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Riverbank Vulnerability Assessment using a Decision Support System: Clarence River (Rogans Bridge to Ulmarra)

WRL Technical Report 2014/12
December 2014

By W C Glamore, I R Coghlan, J E Ruprecht, F Flocard and C D Drummond

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Executive Summary

Clarence Valley Council (CVC), NSW North Coast Local Land Services (LLS) and NSW Roads and Maritime Services (RMS) have jointly funded this study detailing a riverbank vulnerability assessment of a systematic 37 km section of the Clarence River to improve river management. The outcomes of this study can be used to objectively assess riverbank erosion, vulnerability to wave attack and/or within regional and local boating and riverbank plans.

This project was primarily undertaken to provide a baseline for evidence-based management of riverbank erosion for the Riverbank Vulnerability Assessment Working Group (RVAWG). A Decision Support System (DSS) as outlined by Glamore and Badenhop (2006; 2007), was used to objectively assess and rank the riverbank's susceptibility to erode based on a variety of environmental factors. Specifically, the DSS was used to assess:

- The current condition of the riverbanks using a robust and repeatable ranking system;
- The effect of natural wind waves and boat wake waves and other contributing causes to riverbank erosion along key reaches of the Clarence River;
- The vulnerability of the riverbanks to erosion; and
- Potential management actions at key sites.

The DSS includes a database with a range of vessel generated wave energies from recreational boats (wakeboard and waterski) commonly encountered in NSW. As part of this study, three (3) additional wakeboarding vessels were added to the DSS vessel database. To this aim, a full-scale field testing program was conducted near the Junction Hill Boat Ramp on 9 May 2014. The field testing found that the wave energies generated by the three (3) additional wakeboarding vessels tested were consistent with the existing characteristic wakeboarding parameters in the DSS. However, a new vessel activity, wakesurfing (an alternative activity to wakeboarding), was added to the DSS vessel database on a preliminary basis, for application on the Clarence River.

The Clarence River study area (between Rogans Bridge and Ulmarra) was initially divided into eighty-four (84) sections along the river including Susan Island, Elizabeth Island and Peanut Island, the majority being 500 m in length. A field campaign was undertaken to assess the erosion potential at three (3) representative transects on the left and right riverbanks within each riverbank section (504 sites in total). Wind data was then used from Grafton Research Station (the closest local weather station that sufficiently characterises local wind effects) to determine site specific wind wave conditions at each section.

In assessing riverbank erosion potential (i.e. the current condition), key criteria and weighting factors were combined to form an erosion potential rating for each site. These criteria include river type, vegetation coverage and extent, erosion descriptors, adjacent land use and channel features. Erosion potential was assessed at mid – low tide and high tide to accurately observe the wave zone throughout the entire tidal cycle. During the field assessment it was noted that, for a small number of river stretches, the riverbanks were less vulnerable to erosion from wave attack at high tide than at mid - low tide.

An erosion potential score and erosion potential category were determined for each site. 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. All five (5) erosion potential categories in the DSS ('Highly Resistant', 'Moderately Resistant', 'Mildly Resistant', 'Moderately Erosive' and 'Highly Erosive') were observed in the study area. However, the

majority of the region (75%) is considered 'Mildly Resilient' (or better) to erosion throughout the tidal range. At mid – low tide, 9% of all transects were classified as 'Highly Erosive'. Figure ES-1 displays the distribution of the erosion potential categories across the entire study area for mid - low tide conditions.

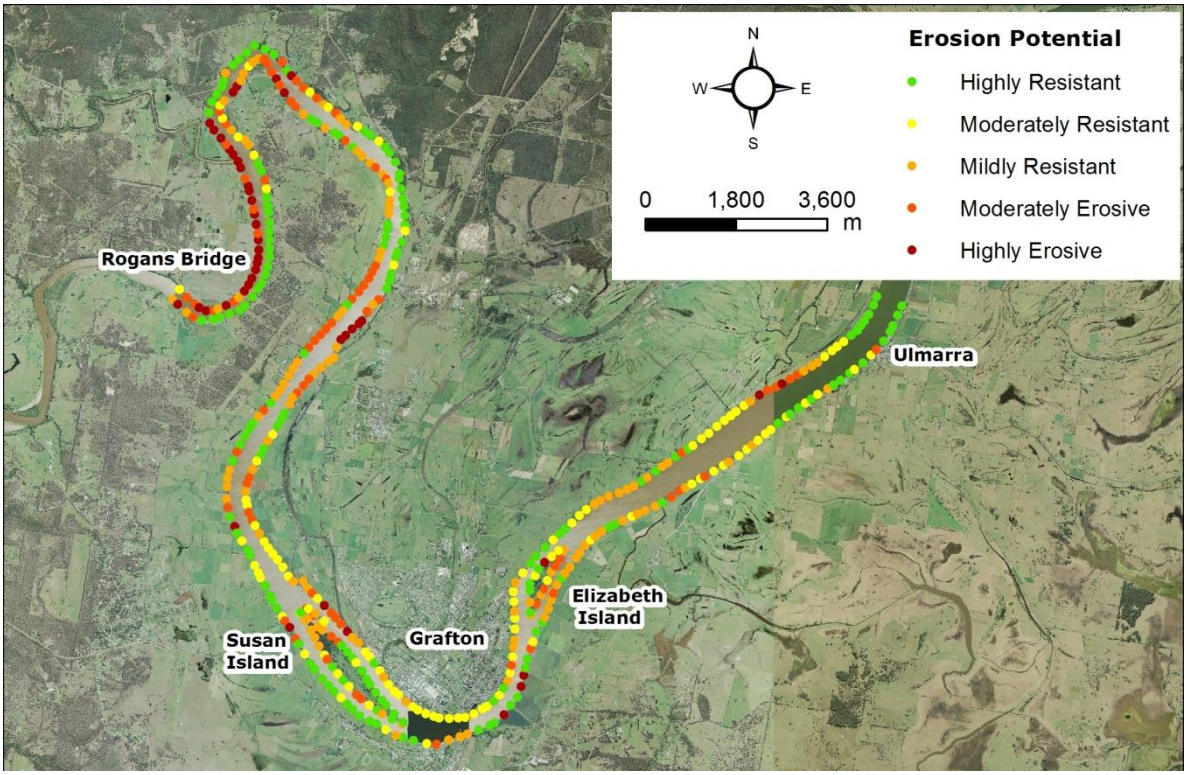

Figure ES-1: Erosion Potential for Each Transect (Mid - Low Tide Conditions)

Waves generated by passing boats on the Clarence River were considered within the DSS. While broad information about boat use between Rogans Bridge and Ulmarra exists, detailed boat pass counts are unavailable. In the absence of this information, a range of daily boat pass numbers were estimated for the waterway in consultation with NSW RMS. The adopted boating numbers between Rogans Bridge and Ulmarra varied between 10 and 300 boat passes per day (10 to 300 boat passes for an 8 hour duration). By definition, a return journey by one boat which passes a riverbank section is counted as 2 boat passes.

The riverbank erosion potential, wind waves and boat waves at each stretch were then assessed within the DSS matrices to produce a final management recommendation of either 'Allow', 'Monitor' or 'Manage'. When the wave attenuation (i.e. as calculated by the distance of a boat from the shore) is a limiting factor in the final outcome, and the maximum wave would result in a different management category, sites are presented as 'Allow*' or 'Monitor*'. In Table ES-1 it is evident that wakesurf 'operating' conditions resulted in the highest number of 'Manage' sites except for the 10 boat passes scenario, approximately doubling the wakeboarding 'operating' conditions for 300 boat passes. Wakeboard 'operating' conditions resulted in the second highest counts of 'Manage' sites compared to waterski 'operating' conditions, except for the 10 boat passes scenario. The outcomes suggest that the majority of the study region is generally suitable for wakeboard and waterski boating numbers of 150 boat passes per day. Figure ES-2,

displays the DSS management outcomes to assist in developing on-ground erosion mitigation measures.

Table ES-1: Number of Stretches Determined in each DSS Management Category (Mid – Low Tide)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	89	66	36	92	92	85	89	23	9
Allow*	5	27	46	17	17	24	0	50	45
Monitor	65	55	41	50	47	41	69	43	30
Monitor*	0	6	26	0	2	6	1	33	46
Manage	9	14	19	9	10	12	9	19	38

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

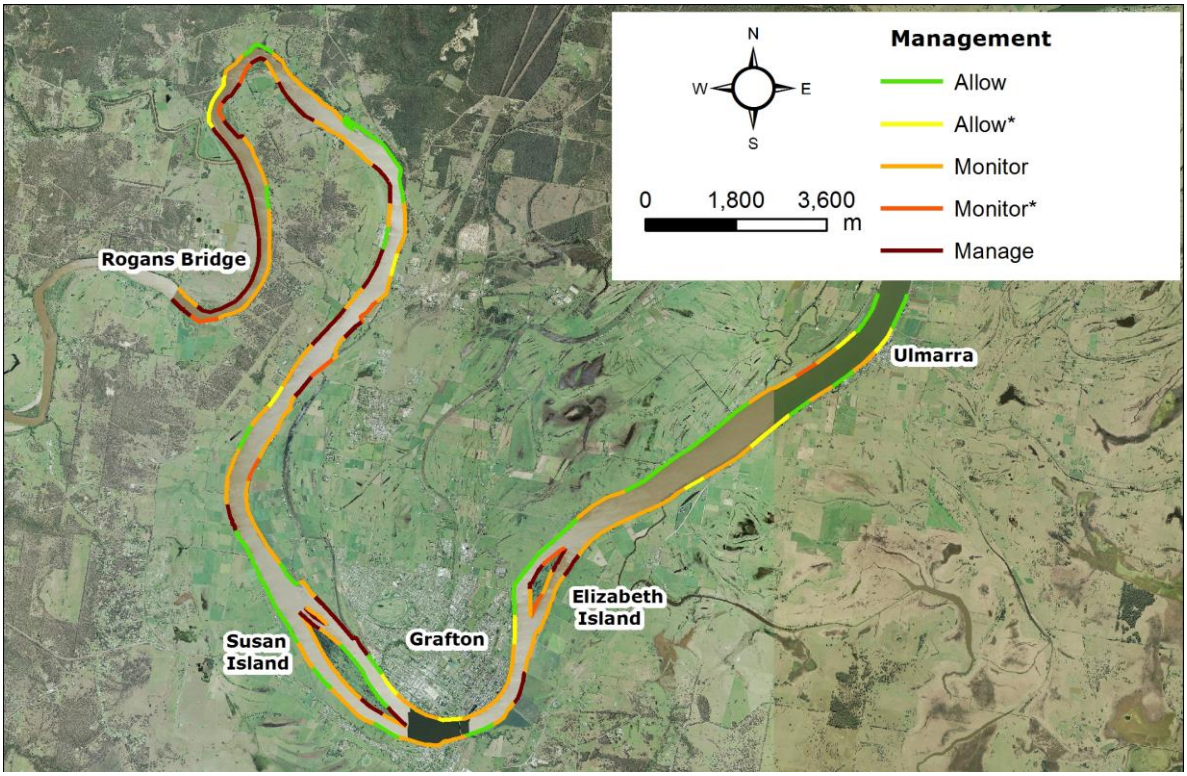

Figure ES-2: Suggested DSS Management Recommendations – Wakeboard Operating – Boat Wave Attenuation – 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

Land- and water-based management options have been outlined to reduce the DSS management outcomes from 'Manage' to 'Monitor' at sites with the highest vulnerability. Land-based management options include weed removal, native regeneration, stock management, bank battering, repairs to existing rock revetments and construction of new rock revetments. Water-based management options include enforcing 'No Wash' zones and/or buoy deployment ('distance off' restrictions). Land-based management options would have a longer implementation timeframe and greater associated costs but provide a sustainable solution.

However, water-based management options may be useful as an immediate mitigation measure at some sites. For many locations a mixed approach including both onsite remediation and boating management may be required.

The recommended riverbank erosion management strategies 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 outcomes are as follows:

1. **Immediate Management Plan (implementation timeframe: 0-6 months)** involves enforcing 'no wash' zones and buoy deployment across the study region as shown in Figure ES-3. Sites that require riverbank remediation to reduce erosion are also shown in Figure ES-3.
2. **Riverbank Management Program (implementation timeframe: 0-24 months)** involves undertaking riverbank remediation works at sites not addressed by the *Immediate Management Plan* including weed removal, native vegetation regeneration, stock access removal, renourishment and repairs to rock revetments as recommended in Figure ES-4.

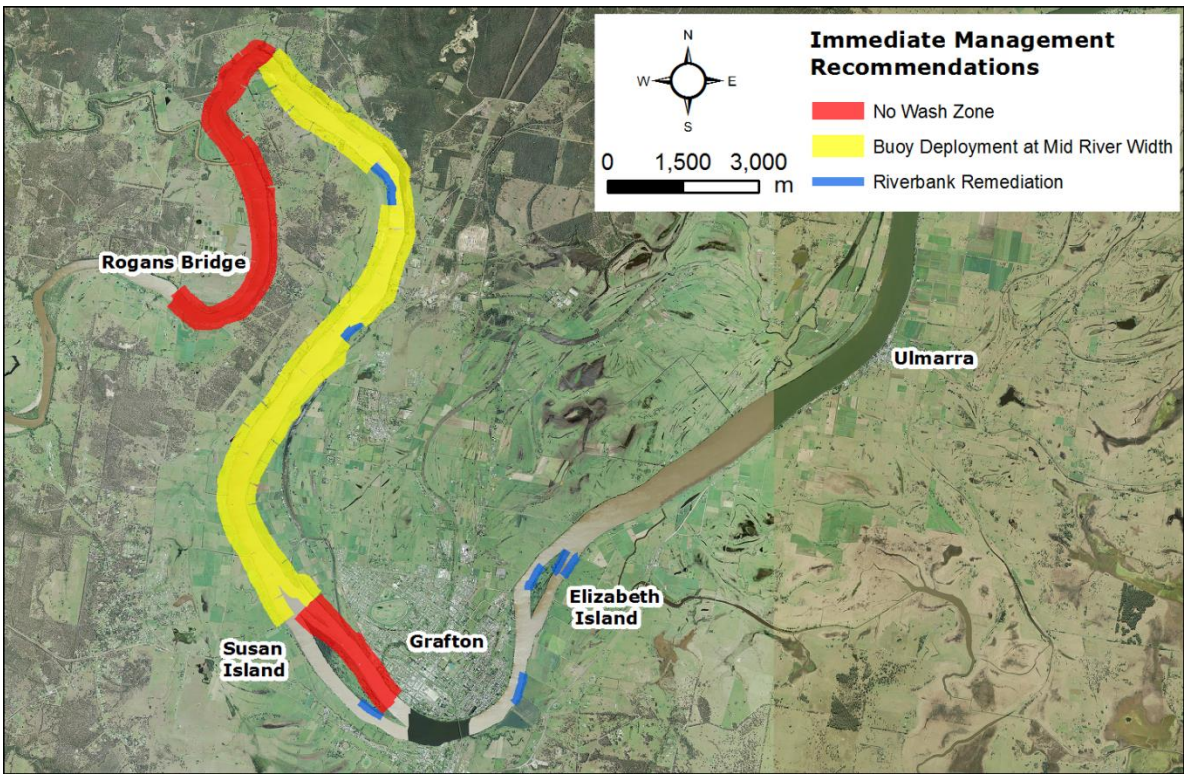

Figure ES-3: Recommended Onsite Actions for the Immediate Management Plan

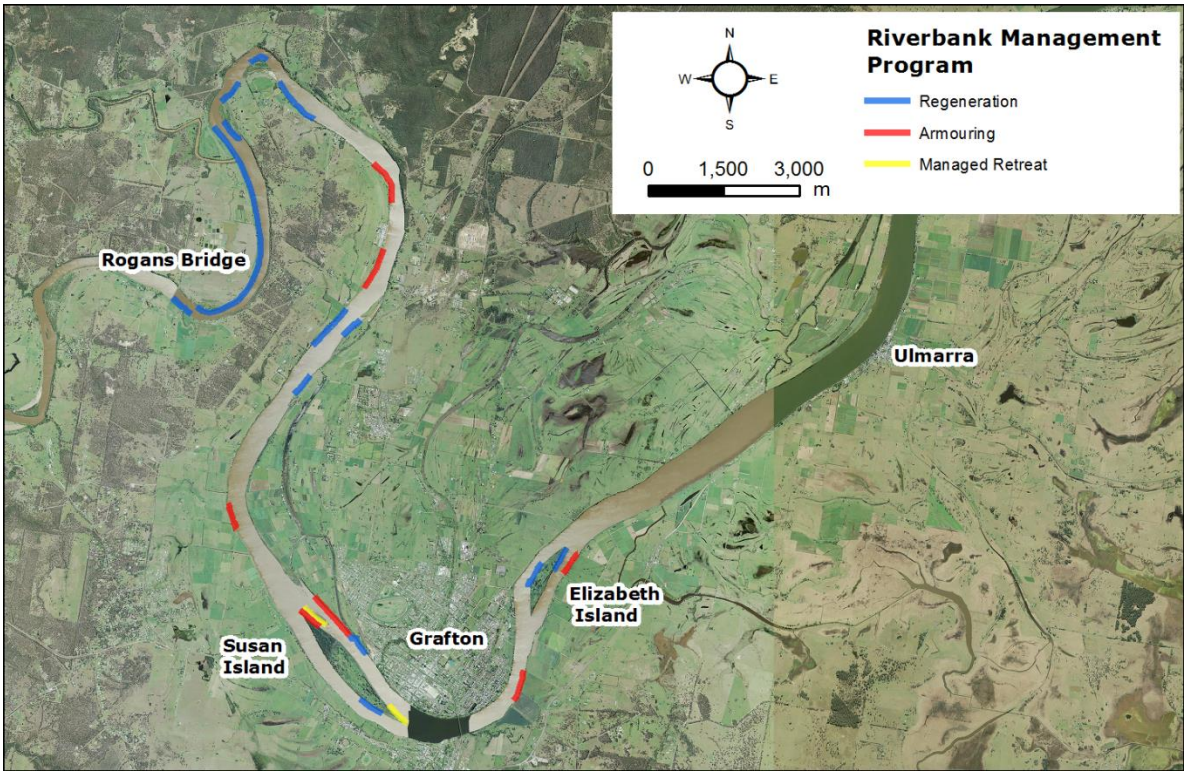

Figure ES-4: Recommended Riverbank Management Program for Onground Works

RECOMMENDATIONS

Key management recommendations are provided in order of priority. These recommendations are supported by important research items that can improve the management outcomes with time.

Management Recommendation 1: Implement the *Immediate Management Plan* (timeframe: 0-6 months).

An *Immediate Management Plan* (as provided in Figure 4-2) is recommended, including:

1. Enforcing 'No Wash' zones between stretches 1-15 (full river width) and stretches 43-47 (left channel only) and buoy deployment at the mid-river width from the shore between stretches 16-42.
2. Immediate water and land based management interventions at stretches 22-23 (right bank only) and stretch 29 (left bank only). The latter can be achieved by encouraging mid-river boating (e.g. placing buoys, education, etc.) and undertaking remediation works on the riverbank stretches.
3. Immediate land based management interventions at stretches 47, 53, 57 and 58 based on the recommendations provided in Table 4-1.
4. All other 'Manage' sites identified across the study region can be managed in the interim with water-based restrictions and improved river management (e.g. education, deployment of buoys, etc.).

Note that a fundamental component of the *Immediate Management Plan* is an education and training program for river users to manage riverbank erosion during non-flood periods.

Management Recommendation 2: Implement the *Riverbank Management Program* outlined below (timeframe: 0-24 months).

The *Riverbank Management Program* targets the sites not addressed by the *Immediate Management Plan* and applies the land management strategies as recommended in Table 4-1 and Figure 4-3. A site-by-site forensic examination is provided in Appendix N. Note that mid-river boating traffic (e.g. buoy deployment) is recommended until native vegetation on the riverbank is re-established.

It is important to note that the *Riverbank Management Program* only addresses the worst erosion areas identified by the DSS riverbank vulnerability assessment. This report provides preliminary recommendations based on a desktop forensic examination at individual transects. Additional site-specific detailed engineering design and costing is required. Detailed planning should include site inspections to assess the entire riverbank stretch.

Management Recommendation 3: DSS management outcomes are used to help formulate the *Regional Boating Plan for the Tweed-Clarence Valley Region*.

Management Recommendation 4: Establish a long-term monitoring program, including the reapplication of the DSS.

A comprehensive and established monitoring program will provide an objective baseline for future comparison and management of the Clarence River between Rogans Bridge and Ulmarra. Glamore and Badenhop (2006) recommend a reassessment of 'Monitor' sections every two years, and 'Allow' sections every five years. This assessment could be coupled with updated boat statistics (Recommendation 1) at the highly frequented sections of the river.

Research items are provided to further refine the DSS results and data input. Four (4) research items are recommended below:

Research Item 1: Develop updated information on boat usage patterns on the waterway.

There is limited data available on boat pass numbers, including boat numbers and user activity. Further to regular patrol observations by NSW RMS, an assessment of boating numbers encompassing both busy, and normal, weekends and weekdays, as recommended by Glamore and Badenhop (2006), would provide a more accurate understanding of recreational boating within the study area. This data gathering, coupled with a survey of users, would help establish preferred areas for recreational boating and focus further investigations.

It is important to note that even if boat numbers were known for this study that this would not have reduced the number of "Manage" sites. There are nine (9) sites (L02, L05, L06, L07, L08, L09, L10, L11, L29 as shown in Figure 3-25) in the study region with the worst case "Highly Erosive" erosion potential which are classified as "Manage" sites regardless of wind and boat wave energies.

Research Item 2: Investigate the extent and impact of extractive industry activities within the Clarence River.

This research item aligns with specific actions outlined in the Clarence Valley Estuary Management Plan (2003), including:

1. Action W21: Prepare a sedimentary process drivers study; and
2. Action U1: Prepare a sand and gravel resources management strategy for the whole estuary.

To support this work, bathymetric measurements should be taken both within the licensed areas and immediately upstream and downstream of the licensed areas at regular intervals. This information is required (as a minimum) to estimate the impact of extractive industry.

Research Item 3: Obtain additional wakesurf field measurements to refine the DSS assessment.

On a preliminary basis, a new vessel activity, wakesurf "operating conditions", was incorporated into the DSS database. However, it is acknowledged that there are a limited number of wakesurf field test results available. Further field tests would improve the characteristic parameters of the large wake waves associated with wakesurfing.

Research Item 4: Assess the local wind conditions on the Clarence River over an extended period to develop scaling factors applicable to the existing wind record.

The baseline DSS assessment has used wind data from the Grafton Research Station to stimulate conditions on the Clarence River as it is the best available data. This station is well situated for this purpose, located between 3 and 8 km from any part of the Clarence River study area. Sensitivity tests on the available wind data were undertaken to determine if additional field measurements were required. The influence of these tests on management recommendations was considered significant. Accordingly, WRL recommends that anemometers be deployed along the riverbanks between Rogans Bridge and Ulmarra to calculate scaling factors applicable to the wind conditions at the Grafton Research Station. This wind data collection program would involve approximately 6-10 anemometers deployed along the Clarence River for a minimum of 12 months.

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1. Introduction

The Clarence River is located on the north coast of New South Wales. The river is subject to large floods, invasive species, recreational boating pressures, commercial extraction and other anthropogenic impacts. Concerns have been raised by various stakeholders that human activities may be contributing to riverbank erosion on priority sections of the Clarence River, particularly on riverbank sections comprised of soft, erodible materials. This study provides, for the first time, an objective assessment of the riverbank's vulnerability to erode and associated impacts. The outcomes of this study will provide objective information for the Regional Boating Management Plan in the Tweed-Clarence Valley Region or other river management plans developed in the future.

This study was jointly funded by Clarence Valley Council (CVC), NSW North Coast Local Land Services (LLS) and NSW Roads and Maritime Services (RMS). The Clarence Valley Council's Riverbank Vulnerability Assessment Working Group (RVAWG) proposed that the riverbank vulnerability assessment be undertaken on an approximate 37 km long section of the Clarence River between Rogans Bridge and Ulmarra (the study area) (Figure 1-1). The study area was chosen by RVAWG, in consultation with the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia (UNSW).

This project provides a new baseline for evidence-based management of riverbank erosion on the Clarence River. A Decision Support System (DSS) designed by WRL staff, was used to objectively assess and rank the susceptibility of the riverbanks in the study area to erode based on a variety of environmental factors. Specifically, the DSS was used to assess:

- The current condition of the riverbanks using a robust and repeatable ranking system;
- The effect of natural wind waves and boat wake waves and other contributing causes to riverbank erosion along key reaches of the Clarence River;
- The vulnerability of the riverbanks to erode; and
- Potential management actions that can best address erosion at key sites.

Many land- and water-based factors can contribute to the erosion of riverbanks. Land-based factors include clearing of native vegetation on riverbanks and hard hoofed stock grazing on riverbanks. Water-based factors include periodic flooding of the Clarence River (which both erodes and deposits material), tidal flows causing natural scour sites coupled with depositional sites and waves (generated by either the wind or boats) breaking against riverbanks. The focus of this study is on wave impacts on riverbanks, with consideration given to land-based factors which influence the riverbank's vulnerability to wave attack. Note that the left and right riverbanks are defined relative to an observer looking downstream.

The core of the DSS assessment process is a field-based evaluation of the riverbank's erosion potential. Key criteria and weighting factors are combined to form an erosion potential rating for each assessed site. 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). 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. For the purpose of informing specific management actions, the DSS highlights riverbank sections potentially impacted by boat wave energy.

1.1 About this Report

Following this introduction, the report has four main sections:

- **Section 2** presents the methodology and details of the Clarence River DSS assessment;
- **Section 3** introduces the results of the DSS analysis, as determined for a range of different scenarios, including the riverbank erosion potential assessment;
- **Section 4** discusses the results and provides recommendations for further development and investigations on the Clarence River including implementation options to minimise erosion at vulnerable areas.
- **Section 5** details the references used throughout 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, including documented recreational boating activity and the design of erosion protection works, 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 included in **Appendix C**.

As part of this study, RVAWG requested that three additional wakeboarding vessels be added to the DSS vessel database prior to application of the DSS on the Clarence River. To this aim, a controlled full scale field testing program, which is summarised in **Appendix D**, was conducted near the Junction Hill Boat Ramp on 9 May 2014. The wave traces from all of these tests are reproduced in full in **Appendix E**. Following the field testing program, the three vessels were added to the DSS vessel database. It was found that the wave energies generated by the three (3) wakeboarding vessels tested were consistent with the characteristic wakeboarding parameters in the existing DSS. However, a new recreational activity, wakesurfing, was added to the DSS vessel database, on a preliminary basis, for application on the Clarence River.

Additional appendices to this report include:

- **Appendix F** provides wind rose and frequency data.
- **Appendix G** provides an example DSS field sheet.
- **Appendix H** provides field examples of erosion potential categories.
- **Appendix I** provides an example wind waves versus boat waves comparison.
- **Appendix J** provides DSS sensitivity tests for high tide conditions.
- **Appendix K** provides DSS sensitivity tests for high boat passes.
- **Appendix L** provides DSS sensitivity tests for adjusted wind conditions.
- **Appendix M** provides DSS sensitivity tests for boat wave attenuation.
- **Appendix N** details the outcomes of the forensic examination and provides a preliminary riverbank management program.

