60%) Reeds

Moderately Resistant – L03C

Upper Bank Cover: >60%
Upper Bank Slope: ~1:5
Bank Height: 1-3 m
Bank Sediment Type: Complex (Sand and Clay)

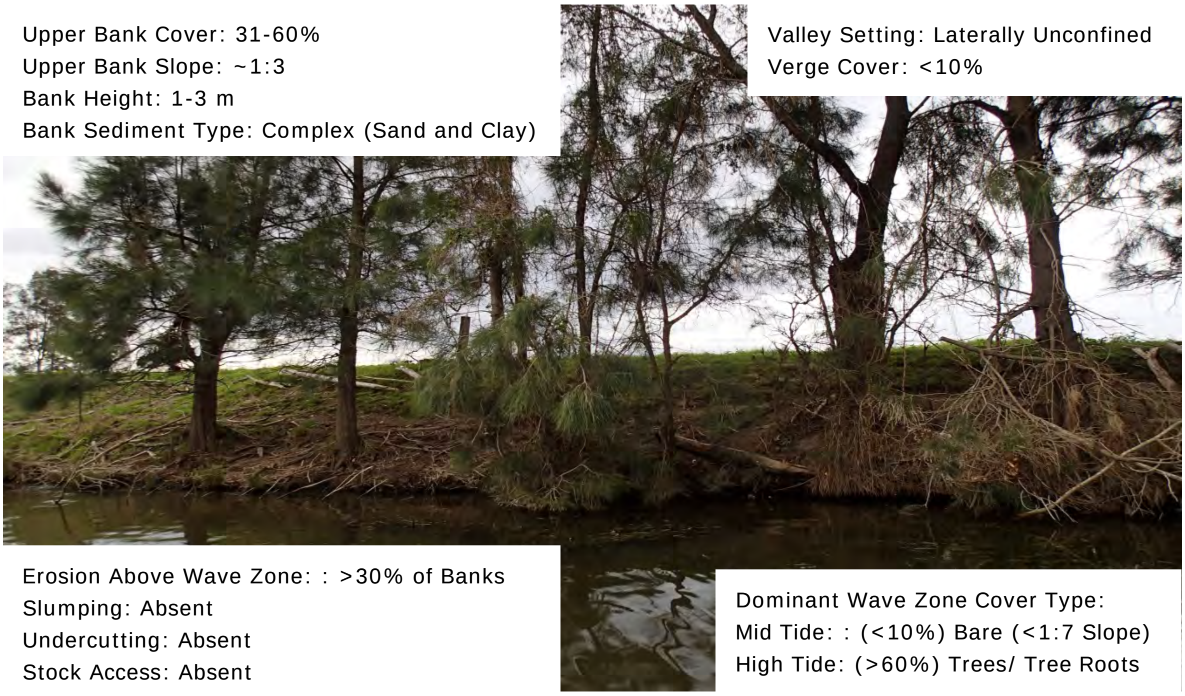
Valley Setting: Laterally Unconfined
Verge Cover: <10%



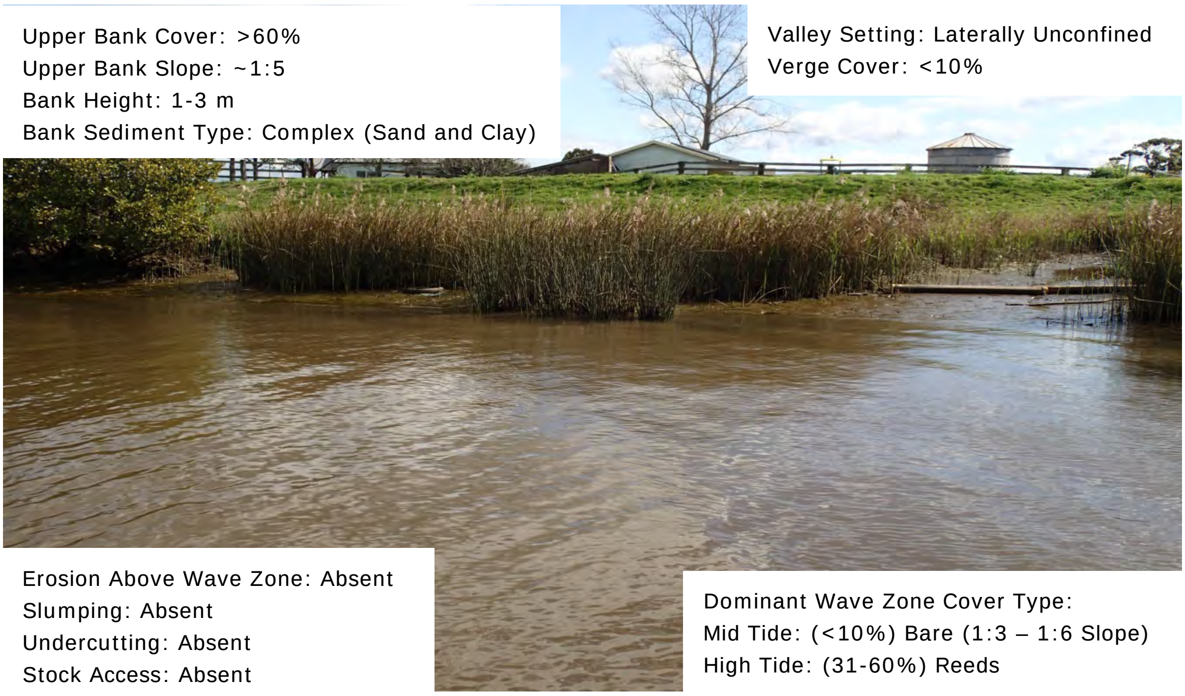
Erosion Above Wave Zone: Absent
Slumping: Absent
Undercutting: Absent
Stock Access: Absent

Dominant Wave Zone Cover Type:
Mid Tide: (>60%) Reeds
High Tide: (>60%) Reeds

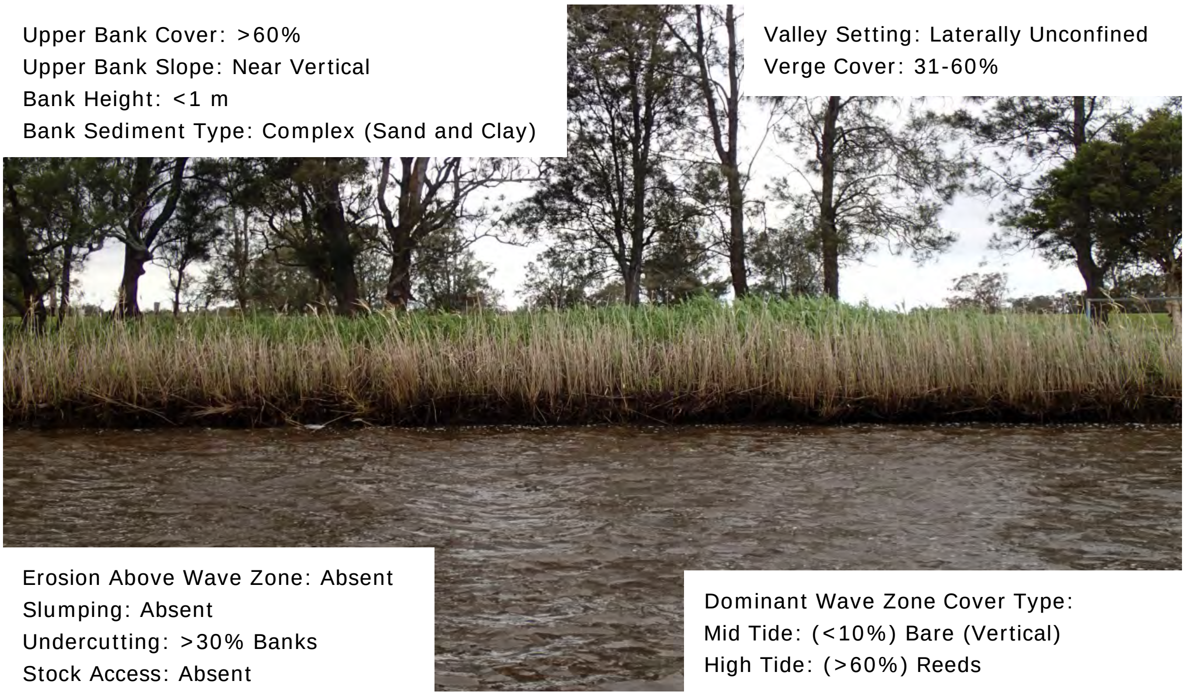
Moderately Resistant – R10A



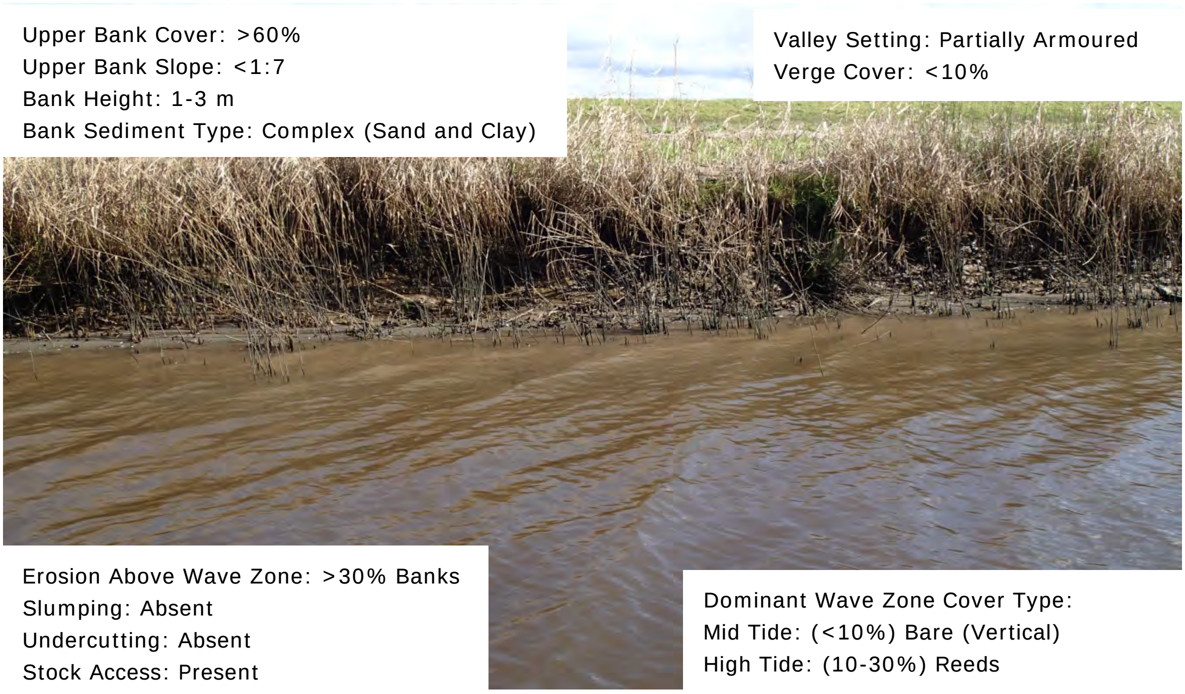
Mildly Resistant – L09A



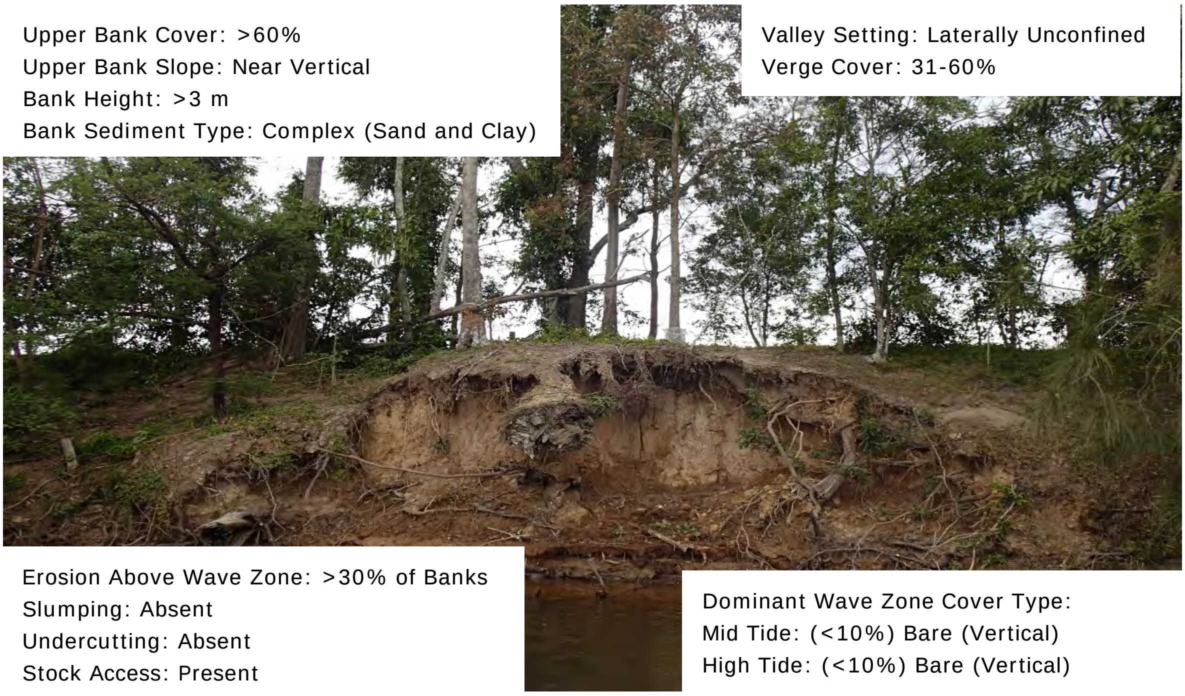
Mildly Resistant – R50A



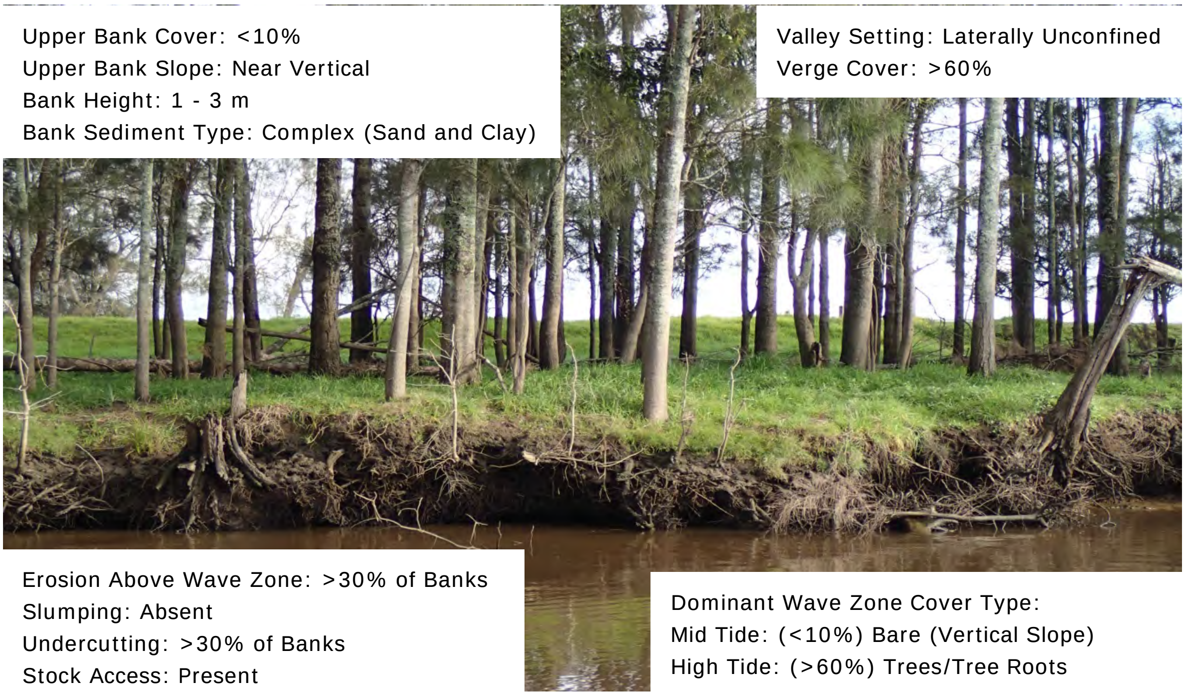
Moderately Erosive – L58A



Moderately Erosive – R72A



Highly Erosive – L11A



Highly Erosive – R63B

Appendix J – Example Wind Wave vs Boat Wave Comparison

J.1 Preamble

The comparison of wind wave and boat wake waves to create an equivalent ARI rating (A-E) is a three step process. Wind information is processed, followed by selection of the boat wave conditions and followed by a comparison of the wind and wake wave energies.

J.2 Processing Wind Information

Processing of the wind information involves five steps:

1. Obtain wind data.
2. Determine fetch lengths, in the centre of each stretch, for each available wind compass direction.
3. Using the local wind rose, complete wave hindcasting for both the single wave and extended duration waves for each wind speed in each direction.
4. Calculate the wind wave energy of the fetch-limited waves and determine the corresponding ARIs of the fetch-limited energy of a single wave.
5. Calculate the total wind wave energy at the site over the extended duration and determine the ARIs of the total wind wave energy for each adjusted wind speed and direction.

Tables J-1 and J-2 provide examples of the ARI, and associated energy of the maximum wave, and the Wind Wave Energy for the extended duration (8 hours), as calculated for two stretches of river (R60 and L60).

Table J-1: Wave Energies and Associated ARI (R60)

Energy of Maximum Wave ($kg.m/s^2$)	Total Wind Wave Energy for the Extended Duration ($kg.m/s^2$)	ARI (years)
0.06	3,327	2.50×10^{-3}
0.10	5,023	2.96×10^{-3}
0.12	6,352	3.32×10^{-3}
0.15	6,956	3.47×10^{-3}
0.17	7,825	5.28×10^{-3}
0.21	9,284	5.59×10^{-3}
0.27	11,491	9.16×10^{-3}
0.32	15,056	1.11×10^{-2}
0.45	18,046	2.04×10^{-2}
0.47	21,336	2.21×10^{-2}
0.66	25,255	2.45×10^{-2}
0.68	26,370	1.01×10^{-1}
0.73	29,112	1.44×10^{-1}
0.93	34,050	2.95×10^{-1}
1.07	36,816	1.77
1.52	49,526	72.60

Table J-2: Wave Energies and Associated ARI (L60)

Energy of Maximum Wave ($kg.m/s^2$)	Total Wind Wave Energy for the Extended Duration ($kg.m/s^2$)	ARI (years)
0.30	12,431	3.99×10^{-3}
0.31	12,489	4.12×10^{-3}
0.60	22,357	5.55×10^{-3}
0.78	28,336	6.18×10^{-3}
0.80	28,980	6.23×10^{-3}
0.88	31,202	6.96×10^{-3}
1.16	39,435	7.03×10^{-3}
1.18	40,672	7.05×10^{-3}
1.25	41,956	8.51×10^{-3}
1.65	52,886	8.54×10^{-3}
1.66	54,985	8.55×10^{-3}
2.24	66,224	1.60×10^{-2}
9.89	237,076	3.90×10^{-2}
27.11	561,899	1.49×10^{-1}
40.79	796,279	3.35×10^{-1}
58.72	1,086,473	72.6

J.3 Wake Wave Data

Wake wave data from previous studies is included in the DSS. Table J-3 provides an overview of the maximum wave generated at operating conditions, maximum waves produced and the waves generated when travelling at 4 knots.

Table J-3: Wake Wave Energies (Glamore and Hudson, 2005)

Condition	Boat	Velocity (knots)	Velocity (m/s)	H_{max} (m)	T_{peak} (s)	Boat Length L_w (m)	F_L	Energy H_{max}
Operating	Waterski	30	15.42	0.12	1.5	6.1	2	62
	Wakeboard	19	9.76	0.25	1.57	6.1	1.3	293
	Wakesurf	10	5.14	0.36	2.03	6.1	0.7	1,102
Maximum Wave	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 knots	Waterski	4	2.05	0.12	1.29	6.1	0.3	46
	Wakeboard	4	2.05	0.13	1.23	6.1	0.3	49

Additionally, in the 2005 study (Glamore and Hudson, 2005), the energy of the entire wave train (not just the individual wave) was calculated for each boat pass. A relationship was fitted to the data, and was used to estimate the total energy of the wave train with where the characteristics of the maximum wave were known.

Wave attenuation is also included in the DSS, with the distance of the boat from the riverbank playing a role in the values of the wave energy received at the bank.

J.4 Comparison of Wave Energies

The wake wave energy is then compared to the ARI of the wind energy. Table J-4 provides some examples of a wakeboarding vessel under operating conditions, for 8 hours with 50 boat passes at distance of 58 m from the shore at Stretch 60. The energy of the maximum wave, and the total waves over the extended duration are then compared according to Table C-2 and an Equivalent ARI Rating determined.

Table J-4: Comparison of Wave Energies

Stretch	Condition	Attenuated Energy Max Wave (J/m)	Equivalent to a Wind Wave with ARI of 1 in ___ years	Energy of Single Attenuated Wave Train (J/m)	Total Energy at the Bank over 8 hours (J/m)	Equivalent to wind waves over 8 hours duration with ARI of 1 in __ years	Equivalent ARI Rating (Table C-2)
R60	Maximum Wave	372	72.6	1,378	68,895	72.6	E
	Operating	152	72.6	673	33,669	2.83×10^{-1}	E
L60	Maximum Wave	372	72.6	1,378	68,895	1.64×10^{-2}	C
	Operating	152	72.6	673	33,669	6.98×10^{-3}	B

Appendix K – Equivalent Wind/Boat Wave ARI Ratings

K.1 Preamble

The wind frequency data was applied to fetch lengths (measured in the centre of each stretch) for all stretches of the study area to determine the ARI of wind events on the river. These wind values were then compared with the energy of both the maximum boat wave and the cumulative wake waves over the entire day (Table C-2) to establish an ARI rating for each boat pass scenario at each location.

K.2 Seaham Weir Pool

The number and distribution of each ARI category for each of the boat pass scenarios on the Seaham Weir Pool was previously reported in WRL TR 2012/05 (Glamore and Davey, 2012). However, as discussed in Appendix D, WRL re-calculated the ARI values on the Seaham Weir Pool for the present study. Table K-1 provides a breakdown of the different ARI ratings for the low, medium and high boat pass numbers. Figures K-1 to K-3 display the distribution of the different ARI ratings along the Seaham Weir Pool for the three (3) boat pass classes. Note that for the final combined boat pass activities adopted on the Seaham Weir Pool, correcting the two (2) wind scaling factor errors discussed in Appendix D only changed the ARI ratings at 3% of sites.

Table K-1: Number of Seaham Weir Pool Stretches in Equivalent ARI Ratings for Adopted Daily Boat Passes

Equivalent ARI Category	Low Boat Passes	Medium Boat Passes	High Boat Passes
A	0	0	0
B	71	71	26
C	10	10	28
D	4	4	8
E	13	13	36

K.3 Lower Williams River

This section presents the number and distribution of each ARI category for each of the boat pass scenarios on the Lower Williams River. A total of 60 ratings are produced, one (1) for each riverbank over the 30 stretches on the Lower Williams River. Appendix I provides an applied example of the comparison between the wind and wake wave data.

Tables K-2 to K-4 provide a breakdown of the different ARI ratings for the 18 boat pass scenarios, including wakeboard, waterski and wakesurf 'operating' conditions for five (5) different boat pass scenarios, and the 'maximum wave' condition as produced for 50 boat passes for each activity. Figures K-4 to K-15 display the distribution of the different ARI ratings along the study region for the 10, 50 and 150 boat pass scenarios for wakeboard, waterski and wakesurf activities. Figures illustrating the ARI ratings of the high boat pass scenarios have been omitted for brevity. For the 10 boat pass boat scenario, the most observed rating is the 'B' category for all activities. For the 50 boat pass scenario, the most observed rating varies from the 'B' category for waterskiing to the 'E' category for wakesurfing. For all other boat pass scenarios and activities, the most observed rating is the 'E' category, except for the waterski 150 and 300 boat pass scenarios where the most observed rating is the 'B' and 'C' category, respectively.

As expected, with increasing boat numbers on the river, the equivalent ARI for the stretches became larger. For all three (3) boating activities, boat passes equal to 150 or more recorded ARI ratings in the 'E' category. The highest number of observations in the 'E' category was recorded for 500 boat passes for both activities. Less observations were recorded in higher ARI categories for all waterski scenarios. However, in comparison to wakeboard and waterski operating conditions, wakesurf operating conditions resulted in significantly larger equivalent ARI ratings for 10, 50 and 150 boat pass scenarios.

Table K-2: Number of Lower Williams River Stretches in Equivalent ARI Ratings for Each Wakeboard Boat Pass Scenario

Equivalent ARI Category	Operating Conditions					Maximum Wave
	10 Passes	50 Passes	150 Passes	300 Passes	500 Passes	50 Passes
A	0	0	0	0	0	0
B	60	16	1	0	0	1
C	0	21	11	5	0	20
D	0	13	8	11	10	8
E	0	10	40	44	50	31

Table K-3: Number of Lower Williams River Stretches in Equivalent ARI Ratings for Each Waterski Boat Pass Scenario

Equivalent ARI Category	Operating Conditions					Maximum Wave
	10 Passes	50 Passes	150 Passes	300 Passes	500 Passes	50 Passes
A	0	0	0	0	0	0
B	60	57	21	6	1	1
C	0	3	19	27	19	20
D	0	0	13	13	9	11
E	0	0	7	14	31	28

Table K-4: Number of Lower Williams River Stretches in Equivalent ARI Ratings for Each Wakesurf Boat Pass Scenario

Equivalent ARI Category	Operating Conditions					Maximum Wave
	10 Passes	50 Passes	150 Passes	300 Passes	500 Passes	50 Passes
A	0	0	0	0	0	0
B	38	1	0	0	0	0
C	19	15	1	0	0	16
D	2	11	9	4	2	6
E	1	33	50	56	58	38

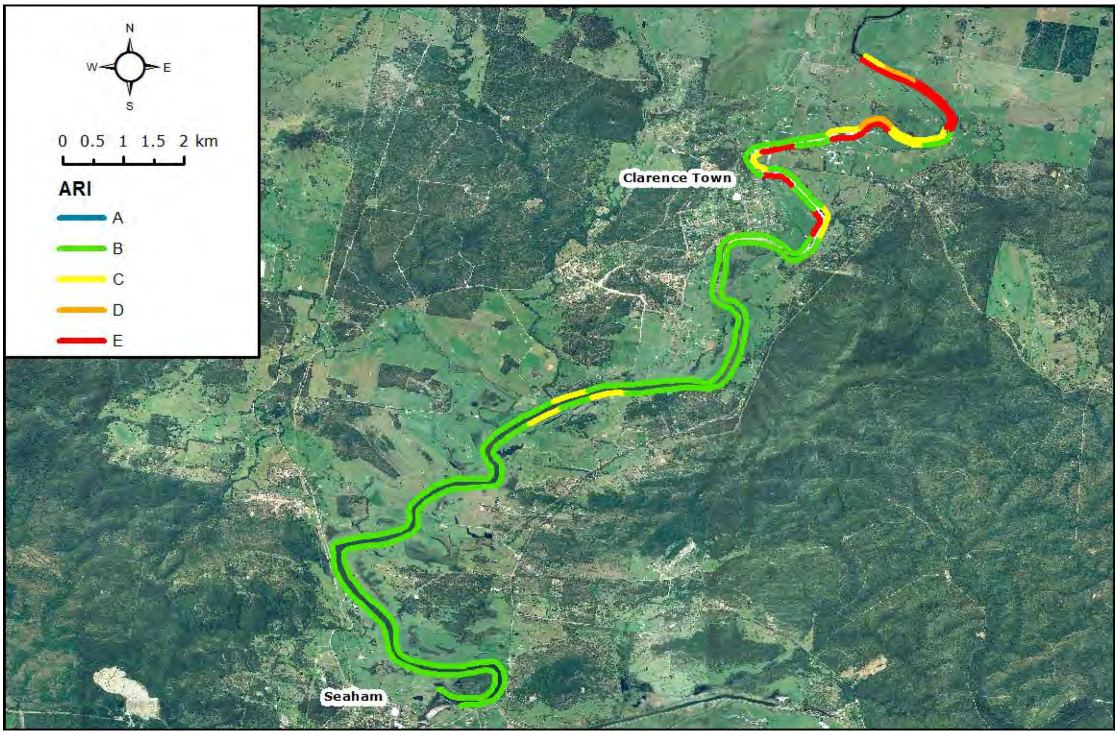


Figure K-4: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - 8 Hour Duration – Low Boat Passes (Seaham Weir Pool)

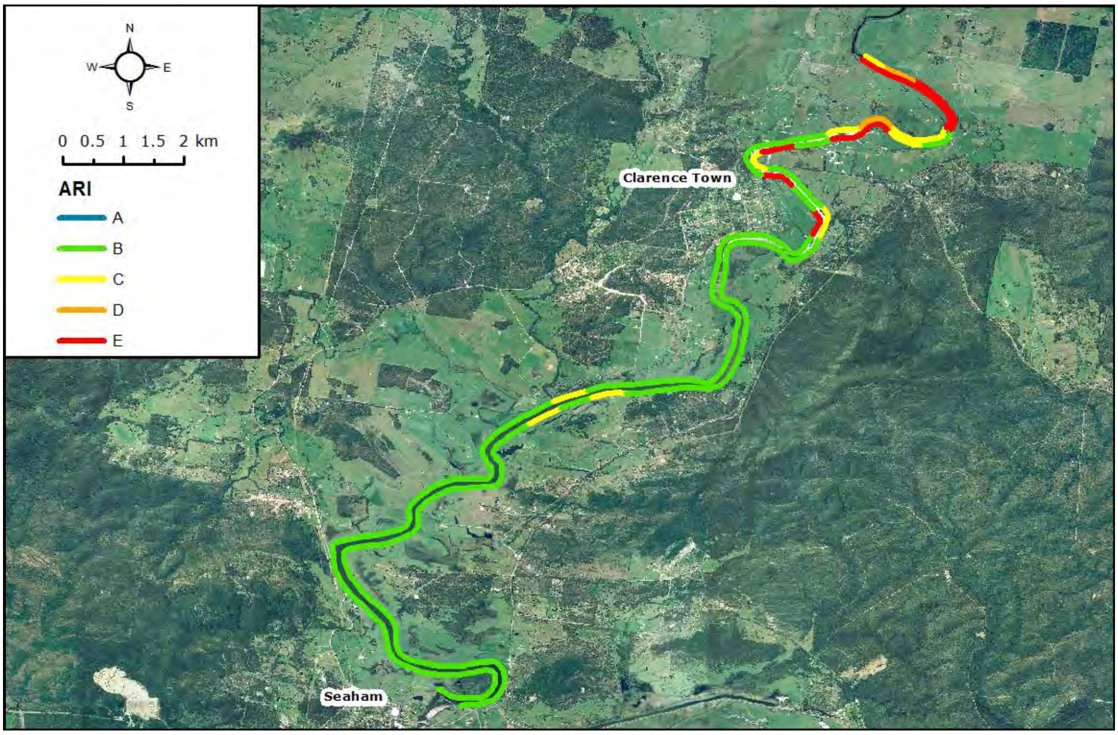


Figure K-5: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - 8 Hour Duration – Medium Boat Passes (Seaham Weir Pool)