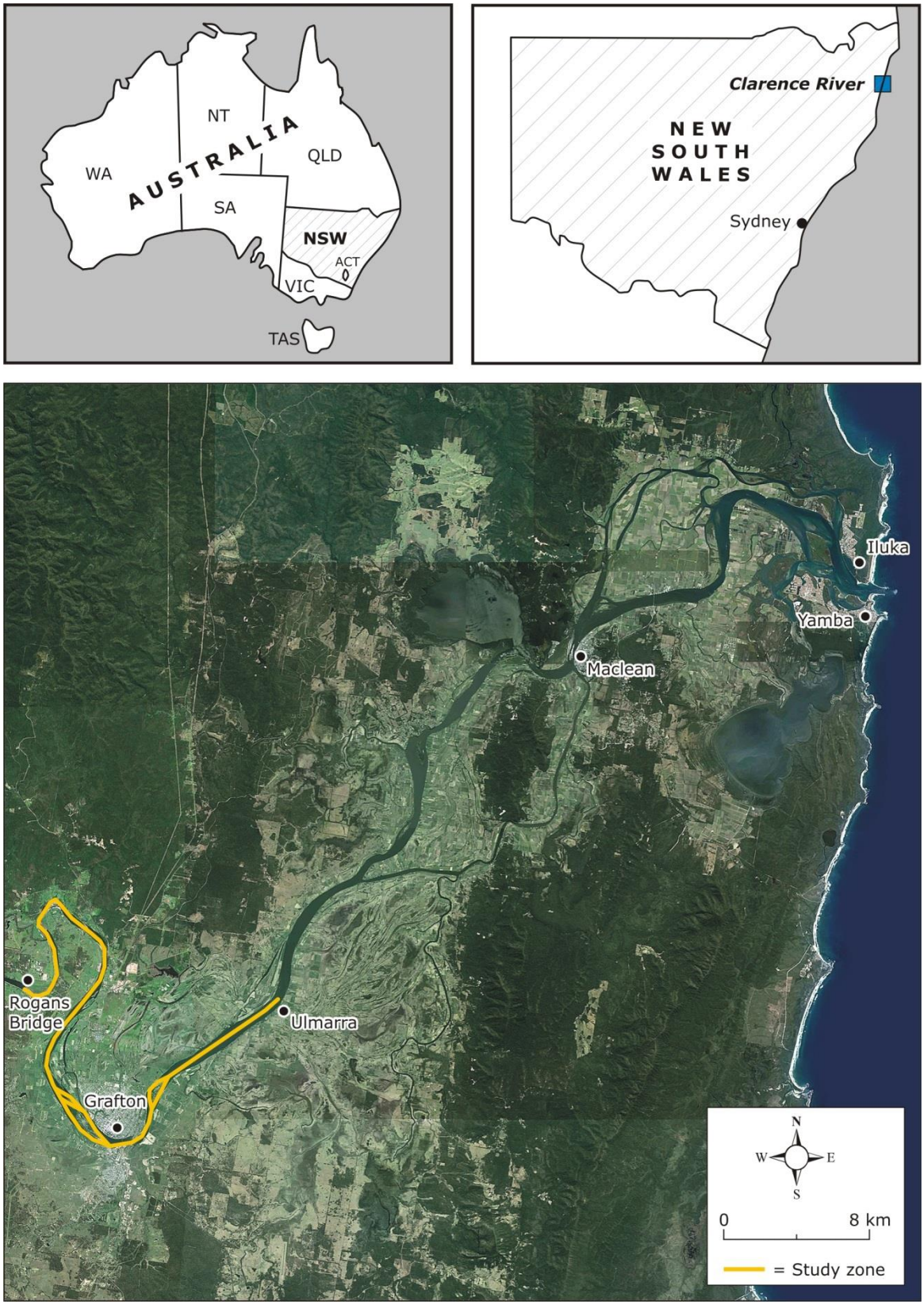

Figure 1-1: The Study Area

2. Assessment Methodology and Details

2.1 Preamble

This section discusses the specific aspects of the Decision Support System and the methodology followed to apply the DSS to the selected region of the Clarence River. Initially the site selection requirements are discussed (Section 2.2), followed by a detailed description of the field based riverbank assessment (Section 2.3). The wind data and locations used for assessment are presented (Section 2.4) along with the rationale behind the selection of boat numbers and conditions (Section 2.5). A full description of the DSS methodology is provided in Appendix C.

2.2 Site Selection

Sites were randomly selected within the study area using aerial photography and GIS mapping of the selected region of the Clarence River between Rogans Bridge and Ulmarra. The river was first segmented into the required stretches, approximately 500 m in length. Overall, a total of 84 stretches were identified for survey (Figure 2-1), which included Susan Island, Elizabeth Island and Peanut Island. Finally, within each stretch, three transects spaced along each bank (a total of 504 transects) were selected as per the DSS methodology (Appendix C).

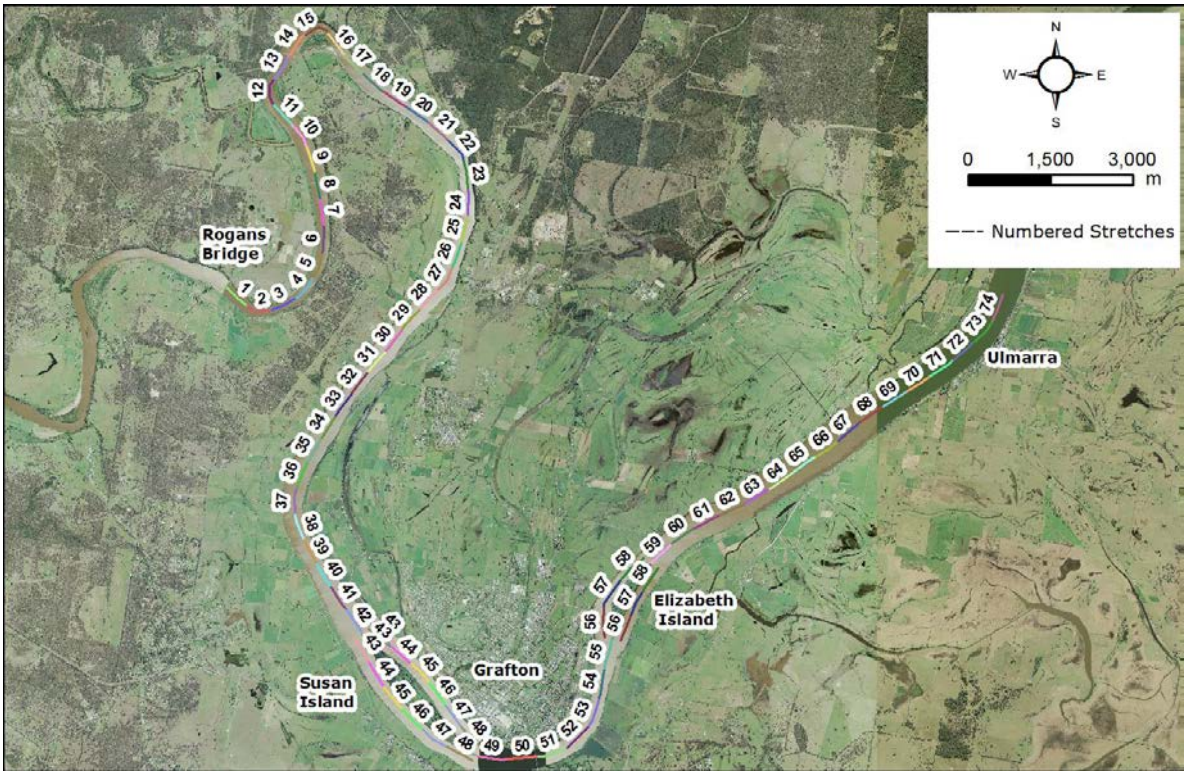

Figure 2-1: Numbered Stretches of the Clarence River

2.3 Riverbank Erosion on the Clarence River

2.3.1 Overview

The DSS incorporates a field assessment of riverbank erosion potential. Three transects on each bank of the 84 stretches were observed, totalling 504 site inspections. These sites were predetermined to eliminate bias and were identified in the field through a combination of aerial photography and GPS methods. NSW RMS provided a boat and a driver for each day of the field assessment.

Six days were allocated for the field assessment in two separate campaigns (4 - 7 April, 2014 and 7 – 8 May, 2014). 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 were selected to incorporate low tides during the middle of the assessment period. Water levels on the Clarence River are monitored at three locations (Figure 2-2): Rogans Bridge, Grafton (Prince Street) and Ulmarra by Manly Hydraulics Laboratory (MHL) on behalf of the NSW Office of Environment and Heritage (OEH). Figure 2-3 and Figure 2-4 display the water levels on the six survey days.

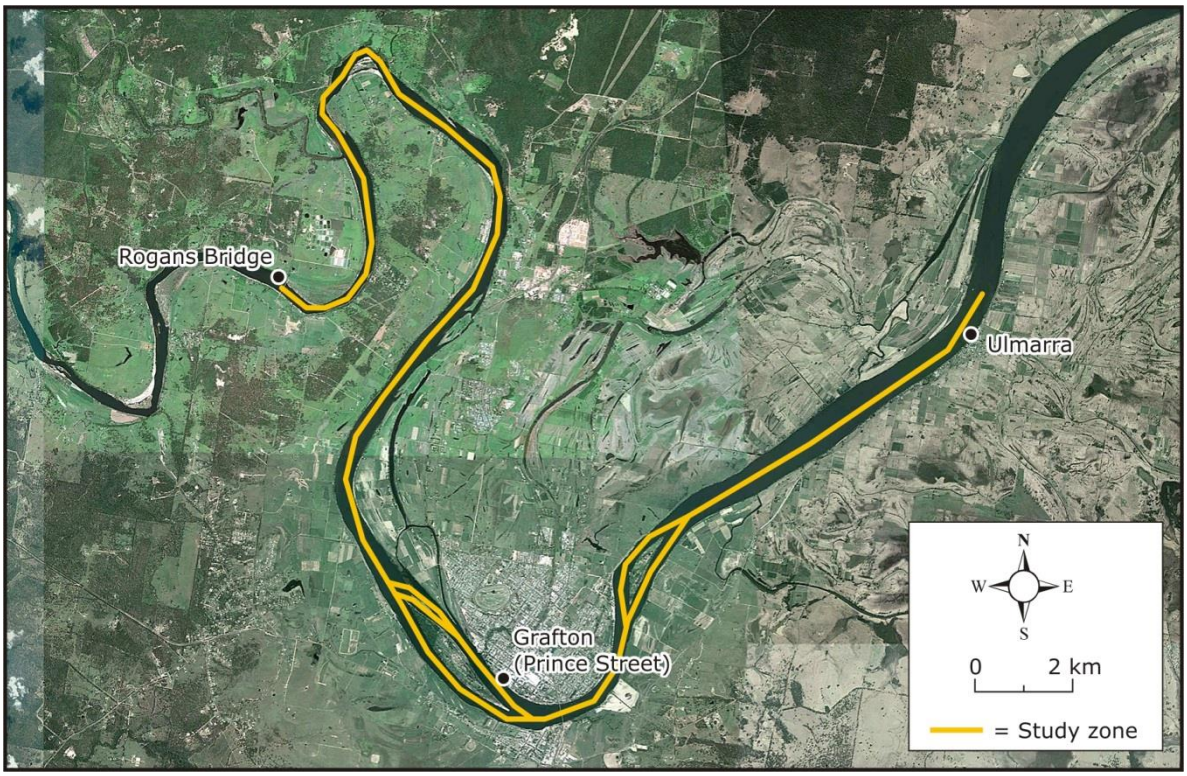

Figure 2-2: Location of Water Level Monitoring Stations

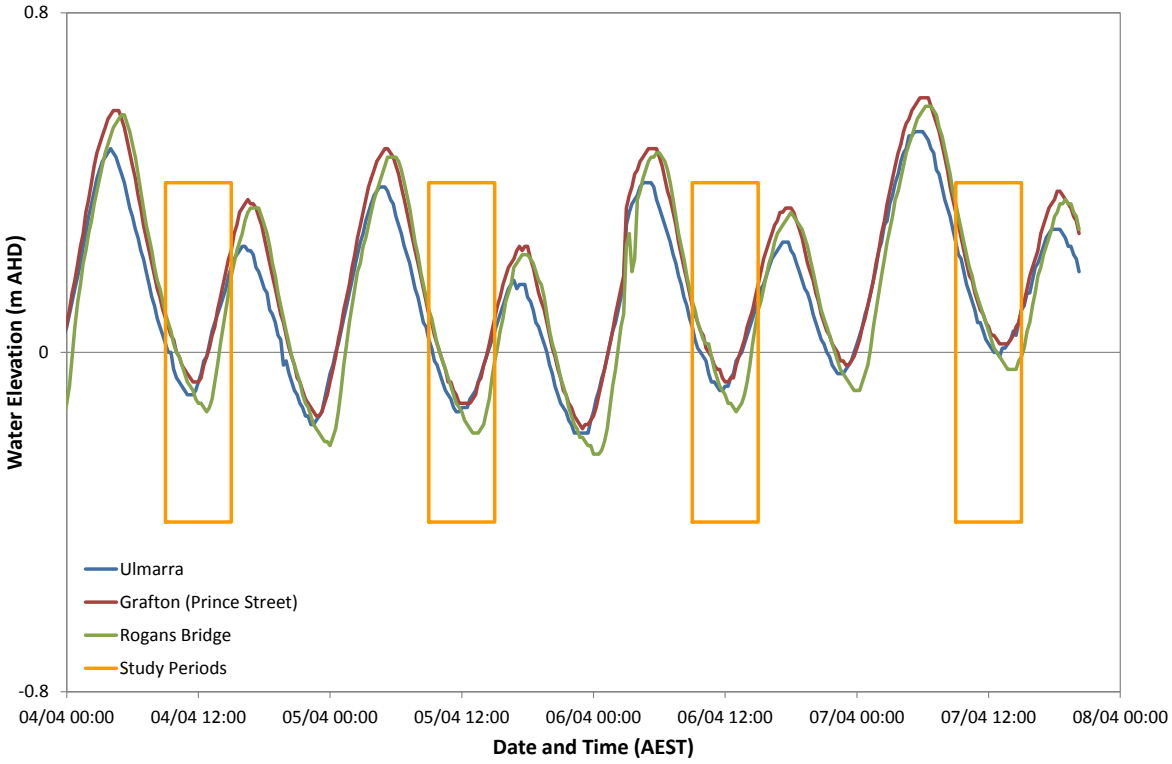

Figure 2-3: Water Levels on the Clarence during Field Campaign 1 of 2 (Source: MHL-OEH)

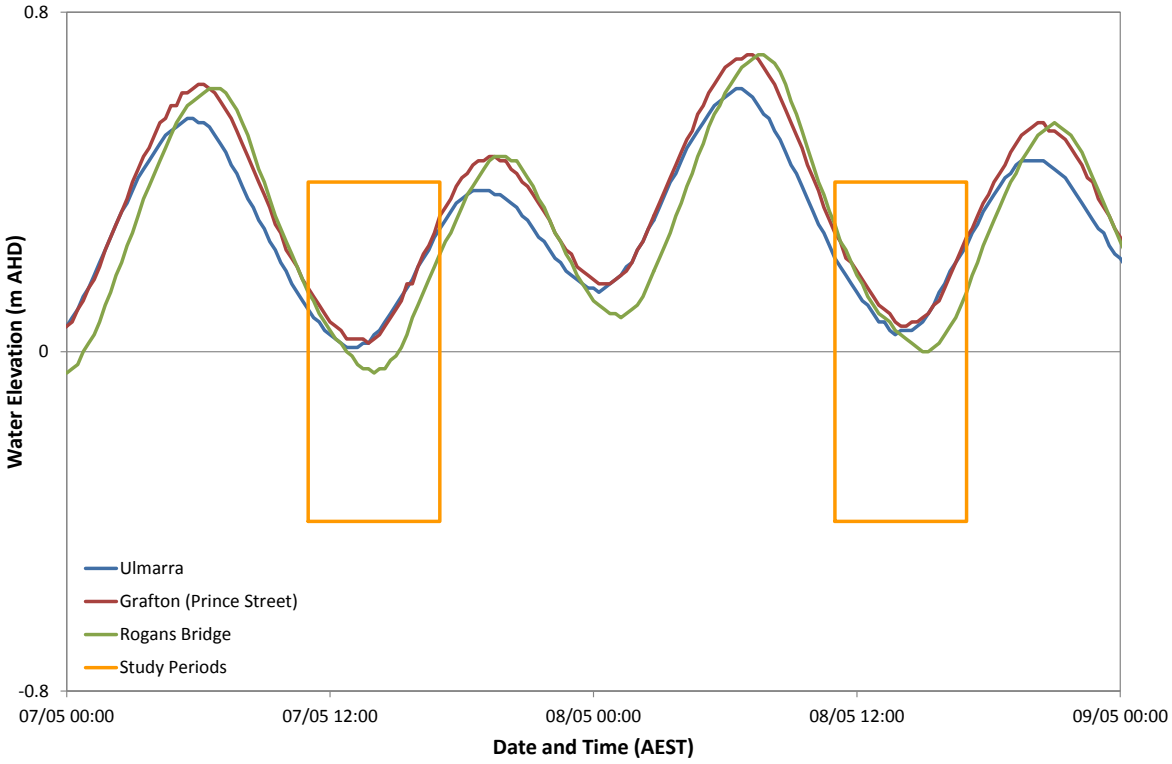

Figure 2-4: Water Levels on the Clarence during Field Campaign 2 of 2 (Source: MHL-OEH)

2.3.2 Site Identification and Erosion Indicators

A combination of aerial photography and GPS co-ordinates were used to locate each pre-selected transect in the field. Prior to the assessment, the exact transect extent was determined to ensure assessors were documenting the same riverbank locations. Two assessors completed the field work. An independent assessor was used to undertake several quality assurance checks to ensure the repeatability of the analysis. At each location a DSS field sheet was completed (see example DSS field sheet in Appendix G), a GPS waymark obtained and two photographs taken. The width of the river was measured with a laser rangefinder. Note that the erosion potential for each site is based only 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 any erosion observed.

Several erosion indicators were constant for the entire 37 km study area, including:

- Stage variability was recorded as 'tidal' due to the nature of the river;
- The lateral stability was recorded as 'high' for all stretches due to the lack of evidence of channel migration;
- Sinuosity (the channel length of the river divided by the valley length) was less than 1.3;
- CVC staff confirmed that no de-snagging had taken place in the river prior to the assessment; and
- Extensive sediment extraction in the study area (as discussed in Section 3.2.3).

2.4 Wind Waves on the Clarence River

2.4.1 Baseline DSS Assessment

An accurate representation of the wind climate is highly important for the DSS analysis. Ideally wind data would have been specifically collected for this study by deploying anemometers along the riverbanks between Rogans Bridge and Ulmarra. However, an initial decision was taken to sensitivity test the available wind data and determine if additional field measurements were required. In the absence of this data, Glamore and Badenhop (2006) recommend the use of local weather stations. Two weather stations exist in close proximity to the study area; one at the Grafton Olympic Pool (located 1 km NW of Grafton CBD) and another at the Grafton Research Station (located 8 km NNE of Grafton CBD). The weather station at the Grafton Olympic Pool has wind records available from 1 September 1966 to the present (48 years). However, wind speed and direction were only recorded twice daily (9 AM and 3 PM) up until 31 August 2012, and since this time are now recorded once daily (9 AM). The weather station at the Grafton Research Station has recorded wind data available every 30 minutes from 30 August 2002 up to the present (12 years of data). While the Grafton Olympic Pool dataset covers a longer period of time, WRL considers that its twice daily sampling frequency does not sufficiently characterise local wind effects. This is illustrated by concurrent plots of wind speed (Figure 2-5) and wind direction (Figure 2-6) from both local weather stations. On this basis, the dataset from the Grafton Research Station (Figure 2-7and Appendix F) was used to analyse for annual recurrence intervals and adopted as the preferred wind source for this study. No scaling adjustments were undertaken to simulate local wind conditions on the river for the baseline DSS assessment.

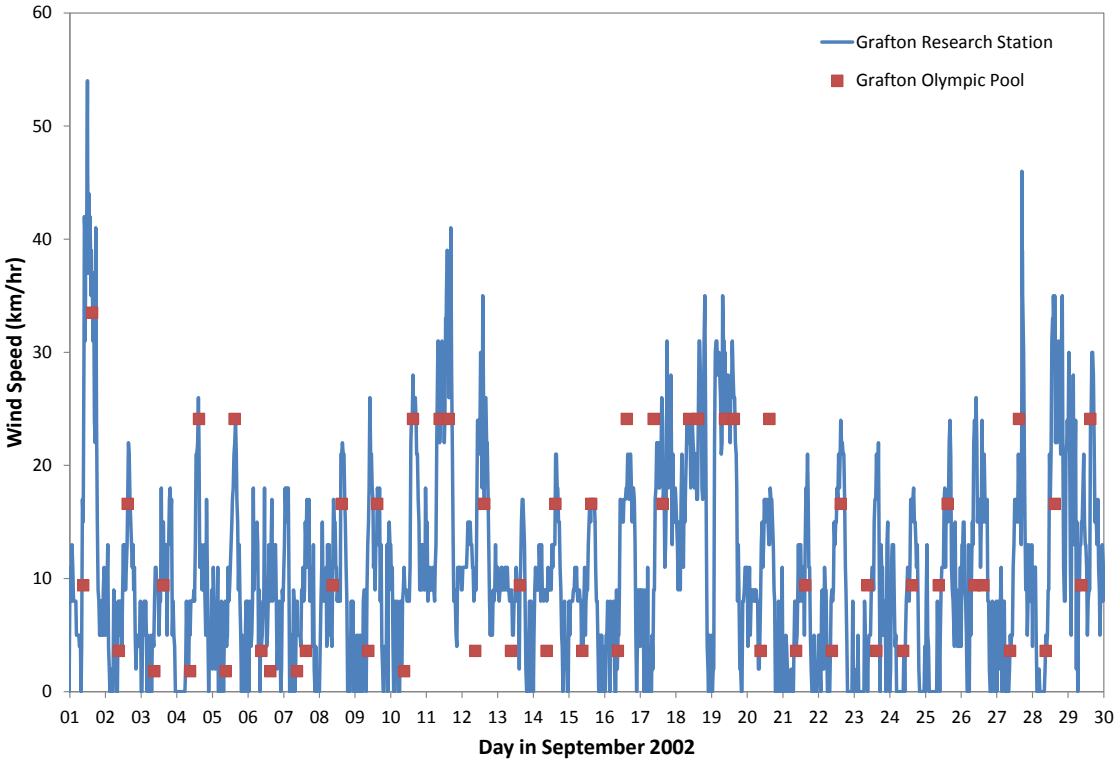

Figure 2-5: Comparison of Wind Speed: Grafton Olympic Pool and Grafton Research Station

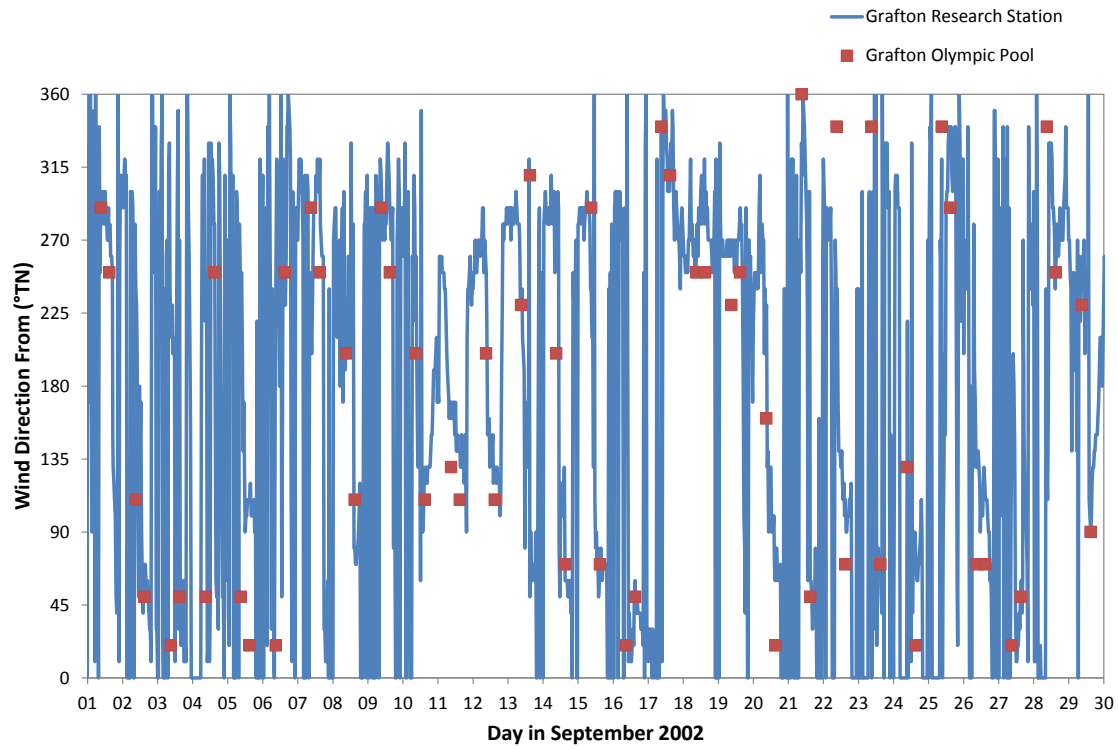

Figure 2-6: Comparison of Wind Direction: Grafton Olympic Pool and Grafton Research Station

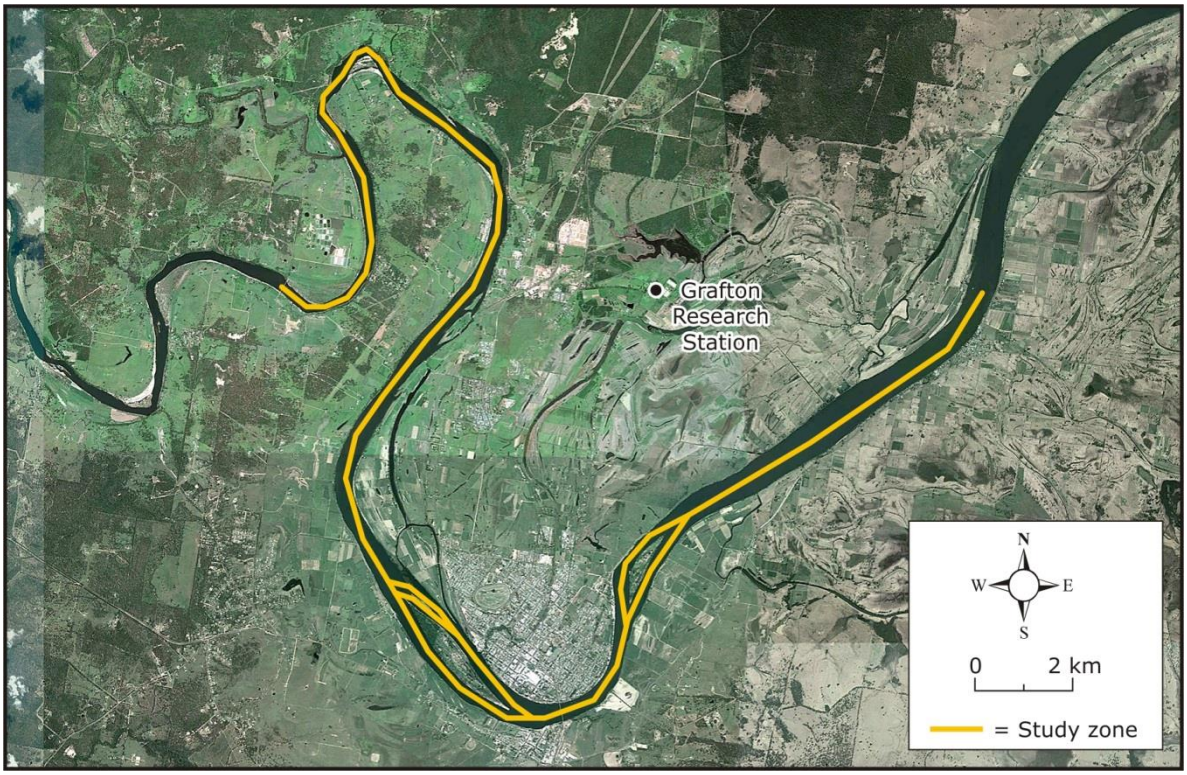

Figure 2-7: Location of the Wind Station with Respect to the Clarence River Study Area

As per the DSS methodology (Appendix C), fetch lengths for each stretch were determined using the centre of the 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.

2.4.2 DSS Sensitivity Test (Adjusted Local Wind Conditions)

Sensitivity tests were also undertaken to examine the assumption that winds at Grafton Research Station are a reasonable approximation of conditions within the study area (Rogans Bridge to Ulmarra). WRL re-assessed the wind wave energy with scaling factors developed to represent worst-case local wind conditions on the Clarence River. These scaling factors were developed by comparing the extreme wind speeds (10 minute) at Grafton Research Station with those set out in 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 2-1 using multipliers for direction (M_d), terrain ($M_{z,cat}$), shielding (M_s) and topography (M_t).

$$V_{sit} = V_R M_d \left(M_{z,cat} M_s M_t\right) \tag{2-1}$$

The Clarence River falls within Region B (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 all directions at Grafton Research Station and AS 1170.2 are presented in Figure 2-8. Since the shortest ARI given in AS 1170.2 is 1 year, WRL extrapolated the Australian Wind Standard for more frequent wind events for application in the DSS. Since the AS 1170.2 wind speeds are approximately 45% faster than at Grafton Research Station for ARI 1 to 12 years, the AS 1170.2 values were extrapolated by multiplying the Grafton Research Station winds speeds less than 1 year ARI by 1.45 (Figure 2-9).

Local wind directions over the Clarence River between Rogans Bridge and Ulmarra may be influenced by local topography. That is, the river valley may channel or funnel the wind on the river. To account for this possibility of wind channelling in the DSS sensitivity test, the extrapolated Australian Wind Standard speeds were applied along the longest fetch at each river stretch. In comparison with the baseline DSS assessment, these worst-case local wind conditions have the effect of increasing the natural wind wave energy acting on each stretch of the river.

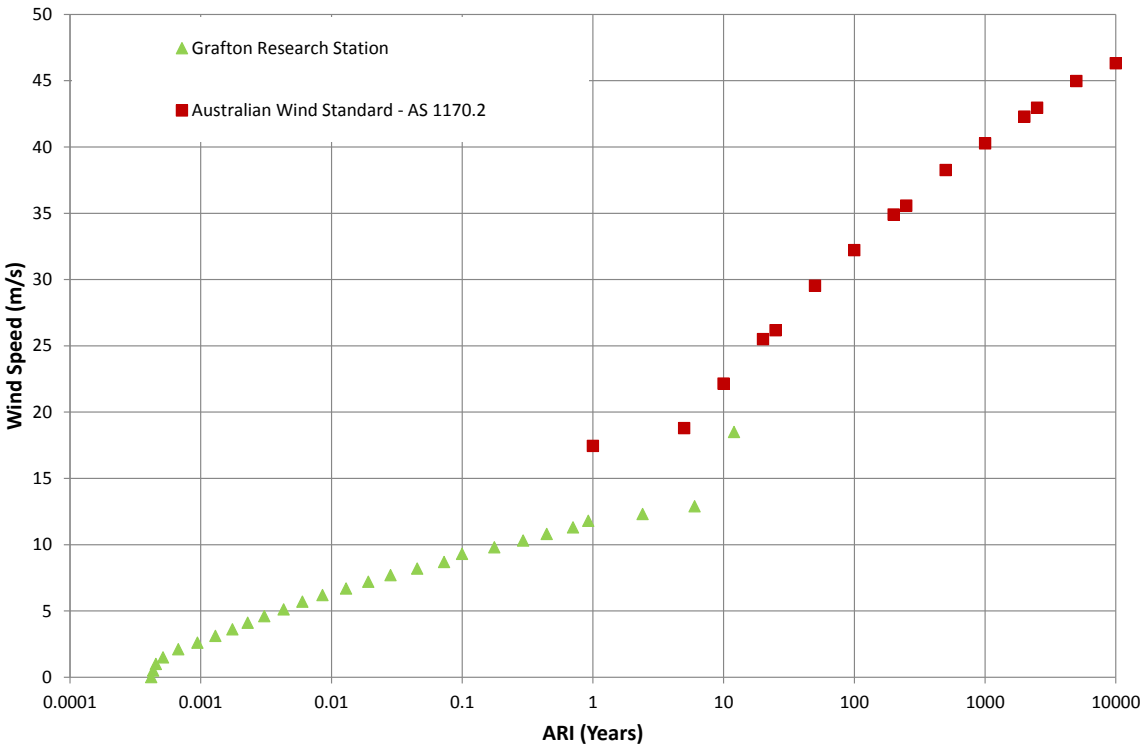

Figure 2-8: Sustained Wind Speeds (10 Minute) – All Directions – Grafton Research Station and AS 1170.2

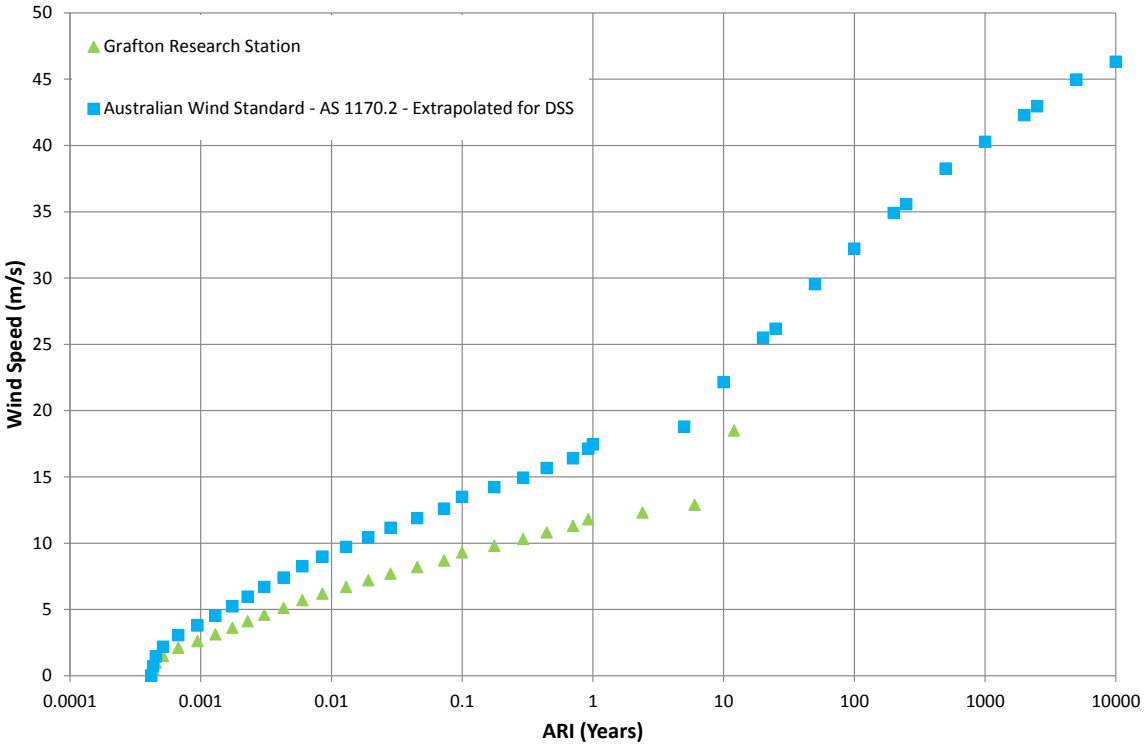

Figure 2-9: Sustained Wind Speeds (10 Minute) - All Directions – Grafton Research Station and AS 1170.2 (Extrapolated)

2.5 Wake Waves on the Clarence River

2.5.1 Preamble

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 Clarence River was limited.

2.5.2 Previous Literature

The Clarence River is a popular destination for many river based boating festivals that take place each year, including the Bridge to Bridge Ski Race and Pro Wakeboard Championships. The Bridge to Bridge Ski Race, held in October each year, between the Crown Hotel in Grafton and Harwood Bridge (and return) includes a total distance of 108 km along the Clarence River. Clarence Tourism (2014) estimated over 900 entries over the weekend (two-days) in 2013. However, Clarence Tourism (2014) provides limited information on the number of competition and/or recreational boats, their size and the number of hours of activity during the event weekend. Based on discussions with NSW RMS, WRL understands that approximately 25-50 competition boats are used to tow skiers repeatedly in successive heats over the weekend.

In recent years, events such as the Pro Wakeboard Summer Series Championships have been hosted on the Clarence River by Pro Wake Australia and the Big River Holiday Park and Ski Lodge in Grafton. The Daily Examiner (2012) estimated more than 40 competitors took part in

the 2012 round on the Clarence River. Detailed information about the boating activity during the event is unavailable. However, WRL understands that the Big River Holiday Park and Ski Lodge has the capacity to lodge more than 110 boats and trailers.

A comprehensive overview of moorings in the North Coast Region is summarised in Table 2-1 (NSW RMS, 2014). This data shows that currently there are 147 private moorings, with 40 applications for moorings across the Clarence Valley.

Table 2-1: NSW Maritime Moorings Across the Clarence Valley (Source: NSW RMS, 2014)

Bay Name	Total No. of Applicants	Date Last Mooring Allocated	No. of Private Moorings
Oyster Channel	0	28/01/2014	5
Maclean	1	8/08/2013	10
Ulmarra	0	20/05/2011	1
Brushgrove	0	19/05/2014	1
Clarence River	0	21/03/2013	15
Wooli River	0	-	0
Yamba Bay	13	19/08/2013	19
Yamba West	14	5/10/2012	18
Iluka Bay	8	7/02/2014	43
Sandon River	0	10/08/1995	0
Crystal Waters	4	3/04/2014	18
Grafton	0	6/12/2013	17
TOTAL	40	-	147

2.5.3 Adopted Wake Waves

While the data outlined in the previous section provides broad information about boat use between Rogans Bridge and Ulmarra, detailed boat counts are unavailable. Specifically, the activity of moored and berthed vessels is unknown, as is the number and activity of vessels stored off-river and deployed from boat ramps. In the absence of this information, WRL has developed a range of daily boat pass numbers estimated for the waterway. These boat pass numbers are based on WRL's experience on the Clarence River, discussions with NSW RMS based on their regular patrol observations and results from detailed boat pass surveys from similar rivers (Table 2-2). 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 water skiing). 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.

Table 2-2: Adopted Daily Boat Passes for All Boat Activities

Boat/Activity	Wave Type	No. Boat Passes (-)	Duration (hours)
Wakeboard	Operating	10	8
Waterski		150	
Wakesurf		300	

A series of boat pass sensitivity tests was undertaken with a second set of higher boat pass numbers likely to occur on public and school holidays and during competitions (Table 2-3). For these high boat passes, a duration of twelve hours has been used as it is estimated this would only take place in summer when daylight hours are maximised. Note that sensitivity tests were not undertaken for wakesurf "operating conditions" and were only included in the baseline DSS assessment on a preliminary basis (see Appendix D).

"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 water skiing) travel at "operating conditions", but rather at the slower velocity of approximately 8 knots. This velocity is related to typical vessel length and is predicted by the length based Froude-number discussed in Appendix B. These conditions are experienced when a boat is accelerating, or slowing down from operational speed.

Table 2-3: Adopted Daily Boat Passes for High Boat Passes

Boat/Activity	Wave Type	No. Boat Passes (-)	Duration (hours)
Wakeboard	Maximum	150	8
Wakeboard	Operating	500	12
Wakeboard	Operating	1,000	12
Waterski	Maximum	150	8
Waterski	Operating	500	12
Waterski	Operating	1,000	12

3. Decision Support System Results

3.1 Preamble

This section summarises the results produced by the DSS for the assessment of the Clarence River. The erosion potential of the riverbanks is discussed in Section 3.2. Annotated images providing examples of the different erosive states are provided in Appendix H. Section 3.3 presents the equivalent average recurrence interval (ARI) ratings for each boat pass scenario. The management recommendations from the DSS, for both the mid – low tide baseline assessment and the sensitivity tests are then presented in Section 3.4.

3.2 Riverbank Erosion Potential Assessment

3.2.1 Outcomes

The riverbank assessment was conducted at mid – low tide and high tide to accurately observe the wave zone. During the field assessment it was noted that the erosion potential may be slightly reduced when conducted at the top of high tide. For these cases, 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 3-1 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.

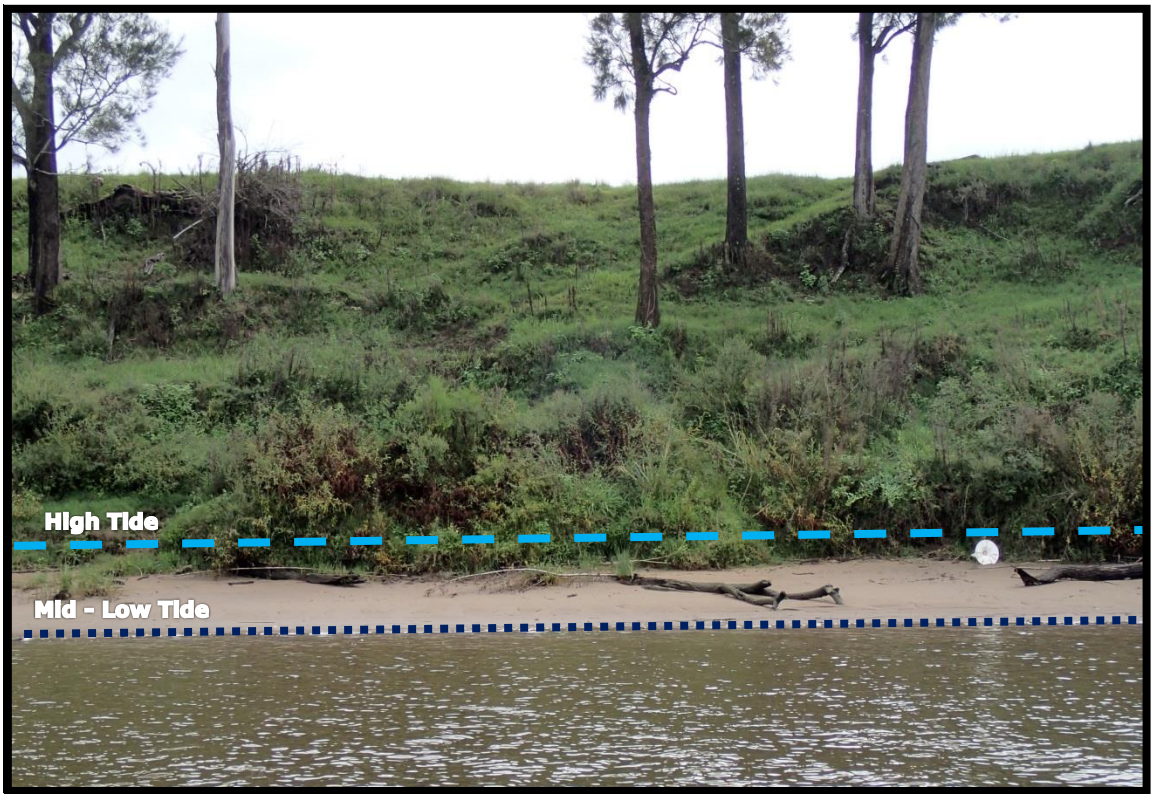

Figure 3-1: Effect of Water Level on Erosion Potential Assessment

Table 3-1 and Table 3-2, and Figure 3-2 and Figure 3-3, display the distribution of the erosion potential categories across the entire study area for mid - low tide and high tide conditions, respectively. All five erosion potential categories in the DSS were observed at transects in the

study area of the Clarence River. The 504 transects documented were averaged for the left and right bank of each stretch to produce a representative erosion potential for each bank of the stretches. Annotated field photos for each observed erosion potential category are provided in Appendix H. Note that the erosion potential for each site was based only 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 any erosion observed.

A comparison between the mid – low tide and high tide assessments highlights minimal difference between the number of occurrences for each erosion potential category. At mid – low tide and high tide, approximately 75 percent 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 123 occurrences at mid – low tide to 117 occurrences at high tide, following a reduction of approximately 3 percent in the 'highly erosive' category. Overall, the majority of the study region is considered resilient to wave attack throughout the tidal range.

Table 3-1: Erosion Potential of the Clarence River Study Area (Mid – Low Tide Conditions)

Erosion Potential (Mid – Low Tide Conditions)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	159	43
Moderately Resistant	106	46
Mildly Resistant	116	46
Moderately Erosive	79	24
Highly Erosive	44	9
Total	**504**	**168**

Table 3-2: Erosion Potential of the Clarence River Study Area (High Tide Conditions)

Erosion Potential (High Tide Conditions)	Number of Occurrences (Individual Transects)	Number of Occurrences (Bank Stretch Average)
Highly Resistant	160	41
Moderately Resistant	120	50
Mildly Resistant	107	47
Moderately Erosive	87	26
Highly Erosive	30	4
Total	**504**	**168**

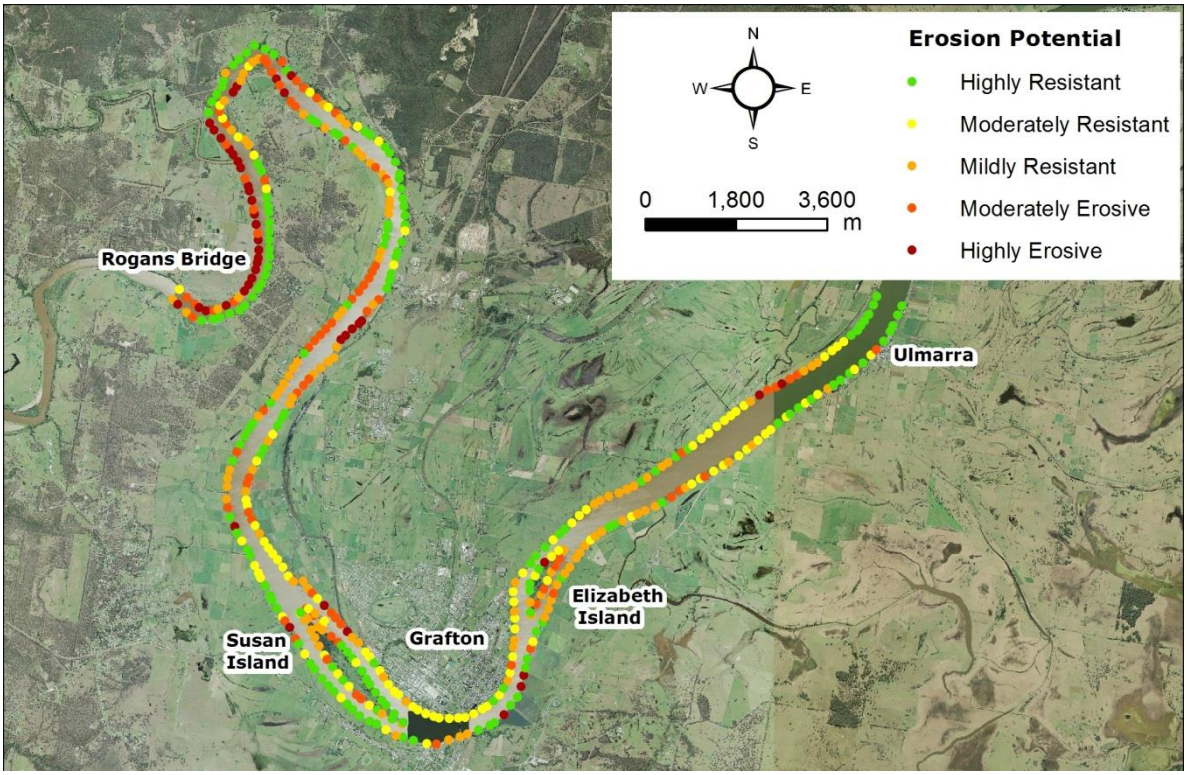

Figure 3-2: Erosion Potential for Each Transect (Mid - Low Tide Conditions)

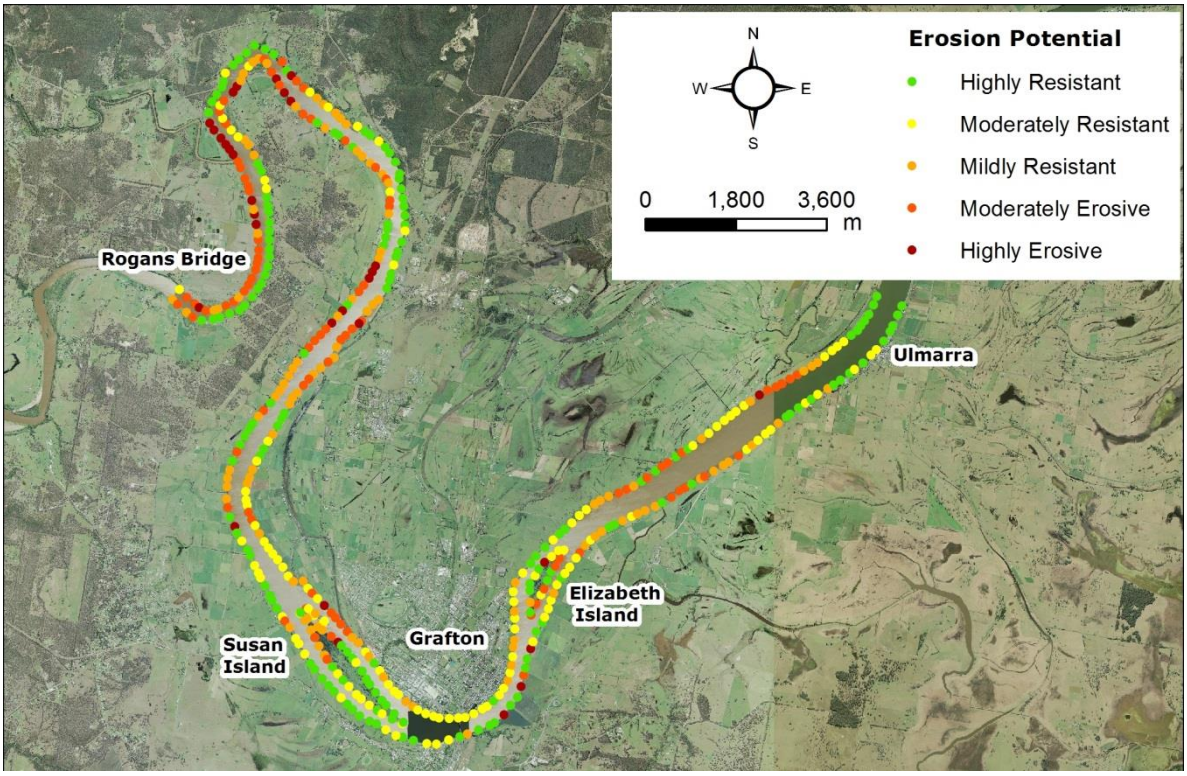

Figure 3-3: Erosion Potential for Each Transect (High Tide Conditions)

Armouring of the riverbank is a major influencing factor in the assessment of riverbank erosion potential. Substantial reaches of the study area are naturally armoured by large rock ledges or cliffs (Figure 3-4 and Figure 3-5), while other reaches have been artificially armoured (Figure 3-6 and Figure 3-7). This armouring, whether it be natural or artificial, generally provides erosion potential ratings of 'Highly Resistant'.

Figure 3-4: Rock Cliffs (Stretch R6)

Figure 3-5: Significant Bedrock Protecting River Banks from Erosion (Stretch L13)

Figure 3-6: Armouring at Transects R25C and R73C

Figure 3-7: Armouring at Transects L63A and L63B

A range of factors influence the lower erosion potential scores (or higher ratings) observed in the DSS assessment of the Clarence River. Many reaches are bounded by alluvial floodplains on one or both sides. These floodplains were typically observed to be open farmlands cleared of native riparian vegetation (Figure 3-8). At many sites there was also obvious uncontrolled stock access to the riverbanks (Figure 3-9 and Figure 3-10). The combination of these factors increases the risk of bank destabilisation including erosion, slumping and undercutting (Figure 3-11 and Figure 3-12). All three indicators were observed along the study area and, as such, these sites scored higher erosion potential ratings.

Figure 3-8: Erosion on Upper Bank Above Completely Armoured Wave Zone

Figure 3-9: Stock Present on the Riverbanks

Figure 3-10: Stock Present on the Riverbanks (Stretch L4)

Figure 3-11: Significant Erosion, Slumping and Undercutting of Riverbanks where Stock Access is Present at Stretch L5

Figure 3-12: Significant Undercutting of Riverbanks with Stock Access Present at Stretches R54A and R63B

3.2.2 Influence of Riverine Geomorphology

In addition to the site specific erosion potential, consideration was given to natural processes such as riverine geomorphology. As such, to incorporate the complexities associated with riverine geomorphology along the study region, each stretch of river was assigned one of three geomorphic zones: inside bank, outside bank or straight. Figure 3-13 displays the classifications for comparison with the DSS erosion potential values provided in Figure 3-2 and Figure 3-3. There is no obvious correlation between these geomorphic zones and the erosion potential values, confirming there are additional factors to consider in riverbank assessment other than just the riverine geomorphology. However, in Section 4.3.1, it was noted that sites rated as 'Manage' were generally located on the upstream or downstream toe of an inside bend.