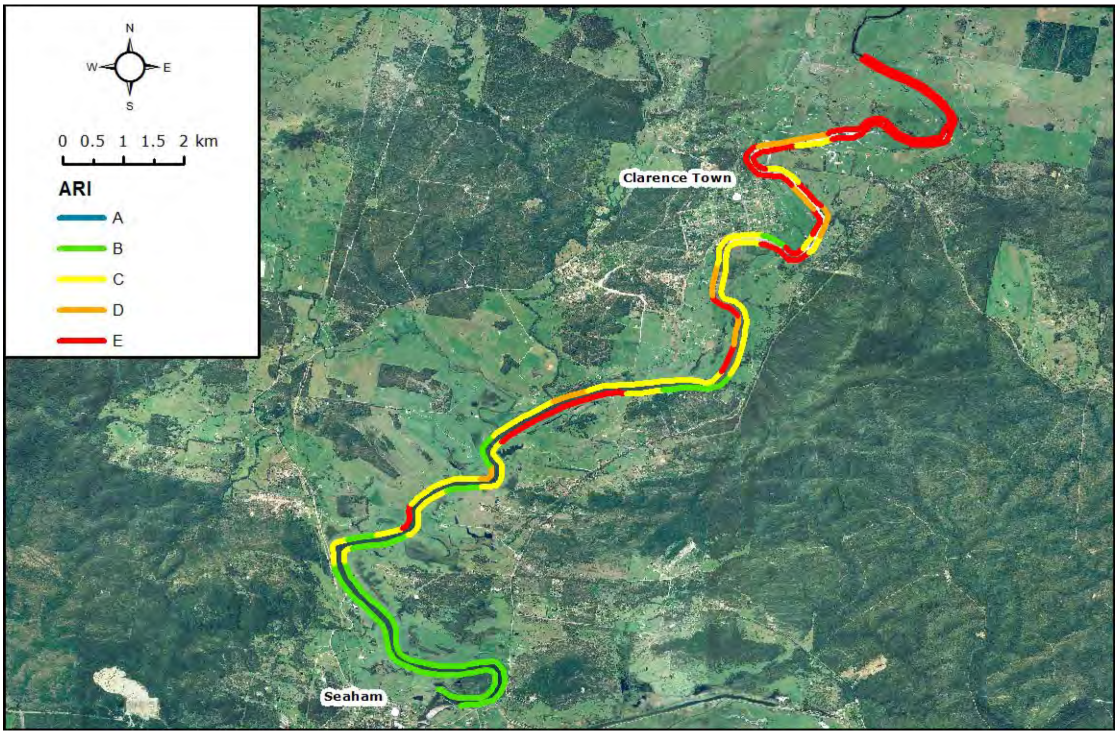


Figure K-6: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - 8 Hour Duration – High Boat Passes (Seaham Weir Pool)

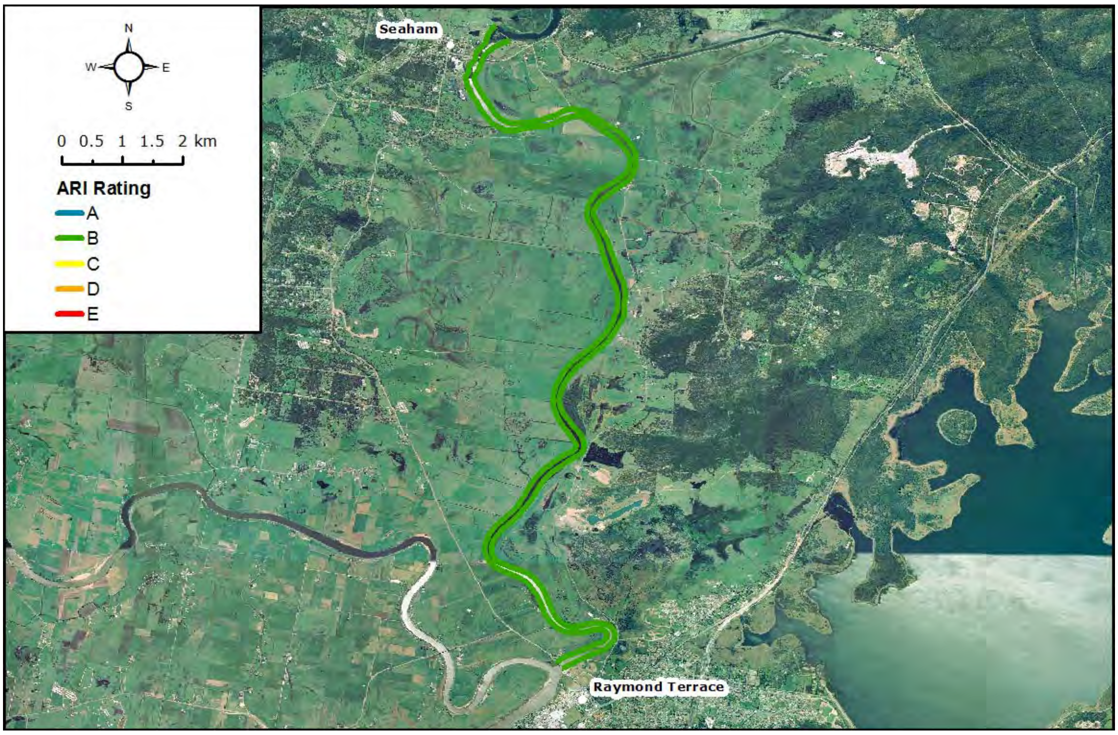


Figure K-7: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakeboard Operating - 8 Hour Duration – 10 Boat Passes (Lower Williams River)

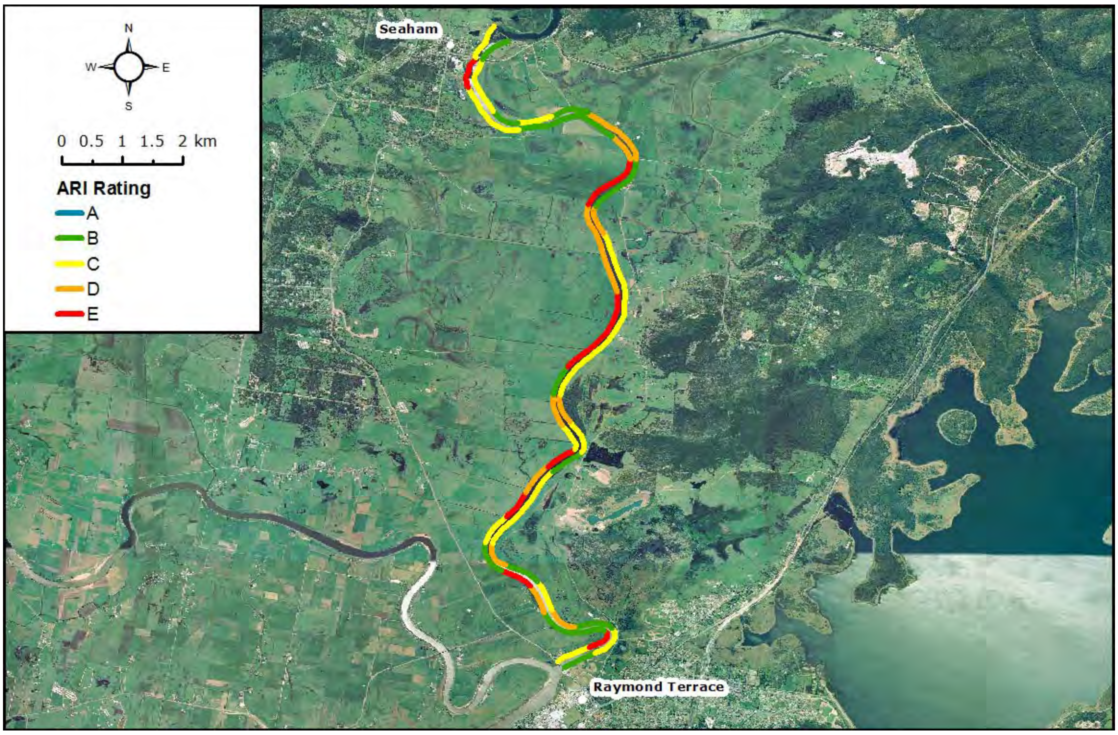


Figure K-8: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakeboard Operating - 8 Hour Duration – 50 Boat Passes (Lower Williams River)

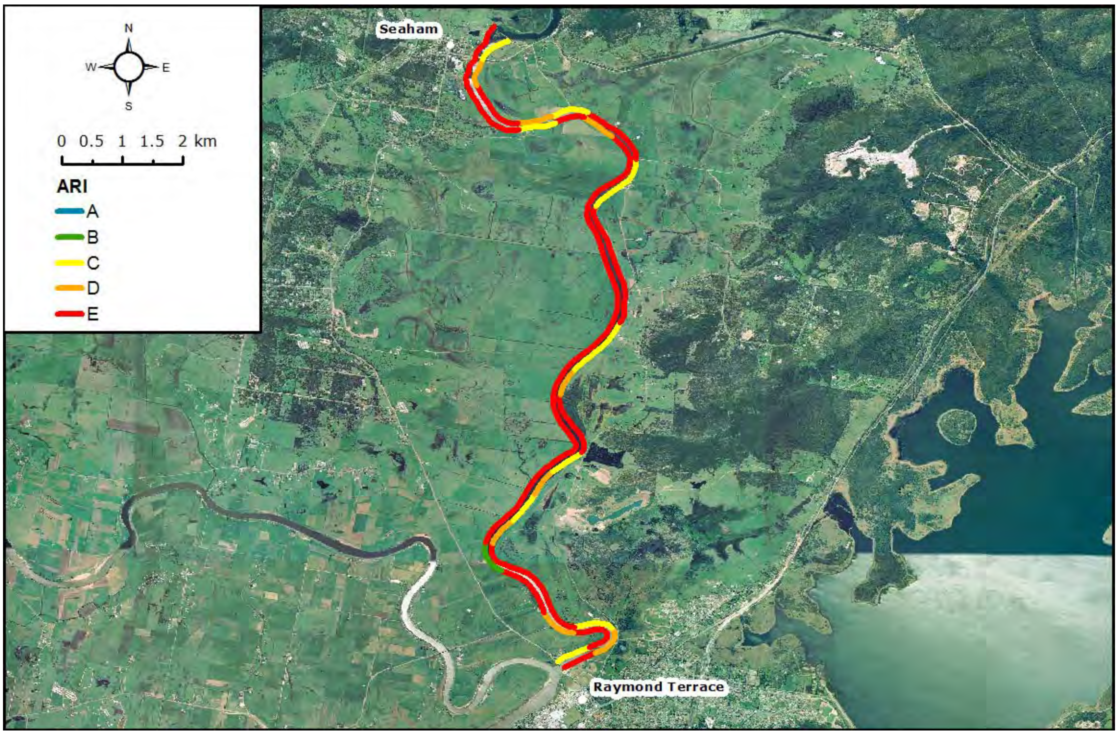


Figure K-9: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakeboard Operating - 8 Hour Duration – 150 Boat Passes (Lower Williams River)

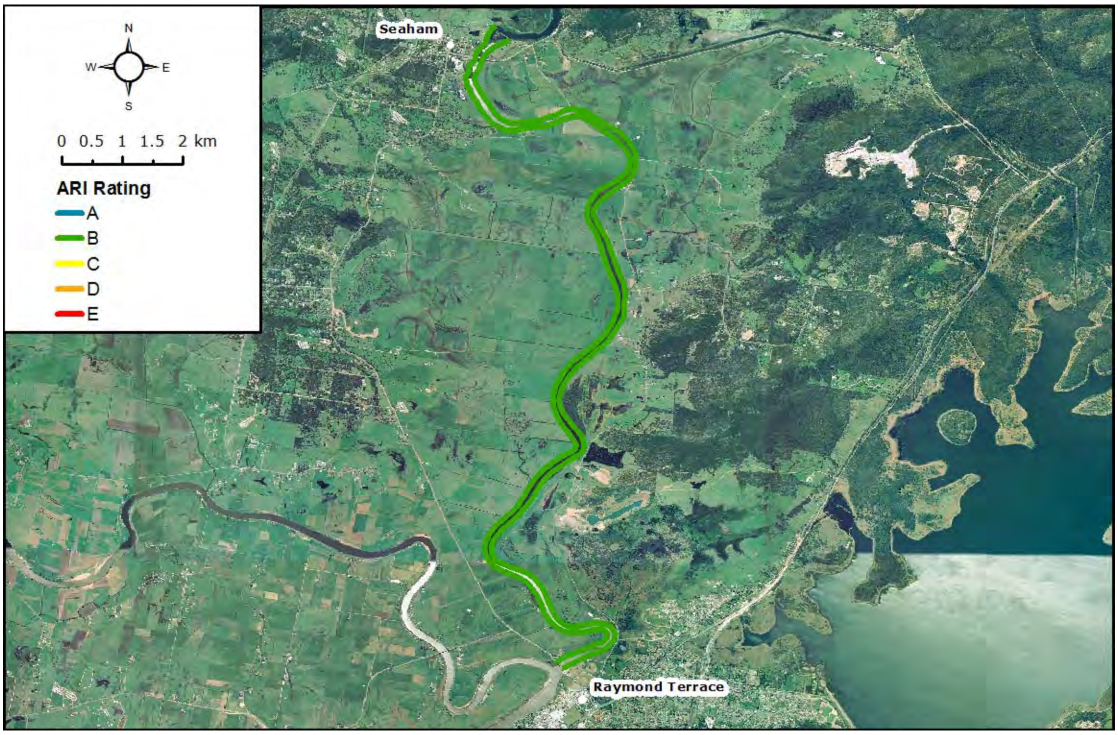


Figure K-10: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Waterski Operating - 8 Hour Duration – 10 Boat Passes (Lower Williams River)

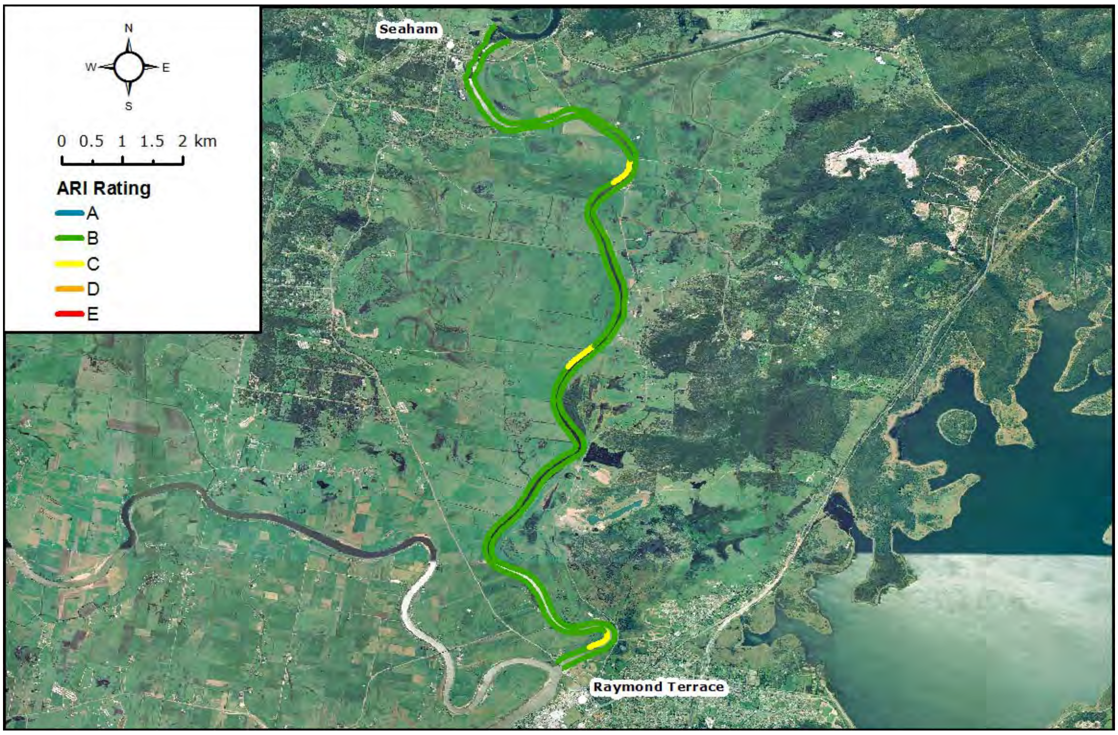


Figure K-11: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Waterski Operating - 8 Hour Duration – 50 Boat Passes (Lower Williams River)

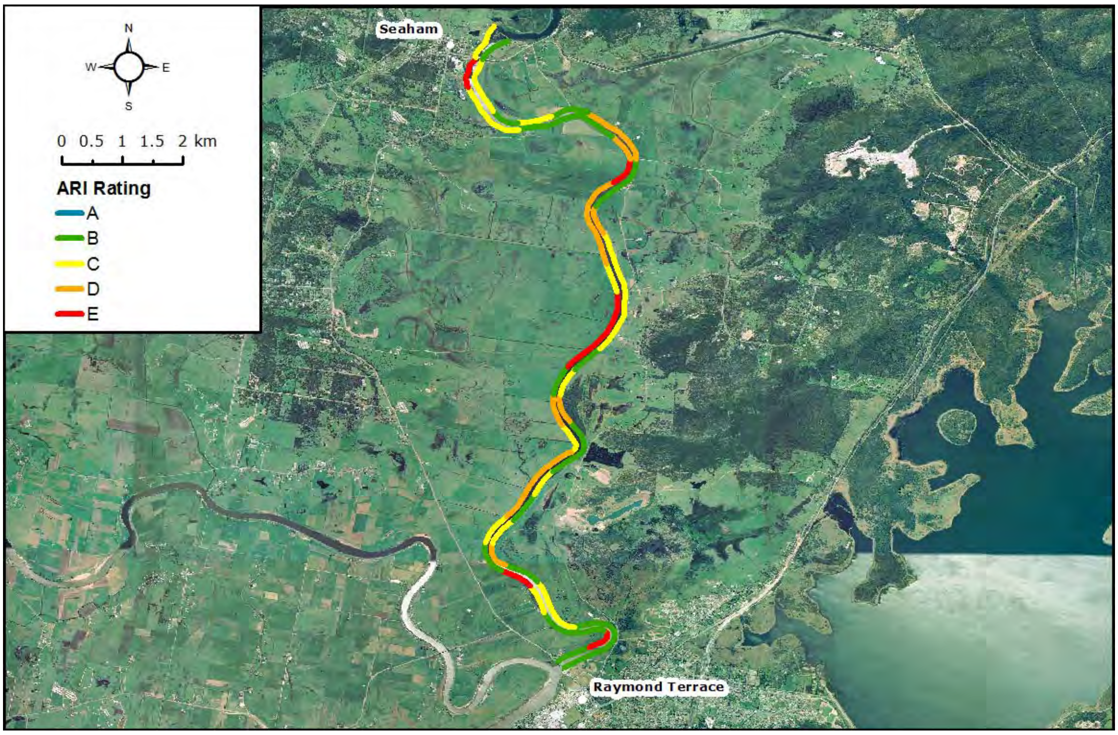


Figure K-12: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Waterski Operating - 8 Hour Duration – 150 Boat Passes (Lower Williams River)

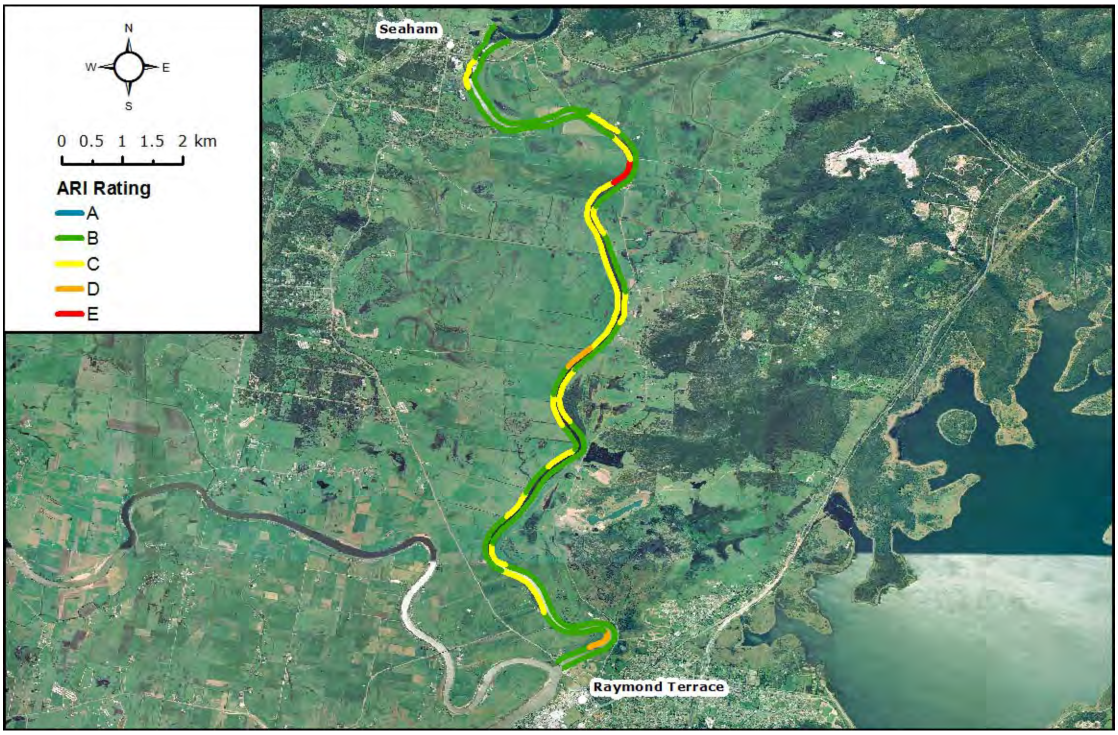


Figure K-13: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakesurf Operating - 8 Hour Duration – 10 Boat Passes (Lower Williams River)

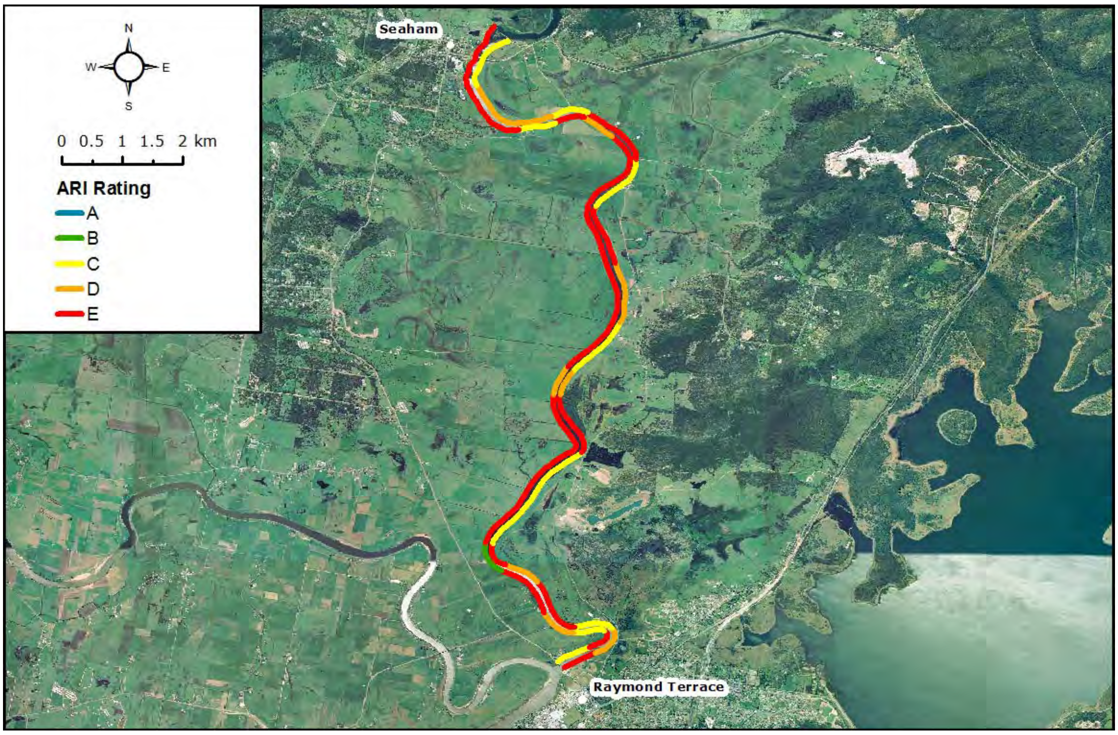


Figure K-14: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakesurf Operating - 8 Hour Duration – 50 Boat Passes (Lower Williams River)

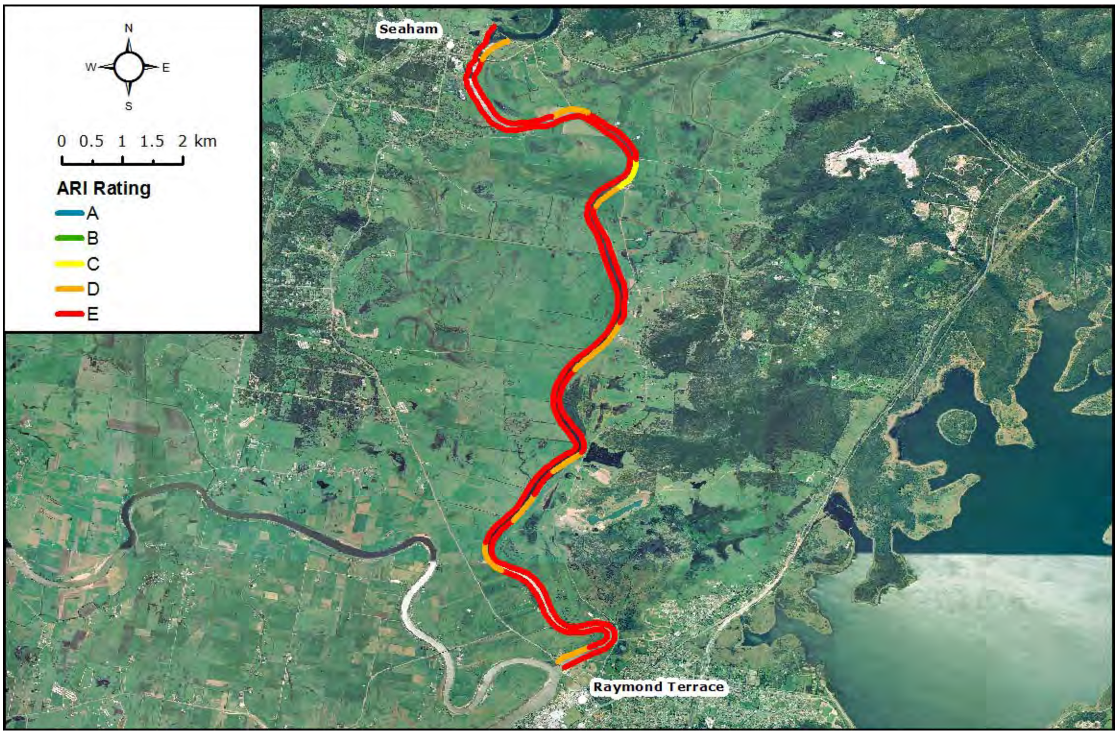


Figure K-15: Equivalent Wind/Boat Wave Average Recurrence Interval Rating - Wakesurf Operating - 8 Hour Duration – 150 Boat Passes (Lower Williams River)

Appendix L – March 2015 Baseline DSS Assessment (Lower Williams River)

Table L-1 and Figures L-1 through L-9 present the March 2015 DSS management ratings for the Lower Williams River study area under mid – low tide conditions. It was evident that increasing boat numbers had an impact on the management ratings for the study area. Wakesurf 'operating' conditions resulted in the highest number of 'Manage' sites in each boat pass scenario for the baseline assessment. Wakeboard 'operating' conditions resulted in the second highest counts of 'Manage' sites compared to waterski 'operating' conditions, except for the 10 boat passes scenario, where the results were approximately the same.

Table L-1: Number of Stretches Determined in Each DSS Management Category (Mid – Low Tide Conditions)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes
Allow	11	0	0	11	7	1	4	0	0
Allow*	0	2	0	0	4	1	3	0	0
Monitor	43	26	15	45	36	30	32	16	7
Monitor*	2	8	3	0	8	5	7	6	5
Manage	4	24	42	4	5	23	14	38	48

Note: Wave attenuation was a limiting factor in the management recommendation for sites presented as 'Allow*' or 'Monitor*'.

The management ratings vary significantly between wakeboard and waterski vessels in the baseline assessment. For wakeboard 'operating' conditions, 38 additional locations recorded the 'Manage' recommendation, following an increase from 10 boat passes to 150 boat passes. However, for waterski 'operating' conditions, 19 additional locations recorded the 'Manage' recommendation, following an increase from 10 boat passes to 150 boat passes. Based on the results of the baseline assessment it was apparent that wave attenuation was not a limiting factor in the overall management recommendation at a number of sites across the study region due to the relatively narrow width of the Williams River. As expected, the stretches recording the 'Monitor' and 'Manage' ratings were regularly associated with alluvial plains as opposed to the armoured sections that were scattered throughout the study area.