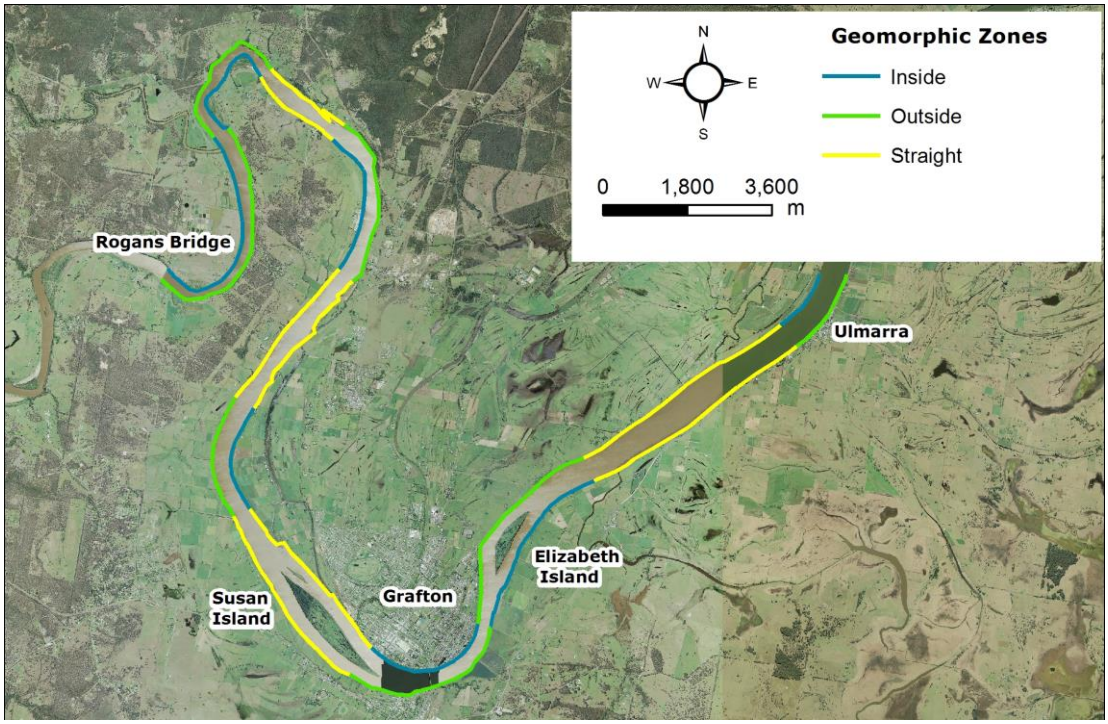

Figure 3-13: Geomorphic Zones along the Clarence River Study Area

3.2.3 Influence of Sediment Extraction

The extraction of sediment from the river channel may change the hydraulics of a river leading to instability. For this reason, the removal of sediment through dredging may be important in the riverbank vulnerability assessment. Within the erosion potential assessment in the DSS, sediment extraction is scored on a simple presence/absence basis.

NSW Department of Trade and Investment (T&I) - Crown Lands Division has issued three extractive industry licenses for five different zones within the Clarence River study area (Figure 3-14). While there are no set extraction limits for these licenses, Table 3-3 shows the mass of material extracted in the 12 months to 31 January 2014 (NSW T&I, 2014). Figure 3-15 shows a photograph of this extractive industry equipment operating on the Clarence Driver during WRL's field assessment.

Table 3-3: Mass of Material Extracted from Clarence River Licensed Areas: 01/02/2013 to 31/01/2014

Licence Area	Mass Extracted (t)
191451	42,592
191452	54,572
191453	12,841
Total	110,004

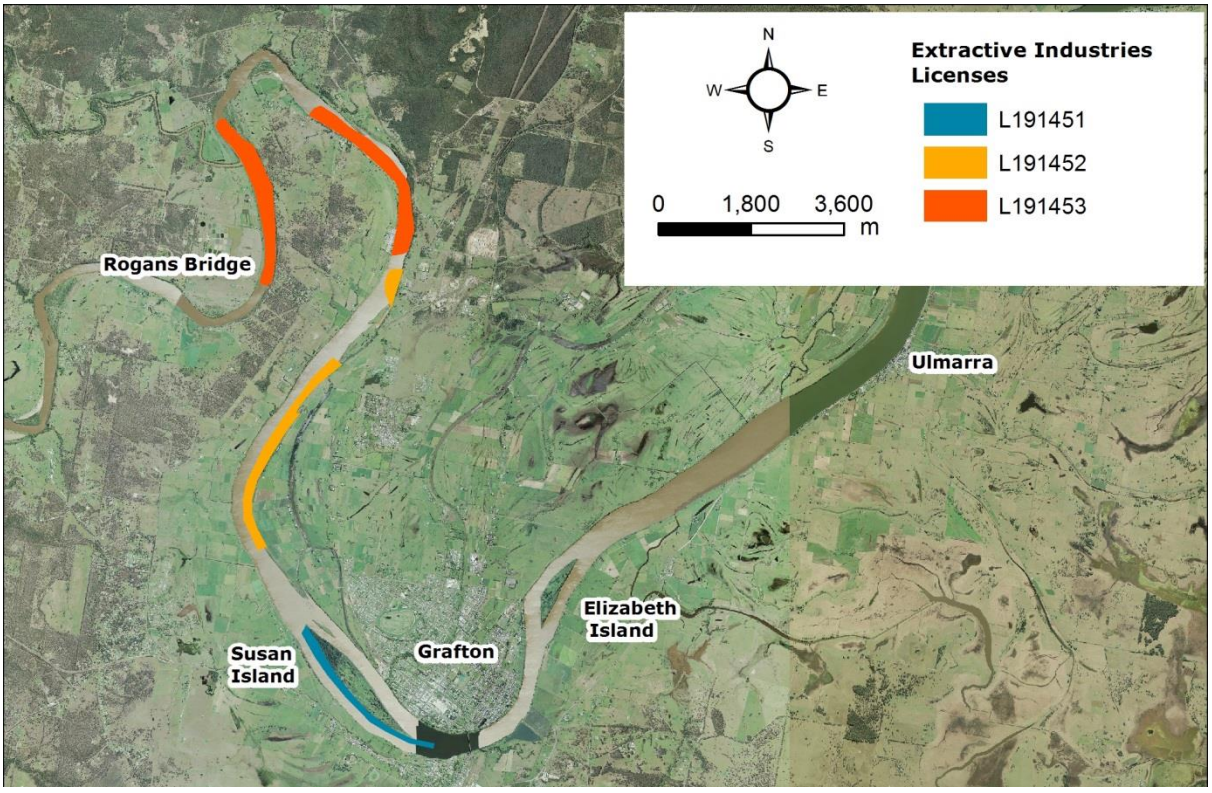

Figure 3-14: Extraction Industries Licensed Zones

Figure 3-15: Extractive Industry Equipment Operating within the Clarence River Study Area

While the extractive industry licenses do not cover the whole Clarence River study area from Rogans Bridge to Ulmarra, WRL conservatively assumed that sediment extraction was present in the erosion potential assessments for every transect. This was made on the basis that the effects of sediment extraction are not confined within the licensed areas. However, it was outside the scope of this study to estimate the extent of the riverbanks within the study area impacted by extractive industry.

It is recommended that RVAWG encourage NSW Crown Lands to investigate the extent of extractive industry activities within the Clarence River. To support this, bathymetric measurements should be taken both within the licensed areas and immediately upstream and downstream of the licensed areas at regular time intervals.

3.3 Equivalent Average Recurrence Interval (ARI)

The wind frequency data was applied to fetch lengths for all stretches of the Clarence River (measured in the centre of each stretch) to determine the average recurrence interval 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 for each location. This section presents the number and distribution of each occurrence interval for the different boat pass scenarios. A total of 168 ratings were produced, one for each riverbank for the 84 study stretches. Appendix I provides an applied example of the comparison between the wind and the wake wave data.

Table 3-4 and Table 3-5 provide a breakdown of the different ARI ratings for the twelve total boat pass scenarios, applying wakeboard and waterski 'operating' conditions for five different boat passes, and the 'maximum wave' condition as produced for 150 boat passes for both vessel types. Table 3-6 provides the number of stretches in equivalent ARI ratings for wakesurf 'operating' conditions for three baseline boat pass scenarios. Figure 3-16 to Figure 3-24 display the distribution of the different ARI ratings along the study region for the 10, 150 and 300 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. The most observed rating is the 'B' category for all wakeboard scenarios. For waterski operating conditions, the most observed rating is the 'A' category. For wakesurf operating conditions, the most observed rating is the 'B' category.-

Table 3-4: Number of Stretches in Equivalent ARI Ratings for Each Wakeboard Boat Pass Scenario

Equivalent ARI Category	Operating Conditions					Maximum Wave
	10 Passes	150 Passes	300 Passes	500 Passes	1,000 Passes	150 Passes
A	17	17	17	17	17	0
B	151	137	104	96	52	119
C	0	11	30	32	39	32
D	0	1	13	16	29	12
E	0	2	4	7	31	5

Table 3-5: Number of Stretches in Equivalent ARI Ratings for Each Waterski Boat Pass Scenario

Equivalent ARI Category	Operating Conditions					Maximum Wave
	10 Passes	150 Passes	300 Passes	500 Passes	1,000 Passes	150 Passes
A	90	90	90	90	90	1
B	78	77	72	70	53	120
C	0	1	5	7	16	30
D	0	0	0	0	7	13
E	0	0	1	1	2	4

Table 3-6: Number of Stretches in Equivalent ARI Ratings for Each Wakesurf Boat Pass Scenario

Equivalent ARI Category	Operating Conditions		
	10 Passes	150 Passes	300 Passes
A	0	0	0
B	168	113	67
C	0	34	43
D	0	15	29
E	0	6	29

As expected, with increasing boat numbers on the river, the equivalent ARI for the stretches typically becomes larger. For wakeboarding vessels, all boat pass scenarios except 10 passes result in observed ratings in the 'D' and 'E' ARI categories. The highest number of observations in the 'E' category was recorded for 1,000 boat passes. 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, 150 and 300 boat pass scenarios. The 'maximum wave' condition is the same for both wakeboard and waterski vessels and is approximately equivalent to 300 boat passes for the wakeboard operating condition.

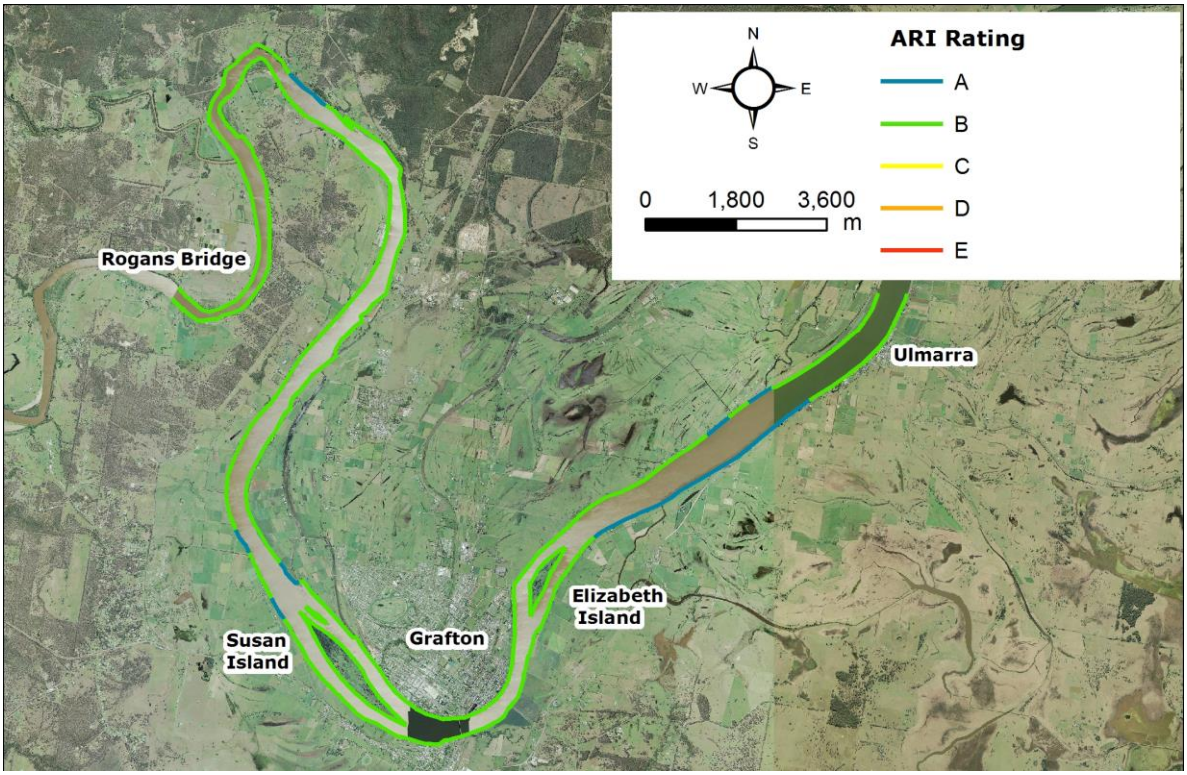

Figure 3-16: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakeboard Operating – 8 hour Duration - 10 Boat Passes

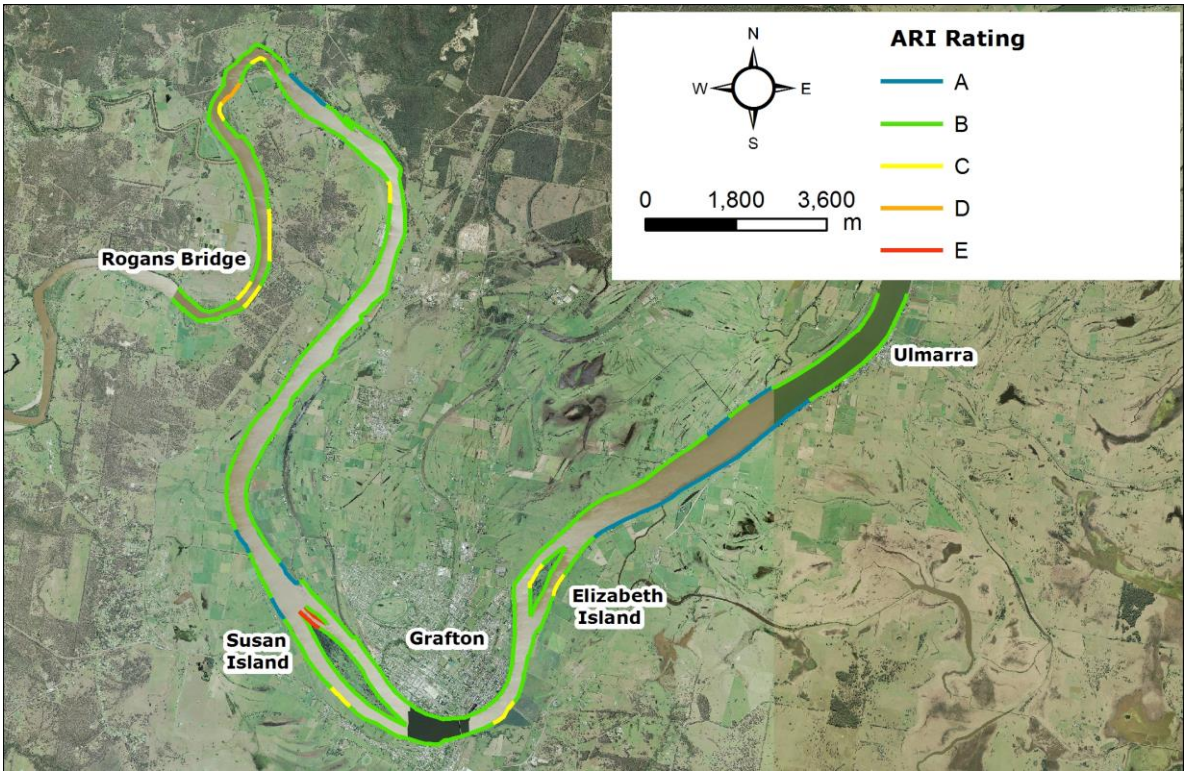

Figure 3-17: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakeboard Operating - 8 hour Duration - 150 Boat Passes

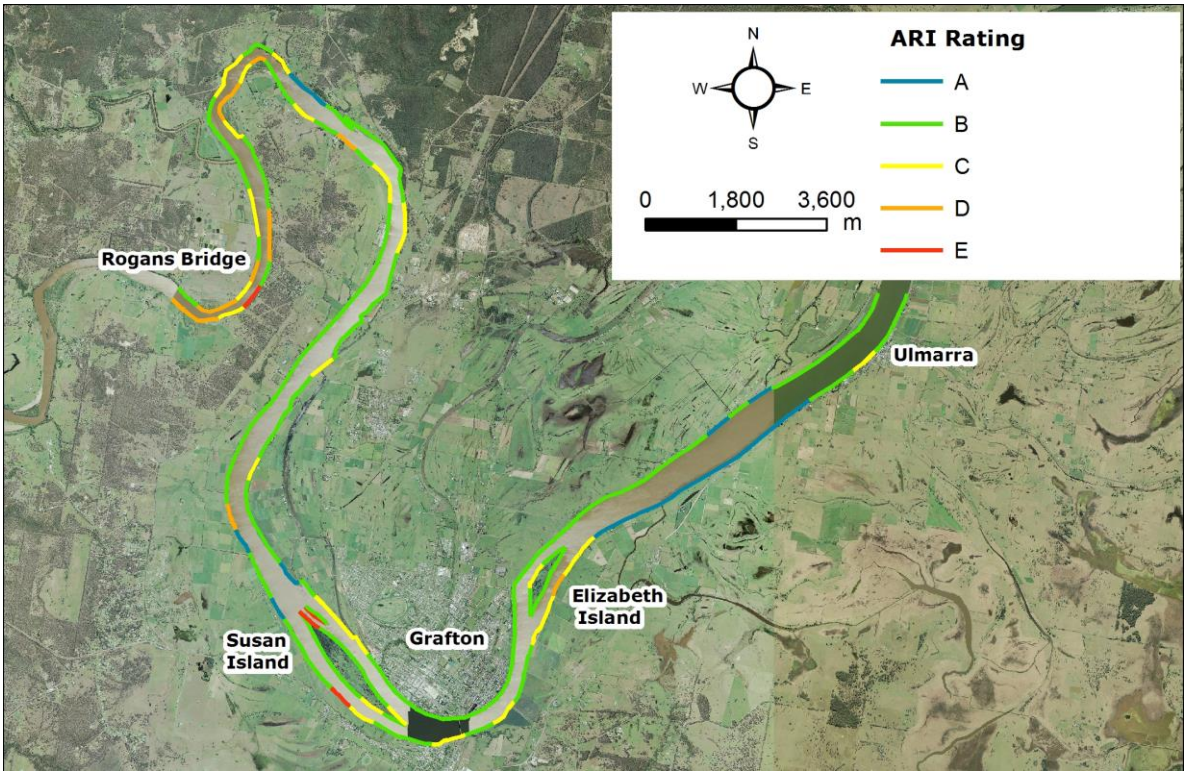

Figure 3-18: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakeboard Operating - 8 hour Duration - 300 Boat Passes

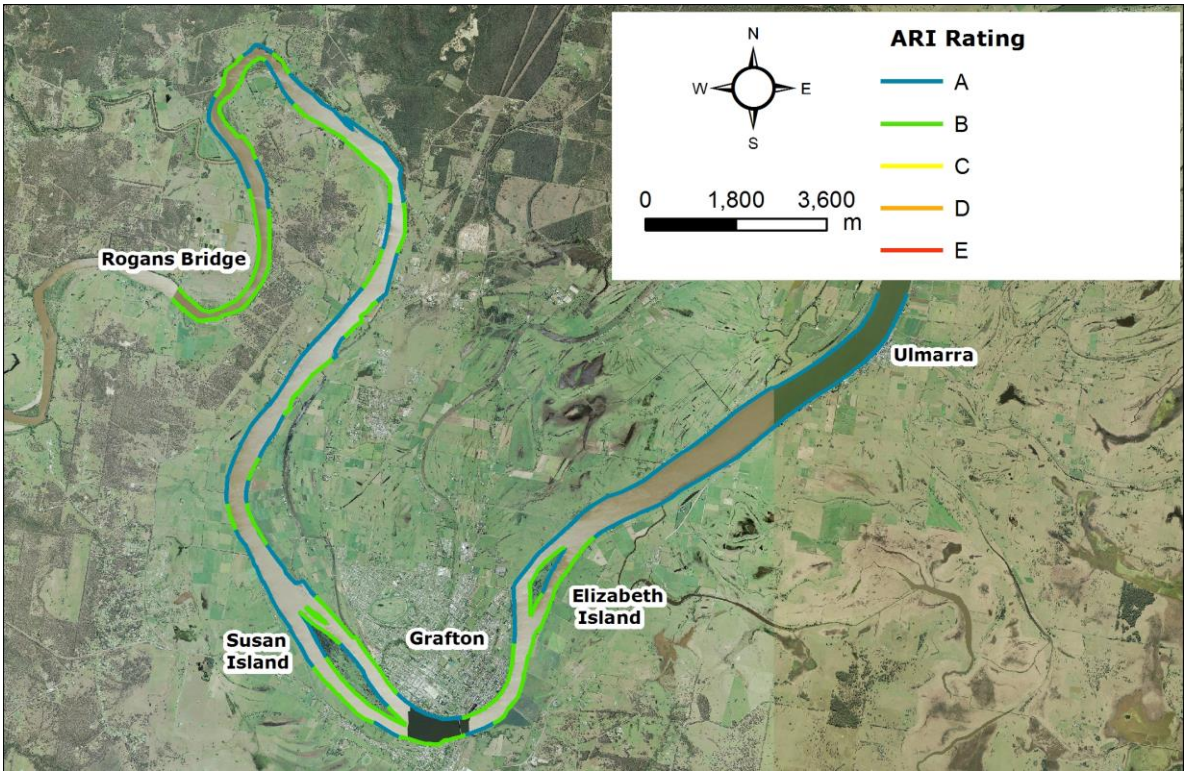

Figure 3-19: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Waterski Operating – 8 hour Duration - 10 Boat Passes

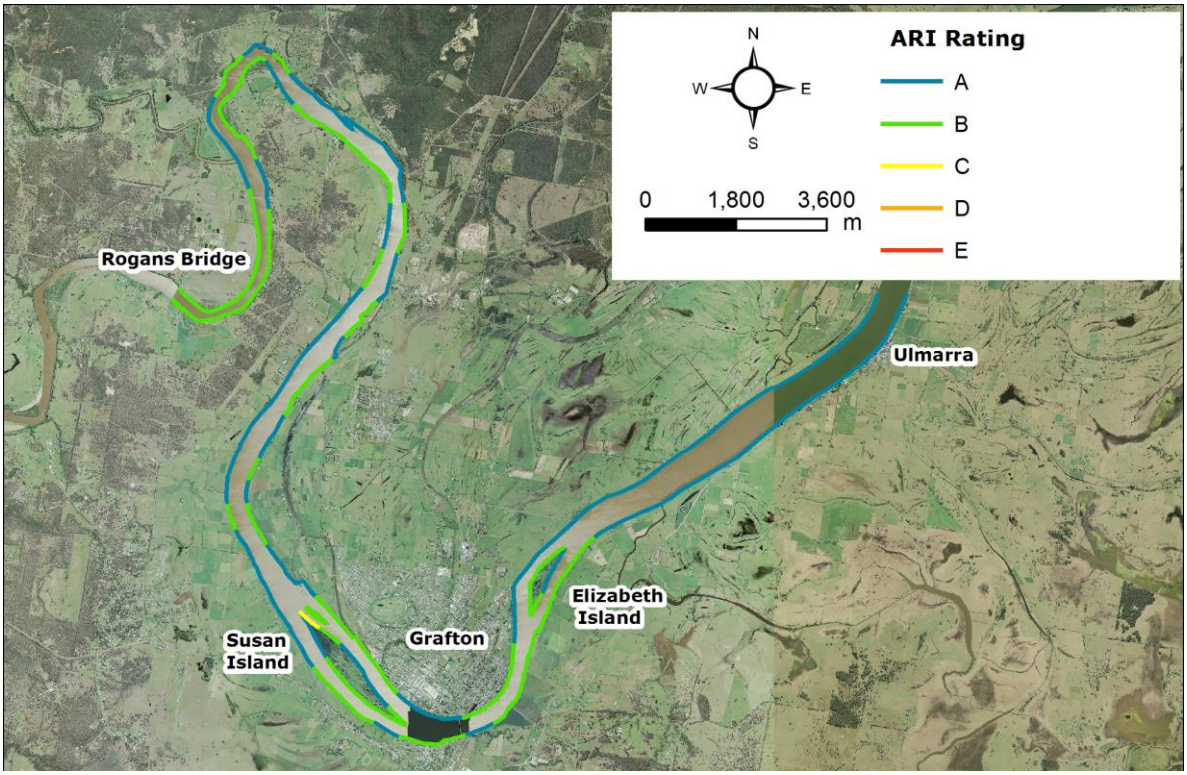

Figure 3-20: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Waterski Operating – 8 hour Duration - 150 Boat Passes

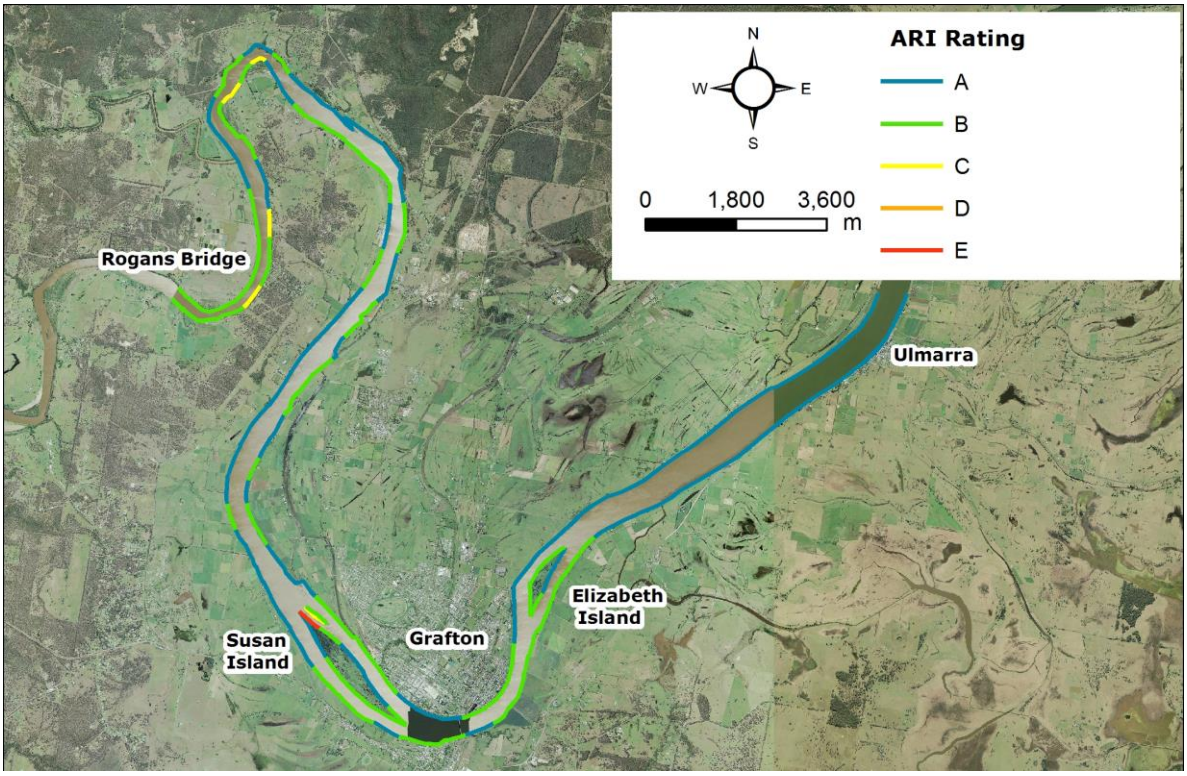

Figure 3-21: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Waterski Operating – 8 hour Duration - 300 Boat Passes

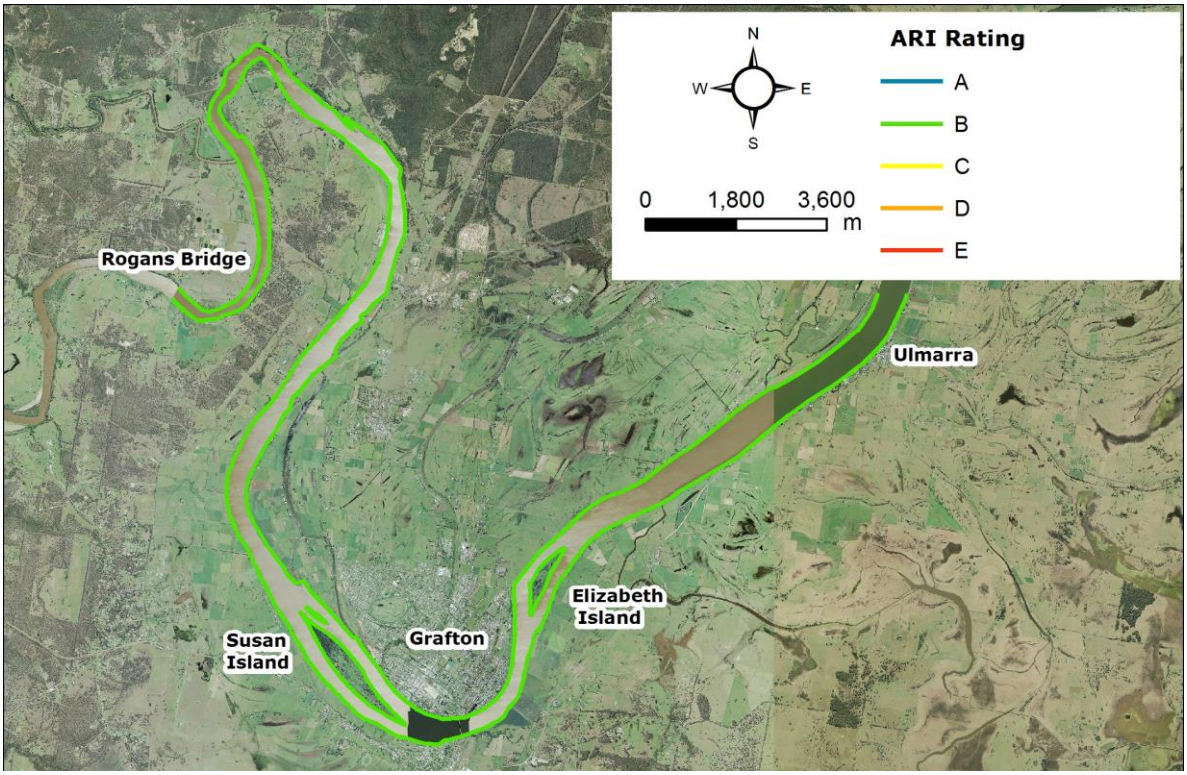

Figure 3-22: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakesurf Operating – 8 hour Duration - 10 Boat Passes

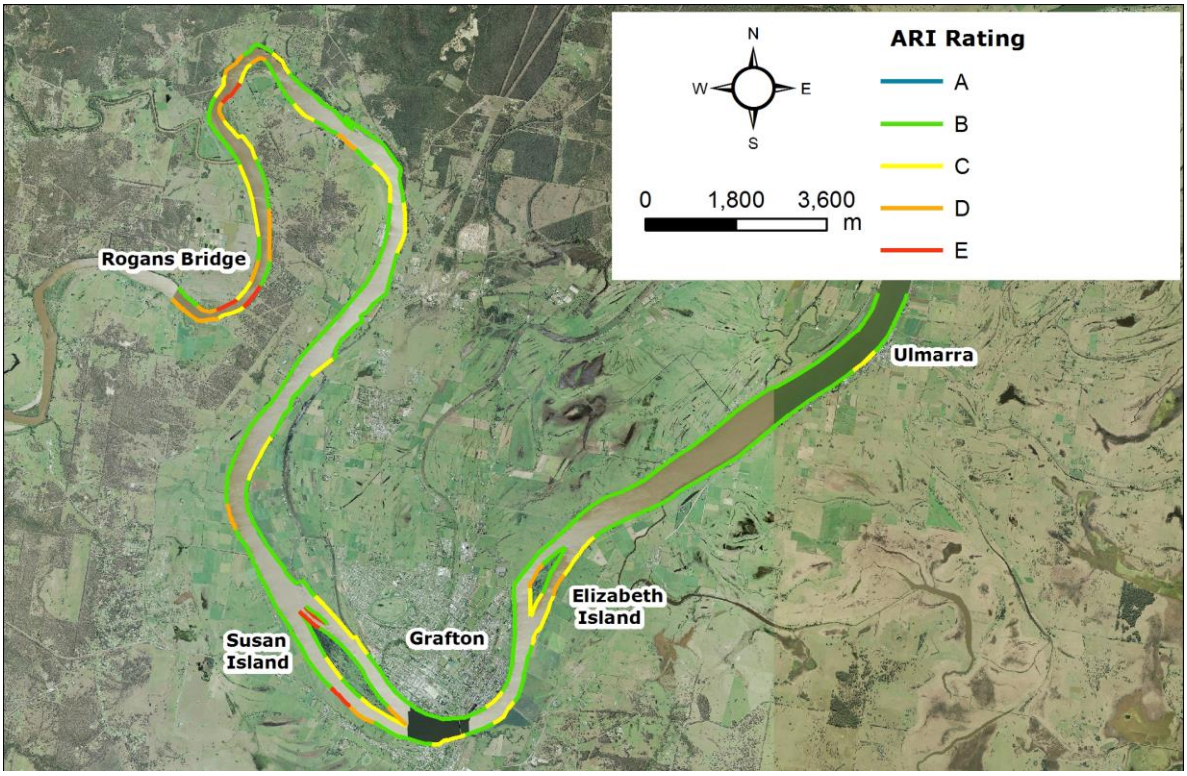

Figure 3-23: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakesurf Operating – 8 hour Duration - 150 Boat Passes

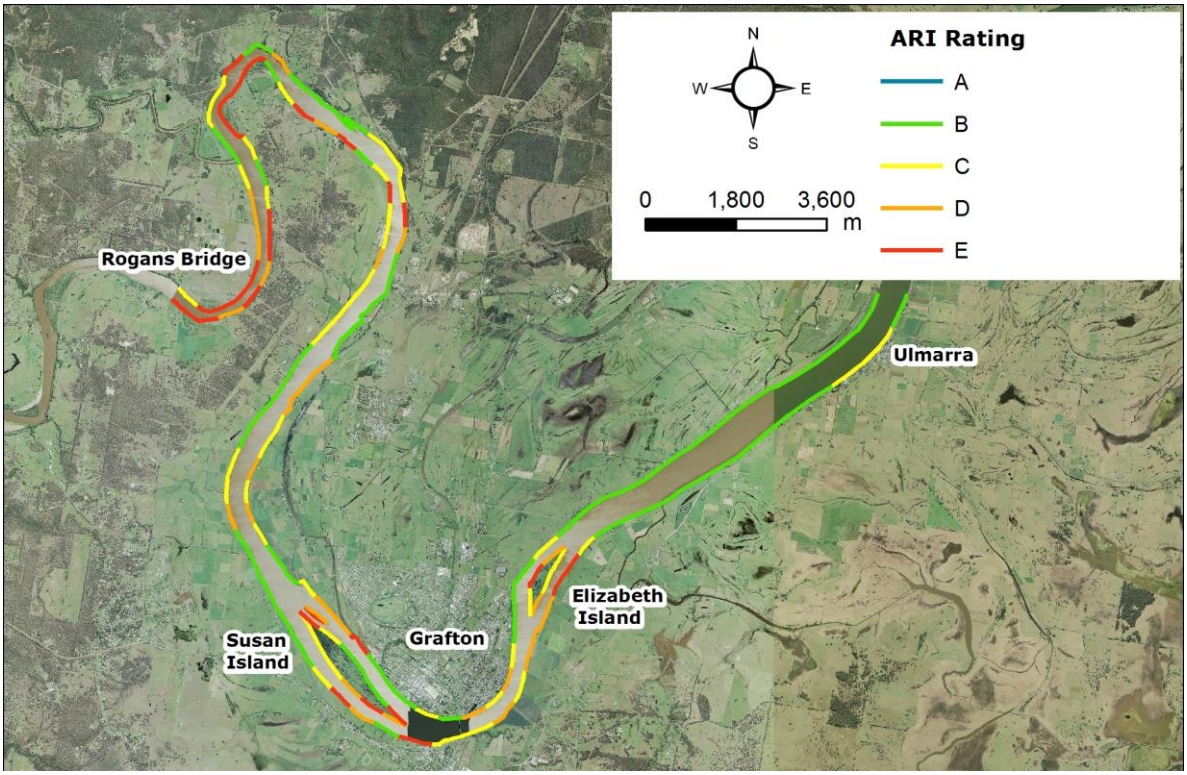

Figure 3-24: Equivalent Wind/Boat Wave Average Recurrence Interval Rating – Wakesurf Operating – 8 hour Duration - 300 Boat Passes

3.4 DSS Management Recommendations

3.4.1 Overview

This section provides an overview of the management recommendations produced using the DSS. Results are presented for both the mid – low tide baseline assessment (assessed for nine different boat pass scenarios) and the sensitivity tests (high tide, high boat passes, adjusted local wind conditions and boat wave attenuation assessed for six different boat pass scenarios). Note that maps of DSS management recommendations for the four sensitivity tests are provided in Appendices J to M for report brevity. A summary of the scenarios investigated include:

- Baseline DSS Assessment
    - Wakeboarding 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying regional winds;
    - Waterskiing 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying regional winds; and
    - Wakesurfing 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying regional winds.

- Sensitivity Test for High Tide Conditions
    - Wakeboarding 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at high tide, applying regional winds; and
    - Waterskiing 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at high tide, applying regional winds.

- Sensitivity Test for High Boat Passes
    - Wakeboarding 'operating' conditions for 500 and 1,000 boat passes (12 hour duration)and 'maximum wave' condition for 150 boat passes (8 hour duration) at mid – low tide, applying regional winds; and
    - Waterskiing 'operating' conditions for 500 and 1,000 boat passes (12 hour duration) and 'maximum wave' condition for 150 boat passes (8 hour duration) at mid – low tide, applying regional winds.

- Sensitivity Test with Adjusted Local Wind Conditions
    - Wakeboarding 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying adjusted local winds; and
    - Waterskiing 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying adjusted local winds.

- Sensitivity Test with Boat Wave Attenuation
    - Wakeboarding 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying boat wave attenuation; and,
    - Waterskiing 'operating' conditions for 10, 150 and 300 boat passes (8 hour duration) at mid – low tide, applying boat wave attenuation.

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

negative erosion potential scores and significant difference between the wind and wake energies. Note that there are nine (9) sites (L02, L05, L06, L07, L08, L09, L10, L11, L29 as shown in Figure 3-25) in the study region with the "Highly Erosive" erosion potential. These sites are classified as 'Manage' sites regardless of wind and boat wake wave energies.

The baseline DSS assessment (Section 3.4.2) adopted the 'distance of boat from shore' as half the width of the river at each stretch (the average 'distance of boat from shore' was 190 m). However, in some sections of the study recreational boaters are likely to be closer to the riverbank than half the width of the river. For the boat wave attenuation sensitivity test (Section 3.4.6), WRL selected a 'distance off' value of only 30 m for all scenarios assessed. This distance is consistent with boating management plans found elsewhere in NSW. When the 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.

3.4.2 DSS Management Recommendations for Mid – Low Tide Conditions (Baseline Assessment)

Table 3-7 and Figure 3-25 to Figure 3-33 present the DSS management recommendations for the Clarence River study area under mid – low tide conditions. It is evident that increasing boat numbers has an impact on the management recommendations. Wakesurf 'operating' conditions resulted in the highest number of 'Manage' sites in each boat pass scenario for the baseline assessment, approximately doubling the wakeboarding 'operating' conditions for 300 boat passes. Wakeboard 'operating' conditions resulted in the second highest counts of 'Manage' sites compared to waterski 'operating' conditions, except for the 10 boat passes scenario.

The management recommendations vary significantly between wakeboard and waterski vessels in the baseline assessment. For wakeboard 'operating' conditions, 10 additional locations recorded the 'Manage' recommendation, following an increase from 10 boat passes to 300 boat passes. However, the management recommendations changed little between all scenarios for waterski 'operating' conditions. Based on the results of the baseline assessment it is apparent that wave attenuation is a limiting factor in the final management recommendation at a number of sites across the study region.

As expected, the stretches recording the 'Monitor' and 'Manage' recommendations are regularly associated with alluvial plains as opposed to the armoured sections found in the lower reaches or the steep bedrock riverbanks, scattered throughout the study area.

Table 3-7: Number of Stretches Determined in each DSS Management Category (Mid – Low Tide)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration			Wakesurf – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	89	66	36	92	92	85	89	23	9
Allow*	5	27	46	17	17	24	0	50	45
Monitor	65	55	41	50	47	41	69	43	30
Monitor*	0	6	26	0	2	6	1	33	46
Manage	9	14	19	9	10	12	9	19	38

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

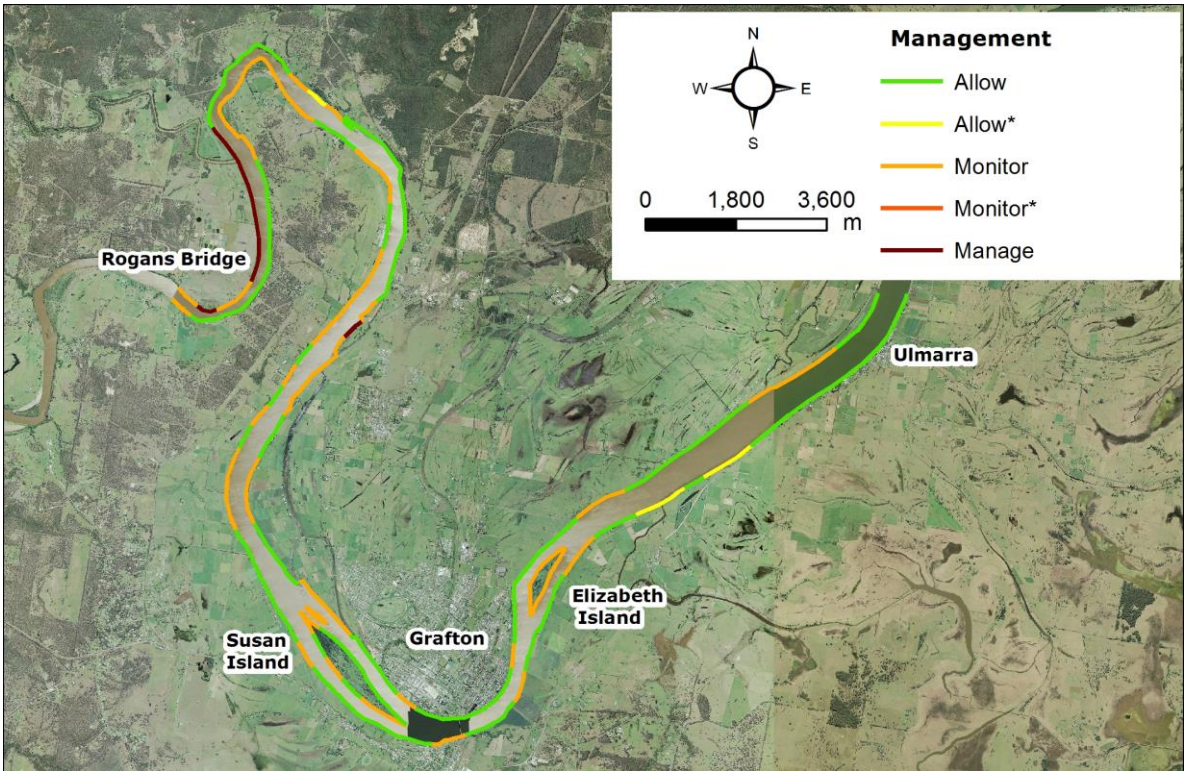

Figure 3-25: DSS Management Recommendations – Wakeboard Operating - 10 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

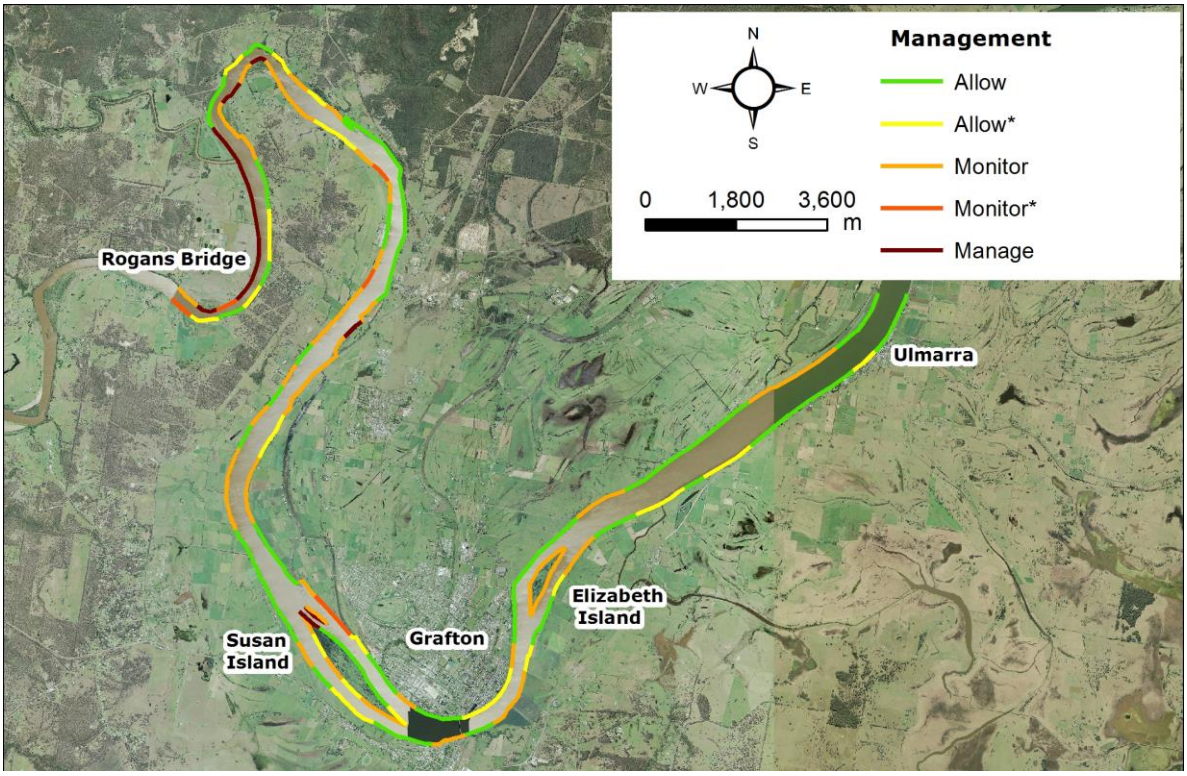

Figure 3-26: DSS Management Recommendations – Wakeboard Operating - 150 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

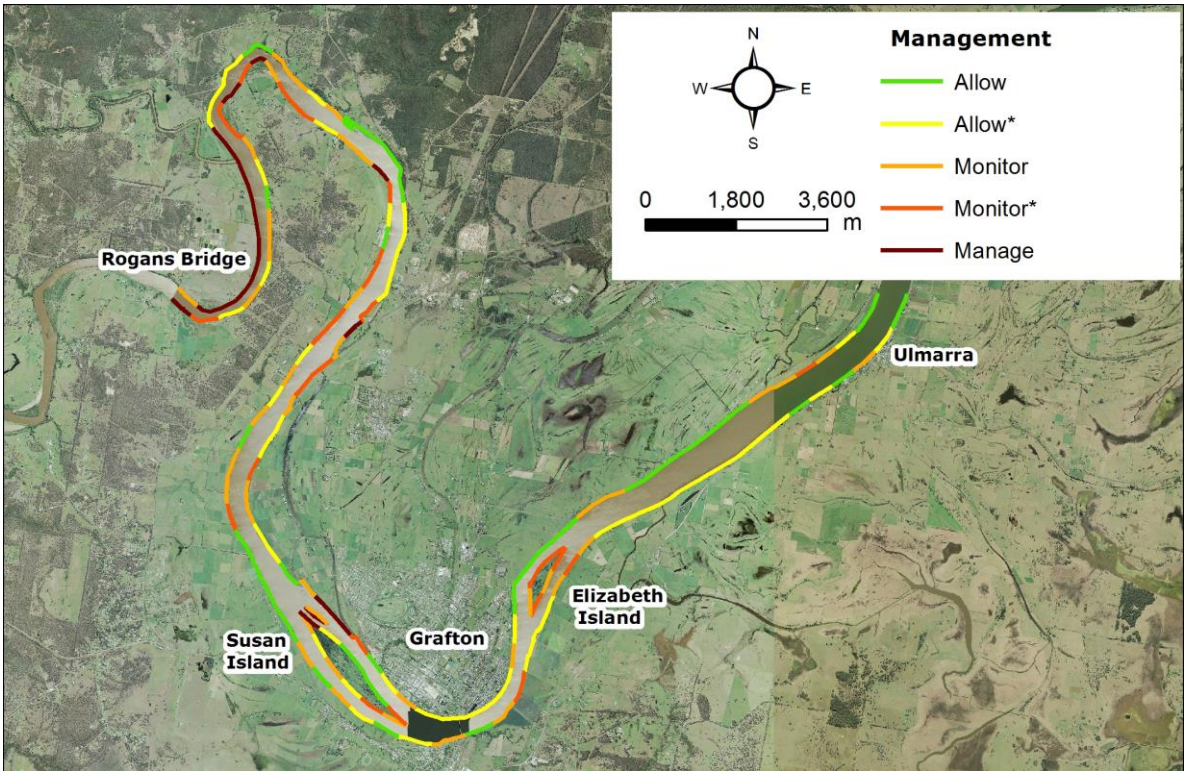

Figure 3-27: DSS Management Recommendations – Wakeboard Operating - 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

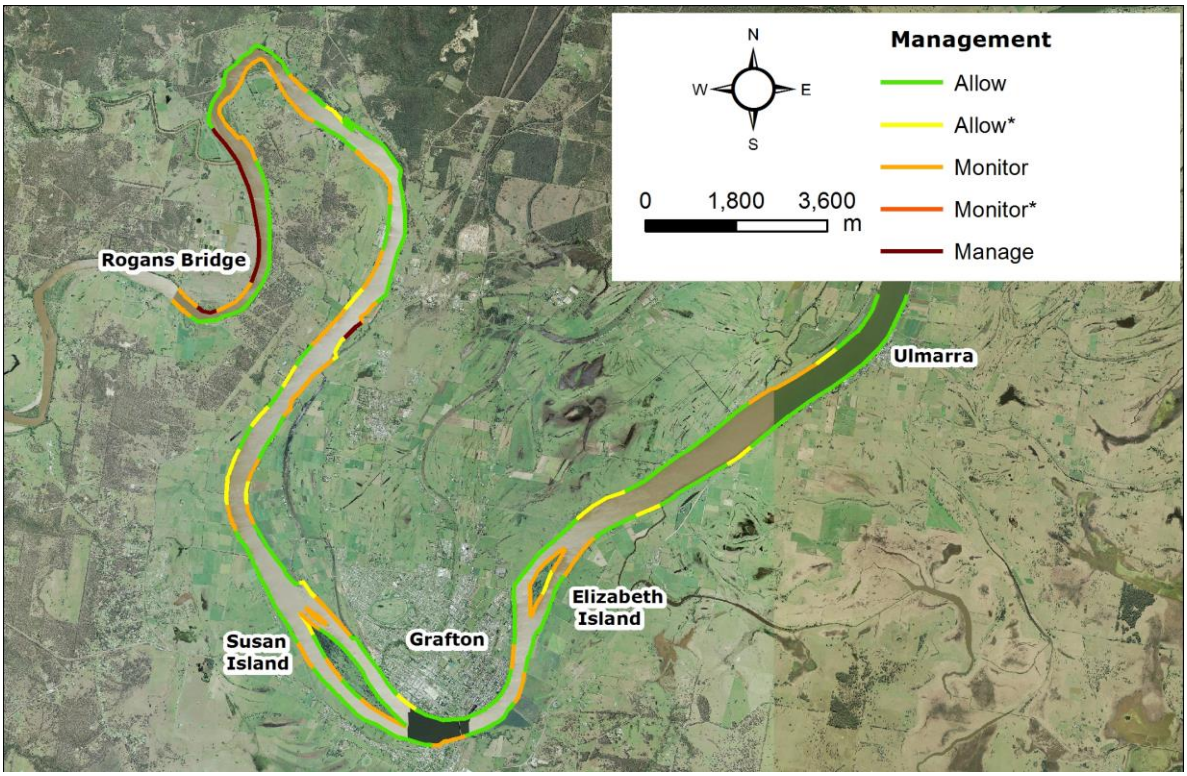

Figure 3-28: DSS Management Recommendations – Waterski Operating - 10 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

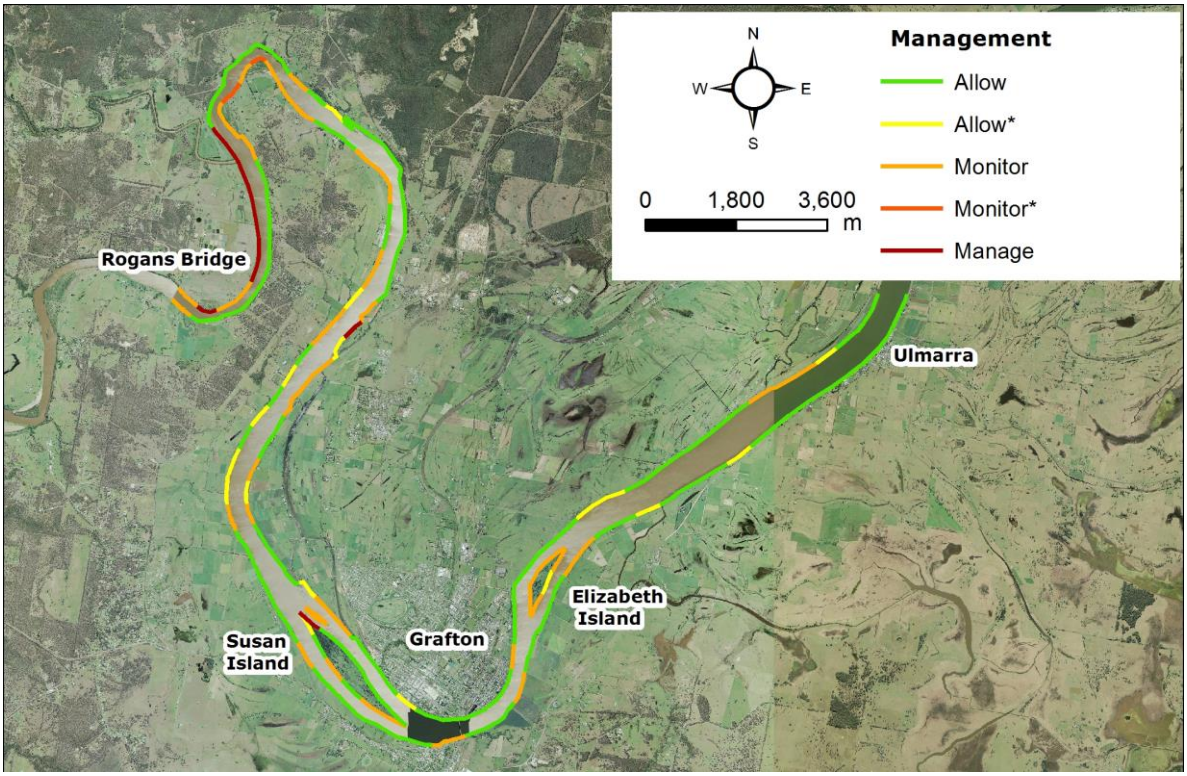

Figure 3-29: DSS Management Recommendations – Waterski Operating - 150 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