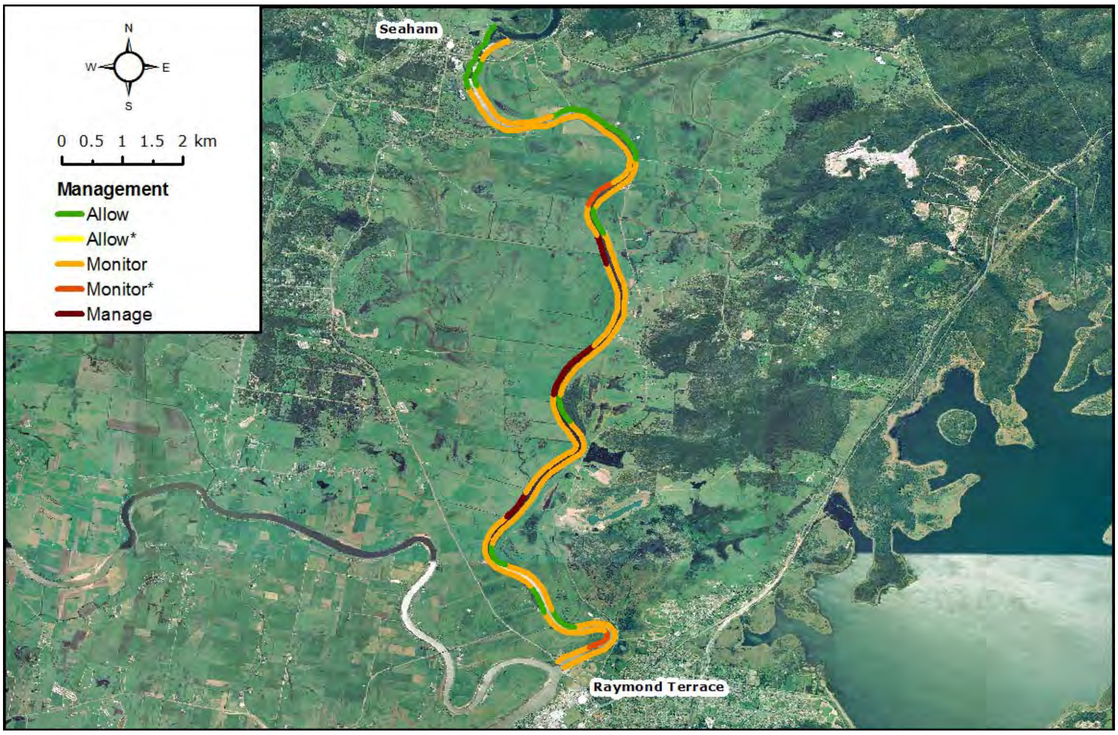


Figure L-1: DSS Management Recommendations - Wakeboard Operating - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

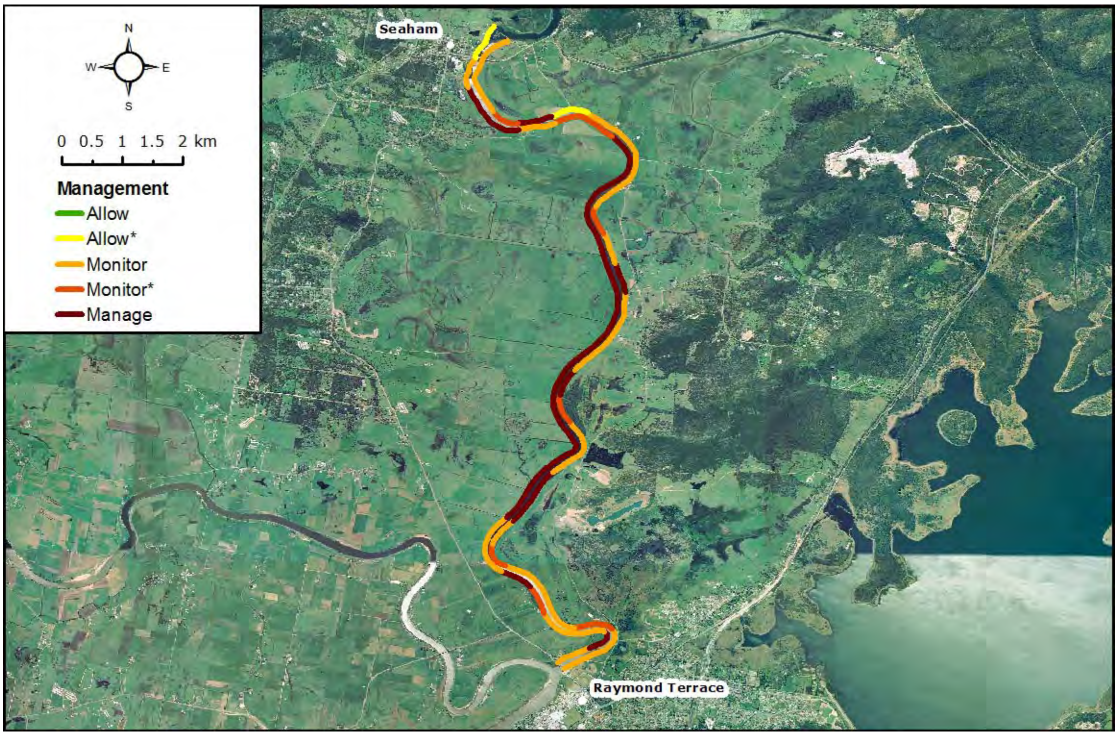


Figure L-2: DSS Management Recommendations - Wakeboard Operating - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

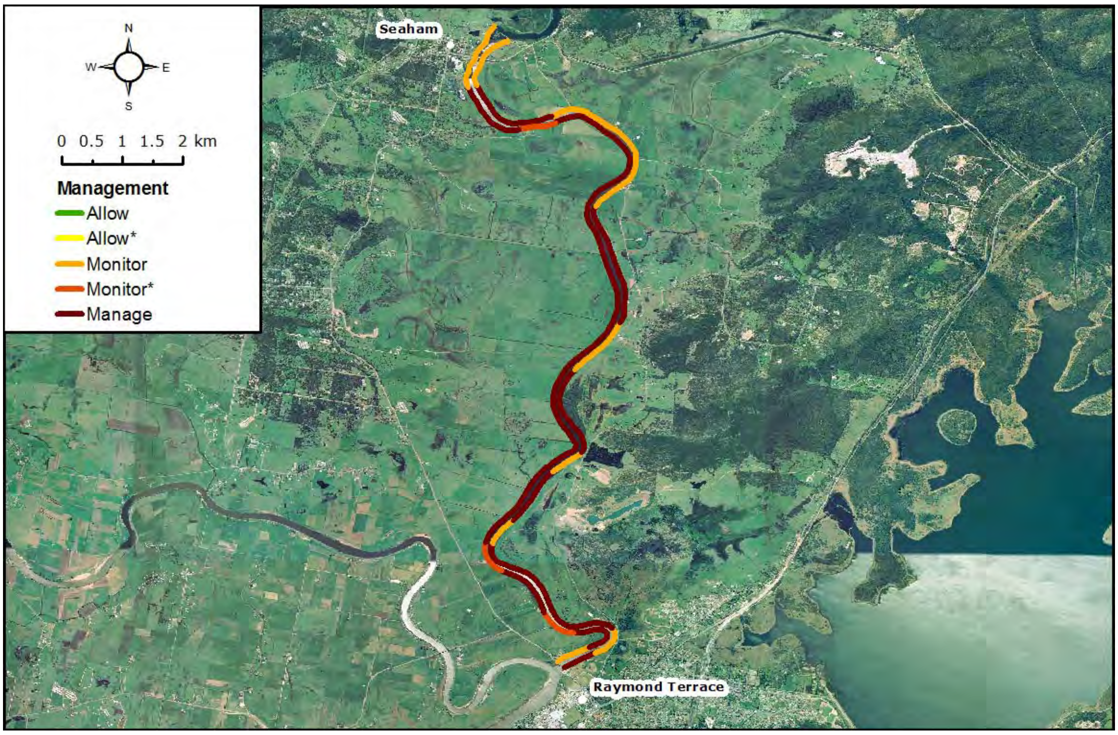


Figure L-3: DSS Management Recommendations - Wakeboard Operating - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

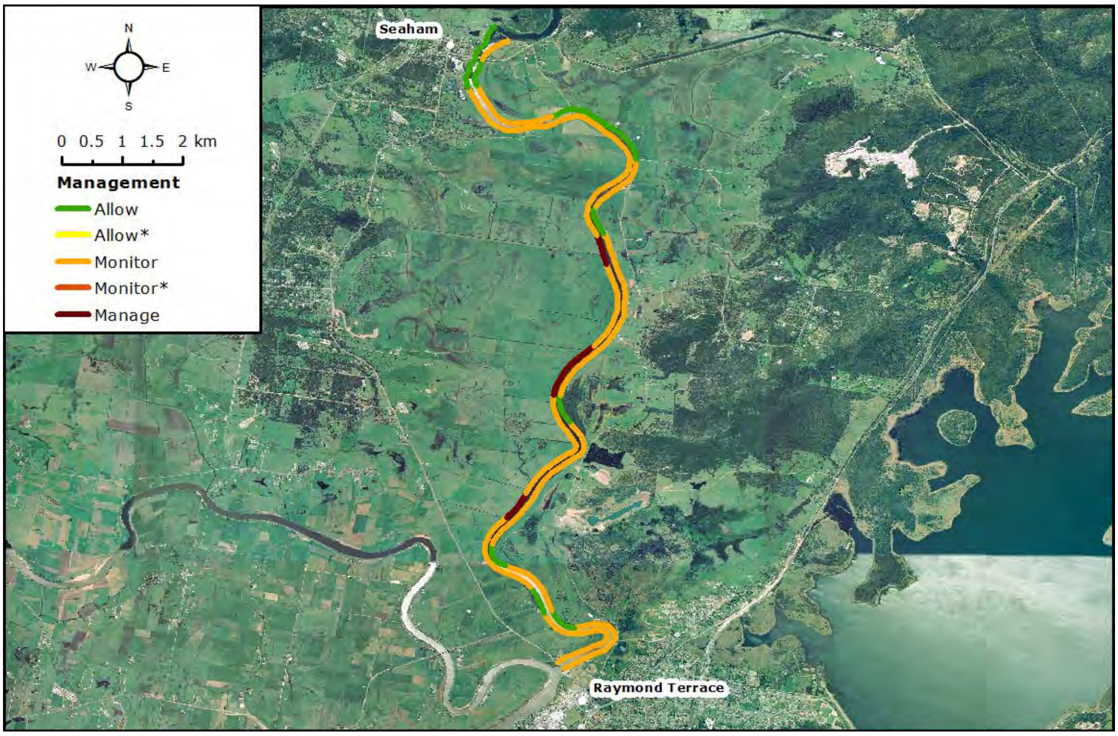


Figure L-4: DSS Management Recommendations - Waterski Operating - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

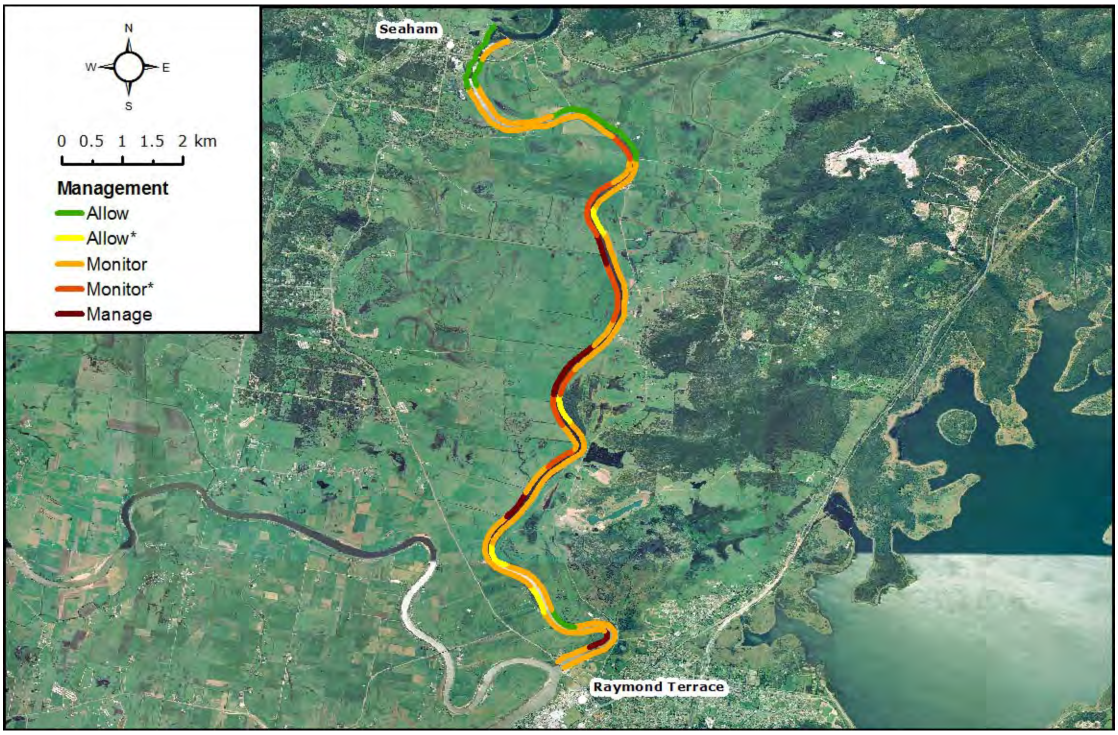


Figure L-5: DSS Management Recommendations - Waterski Operating - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

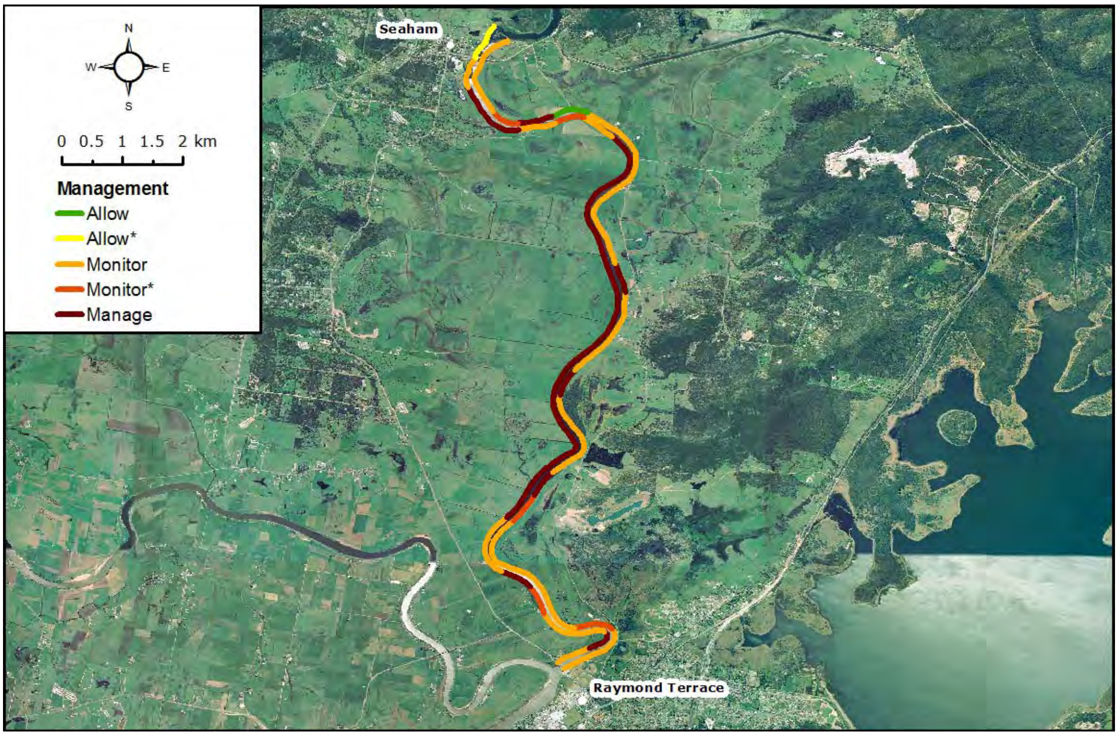


Figure L-6: DSS Management Recommendations - Waterski Operating - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

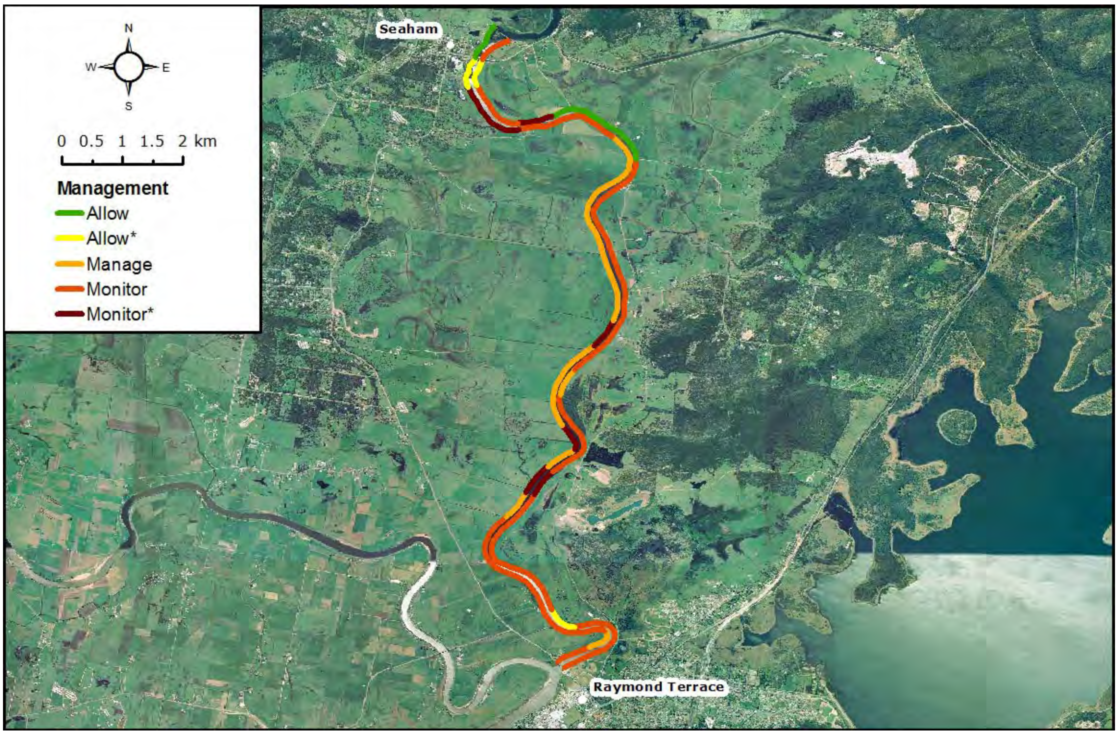


Figure L-7: DSS Management Recommendations - Wakesurf Operating - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

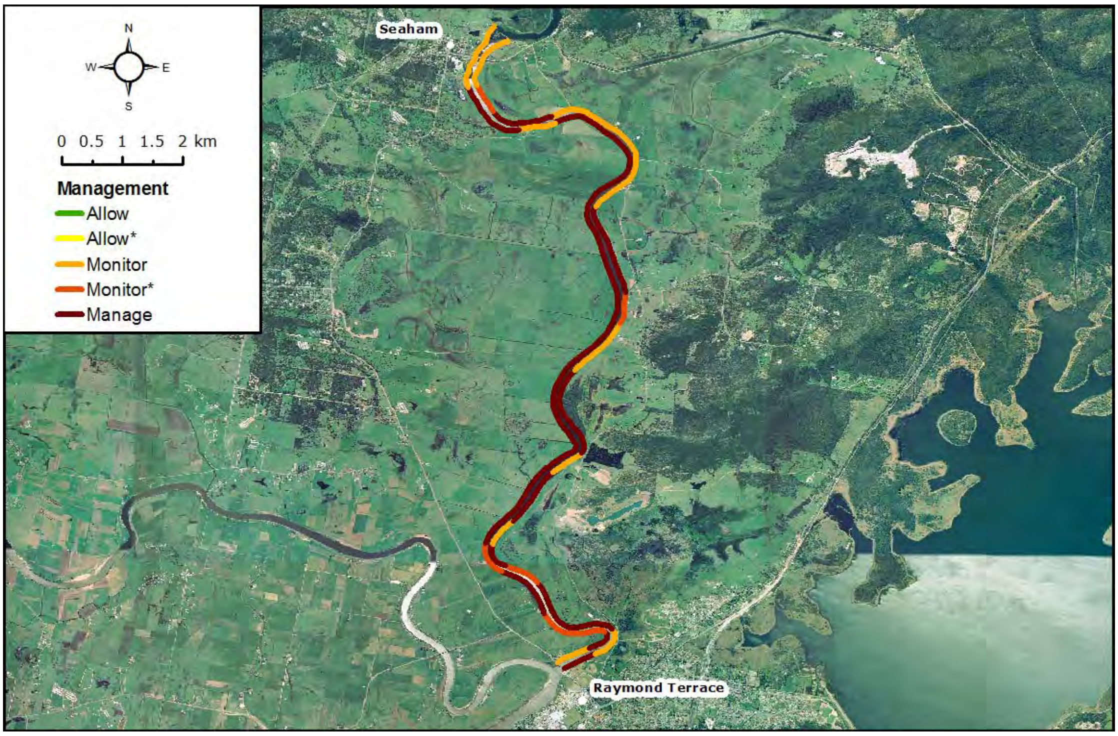


Figure L-8: DSS Management Recommendations - Wakesurf Operating - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

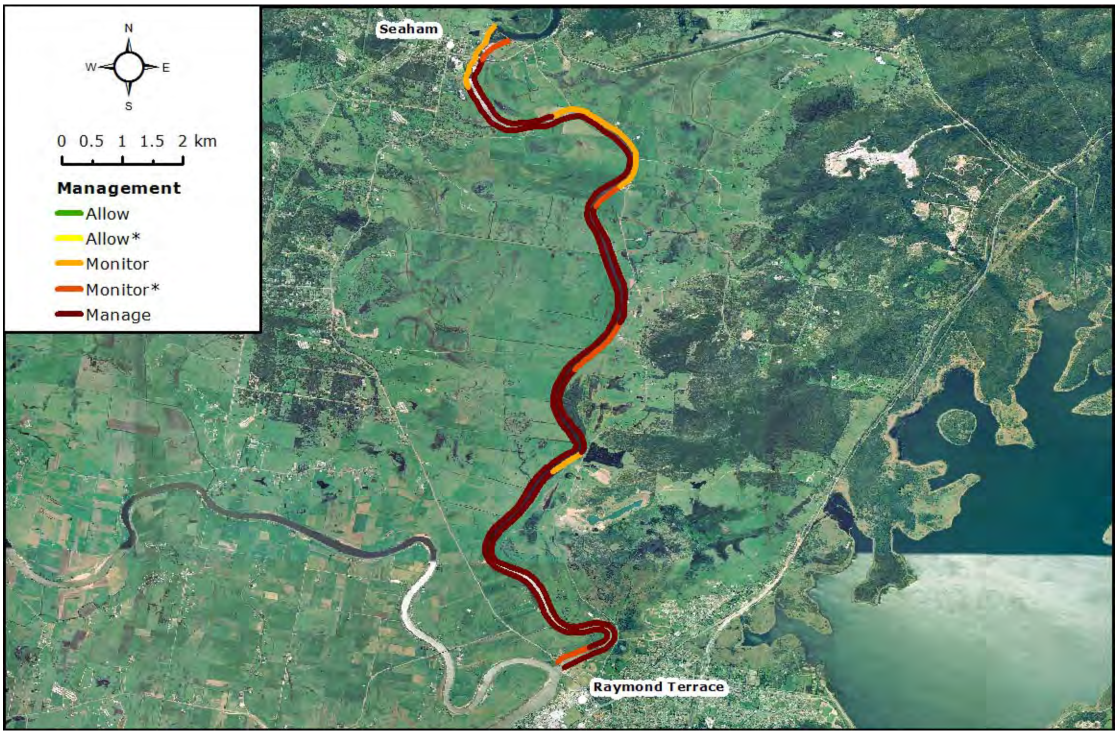


Figure L-9: DSS Management Recommendations - Wakesurf Operating - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

Appendix M – Elevated Water Levels on the Williams River: Erosion Potential and Management Outcomes

M.1 Preamble

This section summarises the DSS results of elevated water levels on the Williams River based on the March 2015 field assessment. Erosion potential was assessed at a potentially raised (+300 mm) water level on the Seaham Weir Pool (Section M.2.1), and at high tide on the Lower Williams River (Section M.3.1) to observe the wave zone throughout the entire tidal cycle. Management outcomes for elevated water levels on the Williams River are also presented for the Seaham Weir Pool (Section M.2.2) and Lower Williams River (Section M.3.2) study areas.

M.2 Raised Operational Water Level for Seaham Weir Pool (March 2015)

M.2.1 Erosion Potential Assessment

Table M-1 and Figure M-1 provide the distribution of riverbank erosion potential categories for a raised operational water level for the Seaham Weir Pool based on the March 2015 assessment. For this assessment less than 50% of all transects observed were 'Mildly Resistant' to erosion or better. The number of sites in the 'Moderately Erosive' or 'Highly Erosive' categories reduced from 161 occurrences at the existing operational water level (Section 5.2.1) to 154 occurrences at a raised operational water level, following a reduction of approximately 7% in the 'Highly Erosive' category. On this basis, there is insufficient evidence to recommend raising the operational water level for the Seaham Weir Pool.

Table M-1: Erosion Potential of the Seaham Weir Pool Under a Raised Operational Water Level Scenario in March 2015

Erosion Potential (Raised Operational Water Level)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	10	0
Moderately Resistant	36	8
Mildly Resistant	82	36
Moderately Erosive	102	44
Highly Erosive	52	6
Total	**282**	**94**

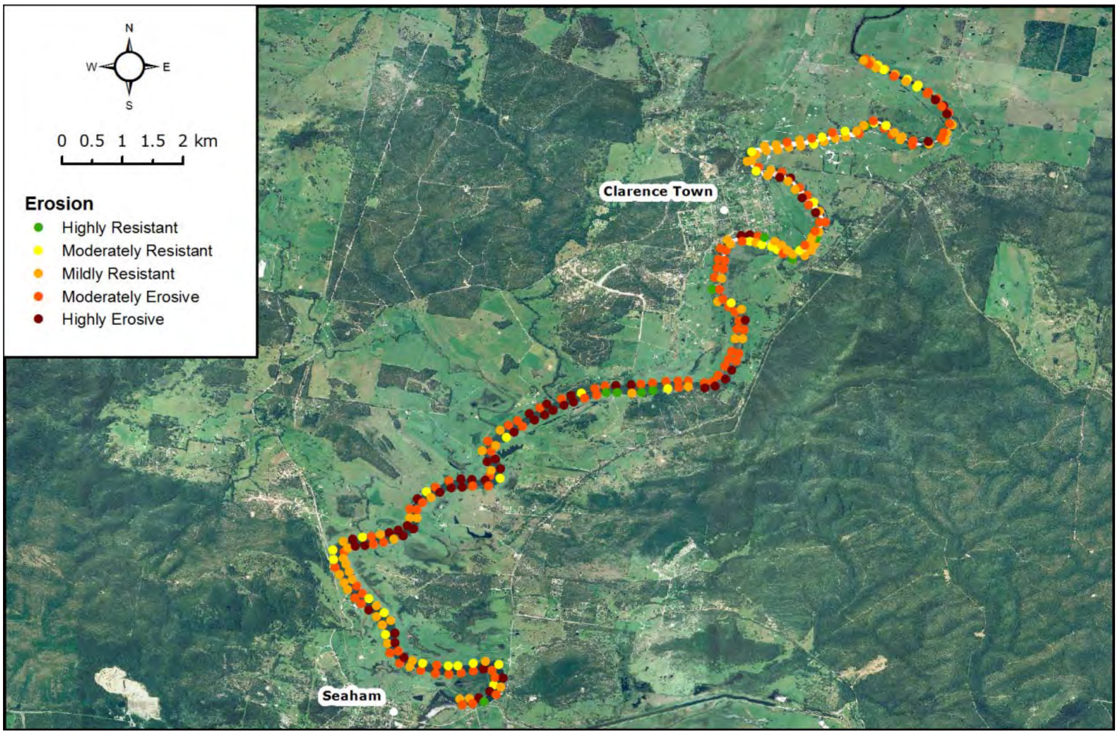


Figure M-1: Erosion Potential of the Seaham Weir Pool Under a Raised Operational Water Level Scenario in March 2015

M.2.2 Management Ratings

Table M-2 and Figure M-2 provide the DSS management outcomes from March 2015 for the Seaham Weir Pool study area under a raised operational water level management scenario. The DSS results for this scenario yielded a 76% majority of 'Monitor' recommendations for the study area, followed by 10% 'Monitor*', 7% 'Manage' and 7% 'Allow' sites. It was evident that there was a modest reduction in the number of 'Manage' sites, corresponding to an increase in the number of 'Monitor' and 'Allow' sites. Aside from these changes, the overall DSS results for the two management scenarios in March 2015 were very similar.

Table M-2: Number of Stretches Determined in Each DSS Management Category in March 2015

Stretch	River Section	# Passes	Management Option				
			Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	1	1	0	10	0	1
7-9	4 knot Section (D/S)	10	0	0	6	0	0
10-17	Waterskiing Section (D/S)	50	0	0	11	3	2
18-22	Wakeboarding Section	50	1	0	3	3	3
23-26	Waterskiing Section (U/S)	50	0	0	5	2	1
27-30	4 knot Section (U/S)	50	0	0	7	1	0
31-47	U/S of the 4 knot Section	1	5	0	29	0	0
1-47	***TOTAL***		**7**	**0**	**71**	**9**	**7**

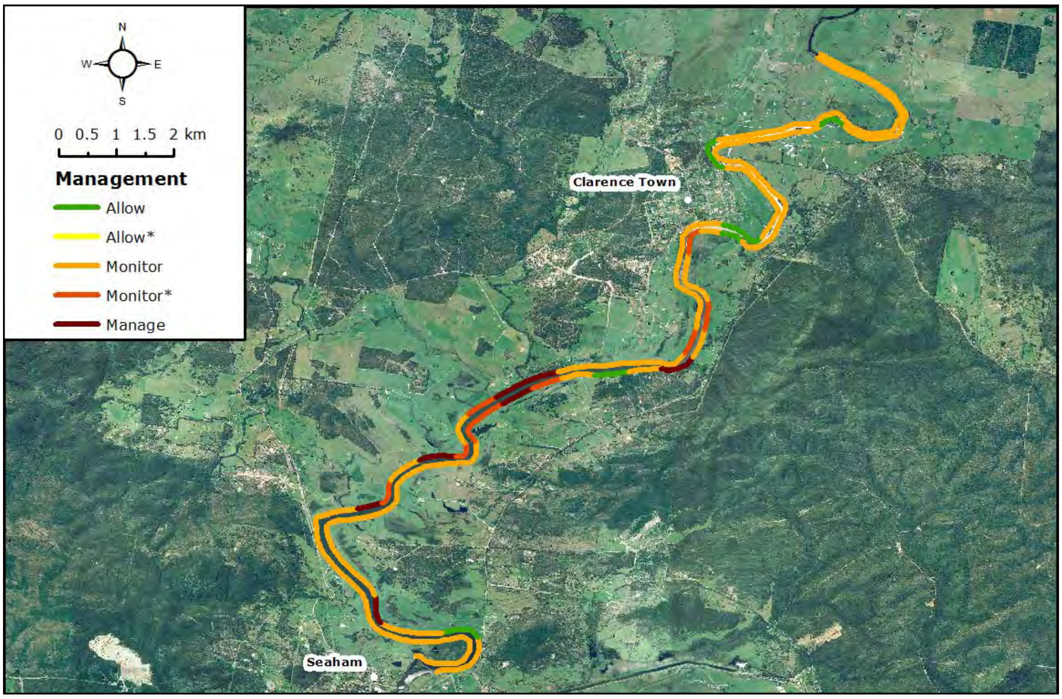


Figure M-2: March 2015 (Pre-Flood) DSS Management Outcomes for Seaham Weir Pool - Scaled Williamtown RAAF Base Wind Data - Raised Operational Water Level

M.3 High Tide Assessment on Lower Williams River (March 2015)

M.3.1 Erosion Potential Assessment

Table M-3 and Figure M-3 provide the distribution of riverbank erosion potential categories for the high tide assessment of the Lower Williams River in March 2015. A comparison between the mid – low tide (see Section 5.2.3) and high tide assessments illustrates the differences between the number of occurrences for each erosion potential category. The results show that the number of transects observed to be 'Mildly Resistant' to erosion, or better, increased to 67% at high tide. Conversely, the number of sites in the 'Moderately Erosive' or 'Highly Erosive' categories reduced from 84 occurrences at mid – low tide to 59 occurrences at high tide, following a reduction of approximately 4% in the 'Highly Erosive' category.

Table M-3: Erosion Potential of the Lower Williams River Study Area in March 2015 (High Tide Conditions)

Erosion Potential (High Tide)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	23	2
Moderately Resistant	55	19
Mildly Resistant	41	21
Moderately Erosive	34	16
Highly Erosive	26	2
Total	**179**	**60**

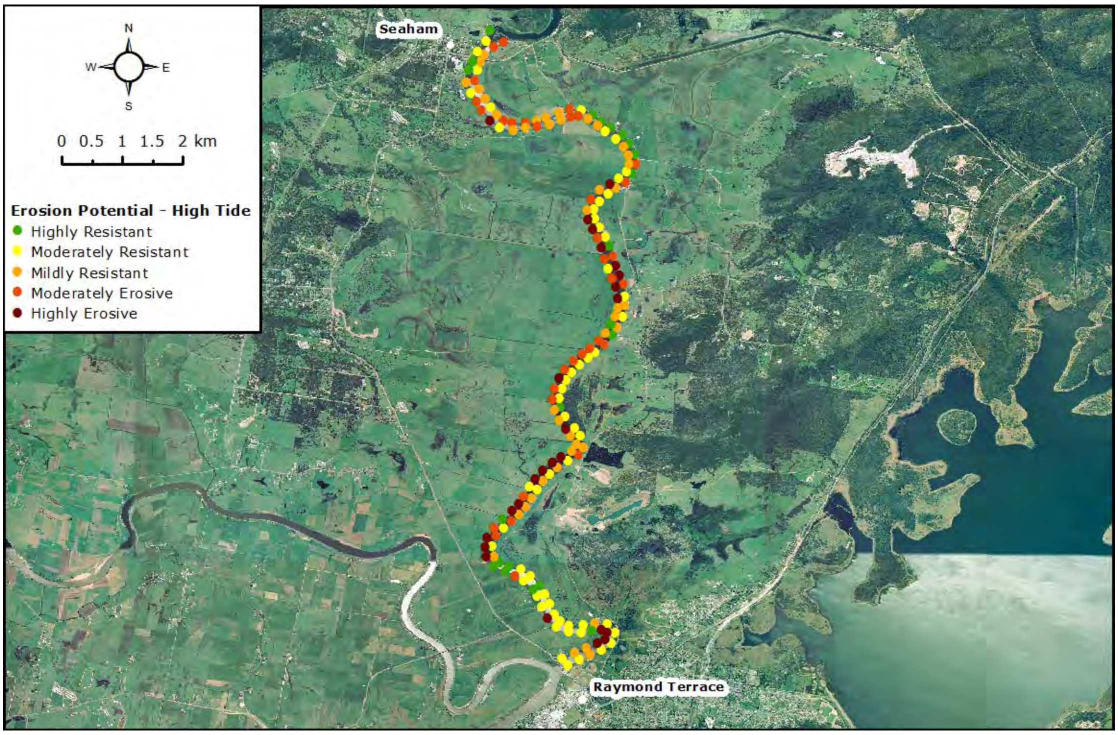


Figure M-3: Erosion Potential for Each Transect on the Lower Williams River in March 2015 (High Tide Conditions)

M.3.2 Management Ratings

The DSS management recommendations for the high tide assessment on the Lower Williams River are provided in Table M-4 and Figure M-4, while Figure M-5 through M-13 provide the distribution of the management recommendations along the waterway under different boat pass conditions and activities. The combined management approach for the March 2015 field assessment at high tide (Table M-4) resulted in 45% of all sites assigned with a 'Monitor' recommendation, and a distribution of 23% 'Monitor*', 13% 'Allow*', 10% 'Allow', and 8% 'Manage', for all other sites. At high tide, every river section received at least one (1) 'Monitor' rating, whereby 30% were located in the two (2) wakeboarding sections (15% downstream and

15% upstream), and 12% were located in the waterski zone. The two (2) wakeboarding sections had approximately three (3) times the number of 'Manage' sites (7%) compared to the waterski zone (2%). Those sites rated as 'Allow' are located within two sections (Section 78 and 79) with existing boating restrictions. There are 22 sites (8 'Allow*' and 14 'Monitor*') where wave attenuation was a limiting factor in the management recommendations. Overall, high tide conditions improved the management ratings along the study area of the Lower Williams River.

Table M-4: Lower Williams River March 2015 (Pre-Flood) Assessment for High Tide Conditions

Stretch	River Section	Scenario	# Passes	Management Option				
				Allow	Allow*	Monitor	Monitor*	Manage
50-58	Wakeboarding Zone (D/S)	Wakeboard Operating	50	0	3	9	3	3
59-70	Waterskiing Zone	Waterski Operating	50	4	5	7	7	1
71-77	Wakeboarding Zone (U/S)	Wakeboard Operating	50	0	0	9	4	1
78	4 knot Zone	Waterski 4 knots	50	1	0	1	0	0
79	No Boats Permitted (U/S)	Waterski 4 knots	1	1	0	1	0	0
50-79	***TOTAL***			**6**	**8**	**27**	**14**	**5**

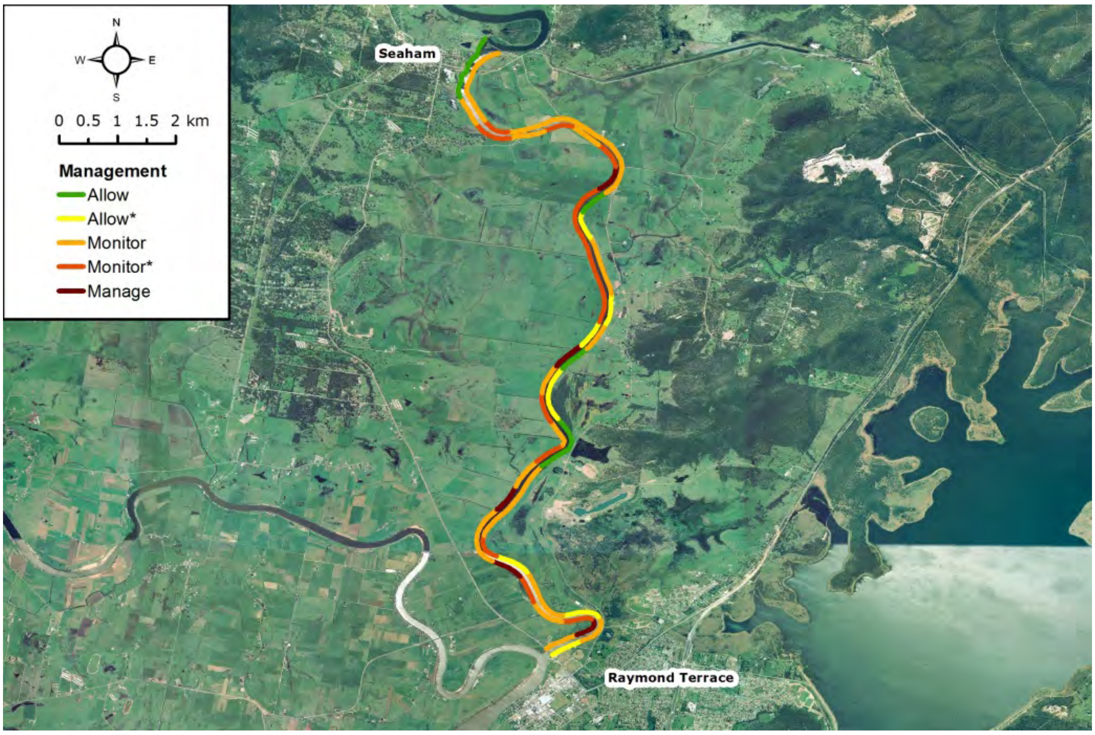


Figure M-4: Lower Williams River March 2015 (Pre-Flood) Assessment (Scaled Williamtown RAAF Base Wind Data, High Tide Conditions, 8 hour Duration)

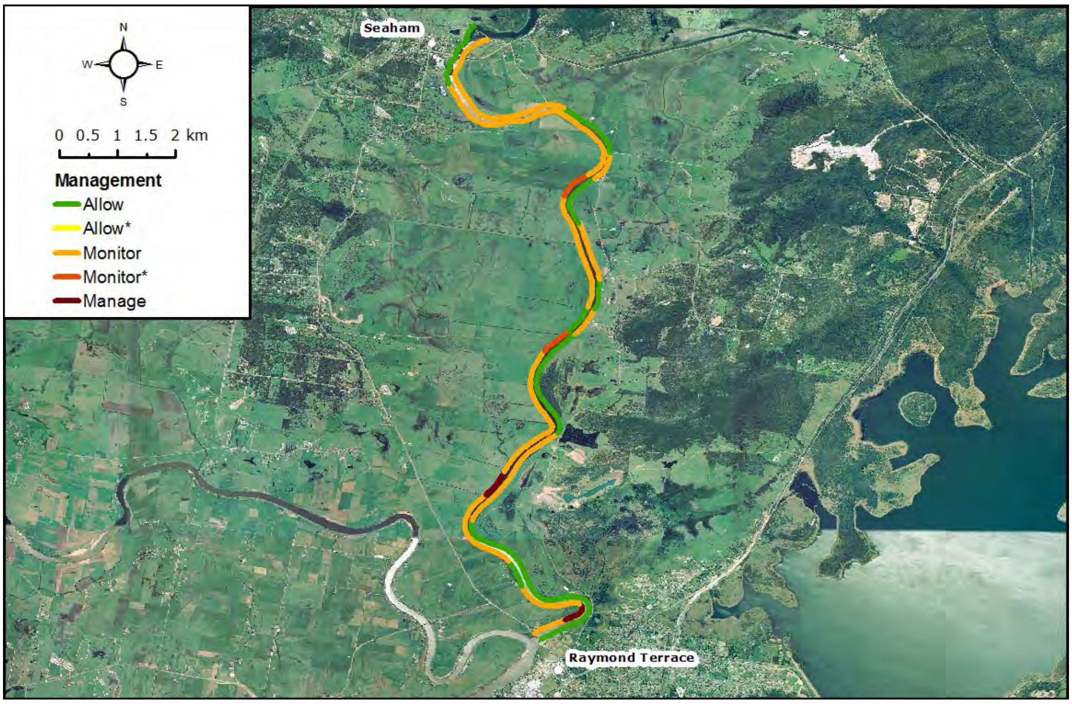


Figure M-5: DSS Management Recommendations - Wakesurf Operating - 10 Boat Passes – 8 Hour Duration (High Tide Conditions)

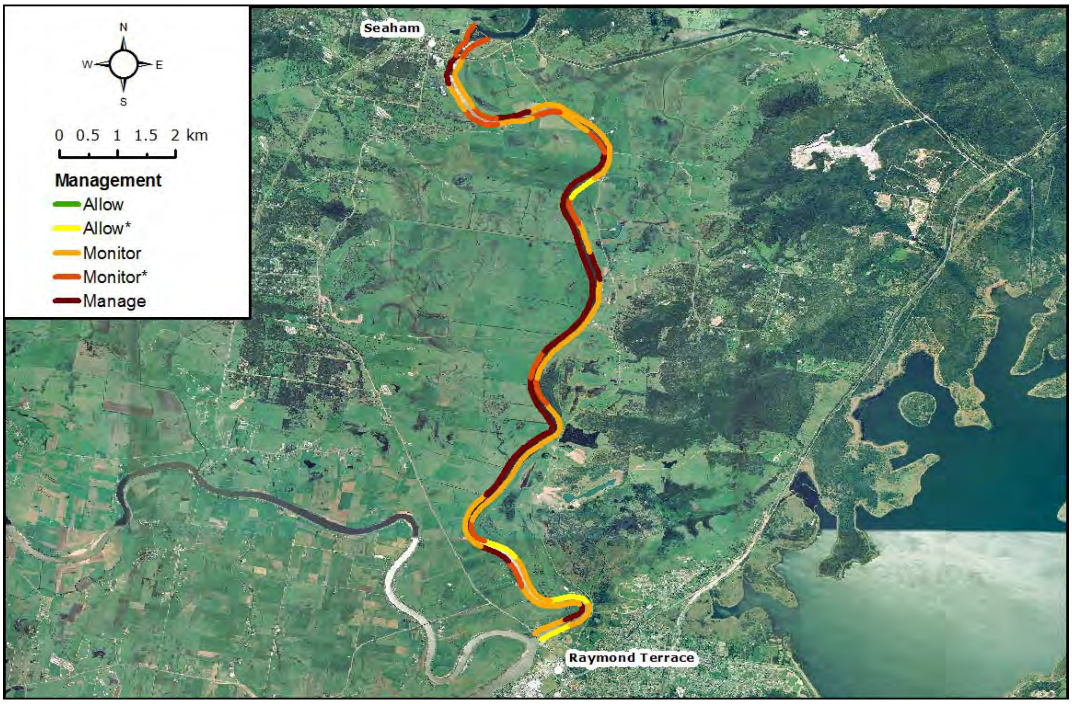


Figure M-6: DSS Management Recommendations - Wakesurf Operating - 50 Boat Passes – 8 Hour Duration (High Tide Conditions)

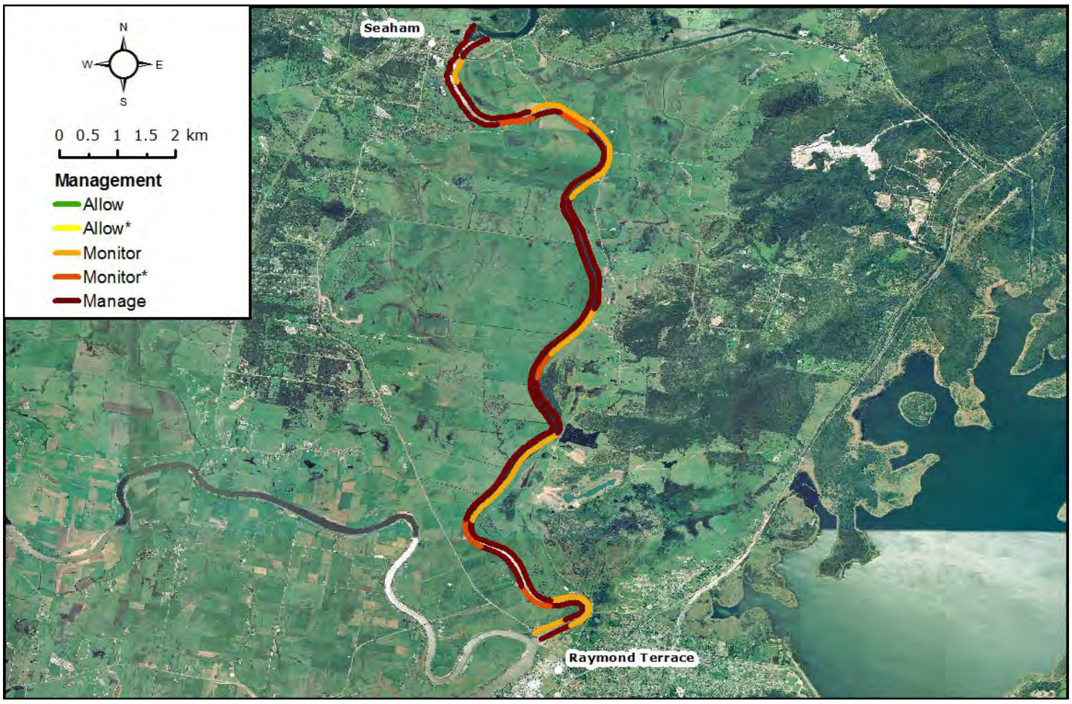


Figure M-7: DSS Management Recommendations - Wakesurf Operating - 150 Boat Passes – 8 Hour Duration (High Tide Conditions)

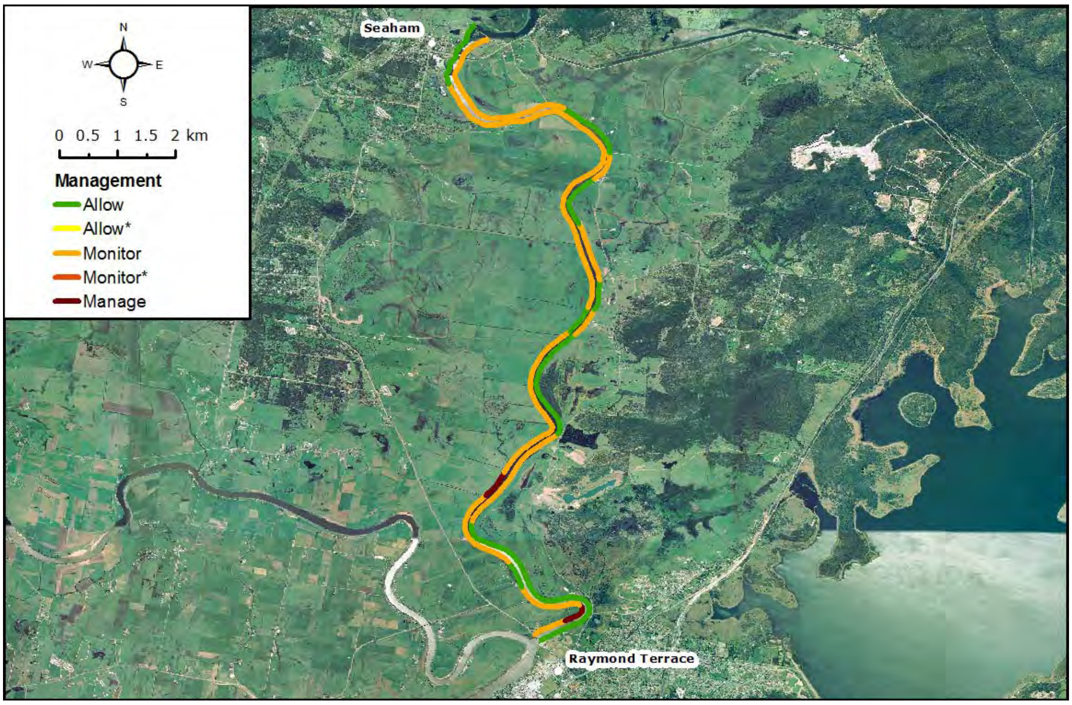


Figure M-8: DSS Management Recommendations - Waterski Operating - 10 Boat Passes – 8 Hour Duration (High Tide Conditions)

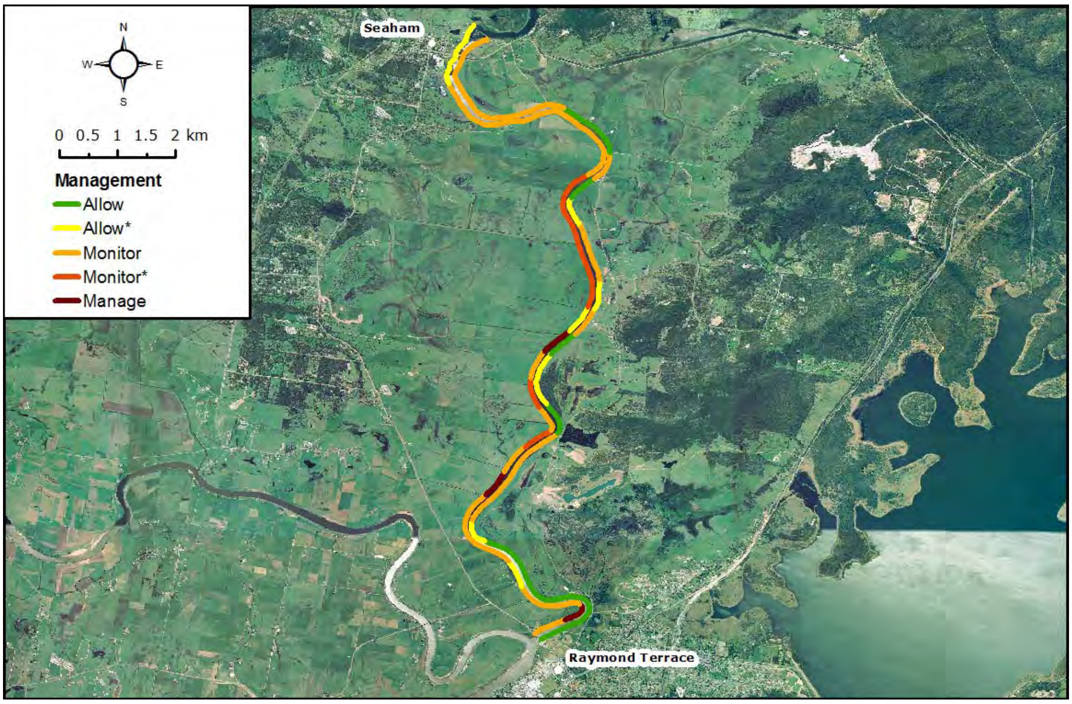


Figure M-9: DSS Management Recommendations - Waterski Operating - 50 Boat Passes – 8 Hour Duration (High Tide Conditions)

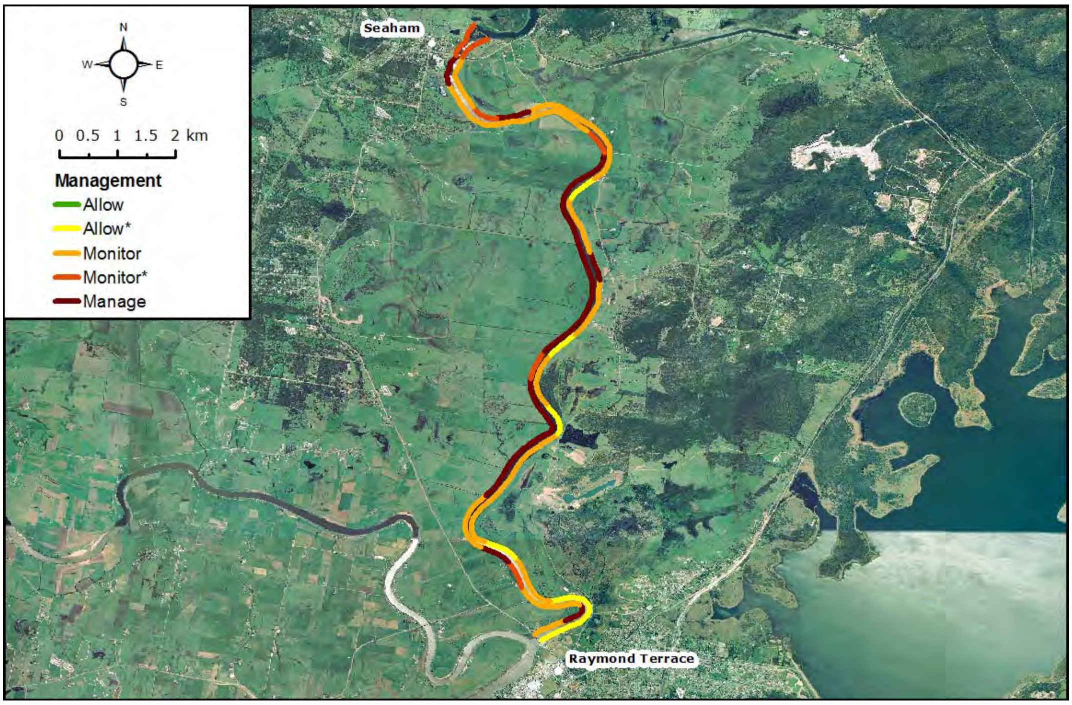


Figure M-10: DSS Management Recommendations - Waterski Operating - 150 Boat Passes – 8 Hour Duration (High Tide Conditions)

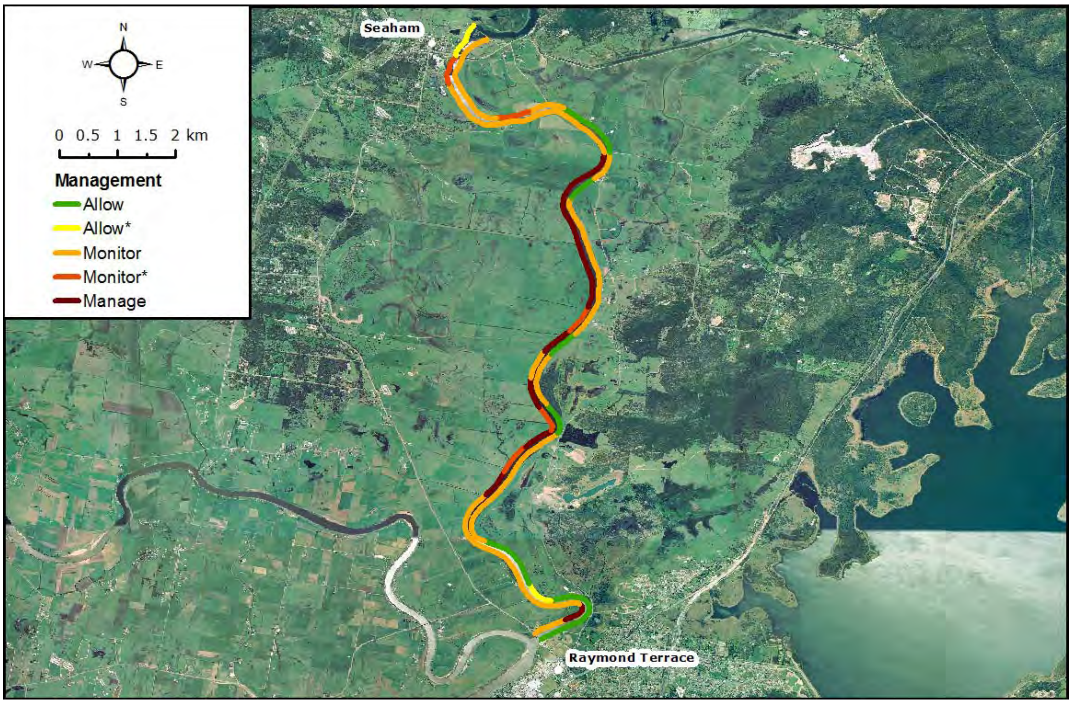


Figure M-11: DSS Management Recommendations - Wakesurf Operating - 10 Boat Passes – 8 Hour Duration (High Tide Conditions)

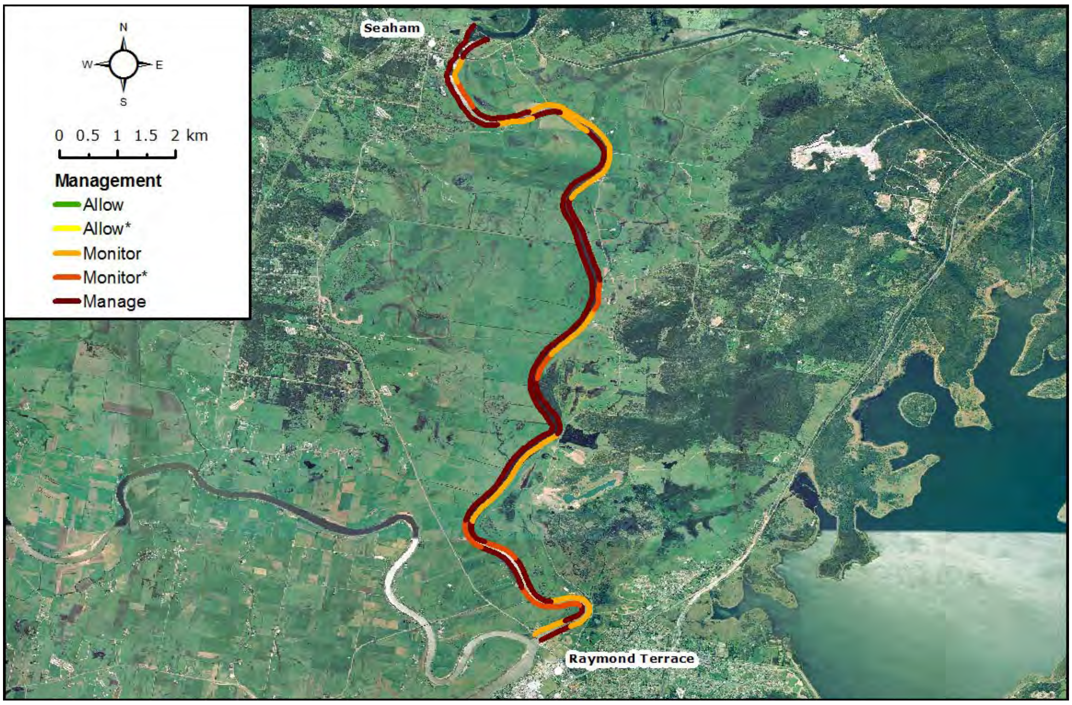


Figure M-12: DSS Management Recommendations - Wakesurf Operating - 50 Boat Passes – 8 Hour Duration (High Tide Conditions)

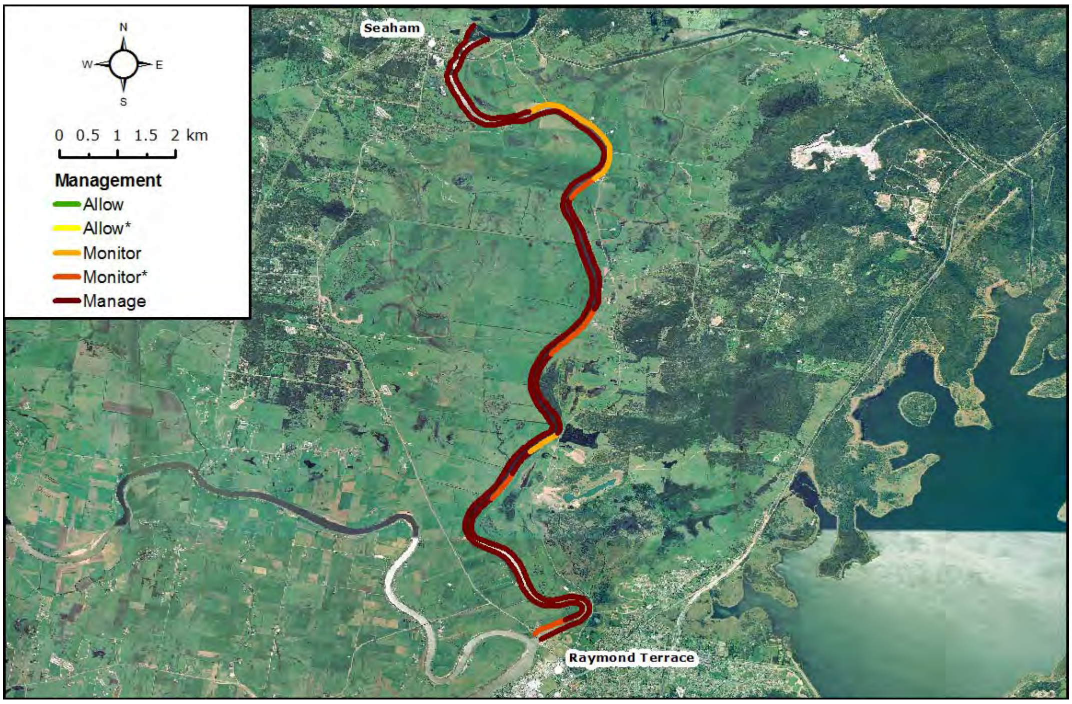


Figure M-13: DSS Management Recommendations - Wakesurf Operating - 150 Boat Passes – 8 Hour Duration (High Tide Conditions)

Appendix N – March 2015 DSS Sensitivity Test for High Boat Passes (Lower Williams River)

Boat pass numbers higher than those included in the baseline assessment have been considered as a sensitivity test. Eight (8) scenarios were investigated at mid – low tide for wakeboarding, waterskiing and wakesurfing activities, including 300 and 500 boat passes, as well as, the 'maximum wave' condition as recorded for 50 boat passes. The DSS management recommendations for the high boat pass conditions are provided in Table N-1, while Figure N-1 through N-9 provide the distribution of these recommendations for the study region.