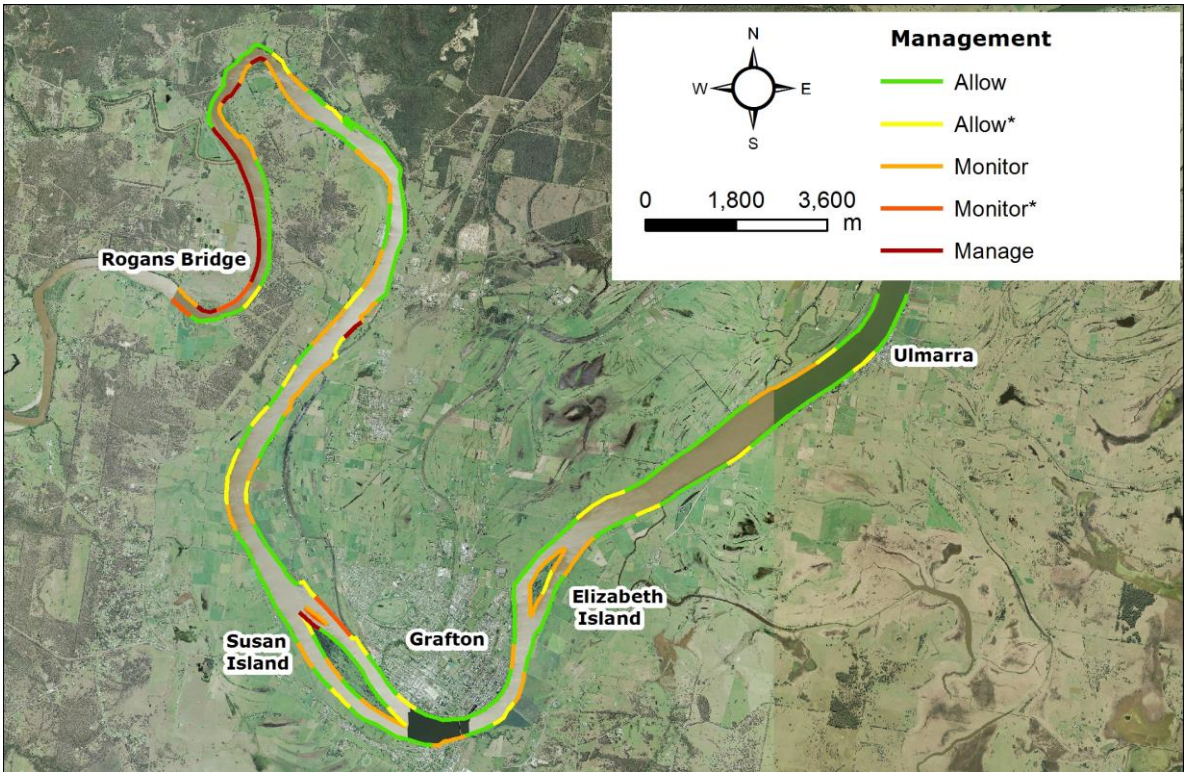

Figure 3-30: DSS Management Recommendations – Waterski Operating - 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

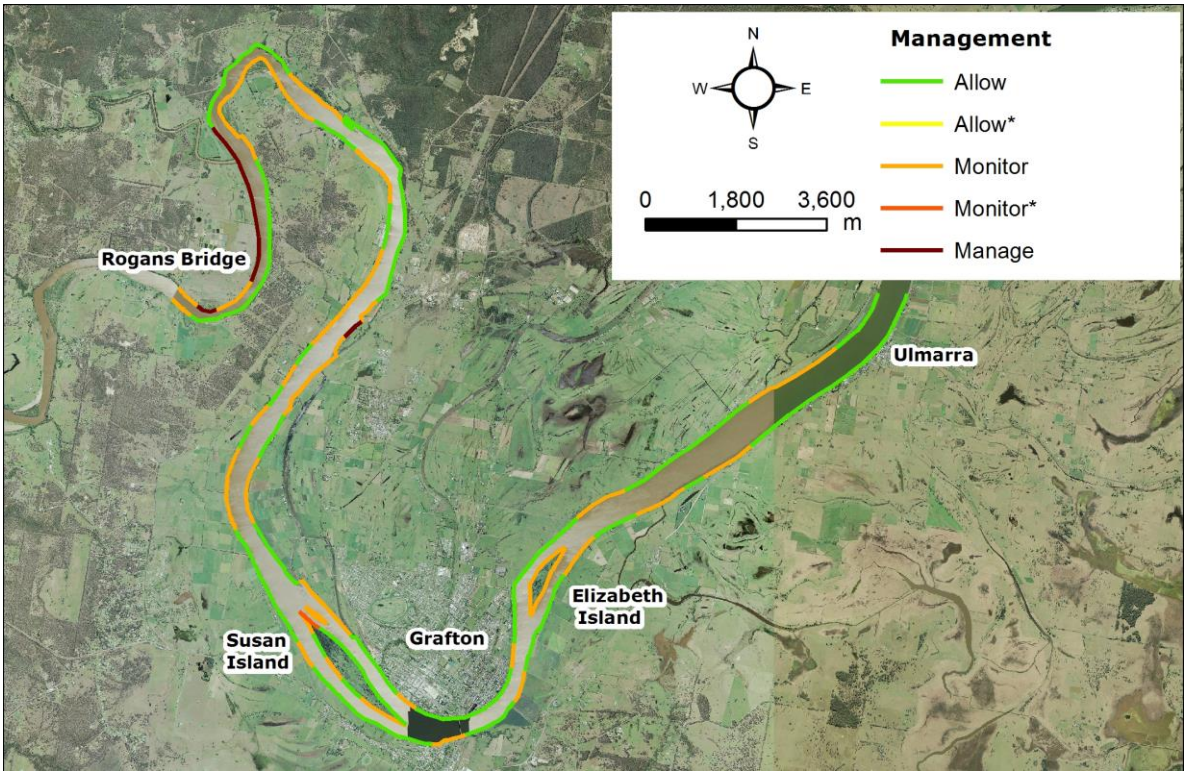

Figure 3-31: DSS Management Recommendations – Wakesurf Operating - 10 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

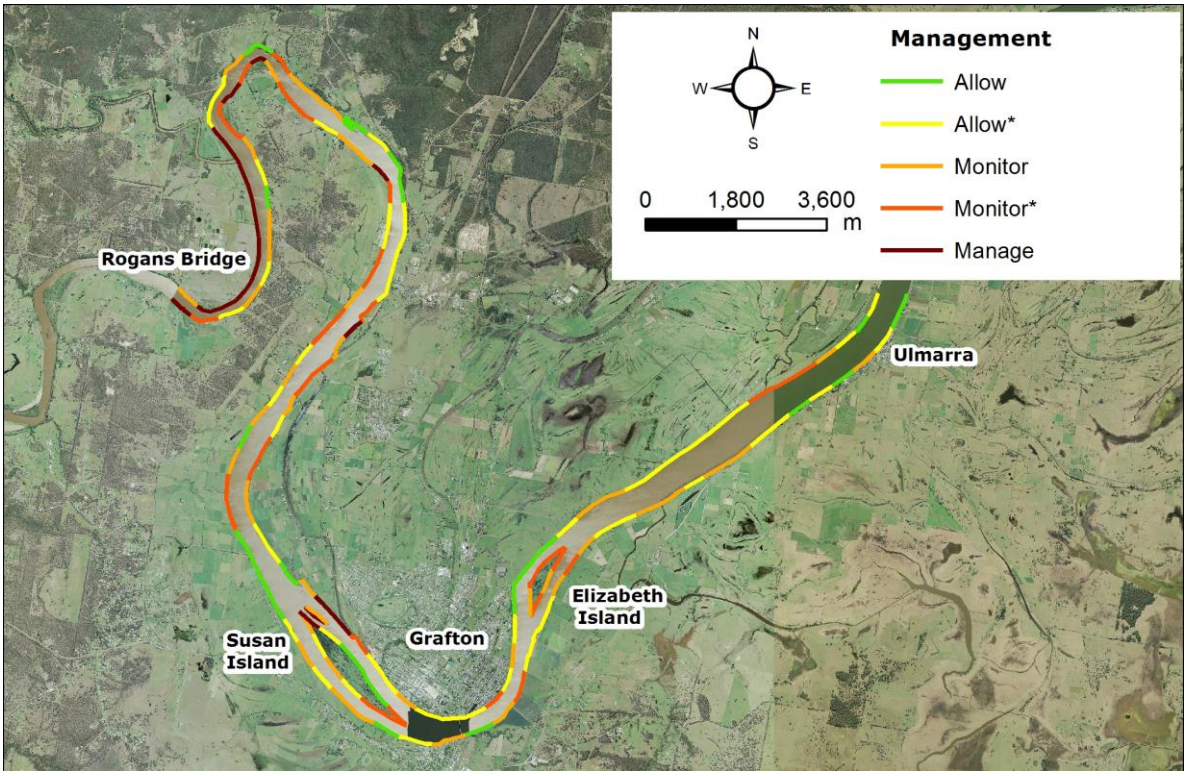

Figure 3-32: DSS Management Recommendations – Wakesurf Operating - 150 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

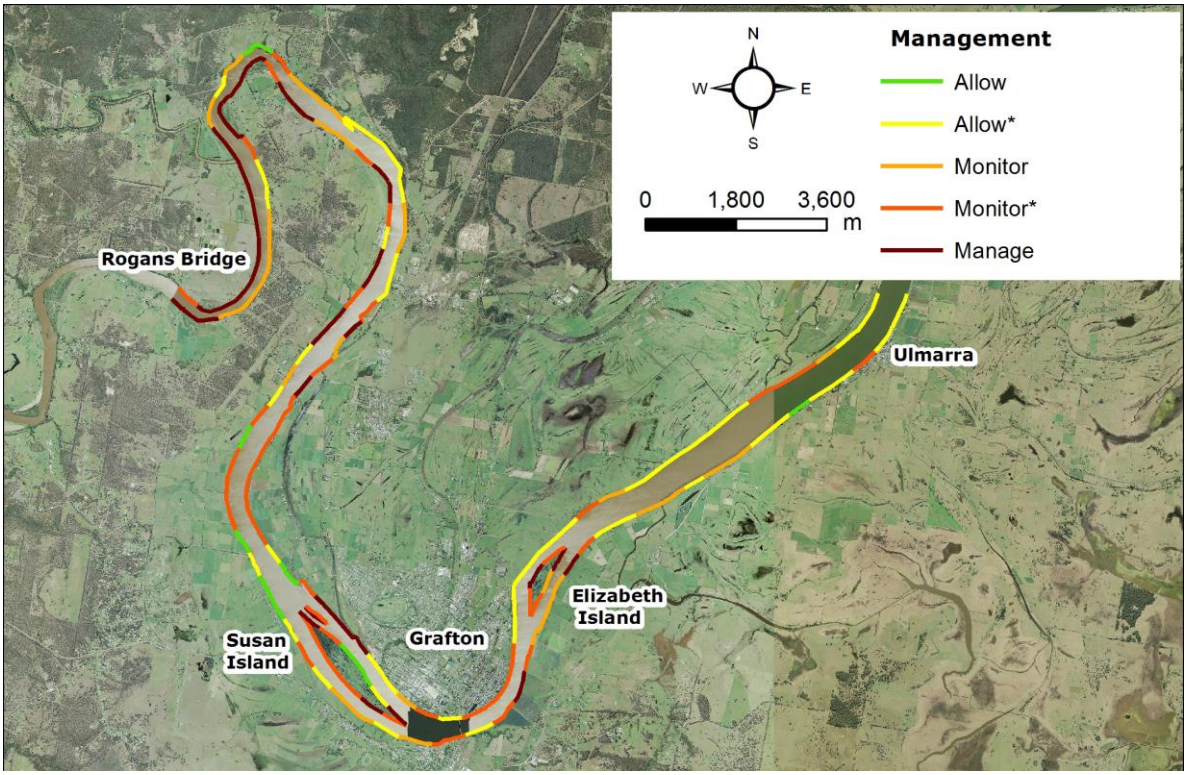

Figure 3-33: DSS Management Recommendations – Wakesurf Operating - 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

3.4.3 DSS Sensitivity Test for High Tide Conditions

The DSS management recommendations for the high tide assessment are provided in Table 3-8, while Appendix J provides the distribution of these recommendations along the waterway under different boat pass conditions. Table 3-9 provides a direct comparison between mid – low tide (Table 3-7) and high tide (Table 3-8) assessments. This data shows a modest increase in the number of reaches observed in the 'Allow*' category and a decrease of a similar magnitude is observed in the 'Manage' category for all scenarios. Based on these results, it is evident that wave action at mid - low tide is slightly more likely to cause riverbank erosion than at high tide. However, as discussed previously, these results assume that recreational boaters are travelling at half the width of the river from the riverbank.

Table 3-8: Number of Stretches Determined in each DSS Management Category (High Tide)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	91	63	34	94	93	81
Allow*	6	32	46	22	23	35
Monitor	67	56	44	48	46	40
Monitor*	0	9	28	0	2	6
Manage	4	8	16	4	4	6

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

Table 3-9: Comparison of DSS Management Recommendations for Varying Tidal Conditions

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	2	-3	-2	2	1	-4
Allow*	1	5	0	5	6	11
Monitor	2	1	3	-2	-1	-1
Monitor*	0	3	2	0	0	0
Manage	-5	-6	-3	-5	-6	-6

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

3.4.4 DSS Sensitivity Test with High Boat Passes (Mid – Low Tide Conditions)

Boat pass numbers higher than those included in the baseline assessment have been considered as a sensitivity test. Six scenarios are investigated at mid – low tide, including 500 and 1,000 boat passes, as well as, the 'maximum wave' condition as recorded for 150 boat passes. The DSS management recommendations for the high boat pass conditions are provided in Table 3-10, while Appendix K provides the distribution of these recommendations for the study region.

The results provided in Table 3-10 indicate a significant increase from baseline conditions in the number of sites that require monitoring and management for all scenarios. Higher counts were observed in all categories for wakeboard 'operating' conditions compared with waterski 'operating' conditions. 'Maximum wave' condition results are approximately equivalent to the results from the wakeboard 'operating' conditions with 300 boat passes. It should be noted the 'maximum wave' conditions occur when boats are accelerating and decelerating (i.e. when it is necessary to retrieve fallen wakeboarders or skiers).

Table 3-10: Number of Stretches Determined in each DSS Management Category (High Boat Passes)

Management Option	Wakeboard			Waterski		
	Operating Conditions – 12 Hour Duration		Maximum Wave – 8 Hour Duration	Operating Conditions – 12 Hour Duration		Maximum Wave – 8 Hour Duration
	500 Passes	1,000 Passes	150 Passes	500 Passes	1,000 Passes	150 Passes
Allow	23	9	36	79	63	36
Allow*	55	51	41	30	41	41
Monitor	37	24	46	40	34	46
Monitor*	34	44	26	7	14	26
Manage	19	40	19	12	16	19

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

3.4.5 DSS Sensitivity Test with Adjusted Local Wind Conditions (Mid – Low Tide Conditions)

As discussed in Section 2.4, data from the local weather station at Grafton Research Station was acquired for use with the DSS. To test the sensitivity of the baseline DSS management recommendations (Section 3.4.2) established on this wind climate, management recommendations were recalculated with increased natural wind wave energy based upon the Australian Wind Standard (AS 1170.2) speeds. The DSS management recommendations for the local wind conditions sensitivity tests are provided in Table 3-11, while Appendix L provides the distribution of these recommendations along the waterway under different boat pass conditions at mid – low tide. Table 3-12 provides a direct comparison between the baseline DSS assessment based on offsite winds (Table 3-7) and the worst-case local wind conditions (Table 3-11).

Table 3-11: Number of Stretches Determined in each DSS Management Category (Adjusted Local Winds)

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	101	101	98	118	118	118
Allow*	13	13	16	14	14	14
Monitor	45	44	38	27	27	26
Monitor*	0	0	6	0	0	1
Manage	9	10	10	9	9	9

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

Table 3-12: Comparison of DSS Management Recommendations for Varying Wind Conditions

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	12	35	62	26	26	33
Allow*	8	-14	-30	-3	-3	-10
Monitor	-20	-11	-3	-23	-20	-15
Monitor*	0	-6	-20	0	-2	-5
Manage	0	-4	-9	0	-1	-3

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 has significant consequences on the overall DSS management results. The data in Table 3-12 shows an overall reduction in the number of reaches observed in the 'Manage', 'Monitor', 'Monitor*' and 'Allow*' categories. There is a corresponding increase in the number of reaches observed in the 'Allow' category. This result is anticipated since, for a given boat pass scenario, the wave wake energy has a lower magnitude relative to the wind wave energy. At most, there was a 37% reduction in the number of reaches categorised as 'Manage', 'Monitor', 'Monitor*' or 'Allow*' and a 37% increase in reaches categorised as 'Allow'. The magnitude of these changes is considered significant. Accordingly, WRL recommends that anemometers be deployed along the riverbanks

between Rogans Bridge and Ulmarra if RVAWG wishes to develop a more accurate local wind wave estimate for comparison with boat wake waves in the future.

3.4.6 DSS Sensitivity Test – Boat Wave Attenuation

The DSS management recommendations for the boat wave attenuation sensitivity test (30 m 'distance of boat from shore' value) are provided in Table 3-13, while Appendix M provides the distribution of these recommendations along the waterway under different boat pass conditions at mid – low tide. Table 3-14 provides a direct comparison between the baseline DSS assessment. The results of this sensitivity test show a relative increase in the 'Monitor' and 'Manage' categories, where there was a decrease in the number of 'Allow*' and 'Monitor*' management recommendations. This result is anticipated as wave attenuation was a limiting factor in the baseline management recommendation at these sites.

Table 3-13: 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		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	89	66	36	92	92	85
Allow*	0	8	12	3	3	6
Monitor	70	73	75	64	61	59
Monitor*	0	2	9	0	0	5
Manage	9	19	36	9	12	13

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

Table 3-14: Comparison of DSS Management Recommendations for Varying Wave Attenuation

Management Option	Wakeboard – Operating Conditions – 8 Hour Duration			Waterski – Operating Conditions – 8 Hour Duration		
	10 Passes	150 Passes	300 Passes	10 Passes	150 Passes	300 Passes
Allow	0	0	0	0	0	0
Allow*	-5	-19	-34	-14	-14	-18
Monitor	5	18	34	14	14	18
Monitor*	0	-4	-17	0	-2	-1
Manage	0	5	17	0	2	1

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

4. Management Actions

4.1 Preamble

This section discusses the results provided in Section 3.4, highlighting the management recommendations and aspects of current management practices that require further investigation. Initially, potential sources of error regarding boat pass and wind source numbers are discussed. A range of management options are then discussed to reduce the calculated rating from 'Manage' to 'Monitor' for the most vulnerable river stretches. Finally, management techniques to reduce riverbank erosion and improve boat wake management on the Clarence River are outlined and various recommendations provided.

4.2 DSS Management Discussion

WRL recommends that nine (9) sets of management scenarios (10, 150 and 300 boat pass scenarios for wakeboard, waterski and wakesurf activities) are considered to inform the final management recommendations. For these scenarios under mid – low tide conditions, a range of management recommendations are observed. For the 10 and 150 boat pass scenarios (wakeboard and waterski), the majority of sites (between 39% and 53%) were prescribed an 'Allow' rating. For the 300 boat pass scenario, 51% of all sites assessed for waterski 'operating' conditions were 'Allow', whereas 47% of all sites were prescribed an 'Allow*' rating for wakeboard and wakesurf 'operating' conditions. As a result, the remainder of the study region (at least 35% of all sites for the nine scenarios considered) has a rating of 'Monitor', 'Monitor*' or 'Manage', with the majority of the sites (between 18% and 41% of all sites) rated as 'Monitor'.

The study results suggest that the majority of the river assessed is generally suitable for wakeboard and waterski boating numbers of 150 boat passes per day or less (equating to approximately 20 boat passes per hour over an 8 hour operating day). However, the number of suitable wakesurfing boat passes within the study area is lower than this value (between 10 and 150 boat passes) and requires further investigation. Glamore and Badenhop (2006) recommend that when the 'Monitor' option is produced, river reaches should be reassessed every two years. This will determine whether the riverbank condition trajectory is positive, negative or stable.

The results of the high tide assessment indicates that wave action at high tide is generally less likely to cause riverbank erosion than at mid - low high tide. As such, the suitability of 150 boat passes per day is valid throughout the entire tidal cycle.

In reviewing the results it is evident that the erosion potential of the riverbanks is the most important factor influencing the outcomes. To this point, some likely controls on erosion potential were discussed in Section 3.2. However, the high boat pass scenarios demonstrate that boat numbers significantly alter the DSS management recommendations and a better understanding of boat pass numbers on the Clarence River would assist management strategies into the future.

The adjusted local wind scenario results indicate that the wind climate source has a significant impact on the DSS management recommendations. While it is a lower priority than boat pass numbers, the collection of wind data within the study area using anemometers deployed for an extended period would reduce uncertainty within the DSS management recommendations and assist future studies.

The boat wave attenuation sensitivity tests reveal that reducing the distance between a passing boat and the shoreline has a moderate impact on the DSS management recommendations. Boats travelling in the middle of the river have more attenuated waves versus boats travelling at 30 m from the shoreline. Consequently, riverbank vulnerability to erosion is increased for boats travelling closer to the riverbank. As such, implementing a 'distance off' requirement in erosion prone areas of the Clarence River may reduce boating impacts on the riverbanks.

While WRL recommends consideration of all nine (9) sets of management recommendations to inform river management plans, the 300 boat pass scenario for wakeboard 'operating' conditions at mid – low tide with a 30 m 'distance of boat from shore' value is suggested to develop interim boat wake erosion mitigation measures. Importantly, this scenario (Figure 4-1) provides the upper bound of riverbank vulnerability associated with the baseline wakeboarding and waterskiing DSS assessments. Note that the only difference between the management scenarios considered is the number of boat passes used in the assessment; riverbank erosion potential remains unchanged for all cases.

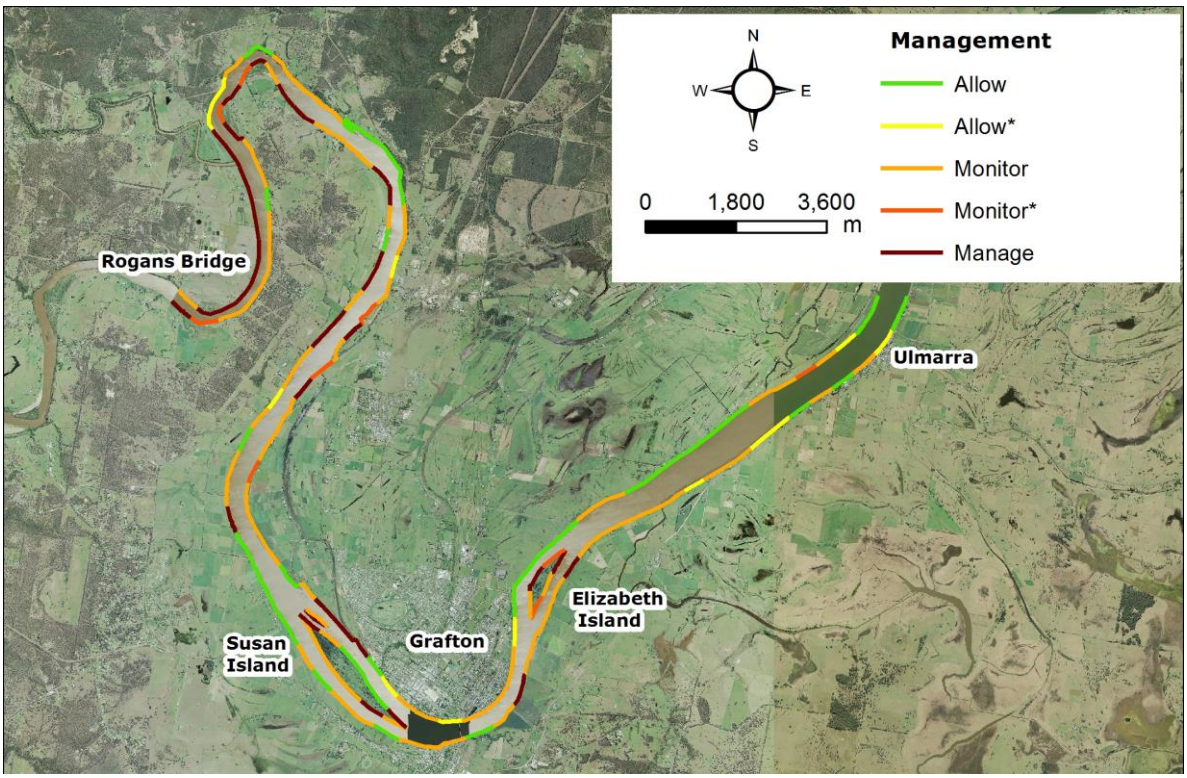

Figure 4-1: Suggested DSS Management Recommendations – Wakeboard Operating – Boat Wave Attenuation – 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

4.3 Forensic Examination of Key Riverbank Vulnerability Factors

A forensic examination was undertaken to determine 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 Clarence River. The forensic examination is 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 site classification types only, including:

1. Sites that were prescribed a 'Manage' rating in the baseline DSS assessment for the 300 boat pass (8 hour duration) scenario for wakeboard 'operating' conditions at mid – low tide (Figure 3-28); and
2. Sites that were prescribed an 'Allow*' or 'Monitor*' rating in the baseline DSS assessment of the 300 boat pass (8 hour duration) scenario for wakeboard 'operating' conditions at mid - low tide, that changed to a 'Manage' rating in the boat wave attenuation sensitivity test (Figure L-3).

4.3.1 Rehabilitation Guidelines for Australian Streams

The forensic examination was undertaken in accordance with the principles of the *Rehabilitation Guidelines for Australian Streams* (RGAS, 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
4. Evaluation

This forensic investigation fulfils stages 1 and 2 of this process. A further detailed design stage is required onsite. RGAS (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 categories:

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.

4.3.2 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 herein under the following categories:

1. Water management strategies
    - Buoys; and
    - No-wash zones.

2. Land management strategies
    - Removal of exotic weeds;
    - Native regeneration (sedges, shrubs and trees with bio-engineering);
    - Renourishment;
    - Reshaping;
    - Battering;
    - Fencing;
    - Armouring (rock revetment);
    - Rock fillets;
    - Bioengineering; and
    - Managed retreat.

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

Armouring results in the placement of hard structure designed to maintain the slope or protect it from erosion.

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.

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

Managed retreat permits bank erosion to continue, while managing any safety or environmental concerns.

Renourishment involves replacing foreshore sediment (usually sand) lost through longshore drift.

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

Revegetation involves re-establishing local native vegetation to stabilise bank sediments by generating a network of roots and partially absorbing wave and current forces.

Rock fillets are a bioengineered approach to riverbank stabilisation. These structures dissipate wave energy and create sheltered environments that are colonised by native vegetation.

Note that in preparing the recommendations for this report WRL has considered two boat zoning types as follows:

- Boat exclusion zone – by definition means that personal water craft (PWC) are not permitted to be driven at any time in the exclusion area, unless it is exempt from boating restrictions (e.g. Sydney Harbour NYE fireworks, Sydney airport etc.).
- 'No Wash' zone – by definition means areas where wash from vessels can cause damage, injury or annoyance to other vessels, the shoreline or people. Every vessel operator must comply with 'No Wash' signs.

However, the management recommendations presented in this report adopt the use of 'No Wash' zones only to allow the continued use of the waterway.

These onsite actions can be used to improve the rating of a site from 'Manage' to '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. Note that for this analysis it was assumed that sediment extraction from the river remains present.

4.3.3 Management Recommendations

The recommended onsite strategies for the two site classification types across the study region consider both immediate and programmed management outcomes. The implications of these management outcomes are as follows:

3. **Immediate Management Plan (implementation timeframe: 0-3 months)** involves enforcing 'No Wash' zones and buoy deployment across the study region as shown in Figure 4-2. Sites that require riverbank remediation to reduce erosion, in accordance with the preliminary land management options provided in Table 4-1, are also shown in Figure 4-2.
4. **Riverbank Management Program (implementation timeframe: 3-24 months)** involves undertaking riverbank remediation works at all sites not addressed by the *Immediate Management Plan* including weed removal, native vegetation regeneration, stock access removal, renourishment and repairs to rock revetments as recommended in Table 4-1 and Figure 4-3.

The *Immediate Management Plan* is directly formulated based on the DSS riverbank vulnerability assessment and provides a sustainable outcome for the study region until the *Riverbank Management Program* is enacted. WRL recommends enforcing 'No Wash' zones between stretches 1-15 (full river width) and stretches 43-47 (left channel only) and buoy deployment at the mid-river width from the shore between stretches 16-42.

The sites prioritised by the *Immediate Management Plan* have been highlighted in bold in Table 4-1. WRL recommends immediate water and land based management interventions at stretches 22-23 (right bank only) and stretch 29 (left bank only). The latter can be achieved by encouraging mid-river boating (e.g. placing buoys, education, etc.) and undertaking remediation works on the riverbank stretches. WRL also recommends immediate land based management interventions at stretches 47, 53, 57 and 58. All other 'Manage' sites identified across the study region can be managed in the interim with boating restrictions/education (e.g. deployment of buoys) as indicated on Figure 4-2.

The *Riverbank Management Program* targets the remaining sites not addressed by the *Immediate Management Plan* and applies the land management strategies as recommended in Table 4-1 and Figure 4-3. A site-by-site forensic examination is provided in Appendix N. Note that mid-river boating traffic (e.g. buoy deployment) continues to be recommended until native vegetation on the riverbank is re-established.

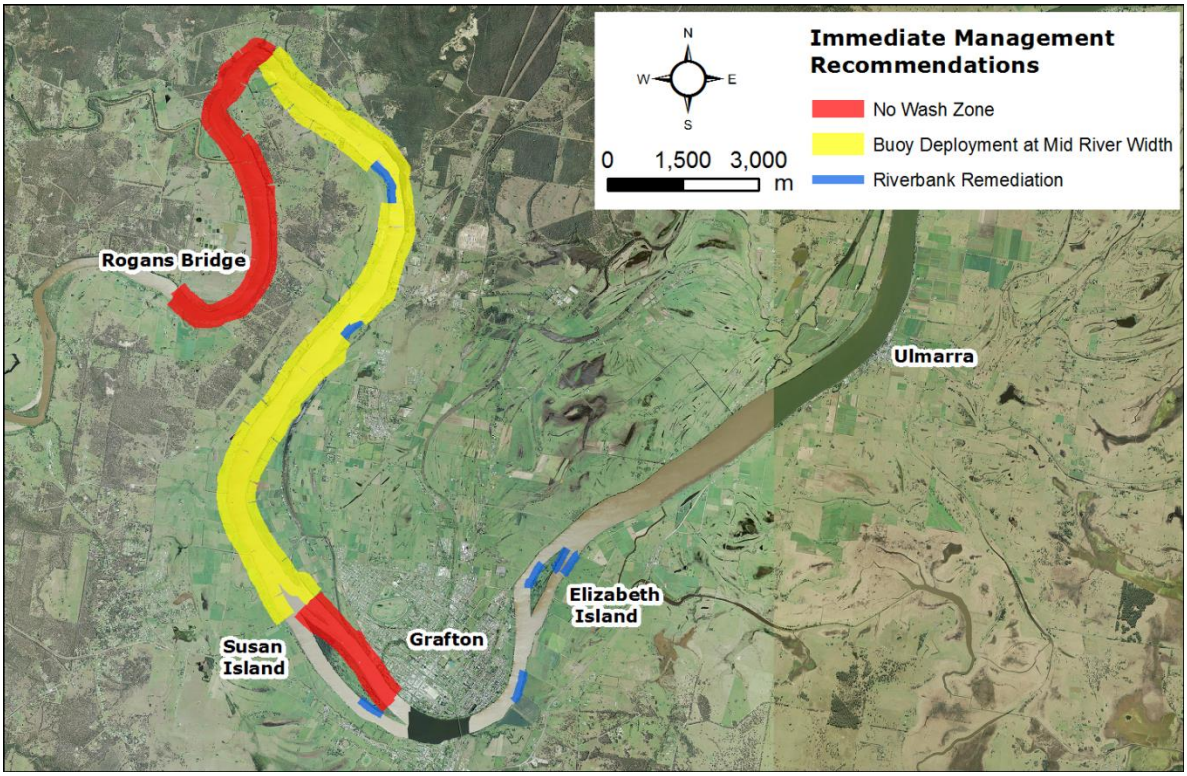

Figure 4-2: Recommended Onsite Actions for the Immediate Management Plan

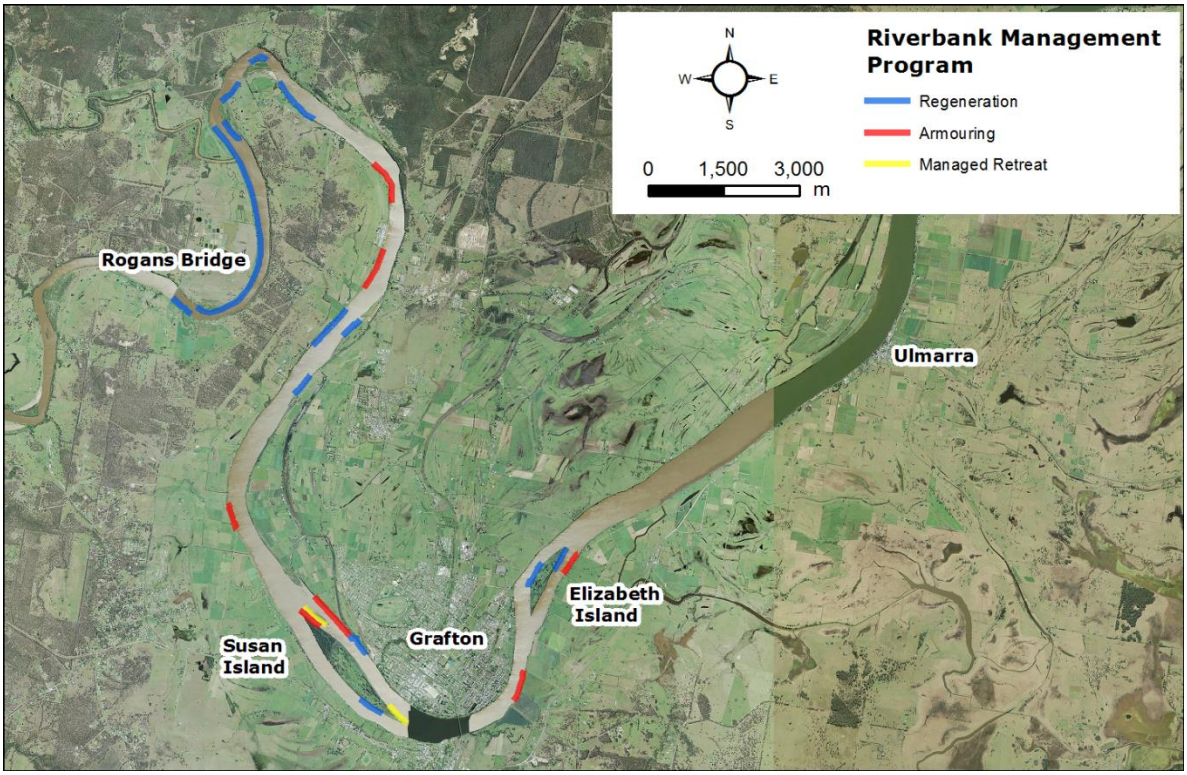

Figure 4-3: Recommended Riverbank Management Program for Onground Works

Table 4-1: Recommended Riverbank Management Program for Onground Works

Transect*	Removal of Exotic Weeds	Native Regeneration	Renourishment	Reshaping	Battering	Fencing	Armouring	Rock Fillets	Managed Retreat
L02	✓	✓	✓	✓		✓			
L03	✓	✓				✓			
L04	✓	✓				✓			
L05	✓	✓	✓		✓	✓			
L06	✓	✓	✓		✓	✓			
L07	✓	✓	✓		✓	✓			
L08	✓	✓				✓			
L09	✓	✓				✓			
L10	✓	✓				✓			
L11	✓	✓				✓			
L29	✓	✓		✓		✓			
L32	✓	✓				✓			
L43	✓	✓	✓		✓	✓	✓	✓	
L44	✓	✓	✓		✓	✓	✓	✓	
L45	✓	✓				✓			
LE58	✓	✓							
LM43									✓
LS47		✓	✓						
R01	✓	✓	✓	✓		✓			
R11	✓	✓	✓			✓			
R13	✓	✓				✓			
R15	✓	✓			✓	✓			
R17	✓	✓	✓			✓			
R18	✓	✓				✓			
R22	✓	✓	✓		✓	✓	✓	✓	
R23	✓	✓		✓		✓	✓	✓	

Transect*	Removal of Exotic Weeds	Native Regeneration	Renourishment	Reshaping	Battering	Fencing	Armouring	Rock Fillets	Managed Retreat
R26	✓	✓	✓		✓	✓	✓	✓	
R27	✓	✓	✓		✓	✓	✓	✓	
R29	✓	✓	✓		✓	✓			
R30	✓	✓	✓		✓	✓			
R38	✓	✓	✓			✓	✓		
R53	✓	✓				✓	✓		
R58	✓	✓				✓	✓		
RE57	✓	✓							
RS43	✓	✓	✓				✓		
RS48									✓

*Bold indicates sites prioritised by the *Immediate Management Plan.*

4.4 Recommendations

This section provides the recommendations resulting from this investigation. Key management recommendations are provided in order of priority and are supported by important research items that can be used to improve the DSS outcomes with time.

4.4.1 Management Recommendations

The key management recommendations are as follows:

Recommendation 1: Implement the management actions outlined in the *Immediate Management Plan* (timeframe: 0-3 months).

WRL recommends in the *Immediate Management Plan* (as provided in Figure 4-2) the following management actions, including:

1. Enforcing 'No Wash' zones between stretches 1-15 (full river width) and stretches 43-47 (left channel only) and buoy deployment at the mid-river width from the shore between stretches 16-42.
2. Immediate water and land based management interventions at stretches 22-23 (right bank only) and stretch 29 (left bank only). The latter can be achieved by encouraging mid-river boating (e.g. placing buoys, education, etc.) and undertaking remediation works on the riverbank stretches.
3. Immediate land based management interventions at stretches 47, 53, 57 and 58 based on the recommendations provided in Table 4-1.
4. All other 'Manage' sites identified across the study region can be managed in the interim with boating restrictions/education (e.g. deployment of buoys).

Note that a fundamental component of the *Immediate Management Plan* is an education and training program for river users to manage riverbank erosion during non-flood periods.

Recommendation 2: Implement the management actions outlined in the *Riverbank Management Program* (timeframe: 0-24 months).

The *Riverbank Management Program* targets the remaining sites not addressed by the *Immediate Management Plan* and applies the land management strategies as recommended in Table 4-1 and Figure 4-3. A site-by-site forensic examination is provided in Appendix N. Note that mid-river boating traffic (e.g. buoy deployment) continues to be recommended until native vegetation on the riverbank is re-established.

It is important to note that the *Riverbank Management Program* only addresses the worst erosion areas identified by the DSS riverbank vulnerability assessment. This 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 and costing. Detailed planning is recommended including site inspections to assess the management recommendation across the entire riverbank stretch.

Recommendation 3: DSS results to assist in finalising the *Regional Boating Plan for the Tweed-Clarence Valley Region*.

Recommendation 4: Establish a monitoring program for reapplication of the DSS for the evaluation of riverbanks in the future and implementation of the management actions.

A comprehensive and established monitoring program will provide an objective baseline for future comparison and management of the Clarence River between Rogans Bridge and Ulmarra. Glamore and Badenhop (2006) recommend a reassessment of 'Monitor' sections every two years, and 'Allow' sections every five years. This assessment could be coupled with improved boat statistics (Recommendation 1) at the more frequented sections of the river.

4.4.2 Research Items

Sensitivity testing indicated that the following items were important in undertaking the riverbank vulnerability assessment on the Clarence River and can be used to improve the DSS outcomes with time. The research items resulting from this investigation are as follows:

Research Item 1: Update and refine boating usage patterns on the waterway.

As mentioned in Section 2.5.2, there is limited data available on boat pass numbers, including both boat numbers and user activity. Further to regular patrol observations by NSW RMS, an assessment of boating numbers encompassing both busy, and normal, weekends and weekdays, as recommended by Glamore and Badenhop (2006), would provide a more accurate understanding of recreational boating within the study area. This data gathering, coupled with a survey of users, would help establish preferred areas for recreational boating and potentially focus further investigations.

It is important to note that even if boat numbers were known for this study that this would not have reduced the number of "Manage" sites. There are nine (9) sites (L02, L05, L06, L07, L08, L09, L10, L11, L29 as shown in Figure 3-25) in the study region with the worst case "Highly Erosive" erosion potential which are classified as "Manage" sites regardless of wind and boat wave energies.

Research Item 2: Investigate the extent and impact of extractive industry activities within the Clarence River.

This research item addresses specific actions outlined in the Clarence Valley Estuary Management Plan (2003), including:

1. Action W21: Prepare a sedimentary process drivers study; and,
2. Action U1: Prepare a sand and gravel resources management strategy for the whole estuary.

To support this work, bathymetric measurements should be taken both within the licensed areas and immediately upstream and downstream of the licensed areas at regular intervals. This information is required if the extent of the riverbanks impacted by extractive industry is to be estimated.

Research Item 3: Obtain additional wakesurf field measurements to improve the statistical robustness of the DSS assessment.

On a preliminary basis, this study incorporated a new vessel activity, wakesurf "operating conditions", into the DSS database following comparison of two datasets collected by

WRL.However, it is acknowledged that there is a limited number of wakesurf field test results available. Further field tests would improve the characteristic parameters of the large wake waves associated with wakesurfing.

Research Item 4: Assess the local wind conditions on the Clarence River over an extended period to develop scaling factors applicable to the existing wind record.

The baseline DSS assessment has used wind data from the Grafton Research Station to approximate conditions on the Clarence River. This station is well situated for this purpose, being located between 3 and 8 km from any part of the Clarence River study area. Sensitivity tests on the available wind data were undertaken to determine if additional field measurements were required. The magnitude of changes to management recommendations observed in these sensitivity tests was considered significant. Accordingly, if more accurate local wind wave estimates are required for comparison with boat wake waves in the future, it is recommended that anemometers be deployed along the riverbanks between Rogans Bridge and Ulmarra. This would allow scaling factors applicable to the wind conditions at the Grafton Research Station to be developed. This wind data collection program would involve approximately 6-10 anemometers deployed along the Clarence River for an a 12 month duration (minimum).

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Appendix A – Literature Review

A-1 South Grafton Levee Scheme – Review of Historical Bank Erosion (Cameron McNamara Consultants, 1987)

This report by Cameron McNamara Consultants outlines the results of an examination of historically recorded riverbank erosion along the right (southern) bank of the Clarence River at Grafton. The South Grafton Levee Scheme proposed the construction of a levee along the river bank with varying setbacks from the river as shown in Figure A-1. The levee now provides flood protection to the South Grafton urban area.

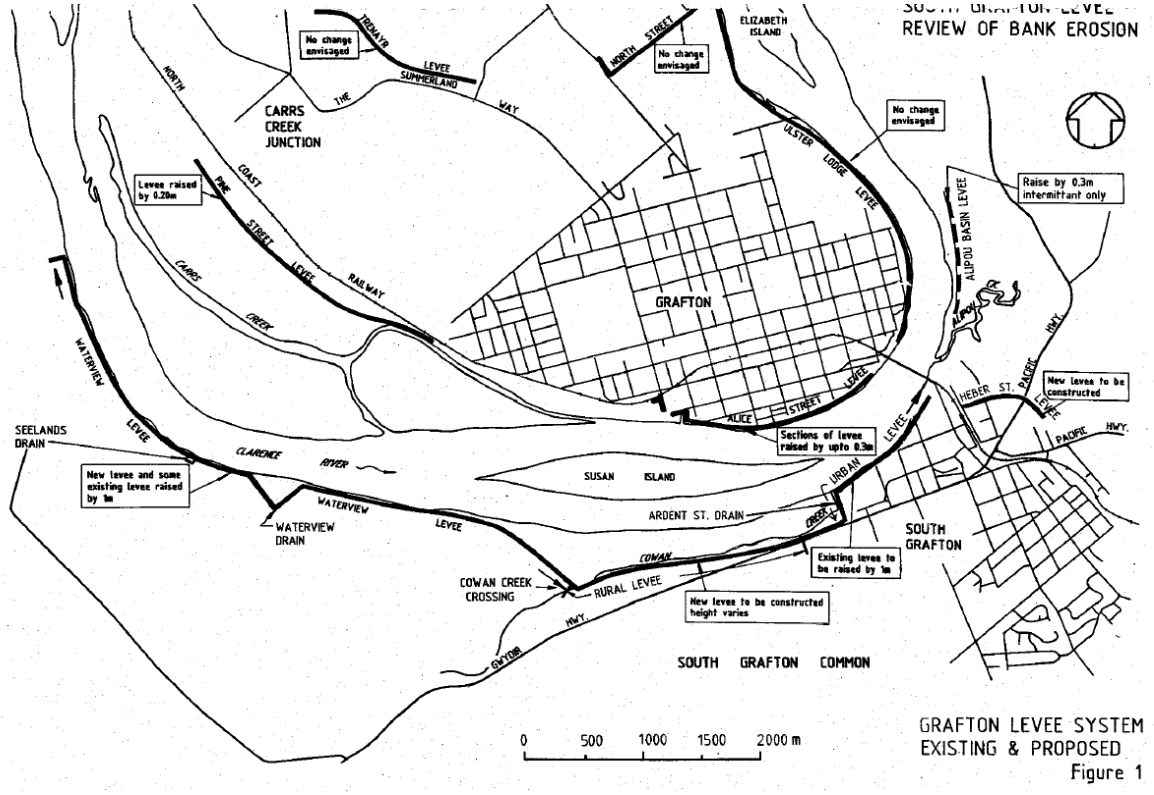


Figure A-1: Grafton Levee System Existing (1987) and Proposed (Source: Cameron McNamara Consultants, 1987)

The long term behaviour and stability of the river was investigated by:

1. Examining river cross-sections hydrographic surveys;
2. Examining aerial photography;
3. Undertaking riverbank survey (CVC); and
4. Undertaking site inspections (Cameron McNamara Consultants).

Key points of Cameron McNamara Consultants' report relevant to the DSS assessment, include:

- Cross-sections of the Clarence River measured in 1870, 1963 and 1979 indicated that the channel had not widened appreciably over the period examined (approximately 100 years). The shape of the cross-sections and location of the islands also demonstrated that the channel had not moved in position significantly. As such, the lateral stability of the river system was considered to be 'high'.
- A possible correlation between the flow regime in the Clarence River and changes in bed elevation was examined using a seven year moving average of annual flows at Lilydale. It was shown that there was periods of very high flow between 1950 and 1955 and another between 1972 and 1977. The author indicated that there may be a relationship between changes in bed elevation and high flood flow, however, due to a lack of data this could not be confirmed.
- Analysis of aerial photography and the riverbank survey supported the hydrographic survey data indicating that widespread and significant movement of the riverbanks had not occurred between 1954 and 1978. However, the right bank, opposite Susan Island, had eroded by up to 30 m.
- It was concluded that riverbank stability and erosion was not a problem over the majority of the levee scheme provided. However, along the Waterview and Urban Levees on the right bank, erosion of up to 20 occurred at several locations. Major slip failures were also observed above the normal water level.
- Aerial photography from 1954 (NSW Film No. 251) showed that the riverbanks in WRL's study area (Rogans Bridge to Ulmarra) were essentially clear of vegetation.
- Extensive rock protection was installed by CVC along the right bank below the Waterview Levee in the early 1970s, which prevent continued erosion. However, despite rock protection, slip failures continued to occur in some areas of the levee.
- A key recommendation from this report included the need for regular riverbank surveys to define historical trends in bank erosion. It was highlighted that bank cross-sections should cover the bank from the top of the levee to below the waterline, extending to the middle of the channel adjacent to the bank to quantify any long term changes.
- It was also recommended that rock protection is the preferred management option for minor or major slip failures, as opposed to full riparian rehabilitation of the riverbanks.

A-2 Pathways to a Living Estuary: Clarence Estuary Management Plan (Umwelt, 2003)

Umwelt (Australia) prepared the Clarence Estuary Management Plan on behalf of the Clarence Estuary Management Committee, whose membership included representatives of local Councils, County Councils, state agencies, industry groups, recreational and commercial users of the estuary and conservation interests. The Estuary Management Plan clearly presents justified and prioritised actions to maintain a healthy estuary. The Estuary Management Plan includes actions to address nine key issues, grouped in four major themes. Actions relevant to the DSS assessment, include:

1. Integrated water cycle management such as, the management of sedimentary processes and dredging to stabilise eroding banks;
2. Threats to ecological values such as, to restore riparian vegetation, with a priority for the tributaries in the lower estuary;
3. User interactions such as, boating management through planning and regulation of recreational use of the waterway to minimise impacts on estuary health; and
4. Overcoming uncertainty and facilitating systemic management.

As part of the first steps towards sustainable estuary management, actions recommended to address these issues included:

- Conducting the necessary studies to clearly understand sediment, erosion, transport and deposition patterns in the estuary; and
- Preparation of operational and environmental management plans for the boat harbours at Yamba and Iluka.

The second stage of implementation of the Estuary Management Plan included actions for:

- Conducting an audit of environmental weeds, including terrestrial, aquatic and wetland habitats, to establish priority areas for weed control works; and
- Preparation of a waterway user strategy, focusing on public recreational user access to the foreshore and waterway, and addressing potential conflicts between users and protection of sensitive aquatic habitats.

The Clarence Estuary Management Study (Umwelt 2002) includes a sub-catchment based assessment of values and risks that affect the priority of different parts of the estuary for management attention. The assessment considered a range of indicators of estuary and floodplain values, usage, risks and threats and potential to improve condition. The DSS study area between Rogans Bridge and Ulmarra was identified as having a low number of values and a high to very high number of threats to the sustainable management of the estuary. As such, the focus of management in these areas is gradual risk reduction.

The Estuary Management Plan identified that great brush forests that previously grew on the coastal floodplain were greatly diminished in the early years of European settlement in the Clarence Valley. The plan also asserted that native riparian vegetation that is not weed infested and extends more than one tree deep from the riverbank is very rare in the estuary.

The Estuary Management Plan included an Action Plan for the sustainable management of the Clarence estuary and its associated coastal floodplain. It recommended the implementation of riverbank management plans for villages and reaches affected by riverbank erosion, including Ulmarra.

A-3 Ulmarra Riverbank Erosion Protection Works – Review of Environmental Factors (Gary Blumberg & Associates, 2003)

Gary Blumberg & Associates in association with estuarine ecologists, Peter Parker & Associates, were engaged by the Department of Commerce on behalf of CVC (formerly Clarence River County Council), to prepare a Statement of Environmental Effects (SEE) for rock protection works along the right bank of the Clarence River in the vicinity of Ulmarra Village (Figure A-2). This work followed the Ulmarra bank erosion investigations carried out by CVC (1997) and the Riverbank Management Plan (RMP) developed and adopted by Ulmarra Shire Council (2000).

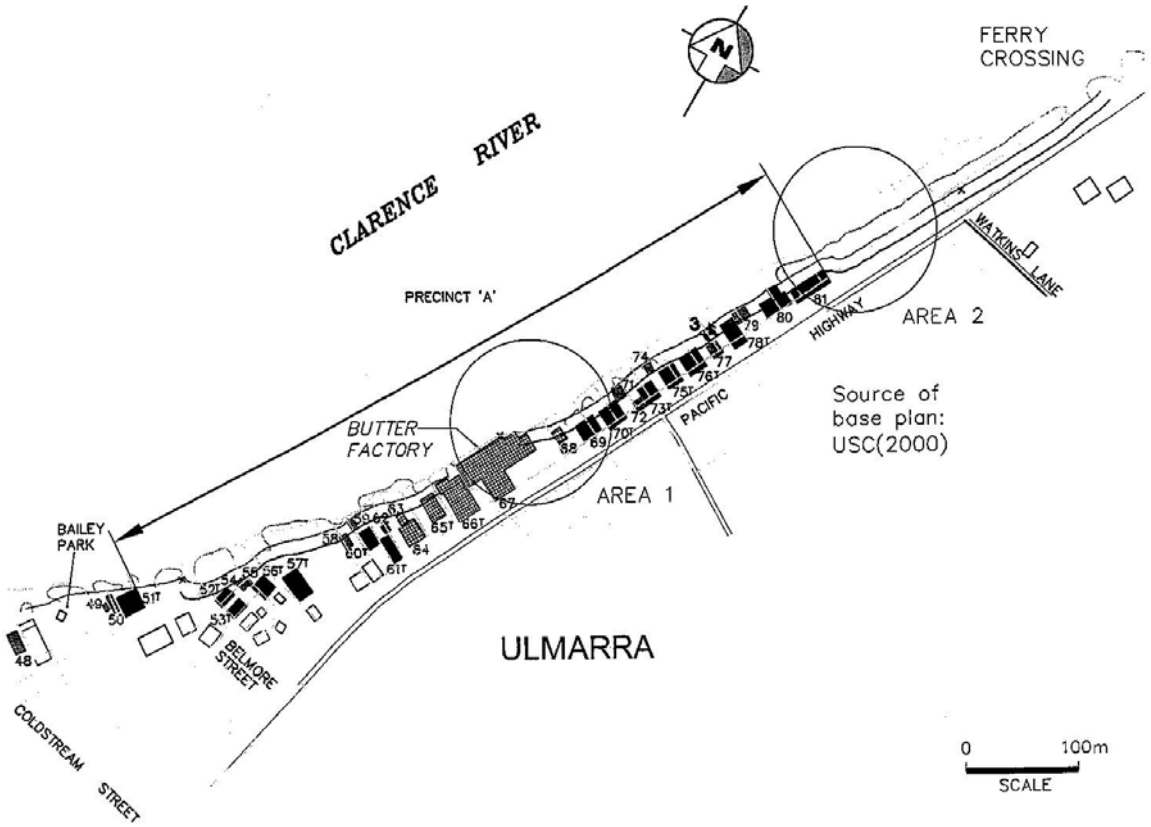


Figure A-2: Rock Protection Works Along the Right Bank of the Clarence River in the Vicinity of Ulmarra Village (Source: Gary Blumberg & Associates, 2003)

Gary Blumberg & Associates (2003) indicated that riverbank erosion has threatened the historic village of Ulmarra since it was first settled in the mid-1800s and placement of rock to protect the riverbank likely dates back to the early 1900s. In 1997, CVC commissioned a detailed riverbank erosion investigation at Ulmarra which found that a section of the riverbank, extending from the abandoned Butter Factory to downstream of the existing ferry, had experienced significant erosion over the last century. It was asserted that erosion due to current shear was acting over the full bank height during major floods, while in smaller floods, the current shear was only concentrated in the lower sections of the riverbank. Localised slip failures triggered by high pore pressures developed during periods of heavy rainfall or flood drawdown, also contributed to riverbank instability.