The results provided in Table N-1 indicated a significant increase from baseline conditions in the number of sites that required monitoring and management for all scenarios. Higher counts were observed in all categories for wakeboard 'operating' conditions compared with waterski 'operating' conditions. It is worth highlighting that 'maximum wave' conditions occurred when boats were accelerating and decelerating (i.e. when it is necessary to retrieve fallen wakeboarders or skiers).

Table N-1: Number of Stretches Determined in Each DSS Management Category (High Boat Passes)

Management Option	Wakeboard			Waterski			Wakesurf	
	Operating Conditions – 12 Hour Duration		Maximum Wave – 8 Hour Duration	Operating Conditions – 12 Hour Duration		Maximum Wave – 8 Hour Duration	Operating Conditions – 12 Hour Duration	
	300 Passes	500 Passes	50 Passes	300 Passes	500 Passes	50 Passes	300 Passes	500 Passes
Allow	0	0	0	0	0	0	0	0
Allow*	0	0	0	1	0	0	0	0
Monitor	10	7	17	22	17	17	5	4
Monitor*	5	5	6	10	6	9	2	2
Manage	45	48	37	27	37	34	53	54

Note: Wave attenuation is a limiting factor in the management recommendation for sites presented as 'Allow*' or 'Monitor*'.

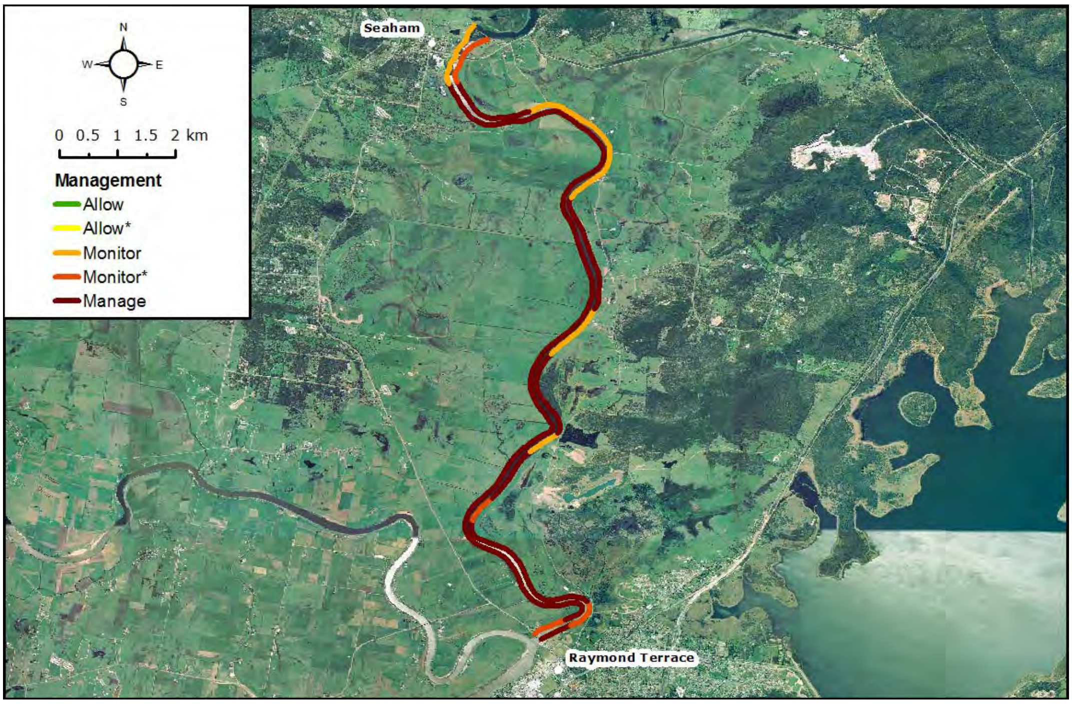


Figure N-1: DSS Management Recommendations - Wakeboard Operating – High Boat Passes – 300 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

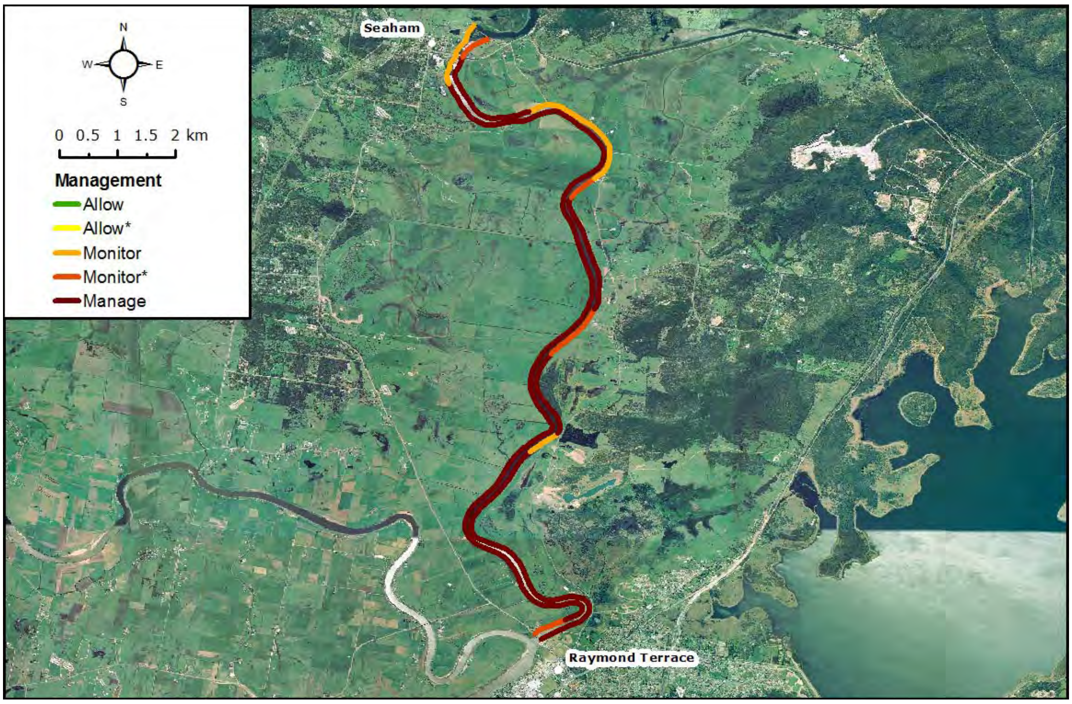


Figure N-2: DSS Management Recommendations - Wakeboard Operating – High Boat Passes – 500 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

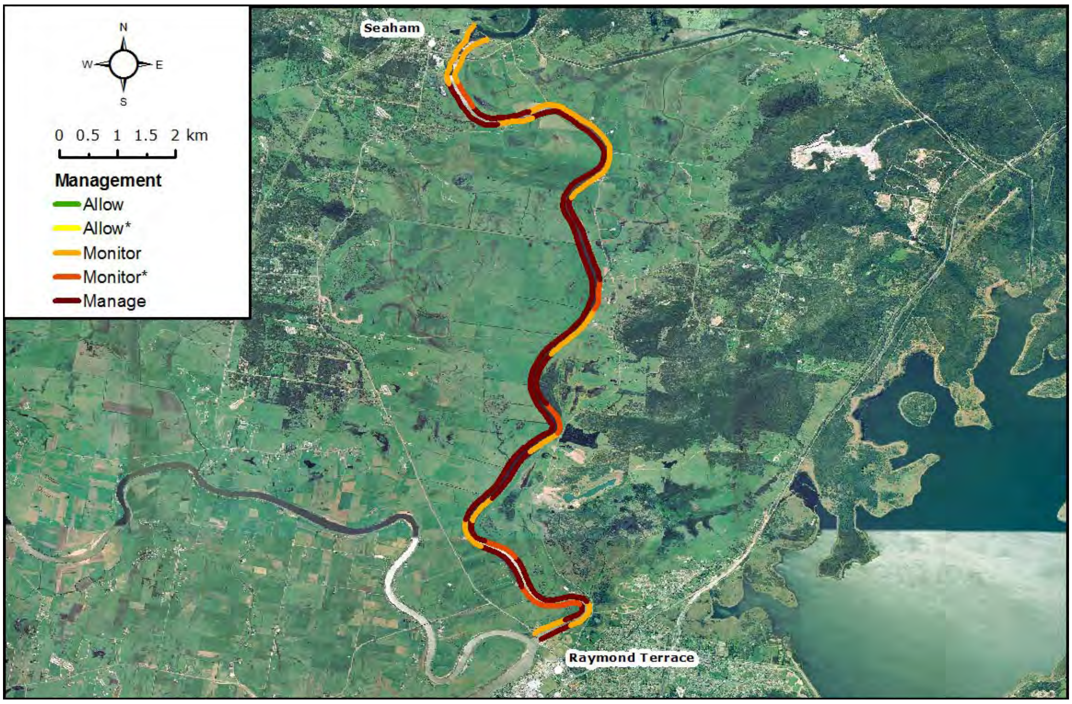


Figure N-3: DSS Management Recommendations – Maximum Wakeboard Wave - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

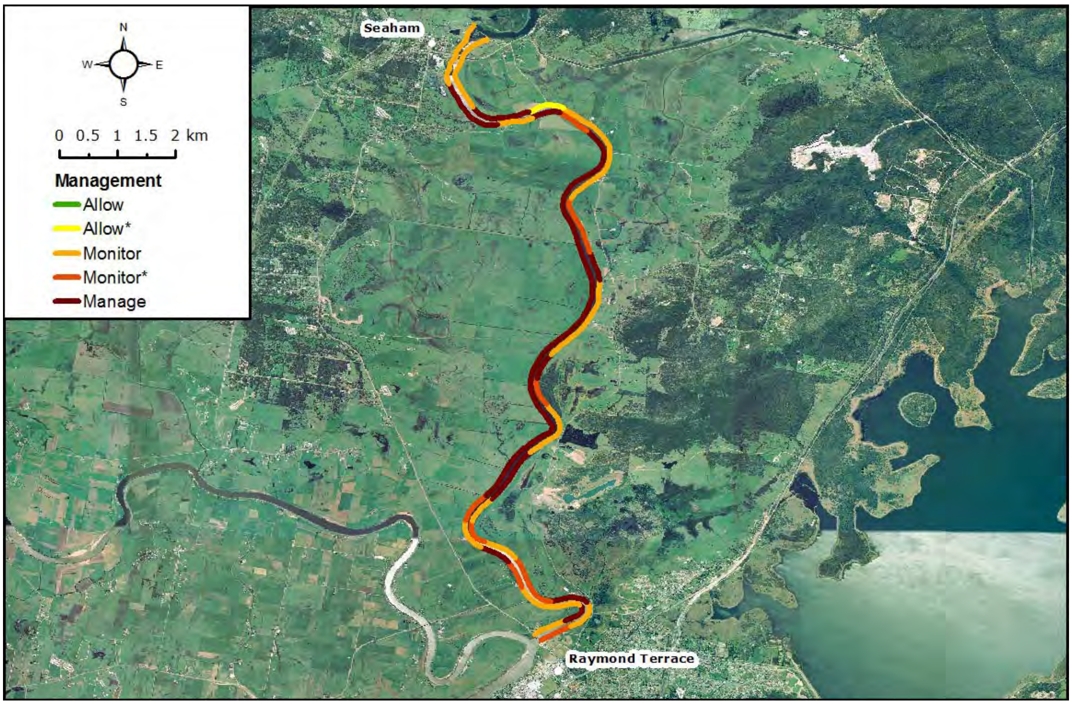


Figure N-4: DSS Management Recommendations - Waterski Operating – High Boat Passes – 300 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

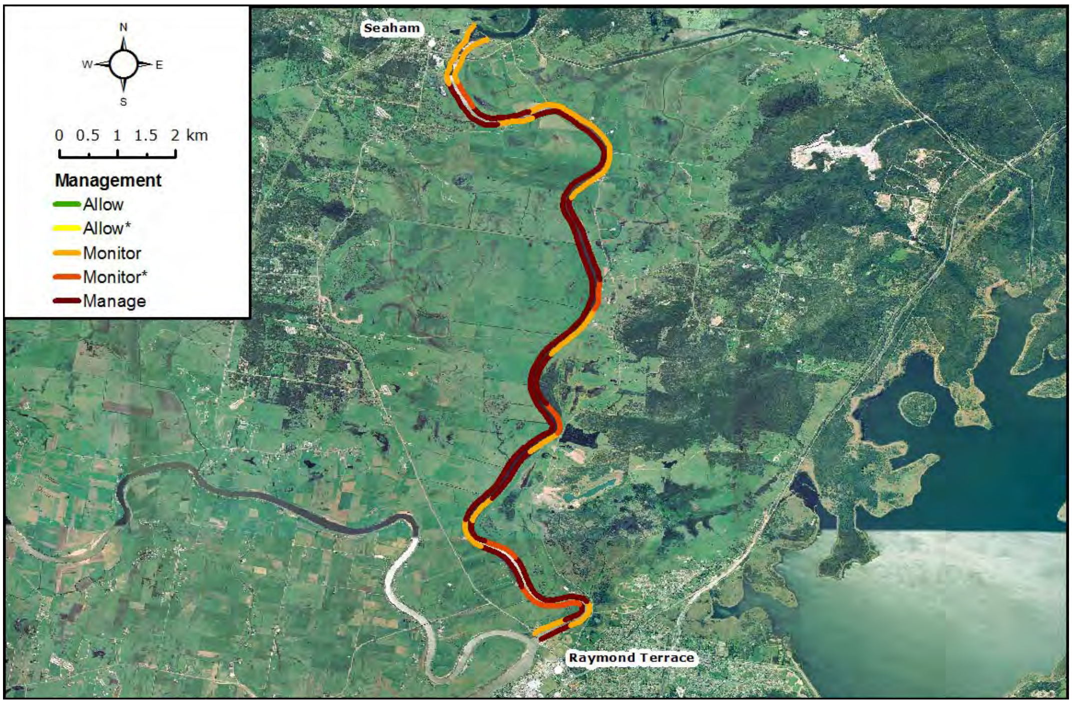


Figure N-5: DSS Management Recommendations - Waterski Operating – High Boat Passes – 500 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

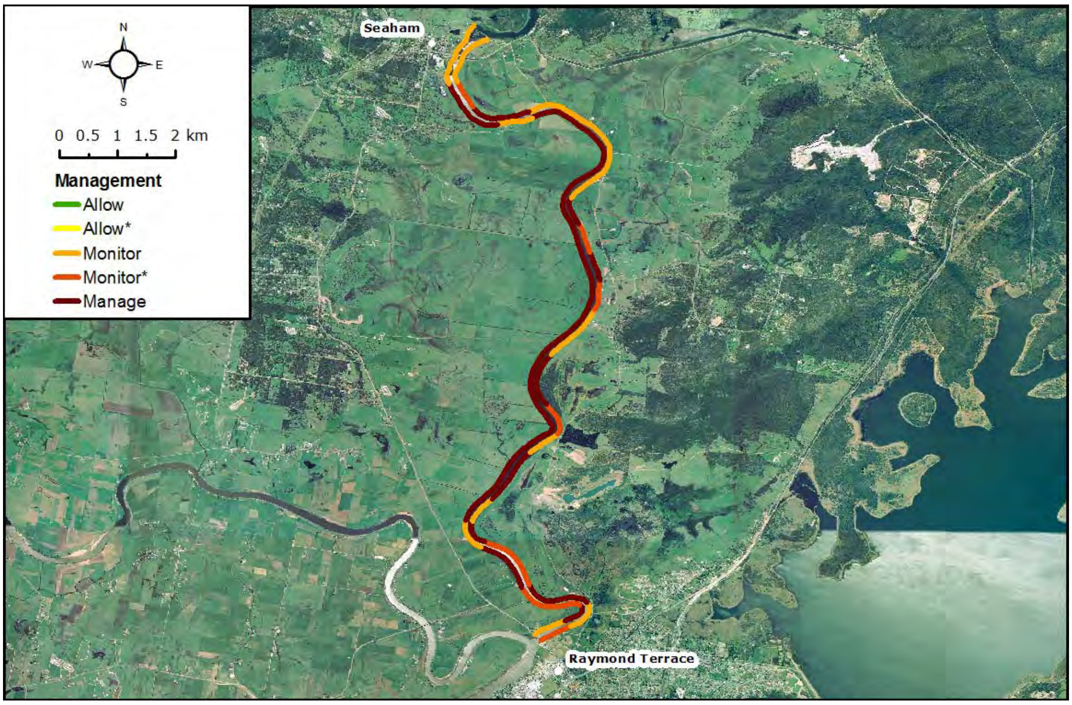


Figure N-6: DSS Management Recommendations – Maximum Waterski Wave - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

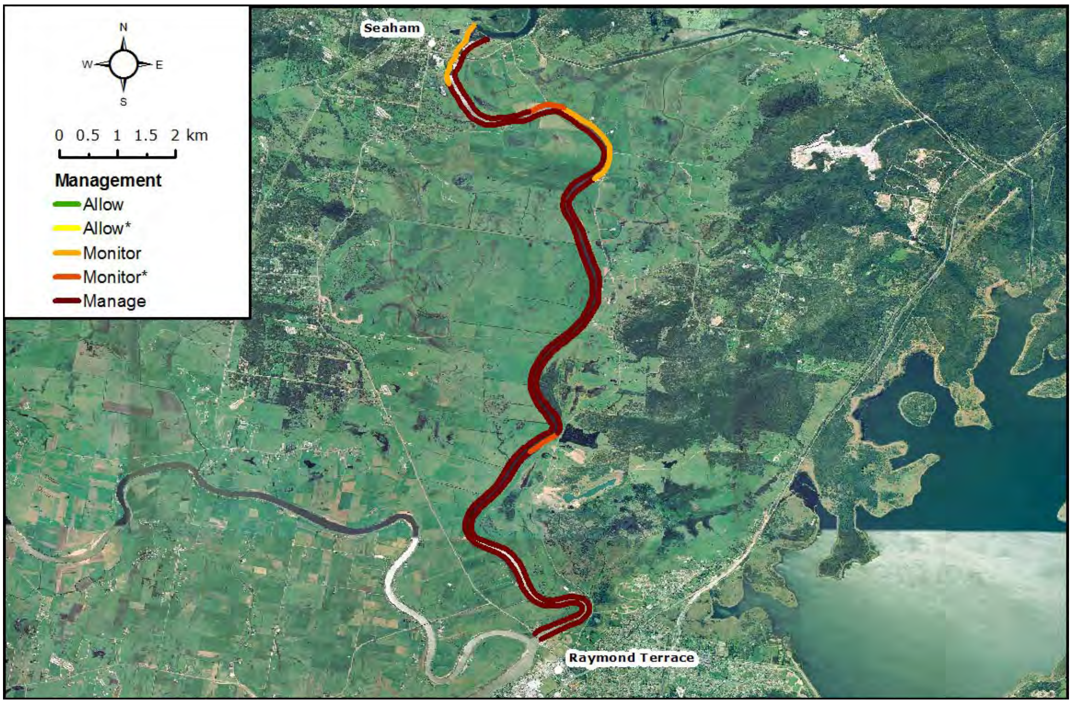


Figure N-7: DSS Management Recommendations - Wakesurf Operating – High Boat Passes – 300 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

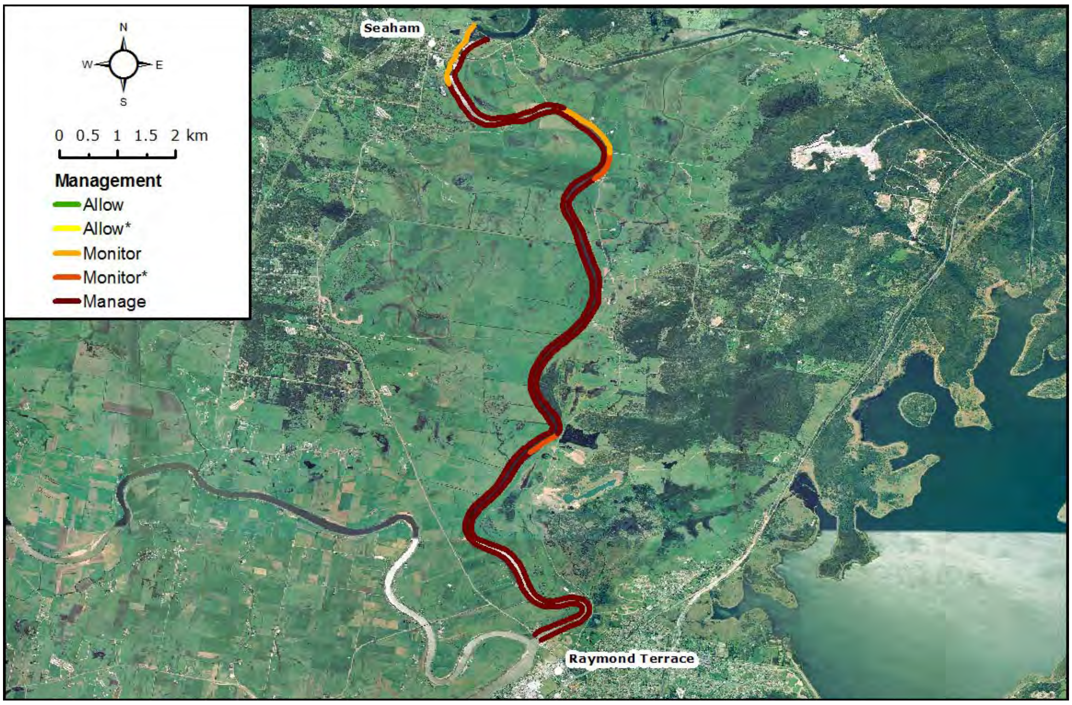


Figure N-8: DSS Management Recommendations - Wakesurf Operating – High Boat Passes – 500 Boat Passes – 12 Hour Duration (Mid - Low Tide Conditions)

Appendix O – March 2015 DSS Sensitivity Test for Australian Standard Winds (Lower Williams River)

As discussed in Section 4.4, data from the nearest weather station at Williamtown RAAF Base was acquired for use with the DSS in this study. To test the sensitivity of the baseline DSS management recommendations (Section 5.5.2) established with this wind climate, management recommendations were recalculated with increased natural wind wave energy based upon the Australian Wind Standard (AS 1170.2) speeds (Section 3.4.2). The Australian Standard wind speeds are applicable for engineering construction, design and development in the study area. The DSS management recommendations for the Australia Standard wind sensitivity tests are provided in Table O-1, while Figures O-1 through O-9 provide the distribution of these recommendations along the Lower Williams River under different boat pass conditions and activities at mid – low tide. Table O-2 provides a direct comparison between the baseline DSS assessment based on scaled Williamtown RAAF winds (Table L-1) and the Australian standard winds (Table O-1).

Table O-1: Number of Stretches Determined in Each DSS Management Category (Australian Standard Winds)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes
Allow	11	11	4	11	11	11	11	4	0
Allow*	0	0	3	0	0	0	0	5	3
Monitor	45	45	31	45	45	45	45	34	16
Monitor*	0	0	9	0	0	0	0	10	13
Manage	4	4	13	4	4	4	4	7	28

Note: Wave attenuation is a limiting factor in the management recommendation for sites presented as 'Allow*' or 'Monitor*'.

The increased natural wind wave energy associated with these sensitivity tests had significant consequences on the overall DSS management results. The data in Table O-2 generally shows an overall reduction in the number of reaches observed in the 'Manage', 'Monitor*' and 'Allow*' categories. There was a corresponding increase in the number of reaches observed in the 'Monitor' and 'Allow' categories. This result was anticipated since, for a given boat pass scenario and activity, the wind wave energy has a higher magnitude relative to the wake wave energy. At most, there was a 52% reduction in the number of reaches categorised as 'Manage', and a 13% reduction in the number of reaches classified as 'Monitor*'. Reaches categorised as 'Allow' increased by 3% to 32%. The magnitude of these changes was considered significant when applying management recommendations to the study area.

Table O-2: Comparison of DSS Management Recommendations (Sensitivity Test – Baseline)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes
Allow	0	11	4	0	4	10	7	4	0
Allow*	0	-2	3	0	-4	-1	-3	5	3
Monitor	2	19	16	0	9	15	13	18	9
Monitor*	-2	-8	6	0	-8	-5	-7	4	8
Manage	0	-20	-29	0	-1	-19	-10	-31	-20

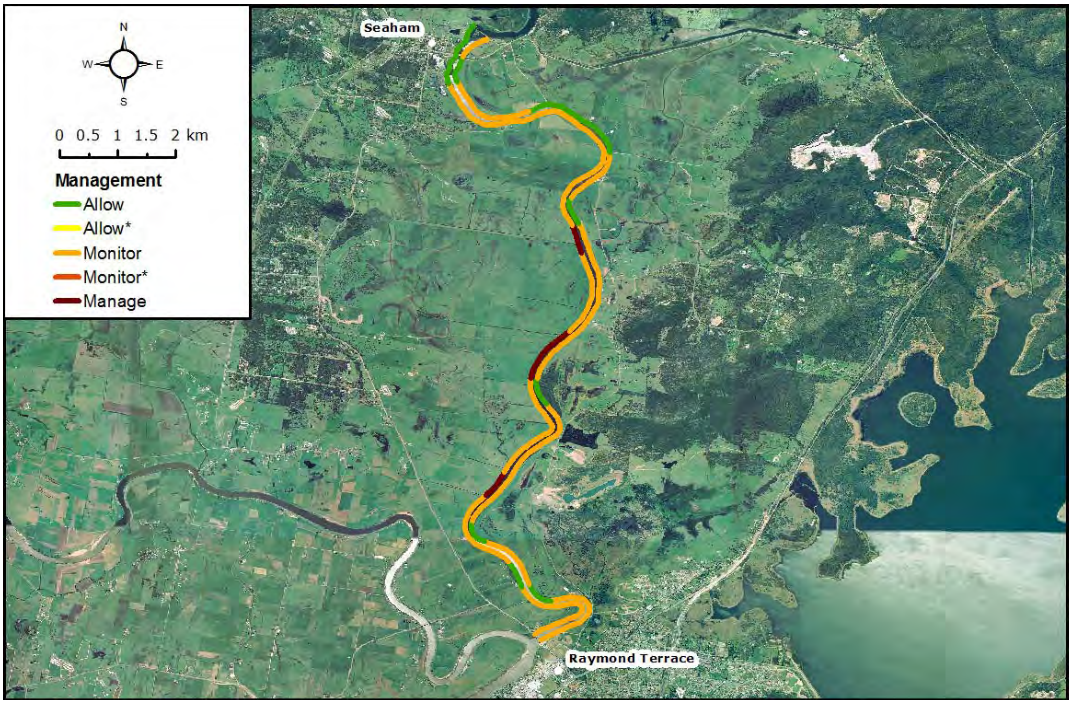


Figure O-1: DSS Management Recommendations - Wakeboard Operating – Australian Standard Winds - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

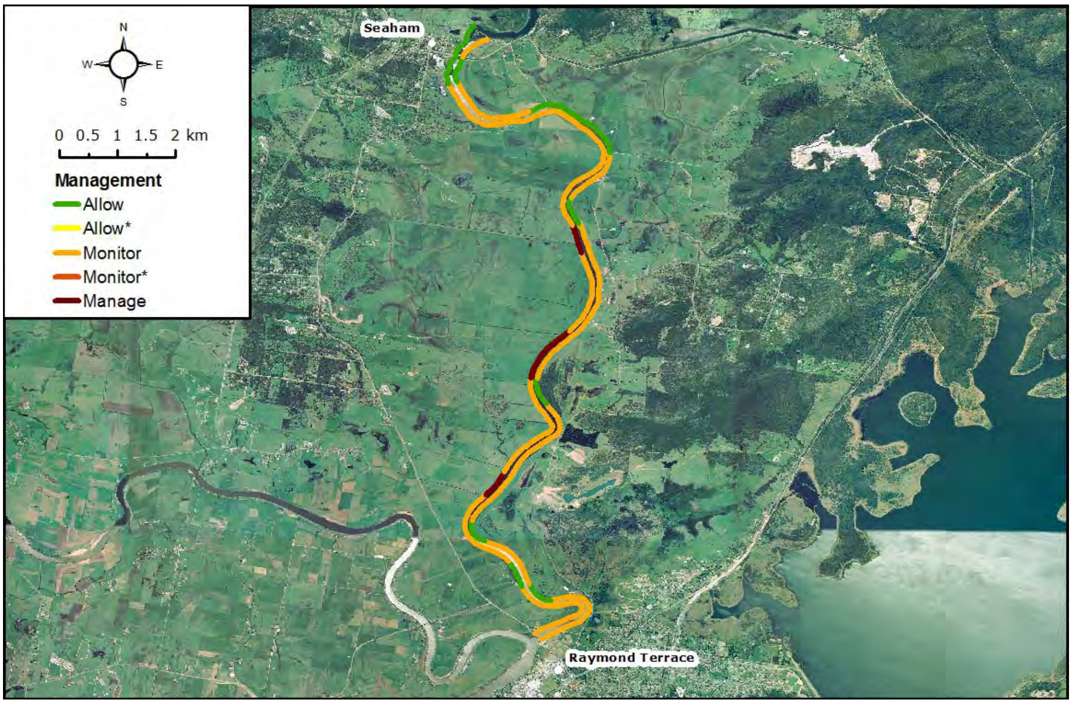


Figure O-2: DSS Management Recommendations - Wakeboard Operating – Australian Standard Winds - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

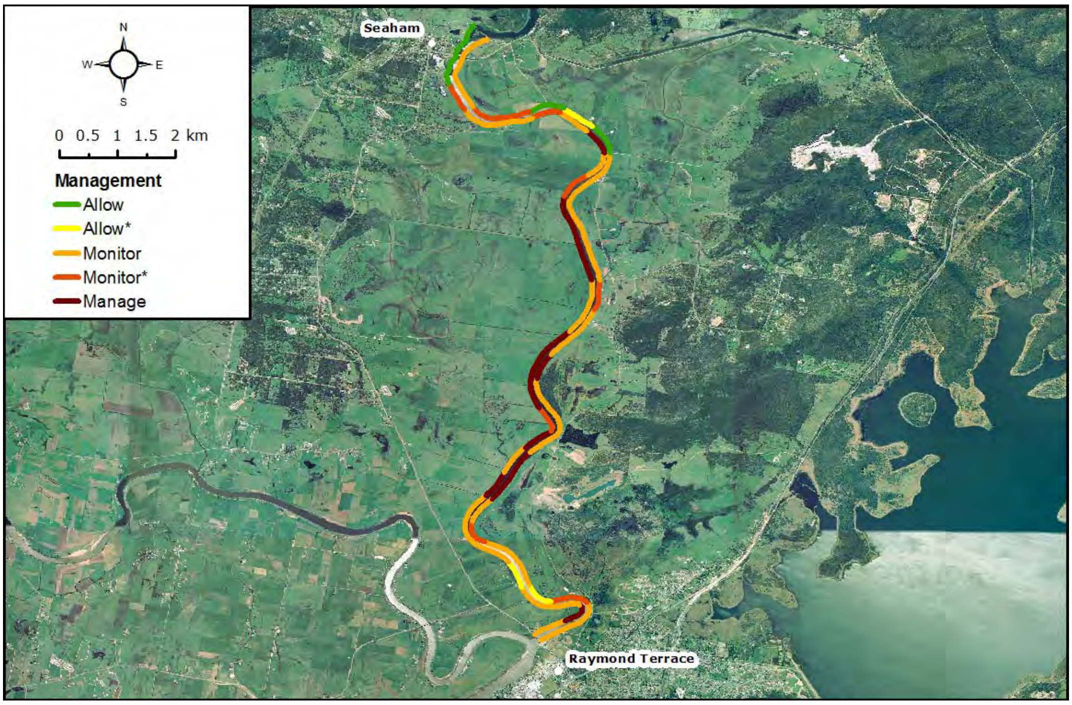


Figure O-3: DSS Management Recommendations - Wakeboard Operating – Australian Standard Winds - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

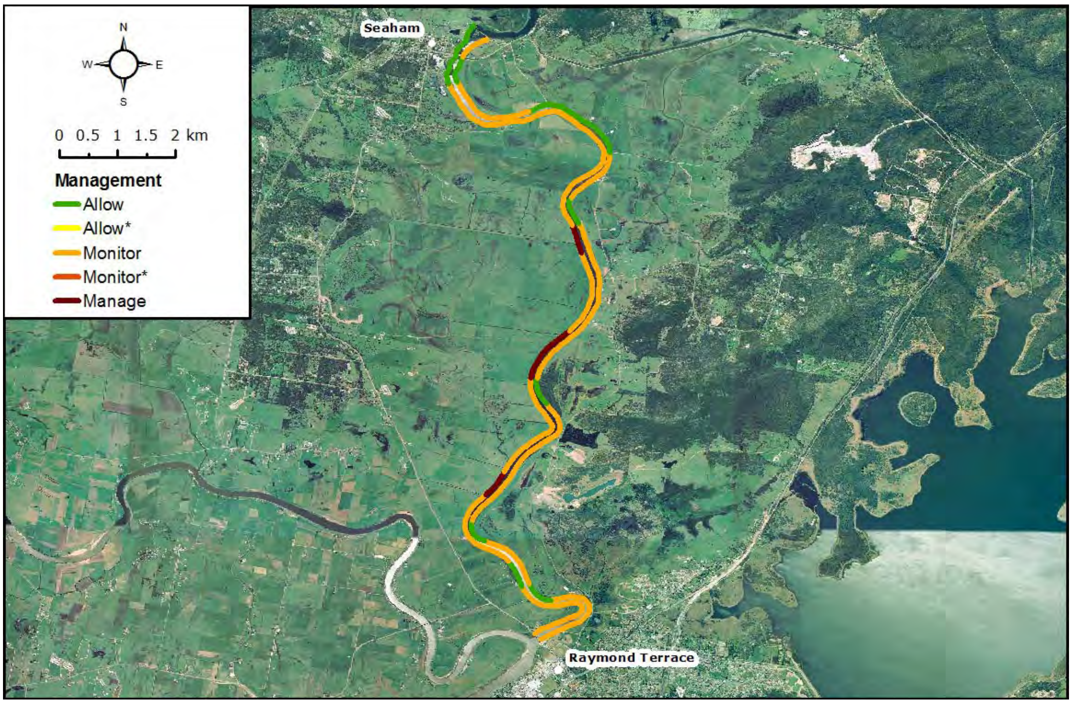


Figure O-4: DSS Management Recommendations - Waterski Operating – Australian Standard Winds - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

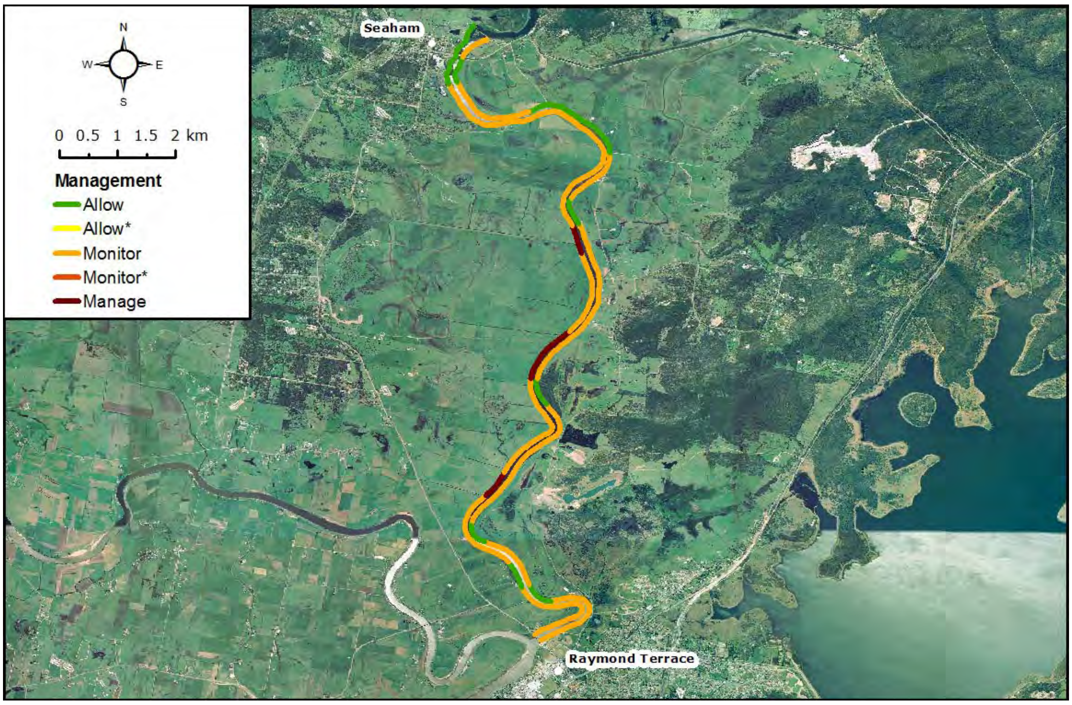


Figure O-5: DSS Management Recommendations - Waterski Operating – Australian Standard Winds - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

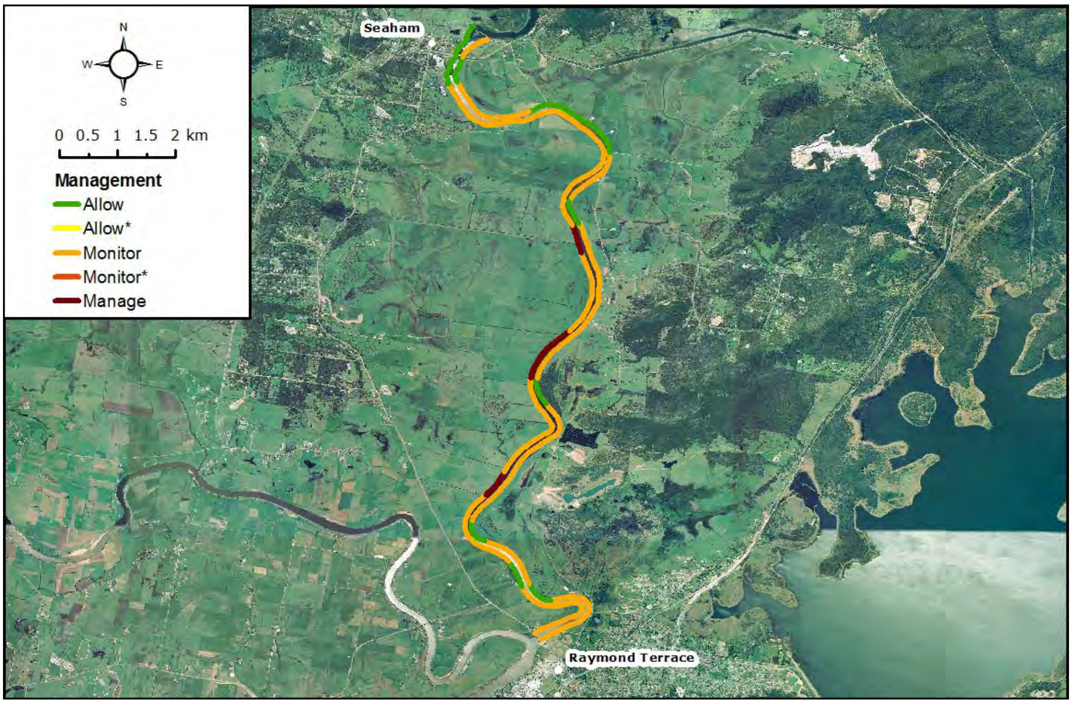


Figure O-6: DSS Management Recommendations - Waterski Operating – Australian Standard Winds - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

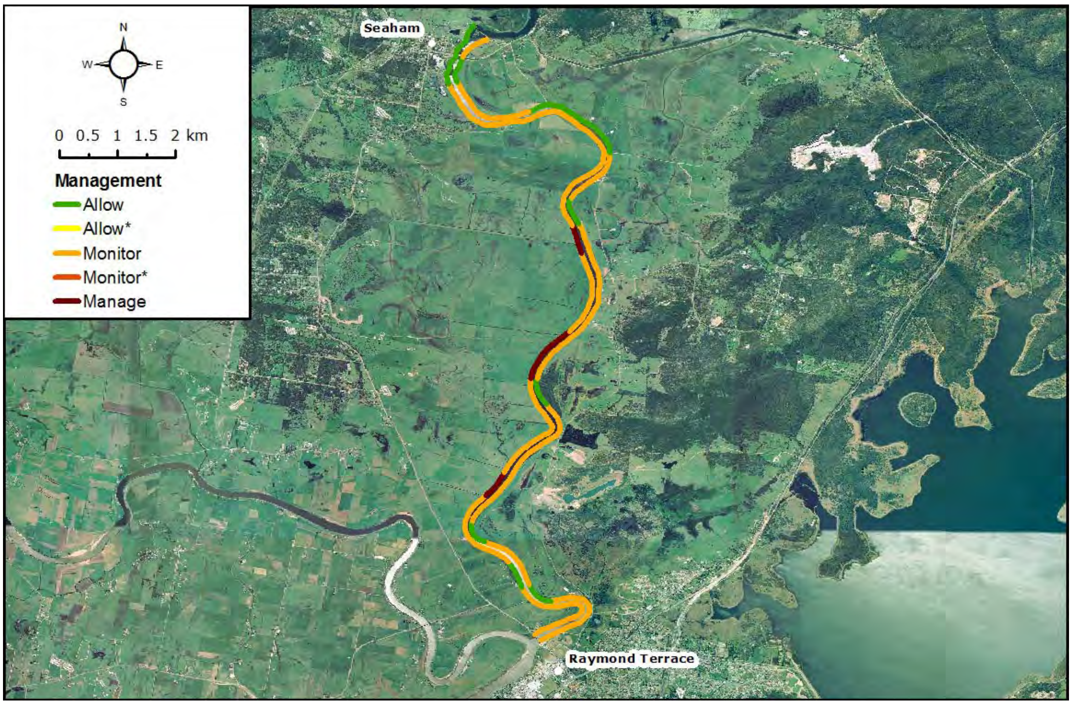


Figure O-7: DSS Management Recommendations - Wakesurf Operating – Australian Standard Winds - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

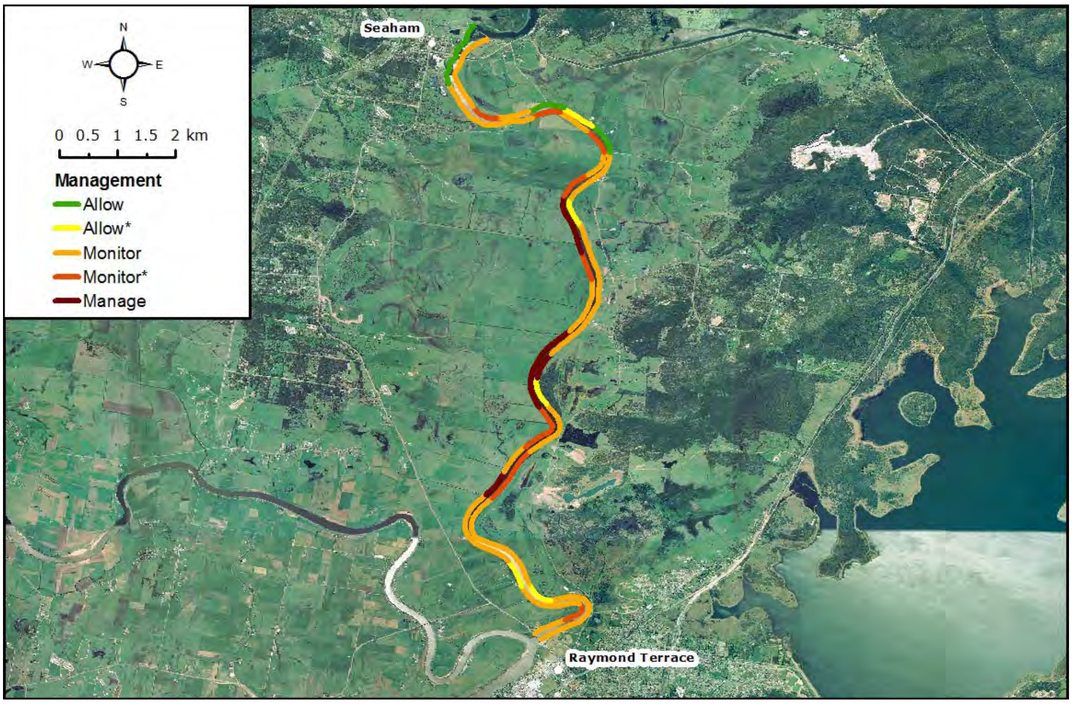


Figure O-8: DSS Management Recommendations - Wakesurf Operating – Australian Standard Winds - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

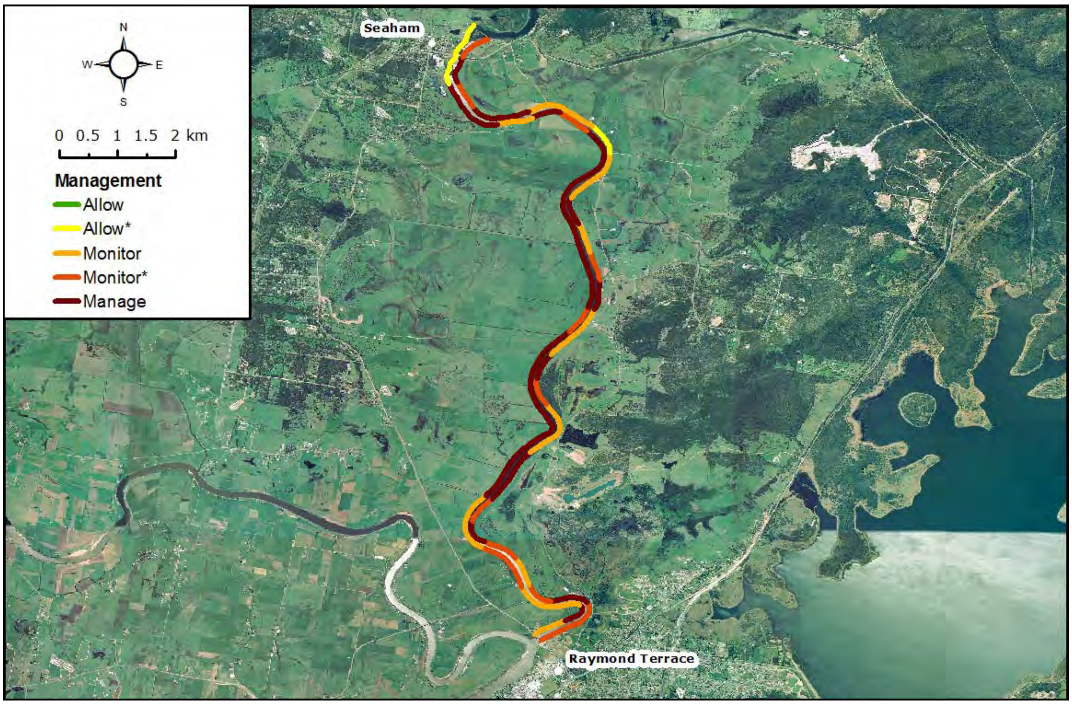


Figure O-9: DSS Management Recommendations - Wakesurf Operating – Australian Standard Winds - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

Appendix P – March 2015 DSS Sensitivity Test for Boat Wave Attenuation (Lower Williams River)

The DSS management recommendations for the boat wave attenuation sensitivity test (30 m 'distance of boat from shore' value) are provided in Table P-1, while Figures P-1 through P-9 provide the distribution of these recommendations along the waterway under different boat pass conditions at mid – low tide. Table P-2 provides a direct comparison between the baseline DSS assessment (Table L-1). The results of this sensitivity test showed a relative increase in the 'Monitor' and 'Manage' categories, while there was a decrease in the number of 'Allow*' and 'Monitor*' management recommendations. This result was anticipated as wave attenuation was a limiting factor in the baseline management recommendation at these sites.

Table P-1: Number of Stretches Determined in Each DSS Management Category (Boat Wave Attenuation)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes
Allow	11	0	0	11	7	1	4	0	0
Allow*	0	1	0	0	2	0	2	0	0
Monitor	43	27	15	45	38	31	33	16	7
Monitor*	1	4	0	0	4	1	5	2	1
Manage	5	28	45	4	9	27	16	42	52

Note: Wave attenuation is a limiting factor in the management recommendation for sites presented as 'Allow*' or 'Monitor*'.

Table P-2: Comparison of DSS Management Recommendations (Sensitivity Test – Baseline)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes	10 Passes	50 Passes	150 Passes
Allow	0	0	0	0	0	0	0	0	0
Allow*	0	-1	0	0	-2	-1	-1	0	0
Monitor	0	1	0	0	2	1	1	0	0
Monitor*	-1	-4	-3	0	-4	-4	-2	-4	-4
Manage	1	4	3	0	4	4	2	4	4

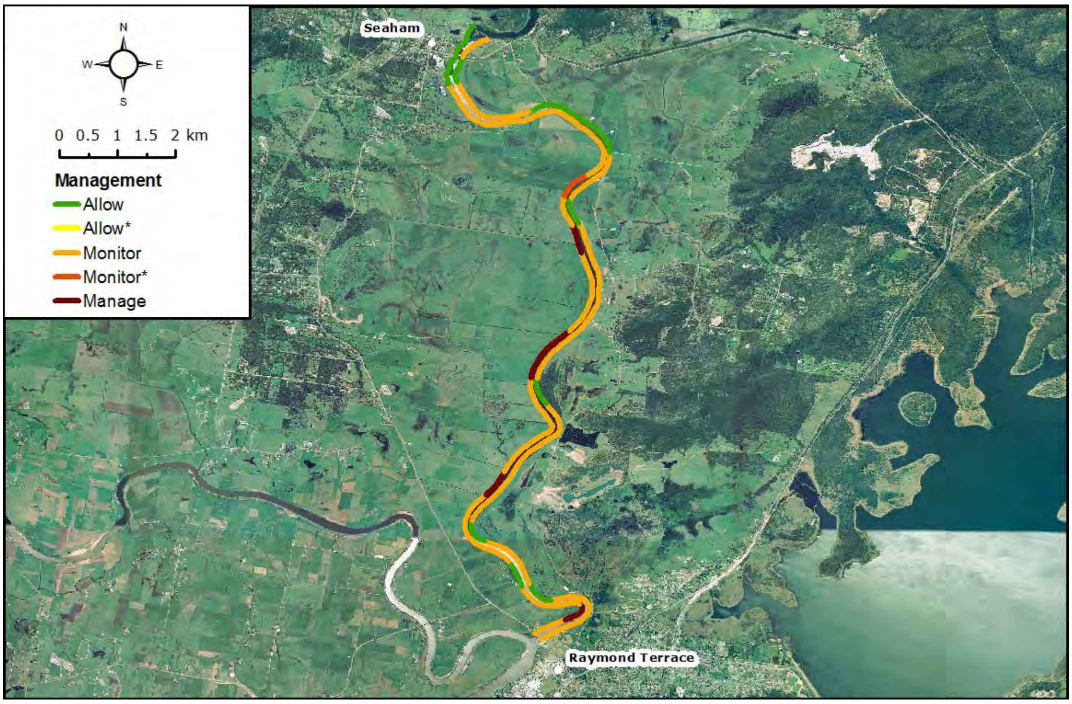


Figure P-1: DSS Management Recommendations - Wakeboard Operating – Boat Wave Attenuation - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

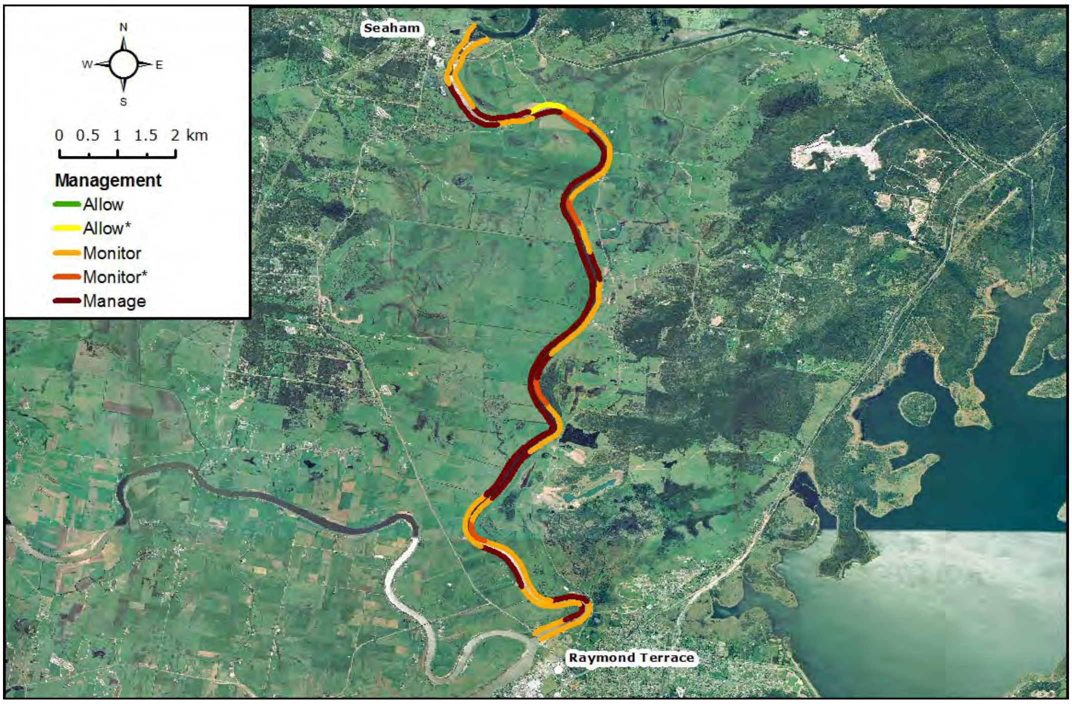


Figure P-2: DSS Management Recommendations - Wakeboard Operating – Boat Wave Attenuation - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

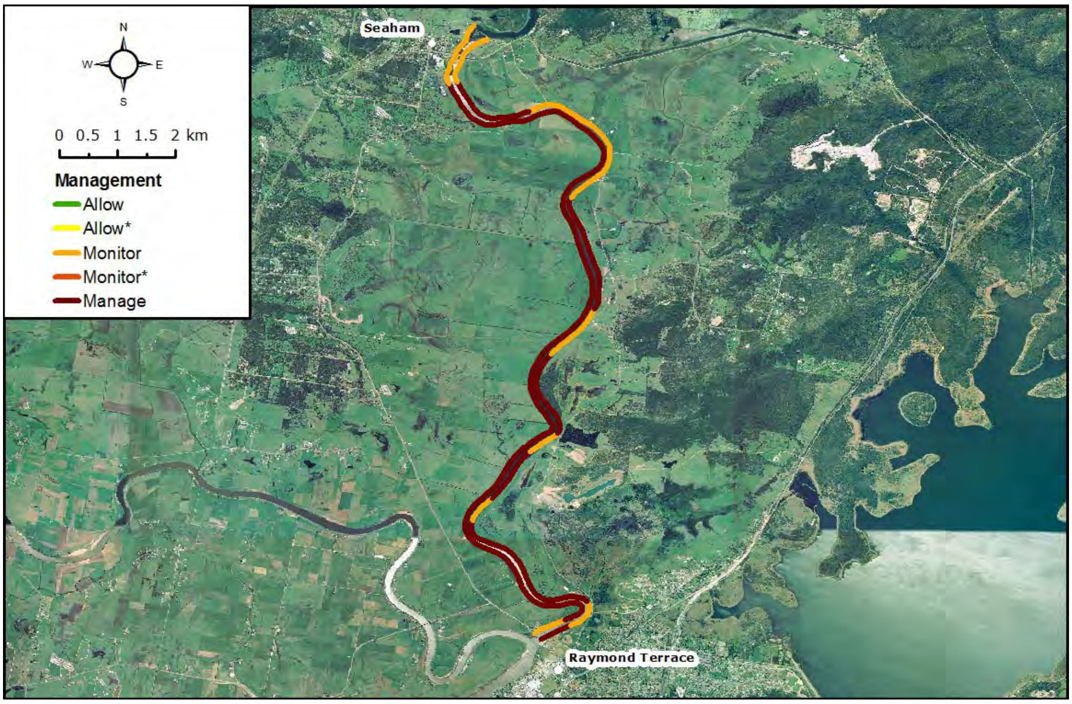


Figure P-3: DSS Management Recommendations - Wakeboard Operating – Boat Wave Attenuation - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

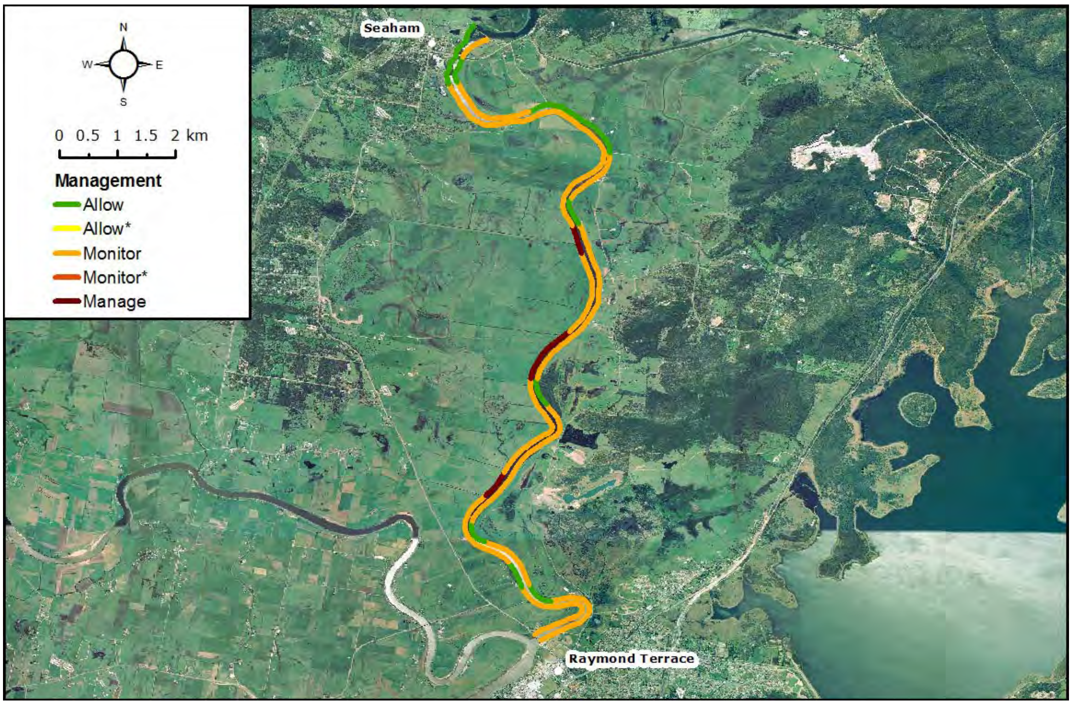


Figure P-4: DSS Management Recommendations - Waterski Operating – Boat Wave Attenuation - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

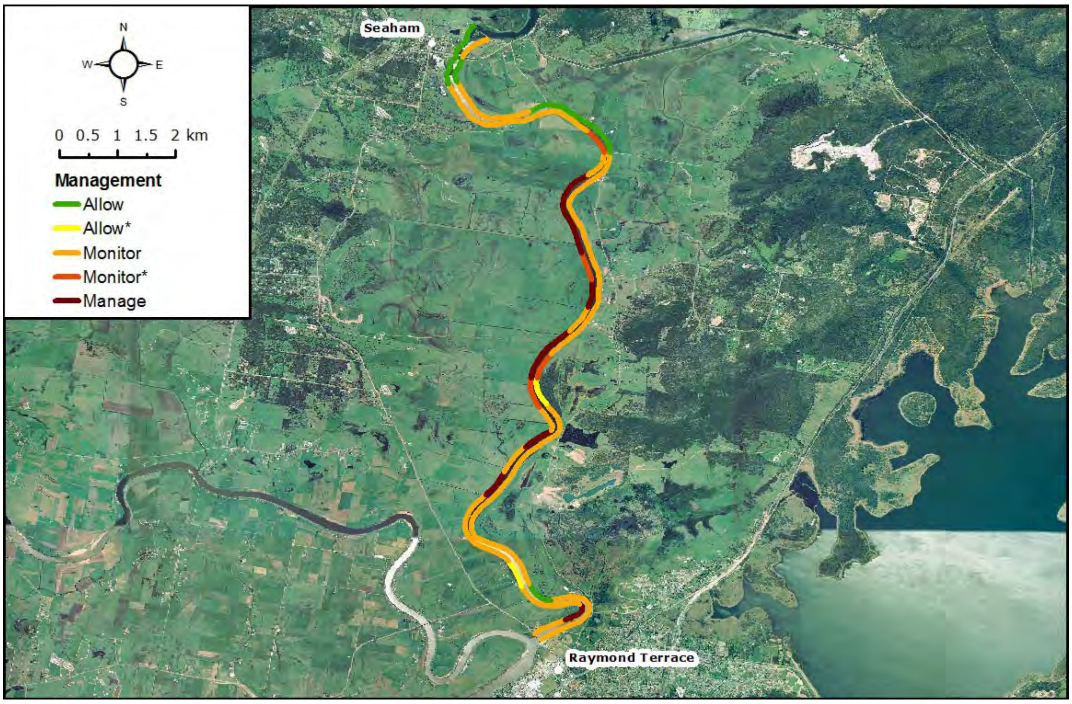


Figure P-5: DSS Management Recommendations - Waterski Operating – Boat Wave Attenuation - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

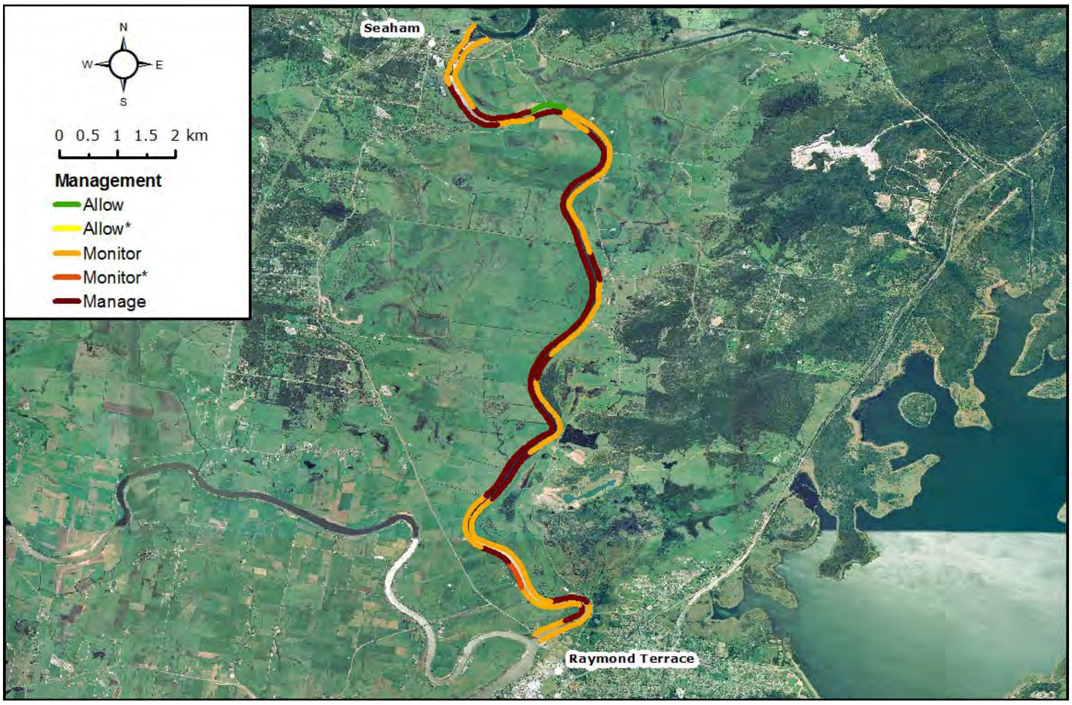


Figure P-6: DSS Management Recommendations - Waterski Operating – Boat Wave Attenuation - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

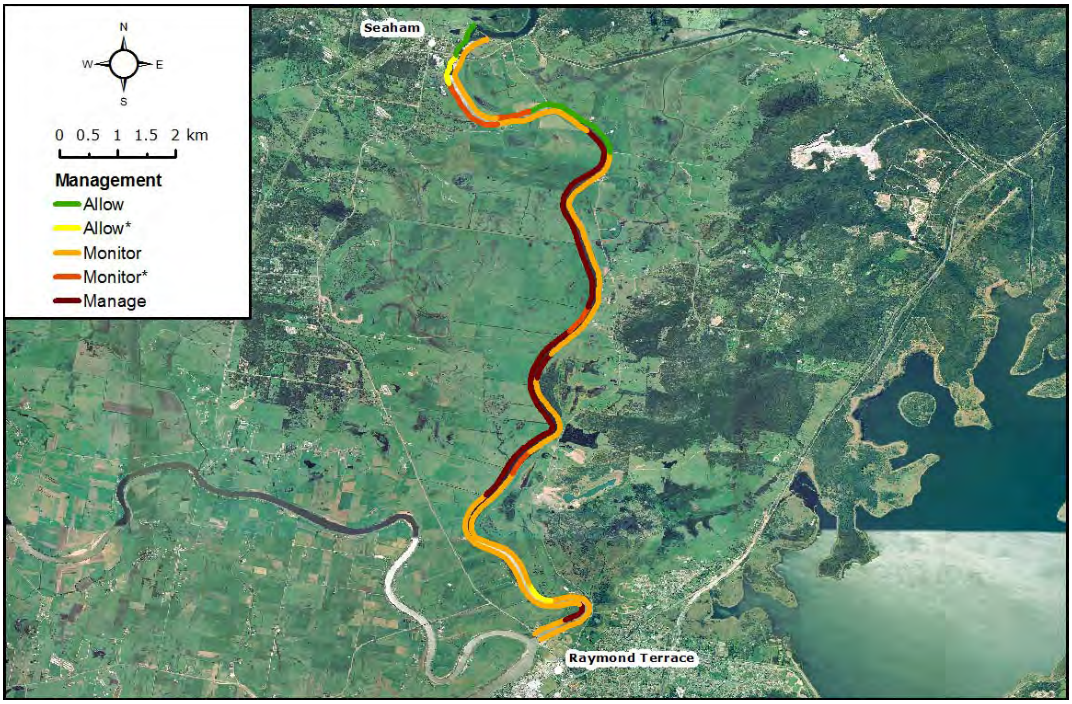


Figure P-7: DSS Management Recommendations - Wakesurf Operating – Boat Wave Attenuation - 10 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

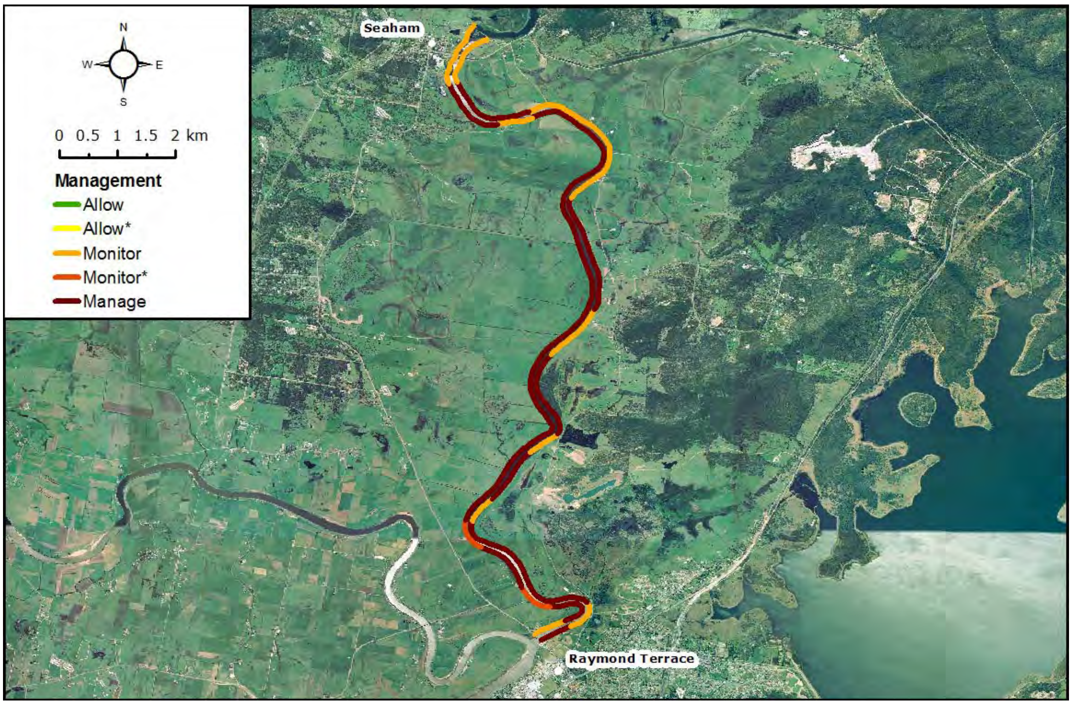


Figure P-8: DSS Management Recommendations - Wakesurf Operating – Boat Wave Attenuation - 50 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

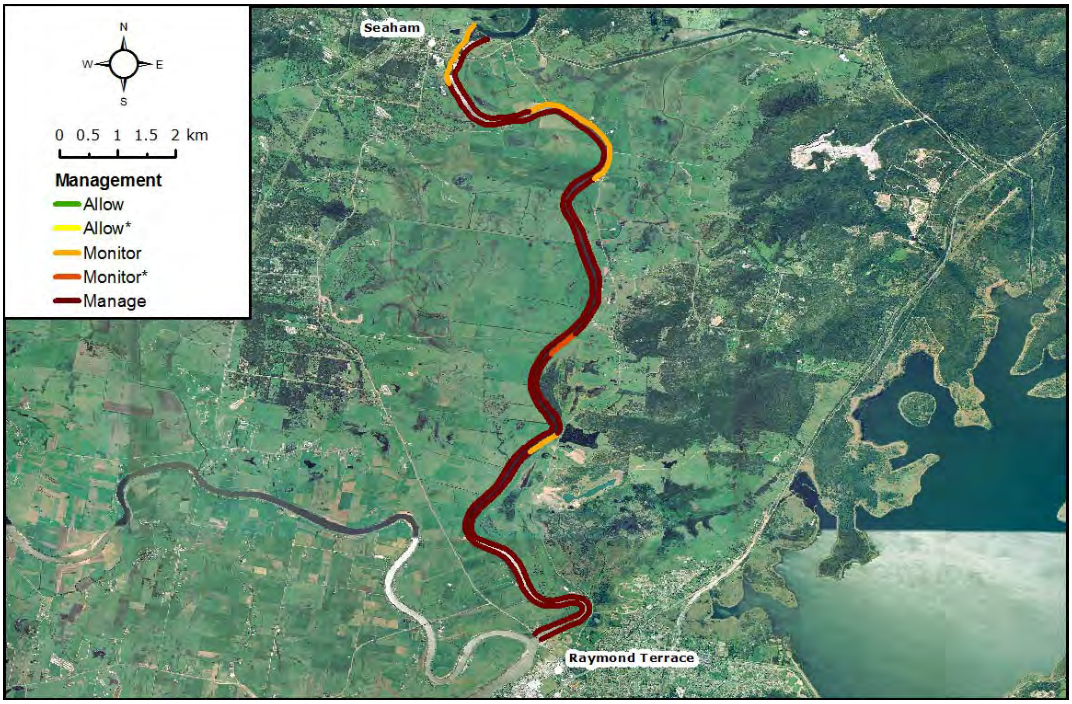


Figure P-9: DSS Management Recommendations - Wakesurf Operating – Boat Wave Attenuation - 150 Boat Passes – 8 Hour Duration (Mid - Low Tide Conditions)

Appendix Q – Updated 2012 DSS Management Discussion

A summary of the erosion potential and final management recommendations for the previous assessment conducted in 2012 is provided in Table Q-1. Note that Table Q-1 includes additional management categories, including 'Allow*' and 'Monitor*', that were not reported in the final management recommendations for the previous assessment (Table 6.1 in WRL TR 2012/05). In Figure 6.1 (WRL TR 2012/05), one site (R26) was reported as 'Monitor*' but was incorrectly reported as 'Monitor' in Table 6.1 (WRL TR 2012/05). Another site (R30) was incorrectly reported as 'Monitor' in both Table 6.1 and Figure 6.1 (WRL TR 2012/05) but was actually rated as 'Manage'. The corrected values were presented earlier in Section 5.3.2 of WRL TR 2012/05. As such, these omissions are considered insignificant to the overall final management recommendations provided in WRL TR 2012/05.

Since the previous DSS assessment on the Seaham Weir Pool (WRL TR 2012/05) was undertaken with DSS version 1.6 (DSS v1.6), the DSS has been updated following revisions to the algorithm used to calculate the erosion potential, and subsequent management recommendation at each site. Several updates incorporated into the DSS methodology, include:

- Adjustments to the application of erosion potential criteria;
- An improved method used for calculating approximate ARIs (refer to the method for calculating ARIs outlined in Appendix section B.3.4);
- The inclusion of additional field data from three wakeboarding vessels to the DSS vessel database based on recent field testing (Glamore *et al.*, 2014); and
- The addition of wakesurf "operating" conditions as a new vessel activity.

As these changes to the DSS may alter the DSS results at each site, data from the previous assessment in 2012 on the Seaham Weir Pool was re-processed using the current DSS version (DSS v2.4) to allow direct comparison with the March 2015 assessment. This included correcting the two wind scaling factor errors discussed in Appendix D. Table Q-2 provides a summary of adjusted erosion potential and management recommendations for the previous assessment using the current version of the DSS. The results provided in Table Q-2 show that the erosion potential is largely unchanged with only one change in the stretch averaged totals. In terms of the management recommendations provided Table Q-2, the results show a 19% reduction in 'Manage' sites, corresponding to a 12% increase in 'Monitor' sites, a 6% increase in 'Monitor*' sites, and a 1% increase in 'Allow*' sites. That is, using the 2012 riverbank conditions, DSS v2.4 is slightly more permissive of boating activities when compared to DSS v1.6. This is predominantly due to the improved method used for calculating the approximate wind wave ARI values. The adjusted 2012 equivalent ARI ratings (DSS v2.4) showed that there is generally less difference between the wind and wake wave energies on the Seaham Weir Pool when compared to DSS v1.6.

Table Q-1: 2012 Baseline Summary (DSS v1.6) for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0	3	6	3	0	3	0	8	0	1
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0	1	4	1	0	1	0	5	0	0
10-17	Waterskiing Section (D/S)	Waterski Operating	50	0	1	5	7	3	1	0	6	0	9
18-22	Wakeboarding Section	Wakeboard Operating	50	0	1	1	8	0	0	0	4	0	6
23-26	Waterskiing Section (U/S)	Waterski Operating	50	0	0	1	6	1	0	0	3	1	4
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0	0	3	5	0	0	0	7	0	1
31-49	U/S of the 4 knot Section	Waterski 8 knots	1	0	0	18	20	0	0	0	34	0	4
1-49	***TOTAL***			**0**	**6**	**38**	**50**	**4**	**5**	**0**	**67**	**1**	**25**

Table Q-2: 2012 Adjusted Baseline Summary (DSS v2.4) for Seaham Weir Pool

Stretch	River Section	Scenario	# Passes	Erosion Potential (Stretch Averaged)					Management Option				
				Highly Resistant	Moderately Resistant	Mildly Resistant	Moderately Erosive	Highly Erosive	Allow	Allow*	Monitor	Monitor*	Manage
1-6	Restricted Area Near Weir	Waterski 4 knots	1	0	1	8	3	0	1	0	11	0	0
7-9	4 knot Section (D/S)	Waterski 4 knots	10	0	1	5	0	0	1	0	5	0	0
10-17	Waterskiing Section (D/S)	Waterski Operating	50	0	2	5	6	3	2	0	10	1	3
18-22	Wakeboarding Section	Wakeboard Operating	50	0	2	1	7	0	1	1	4	3	1
23-26	Waterskiing Section (U/S)	Waterski Operating	50	0	0	1	6	1	0	0	6	1	1
27-30	4 knot Section (U/S)	Wakeboard 4 knots	50	0	0	2	6	0	0	0	6	2	0
31-49	U/S of the 4 knot Section	Waterski 8 knots	1	0	0	16	21	1	0	0	37	0	1
1-49	***TOTAL***			**0**	**6**	**38**	**49**	**5**	**5**	**1**	**79**	**7**	**6**

Appendix R – Cross-Sectional Riverbank Survey Profiles (Seaham Weir Pool)

As outlined in Appendix A (Section A.2.2), riverbank cross-sectional survey profiles (including undercutting) were previously measured at 17 locations along a straight stretch of the Seaham Weir Pool by RPS Group in December 2012, and by Delfs Lascelles Consulting Surveyors (DLCS) in April 2014. WRL sub-contracted DLCS to re-survey these cross-sectional profiles to quantify the impact of the April 2015 flood event. This most recent survey was undertaken in February 2016. The cross-sectional profiles included the ground surface at the time of the survey. Vegetation was not included and any human influence on the riverbanks (i.e. mechanical re-shaping, cut and/or fill) was not assessed.

All profiles are located on the right bank of the Seaham Weir Pool (Figure R-1). Sites 1-9 cover a distance of approximately 400 m directly opposite a rock armoured section on the left bank. Sites 10-17 are located further downstream and cover a distance of approximately 700 m between two creek confluences.

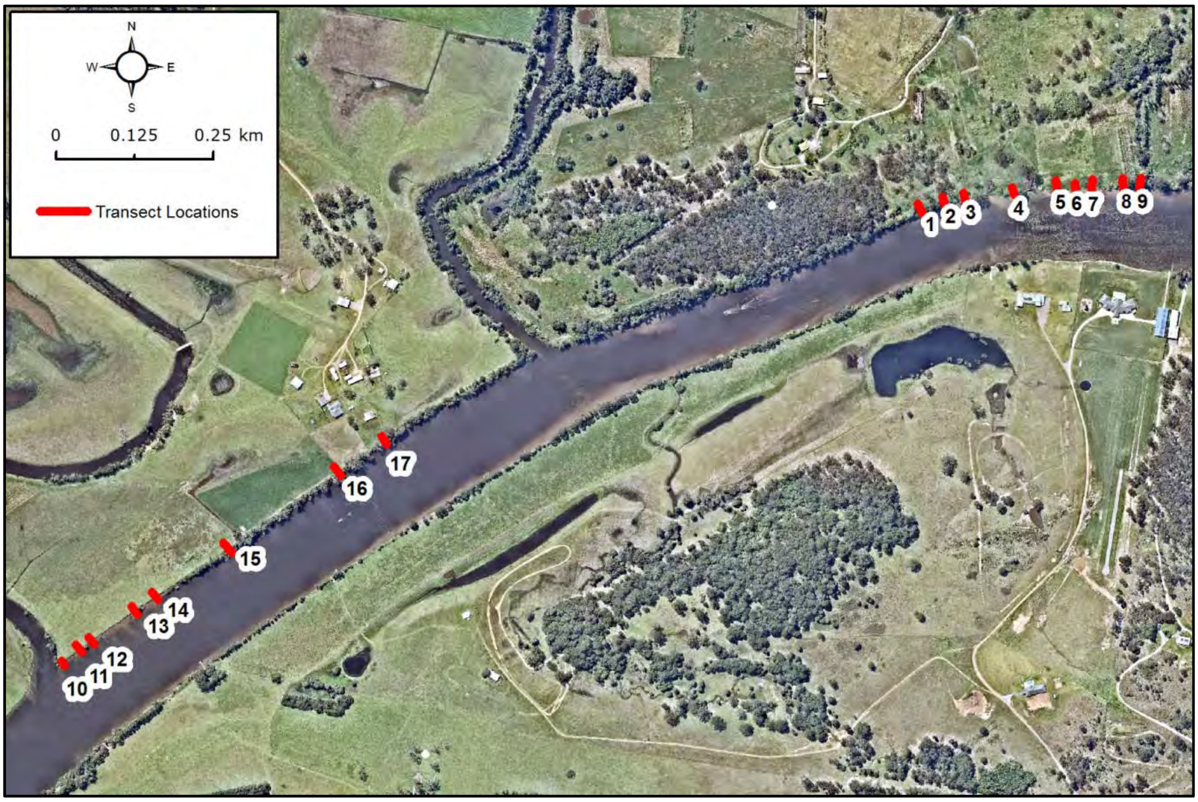


Figure R-1: Riverbank Monitoring Locations

(Aerial Photo 4 October 2015, Source: NearMap)

Photos of a selection of the monitoring sites (including the survey stakes at the top of the riverbank) taken by WRL staff in August 2015 are provided in Figure R-2 (Site 4), Figure R-3 (Site 7), Figure R-4 (Site 8) and Figure R-5 (Site 9).

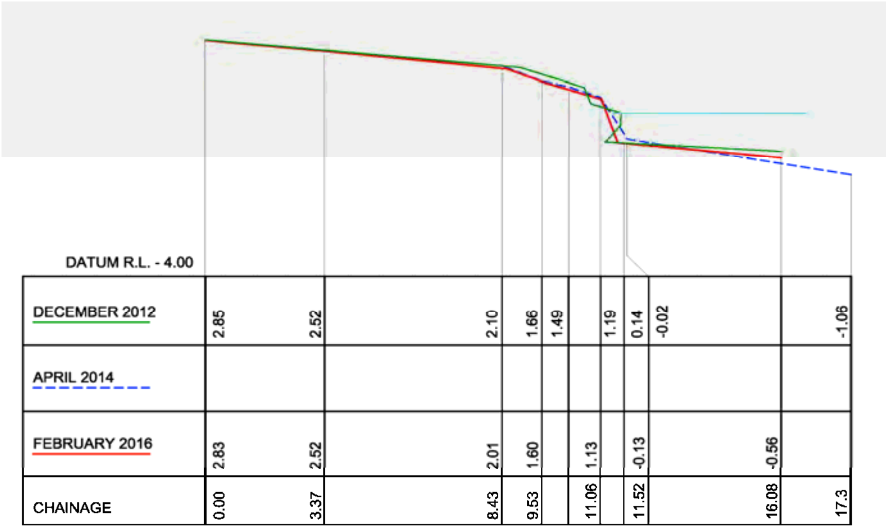
Profiles for each of the three (3) years are reproduced in Figure R-6 (Sites 1-3), Figure R-7 (Sites 4-6), Figure R-8 (Sites 7-9), Figure R-9 (Sites 10-12), Figure R-10 (Sites 13-15) and Figure R-11 (Sites 16-17).

Figure R-2 : DLCS Monitoring Site 4 (August 2015)

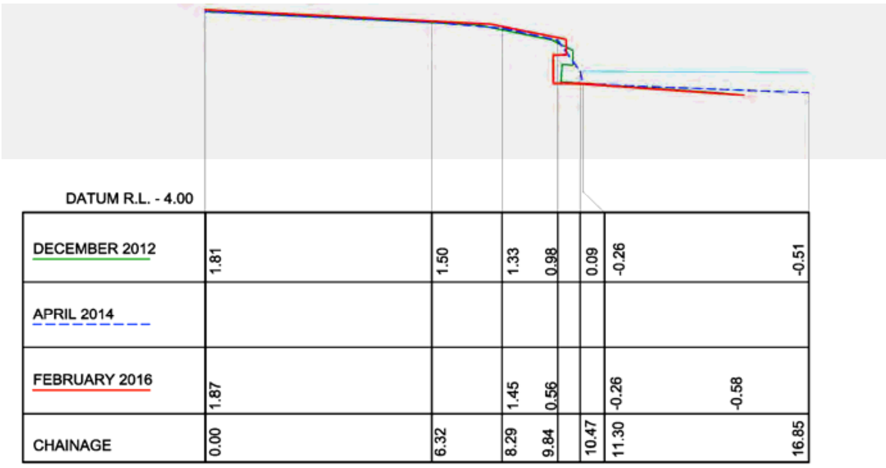
Figure R-3 : DLCS Monitoring Site 7 (August 2015)

Figure R-4 : DLCS Monitoring Site 8 (August 2015)

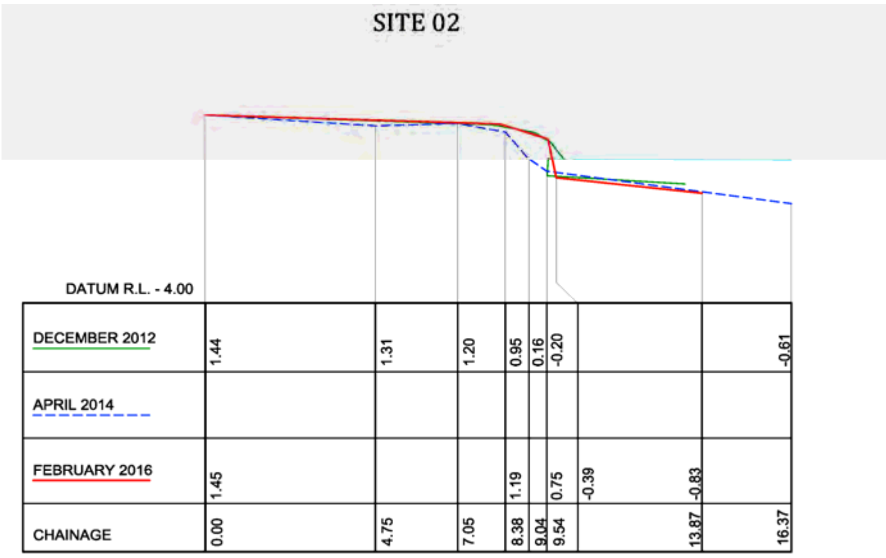
Figure R-5 : DLCS Monitoring Site 9 (August 2015)



SITE 01

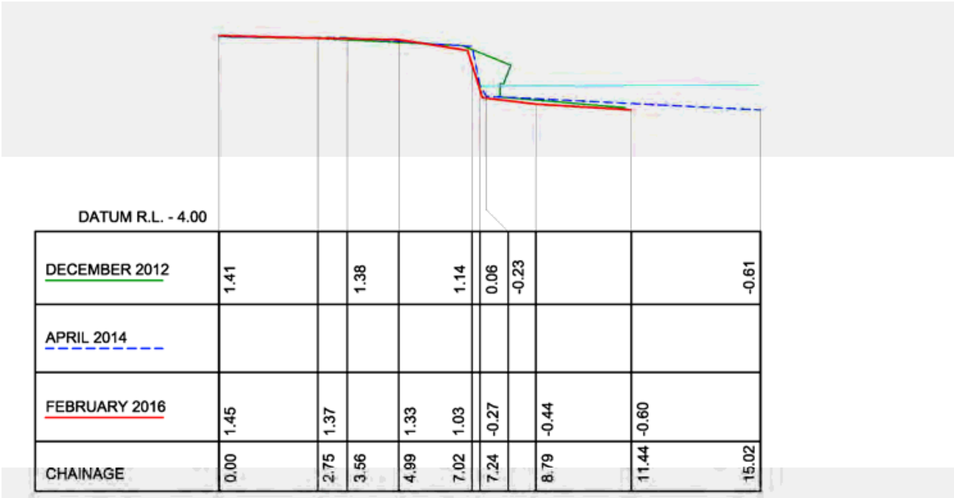


SITE 02

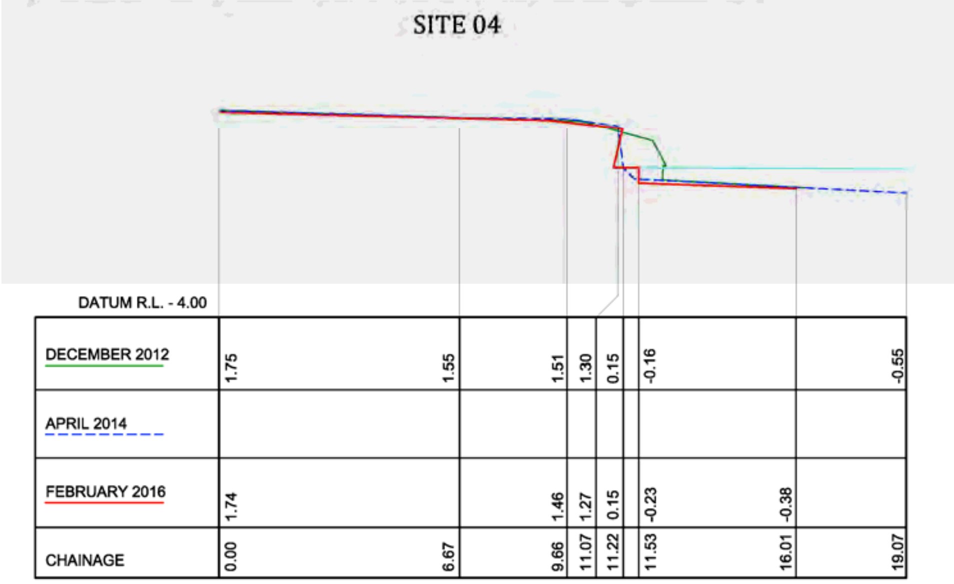


SITE 03

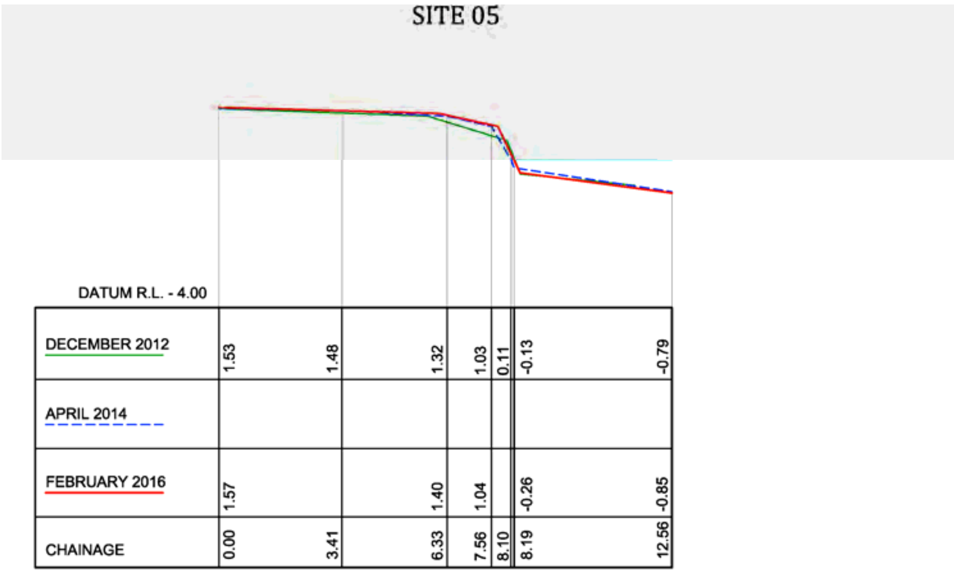
Figure R-6: Cross-Sectional Riverbank Profiles: Sites 1-3



SITE 04



SITE 05



SITE 06

Figure R-7: Cross-Sectional Riverbank Profiles: Sites 4-6

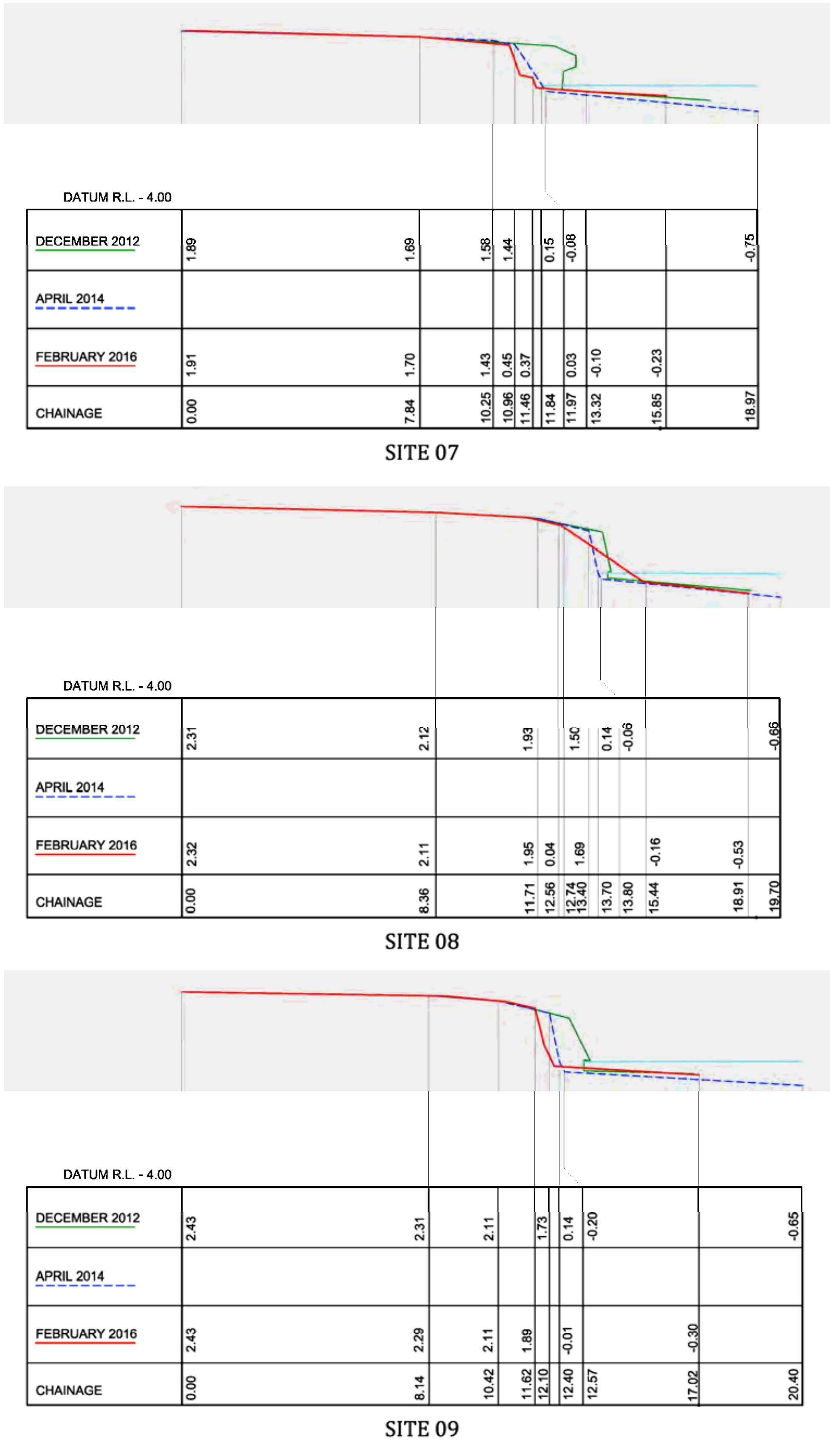
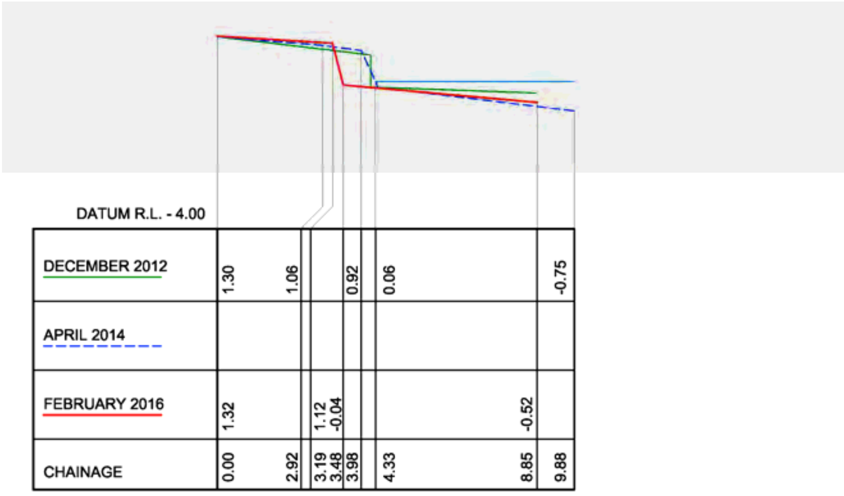
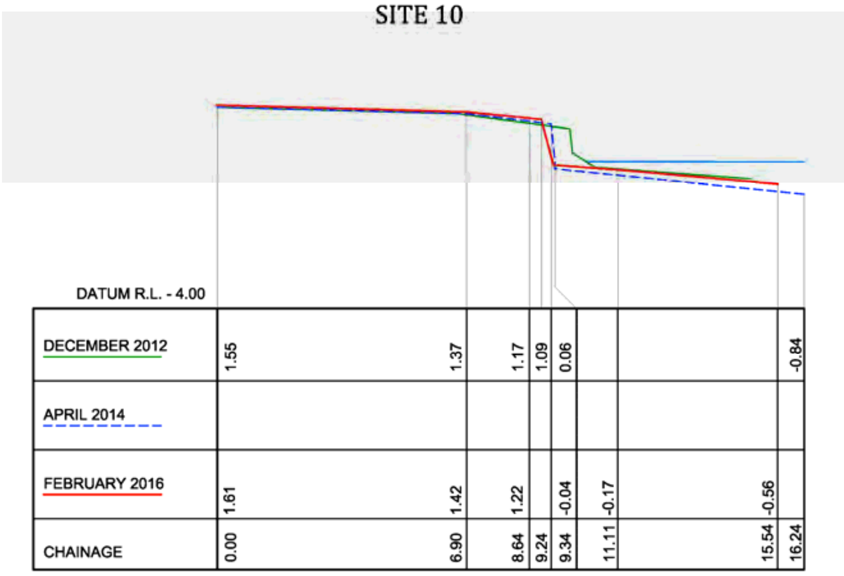


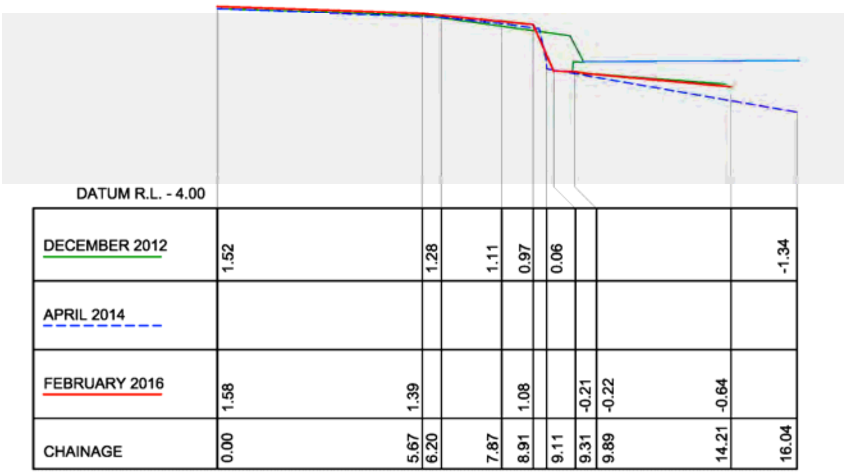
Figure R-8: Cross-Sectional Riverbank Profiles: Sites 7-9



SITE 10



SITE 11



SITE 12

Figure R-9: Cross-Sectional Riverbank Profiles: Sites 10-12

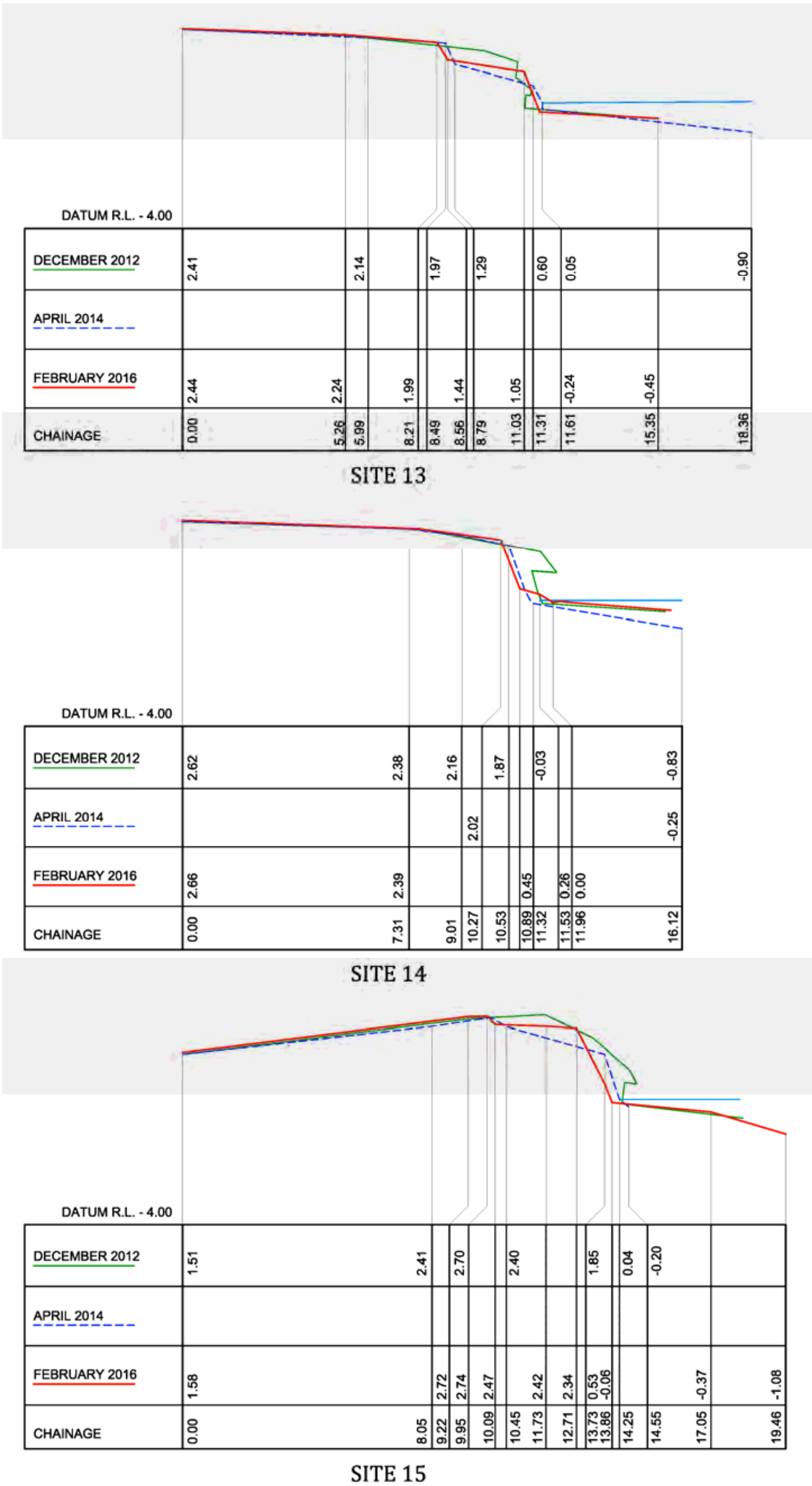


Figure R-10: Cross-Sectional Riverbank Profiles: Sites 13-15

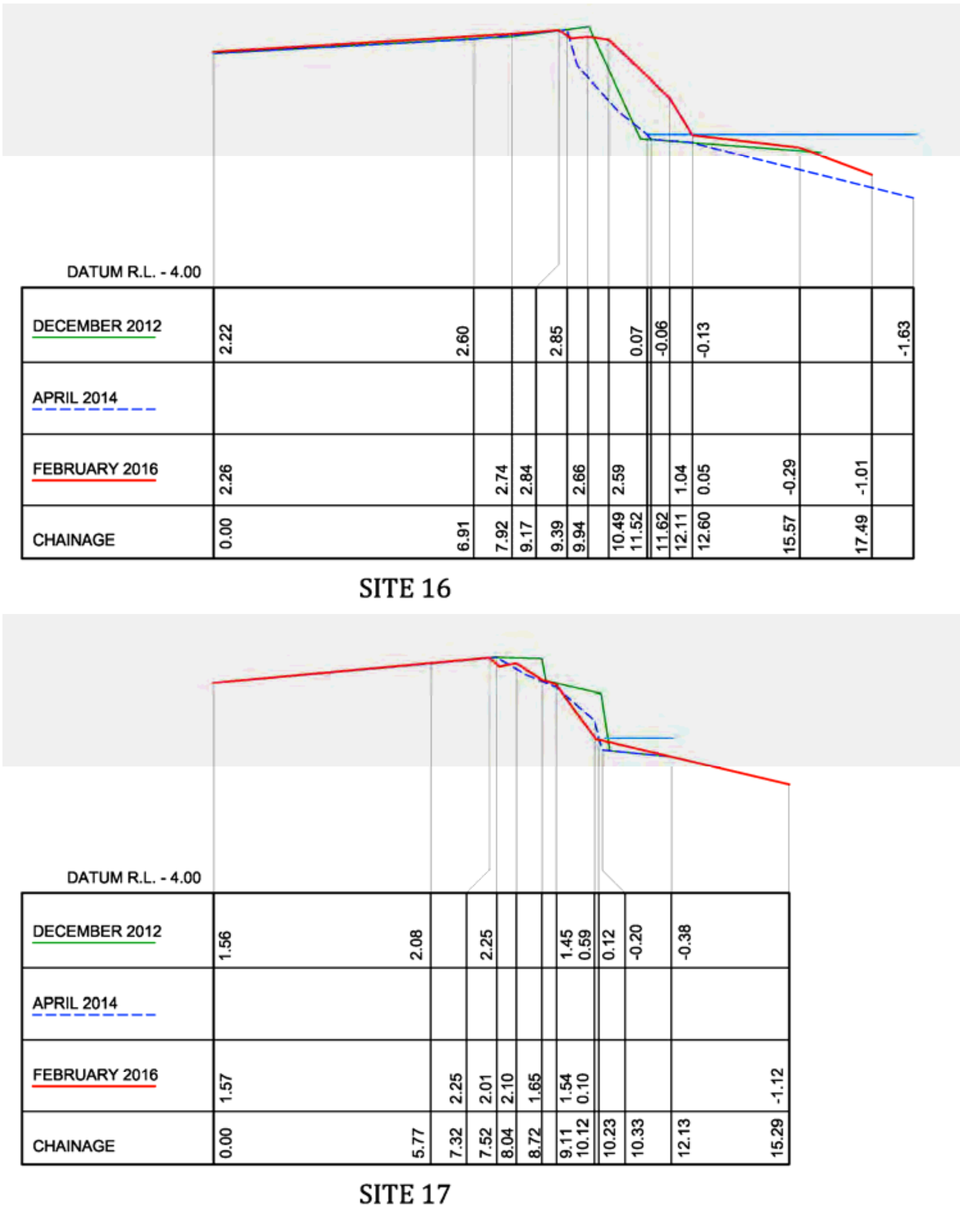


Figure R-11: Cross-Sectional Riverbank Profiles: Sites 16-17

The linear change in riverbank position at the +0.6 m AHD contour, approximately equivalent to the median water level (Glamore and Davey, 2012), was estimated between December 2012 and April 2014, and April 2014 and February 2016. Both results are summarised in Table R-1. Accretion (river-ward riverbank position movement) is noted in green and erosion (landward riverbank position movement) is noted in red.

Table R-1: Change in Riverbank Position at 17 Locations (m)

Location	Change in Position of 0.6 m AHD Contour (m)		
	April 2014-December 2012	February 2016-April 2014	February 2016-December 2012 (Total)
DLCS 1	-0.2	-0.1	-0.4
DLCS 2	-0.2	0.0	-0.2
DLCS 3	-1.0	0.9	-0.1
DLCS 4	-1.0	-0.1	-1.1
DLCS 5	-1.0	-0.1	-1.1
DLCS 6	-0.2	0.1	-0.1
DLCS 7	-1.1	-0.5	-1.6
DLCS 8	-0.4	0.5	0.0
DLCS 9	-0.9	-0.4	-1.3
DLCS 10	-0.1	-0.8	-0.9
DLCS 11	-0.5	-0.2	-0.7
DLCS 12	-0.9	0.0	-0.9
DLCS 13	0.2	-0.1	0.1
DLCS 14	-0.4	0.2	-0.3
DLCS 15	-0.7	0.3	-0.4
DLCS 16	-0.2	1.5	1.3
DLCS 17	-0.3	-0.3	-0.6

Since the change in horizontal riverbank position does not fully describe riverbank morphology, subsequent efforts focused on volumetric analysis of the cross-sectional profiles. For each profile, the volume of soil in the riverbank above -0.25 m AHD was calculated. This threshold generally corresponded to the lower limit of undercutting influence and all but two (2) profiles had survey data down to this elevation. For these two profiles, the transects were extrapolated, based on their most river-ward slope, down to -0.25 m AHD. Riverbank volumes are presented in cubic metres per metre of riverbank (m^3/m) in Table R-2. These values are equivalent to areas (m^2) between the profiles and a horizontal line at -0.25 m AHD. The change in volume between each survey campaign and overall change in volume are presented in Table R-3. Accretion (positive volume change) is noted in green and erosion (negative volume change) is noted in red.

Table R-2: Volumes at 17 Riverbank Measurement Locations (m³/m)

Location	Volume Above -0.25 m AHD (m³/m)		
	December 2012	April 2014	February 2016
DLCS 1	28.6	28.5	27.7
DLCS 2	17.7	18.0	18.0
DLCS 3	14.5	13.0	14.6
DLCS 4	12.0	11.3	11.2
DLCS 5	21.6	20.6	20.0
DLCS 6	12.6	13.1	13.4
DLCS 7	24.8	22.9	22.7
DLCS 8	32.9	32.1	32.6
DLCS 9	32.6	31.1	30.8
DLCS 10	5.9	5.9	5.2
DLCS 11	16.2	15.4	16.0
DLCS 12	15.0	14.2	14.8
DLCS 13	25.8	24.7	25.3
DLCS 14	30.2	28.8	29.7
DLCS 15	35.0	32.0	33.5
DLCS 16	30.2	28.8	33.7
DLCS 17	22.2	20.9	21.0

Table R-3: Change in Riverbank Volume at 17 Locations (m³/m)

Location	Change in Volume Above -0.25 m AHD (m³/m)		
	April 2014-December 2012	February 2016-April 2014	February 2016-December 2012 (Total)
DLCS 1	-0.1	-0.8	-0.9
DLCS 2	0.3	0.0	0.3
DLCS 3	-1.5	1.6	0.1
DLCS 4	-0.6	-0.2	-0.8
DLCS 5	-1.1	-0.6	-1.6
DLCS 6	0.5	0.3	0.8
DLCS 7	-2.0	-0.1	-2.1
DLCS 8	-0.8	0.5	-0.3
DLCS 9	-1.6	-0.2	-1.8
DLCS 10	0.0	-0.7	-0.7
DLCS 11	-0.8	0.6	-0.2
DLCS 12	-0.8	0.6	-0.2
DLCS 13	-1.1	0.6	-0.5
DLCS 14	-1.5	0.9	-0.5
DLCS 15	-3.0	1.5	-1.5
DLCS 16	-1.3	4.8	3.5
DLCS 17	-1.3	0.1	-1.2

The changes in riverbank volumes (m^3/m) in Table R-3 were combined with a riverbank segment distance across which each profile was considered representative (generally across the mid-points between adjacent profiles). The change in volume between each survey campaign and overall change in volume are presented in cubic metres (m^3) in Table R-4.

Table R-4: Change in Riverbank Volume at 17 Locations (m^3)

Location	Adopted Riverbank Segment Distance (m)	Change in Volume Above -0.25 m AHD (m^3)		
		April 2014-December 2012	February 2016-April 2014	February 2016-December 2012 (Total)
DLCS 1	40	-3	-32	-35
DLCS 2	37	11	2	12
DLCS 3	56	-85	91	5
DLCS 4	74	-47	-14	-61
DLCS 5	51	-54	-29	-83
DLCS 6	29	14	9	23
DLCS 7	38	-76	-4	-81
DLCS 8	38	-31	18	-13
DLCS 9	28	-44	-6	-50
DLCS 1-9 Total	391	-316	34	-282
DLCS 1-2,4-9 Total	**336**	**-230**	**-57**	**-287**
DLCS 10	29	1	-21	-20
DLCS 11	29	-24	18	-6
DLCS 12	54	-45	35	-11
DLCS 13	62	-66	37	-28
DLCS 14	89	-130	84	-46
DLCS 15	176	-521	262	-259
DLCS 16	152	-205	735	530
DLCS 17	90	-119	12	-107
DLCS 10-17 Total	680	-1,109	1,162	53
DLCS 10-15, 17 Total	**529**	**-904**	**426**	**-478**
DLCS 1-17 Total	1,072	-1,424	1,195	-229
DLCS 1-2,4-15,17 Total	**864**	**-1,134**	**369**	**-765**

While the volume changes within the two monitoring blocks (Sites 1-9 and 10-17) are variable, Sites 3 and 16 both show accretion which is significantly higher than adjacent monitoring sites between April 2014 and February 2016. As such, the overall volume changes for the upstream block are also presented without Site 3 and for the downstream block without Site 16 in Table R-4.

Between December 2012 and April 2014 approximately 250 m^3 of soil was eroded from riverbank Sites 1-9 and 1,000 m^3 from Sites 10-17.

While it is not possible to attribute all riverbank changes between April 2014 and February 2016 to the April 2015 flood event, it is considered to be a significant influence on the overall erosion (-50 m^3) for Sites 1-9 and accretion (500 to 1,000 m^3) at Sites 10-17. The variable impact of the April 2015 flood event across this small sample of Seaham Weir Pool riverbanks is extremely complex.

Depending on whether Sites 3 and 16 are included in the analysis, there has been a net loss (erosion) of 250 to 750 m^3 of riverbank soil into the Upper Williams River across the 17 monitoring sites (a 1 km stretch on one side of the river) between December 2012 and February 2016.

Note that while several of the profiles, for example Site 8 (Figure R-8), show minimal change in overall riverbank volume above -0.25 m AHD, erosion is evident on the upper bank with corresponding and equivalent accretion within the wave zone.

Table R-5 collates the DSS erosion potential and management ratings for February/March 2012, March 2015 (Pre-Flood) and August 2015 (Post-Flood) near the 17 DLCS monitoring sites. While the DSS assessment dates do not correspond directly with the survey dates (December 2012, April 2014 and February 2016), it is a helpful exercise to compare these two different measures of riverbank condition. Between February/March 2012 and August 2015, the DSS stretch average erosion potential at the DLCS monitoring locations deteriorated from “Moderately Erosive” to “Highly Erosive”. The corresponding management ratings have changed from “Monitor” or “Monitor*” to “Manage”. Either side of the April 2015 flood event, the DSS erosion potential and management ratings either further deteriorated or did not change. Recall that “Highly Erosive” and “Manage” represent the lowest erosion resistance and highest riverbank vulnerability, respectively. Note that DSS stretches with an average “Highly Erosive” erosion potential are classified as “Manage” regardless of wind and boat wake wave energies. While the cross-shore survey profiles and the DSS assessments are different measures of riverbank condition, the survey results independently verify that the DSS is correctly indicating that the riverbank condition trajectory in this area is in an eroding state. However, the measures diverge for Sites 10-17 between April 2014 and February 2016 where significant net accretion was recorded but the DSS ratings either further deteriorated or did not change.

Monitoring of these 17 riverbank locations is considered an important part of ongoing management of water quality in the Seaham Weir Pool. **WRL recommends that these sites be re-surveyed every 24 months to assist with the development of a conceptual sediment budget for the Seaham Weir Pool.**

Table R-5: Comparison of DSS Erosion Potential and Management Recommendations Near DLCS Riverbank Profiles

WRL Transect	Nearest DLCS Site	ARI	February/March 2012		March 2015 (Pre-Flood)		August 2015 (Post-Flood)	
			Erosion Potential	Management Option	Erosion Potential	Management Option	Erosion Potential	Management Option
R21A	DLCS 1	B	Highly Erosive	**Monitor**	Moderately Erosive	**Manage**	Moderately Erosive	**Manage**
R21B	DLCS 2,3,4		Highly Erosive		Highly Erosive		Highly Erosive	
R21C	DLCS 5,6,7,8,9		Moderately Erosive		Highly Erosive		Highly Erosive	
R21 (Stretch Averaged)			**Moderately Erosive**		**Highly Erosive**		**Highly Erosive**	
R18A	DLCS 10,11,12	B	Moderately Erosive	**Monitor***	Mildly Resistant	**Monitor***	Moderately Erosive	**Manage**
R18B	DLCS 13,14		Moderately Erosive		Highly Erosive		Highly Erosive	
R18C	DLCS 15		Mildly Resistant		Moderately Erosive		Moderately Erosive	
R18 (Stretch Averaged)			**Moderately Erosive**		**Moderately Erosive**		**Highly Erosive**	
R19A	DLCS 16	B	Mildly Resistant	**Monitor**	Highly Erosive	**Manage**	Highly Erosive	**Manage**
R19B	DLCS 17		Moderately Erosive		Highly Erosive		Highly Erosive	
R19C			Highly Erosive		Moderately Erosive		Highly Erosive	
R19 (Stretch Averaged)			**Moderately Erosive**		**Highly Erosive**		**Highly Erosive**	