When the SEE was published, it was asserted that this same section of bank still occupied a particularly high stress zone at Ulmarra Bend. The RMP (2000) determined that properly designed and maintained rock placement would limit direct riverbank erosion by river currents and improve bank stability. Based on the outcomes of the DSS assessment undertaken by WRL, it was shown that Ulmarra Bend is now moderately to highly resistant to erosion due to the presence of rock revetment walls (Section 3.2.1). Figure A-3 shows the existing rock revetment works and concrete seawall protecting the old Butter Factory at Ulmarra.

Figure A-3: Existing Rock Revetment Works and Concrete Seawall, Old Butter Factory (Ulmarra)

In addition to rock protection, three other "appropriate" management strategies were identified for protecting riverbank properties in high hazard areas at Ulmarra (CVC, 1997), including:

1. Rezoning of waterfront property;
2. Voluntary purchase of waterfront property; and
3. Relocation of buildings.

Note that full riparian rehabilitation of the riverbank was not considered as a feasible management option for erosion protection at Ulmarra Bend.

As part of the SEE, Gary Blumberg & Associates (2003) investigated several elements of the environment at Ulmarra that are relevant to the current DSS assessment, including:

- River hydraulics and flooding;
- Riverbank instability and erosion;
- Riverbed and riverbank materials; and
- Wind and wave action.

Upstream of Grafton, the Clarence River has a catchment area of approximately 19,800 km^2 and floods with flow rates up to 19,000 m^3/s have been estimated. Gary Blumberg & Associates (2003) indicated that at Ulmarra, the channel is shaped primarily by flood flows. It is postulated that the river at Ulmarra is significantly larger than its "regime" size. This suggests that from a regional perspective, the river at Ulmarra is likely to be narrowing. The trend toward a reduced channel area is said to be broadly consistent with the results of surveys undertaken in 1979 and 1993 which indicate rapid growth in the point bar opposite Ulmarra. The rate of erosion at this location has been estimated at 0.25 m/year (CVC, 1997; as cited in Gary Blumberg & Associates, 2003).

Riverbed and riverbank materials are important factors when considering riverbank erosion potential. Drilling undertaken in the area between the Butter Factory and the ferry crossing, 10 m out from the waterline in a water depth of 5 m, found a 1.5 m thick layer of silty sand overlying stiff clay. It was concluded by Gary Blumberg & Associates (2003) that where sand exists on the riverbed at Ulmarra, it essentially forms a veneer over a stiff clay substrate. In addition, boreholes along the crest of the riverbank revealed a thin fill layer (0.5 to 1.5 m thick) forming the man-made levee, overlying over-consolidated alluvial soils (approximately 10 m

thick), which in turn overlie normally consolidated, alluvial silty clay. Groundwater depths varied from 5.0 m to 6.2 m, which was approximately equivalent to the water level in the river.

Gary Blumberg & Associates (2003) indicated that winds blowing over the river at Ulmarra will generate wind waves which may impact on the riverbank. The height and period of these waves will depend on the wind speed and duration, fetch length and water depth. Generally, wind directions are evenly distributed in all cardinal directions throughout the year. However, morning winds tend south to south-west (summer, autumn and spring) and west to south-west in winter, while afternoon winds blow from east to north-east (summer, autumn and spring). Wind waves predicted by Gary Blumberg & Associates (2003) (Table A-1) indicate that significant wind wave heights up to 0.9 m could occur once a year from the south-west. These would approach from upstream, with a relatively oblique angle to the shoreline. Waves approaching from the opposite shore would be much smaller in height due to the shorter fetch. For the 50 year ARI event, significant wind wave heights could be up to 1.4 m.

Table A-1 - Predicted Wind Waves for Ulmarra Riverbank (Source: Gary Blumberg & Associates, 2003)

Direction	N		NW		W		SW	
Fetch	2.8 km		0.5 km		0.5 km		7 km	
ARI (years)	Hs (m)	T (s)	Hs (m)	T (s)	Hs (m)	T (s)	Hs (m)	T (s)
1	0.5	2.2	0.3	1.4	0.4	1.5	0.9	3.2
10	0.7	2.5	0.4	1.6	0.5	1.7	1.2	3.6
50	0.8	2.7	0.5	1.7	0.6	1.8	1.4	3.8

Gary Blumberg & Associates (2003) also asserted that power boats travelling up and down the Clarence River would typically generate 0.2 m high waves. In the case of a cruiser travelling near the riverbank and close to its critical speed (i.e. speed immediately prior to planing), Gary Blumberg & Associates (2003) estimated that wave heights up to 0.4 m may occur.

A-4 Regional Boating Plan: Tweed-Clarence Valley Region, Consultation Draft (Transport for NSW, 2014)

The Maritime Management Centre within Transport for NSW prepared a Consultation Draft of the Regional Boating Plan for the Tweed-Clarence Valley Region with a view to developing a final plan at a later time. The Consultation Draft was informed by the feedback received through an initial consultation program including engagement with NSW Roads and Maritime Services, local Councils, boating stakeholder groups as well as an online survey open to all waterway users. It was noted that one of the main recreational activities in the Clarence River was waterskiing and wakeboarding, particularly at the "Watersports Precinct" around the Seelands Peninsula.

The Consultation Draft noted that, at the time of writing, there are approximately 14,000 registered recreational vessels in the Tweed-Clarence Valley Region. Of these registered vessels, 70% are classified as "open runabouts" and 90% are 2-6 m in length (i.e. trailerable). Vessel ownership in the region is increasing across all boat sizes at approximately 4% per annum. The Clarence River or one of its tributaries has 33 formalised boat ramps, 21 public access points including wharves jetties, pontoons and landings and approximately 140 private moorings.

Problems caused by vessel wash were highlighted from the perspective of safety of other waterway users and concerns about wash contributing to riverbank erosion in some locations. Complaints relating to vessel wash in the region was one of the top 5 complaint types received by NSW Road and Maritime Services between 2009 and 2013. Figure A-5 illustrates the only two formal "No Wash zones" between Rogans Bridge and Ulmarra, introduced to avoid creating unnecessary wash for rowers (north arm at Susan Island and immediately downstream of the Grafton Bridge).

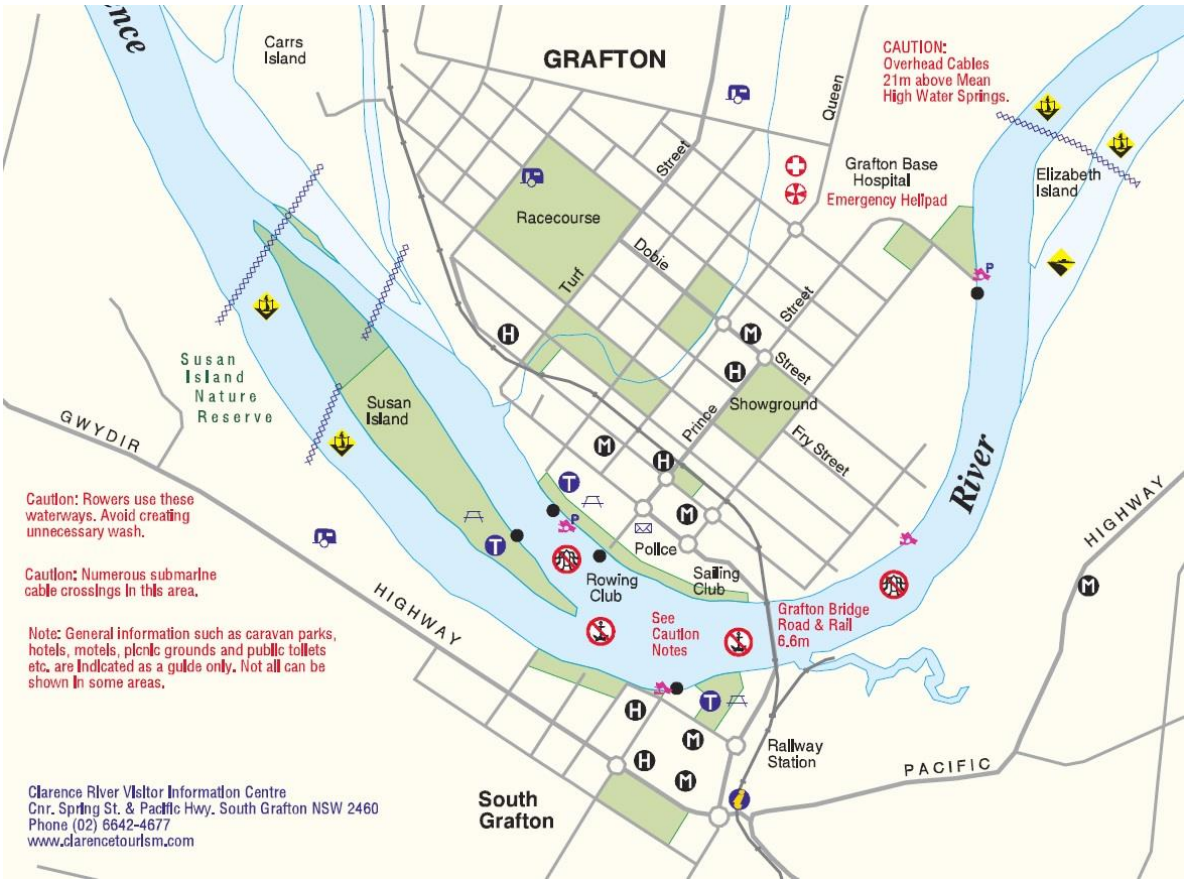


Figure A-5: Boating Safety Restrictions at Grafton (Source: NSW RMS, 2011)

In addition to the main issues of boating safety, access and storage, concern about the impact of boating activity on riverbank erosion was also a significant issue. The Consultation Draft asserted that riverbank stability is influenced by a number of factors including tidal flow, flood events, wind and wave action, cattle grazing and the presence of vegetation on riverbanks. A number of stakeholders viewed the wash generated by boating activity as a primary cause of riverbank erosion. However, other stakeholders cited a number of other catchment-wide factors that may have a more substantial impact on riverbank stability than boating activity. Some stakeholders also noted a need to improve regional boating in the Clarence River in order to support employment and tourism.

It was noted that on a section of a given waterway, evidence may suggest that it is justifiable to impose restrictions on certain types of boating activity. However, on another section of the same waterway, the same boating activity may have minimal environmental impact or an impact that can be mitigated through infrastructure solutions, such as armouring riverbank stretches.

An objective of the Maritime Management Centre is to establish and promote a number of dedicated facilities across the NSW where these types of boating activities can be concentrated (e.g. a wakeboarding park) to alleviate pressure in more environmentally sensitive areas. In the interim, NSW Roads and Maritime Services will continue to work with local user groups to manage riverbank stability, such as voluntary restrictions agreed with waterski and wakeboard vessel operators following floods on the Clarence River in 2013.

In the Consultation Draft, it was asserted that the final Regional Boating Plan for the Tweed-Clarence Valley Region will take a holistic approach to the vessel wake issue. It will account for all environmental and agricultural impacts and consider the interests of all stakeholder groups.

Key findings of the Consultation Draft include:

- The Clarence River is probably the area most affected by riverbank erosion in the Tweed-Clarence Valley Region; particularly upriver from Grafton;
- Wash generated from boating activity, particularly wakeboarding and waterskiing, is often attributed as the primary cause of riverbank erosion in the absence of scientific evidence;
- However, there are competing views, with others claiming that flood events, cattle grazing, tidal and natural wave action and lack of vegetation have a more substantial impact;
- Evidence to support future riverbank erosion mitigation measures upstream of Grafton on the Clarence River is required;
- The social and economic impacts of restricting boating activity in particular areas also needs to be taken into account, particularly given that the tourism revenue generated by these activities can make a significant contribution to local and regional economies.

Key actions (relevant to the Rogans Bridge to Ulmarra study area) for NSW Road and Maritime Services include:

- Develop a long term strategy to address wake from vessels that is informed by further evidence and a State-wide approach to promoting these activities in areas where the impacts of vessel wash can be minimised;
- In the interim, maintain existing measures at known erosion problem areas including monitoring, compliance and education;
- Review the placement and planning of navigation aids;
- Review strategies to improve user behaviours; and
- Review signage for clarity and visibility.

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).

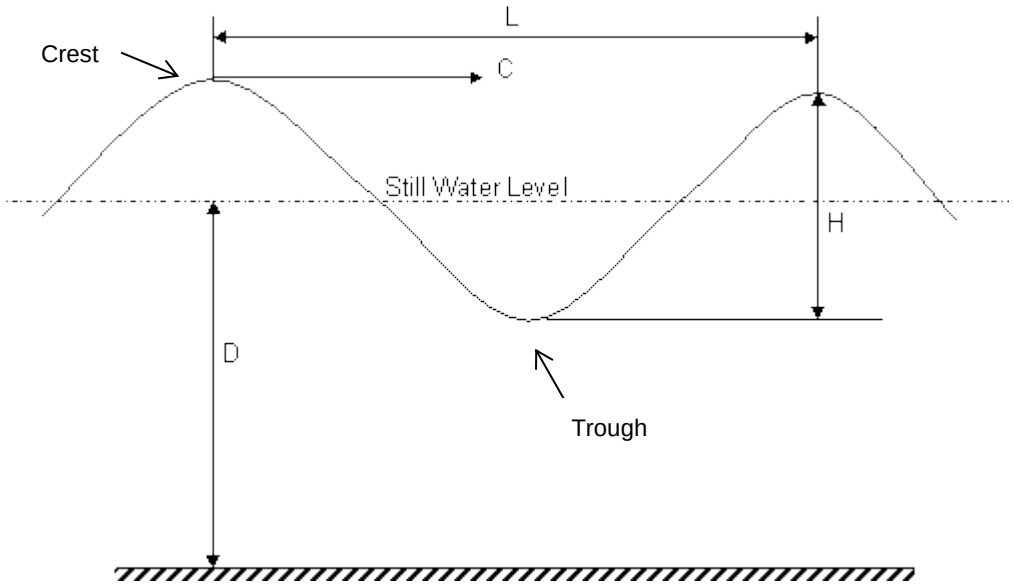


Figure B-1: Wave Characteristics

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 Clarence River, 1000 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.

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

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:

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

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

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

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

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

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 ($rank_i$).

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

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:

$$F_L = v_s/\sqrt{gL_w} \quad \text{(B-2)}$$

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:

$$F_d = v_s/\sqrt{gh} \quad \text{(B-3)}$$

where

h = water depth (m)

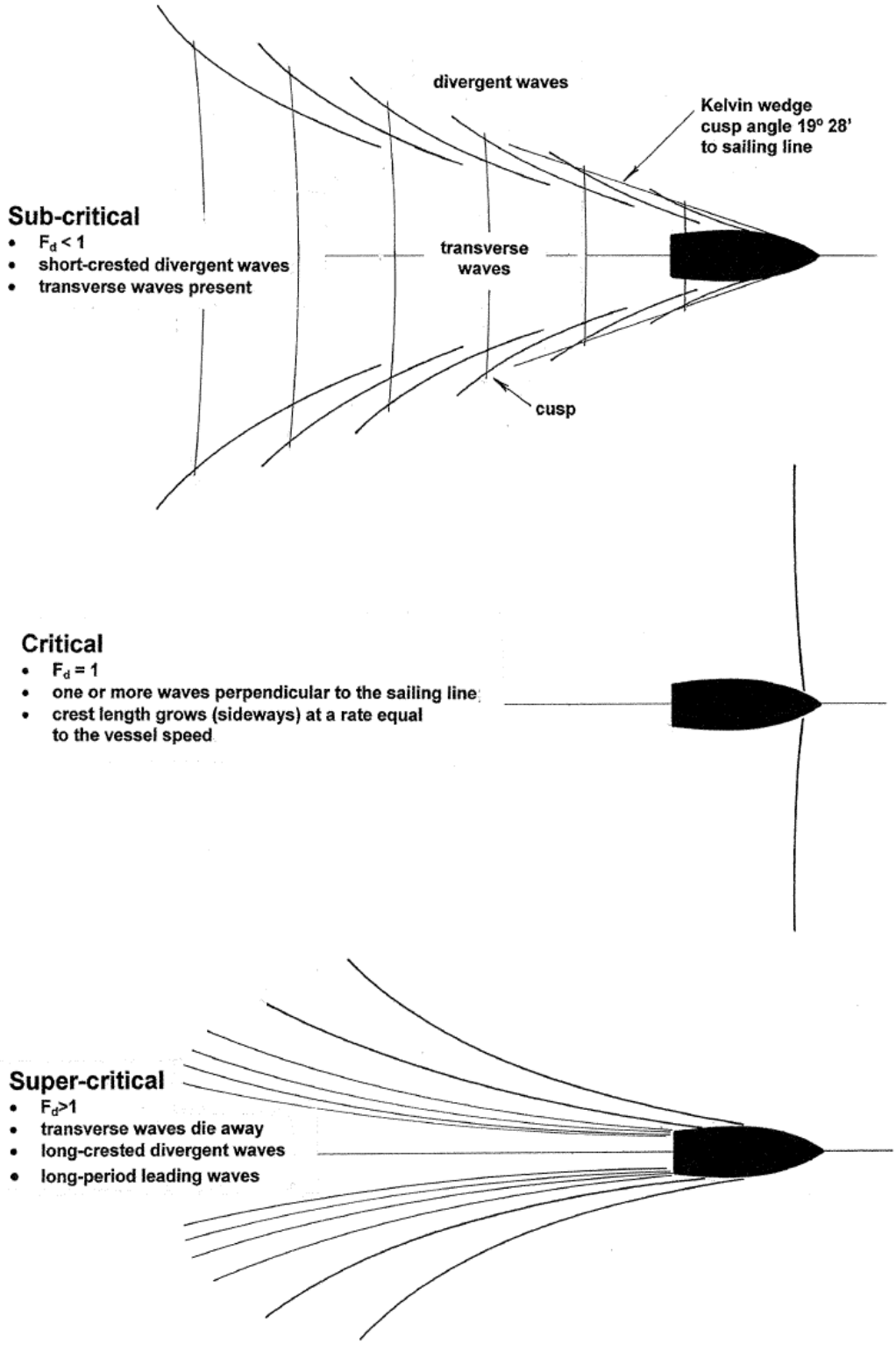


Figure B-2: Wake Wave Patterns (Source: Macfarlane and Cox, 2003)

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 ~ 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.

$$H = \gamma y^{-1/3} \tag{B-4}$$

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) Methodology

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 2 of the main body of the report and the results of the study in Section 2, with accompanying discussion and recommendations in Section 2.

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 (WRL, 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.*

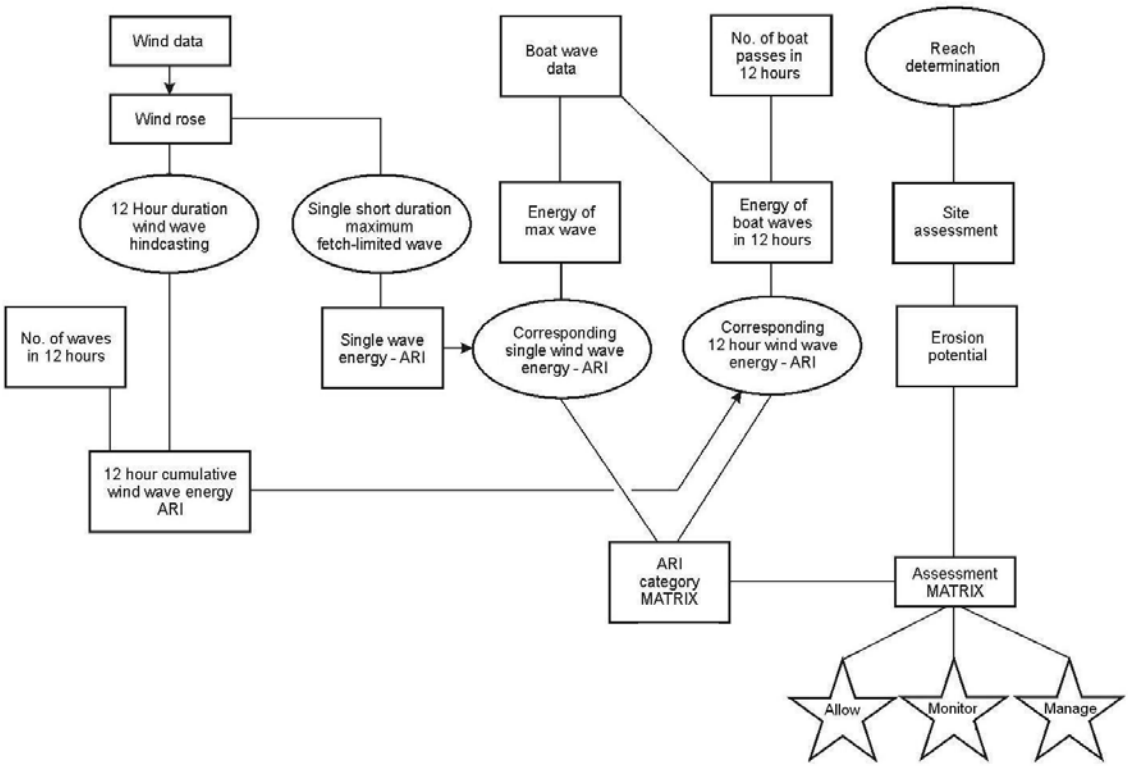


Figure C-1: Flow Diagram of the Decision Support System

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 transects is averaged for each stretch. Note that for this study 100 % of all stretches selected were assessed.

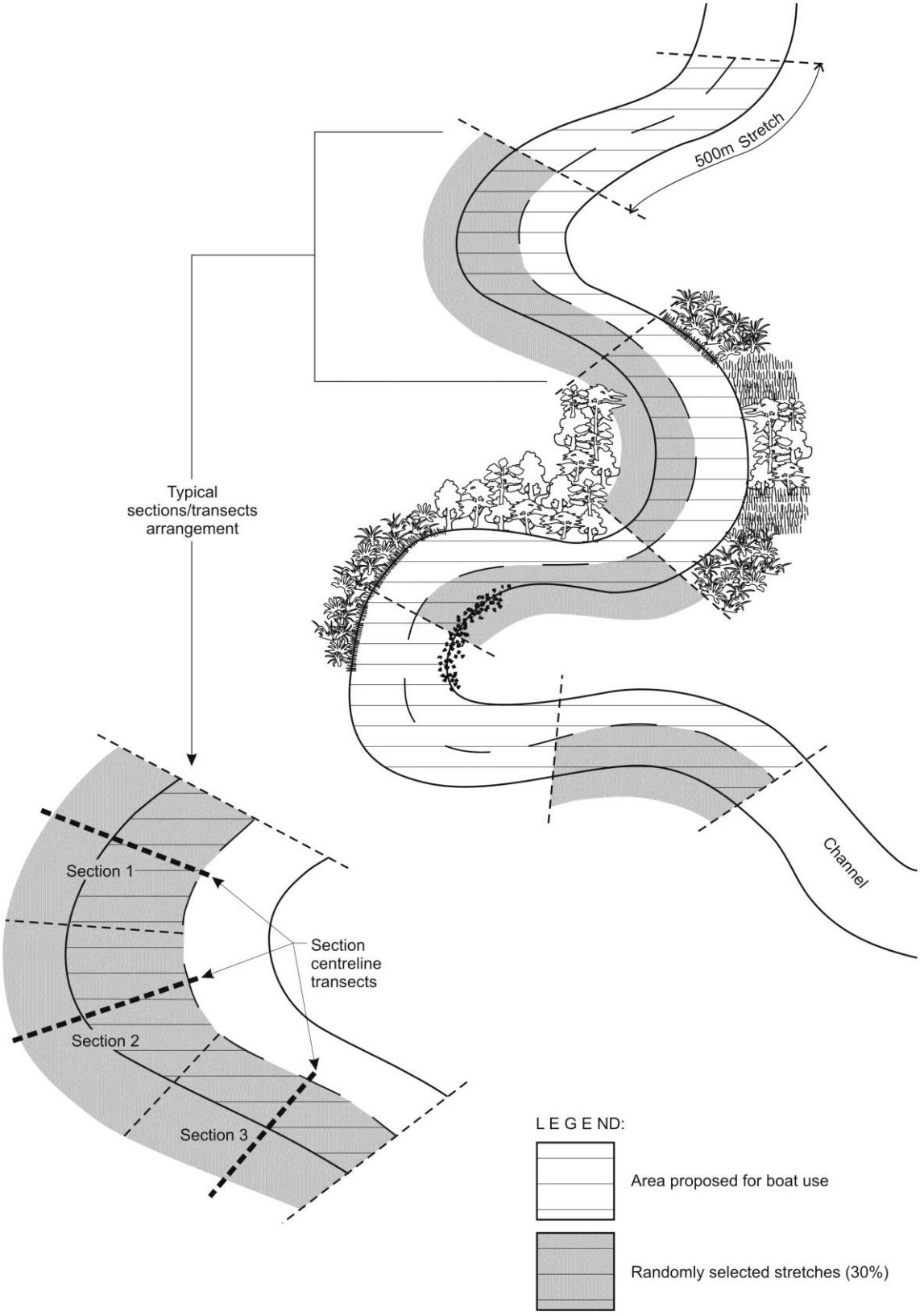


Figure C-2: Transect Locations

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 G). 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. Appendix H provides some examples of riverbanks in each of the erosion potential categories for the Clarence River study.

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 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 - Controlled Full Scale Field Testing Program for Three Wakeboarding Vessels: Summary

D.1 Introduction

The vessel generated wave energies included in the Decision Support System (DSS) are from controlled field tests conducted on Manly Dam (2004 to 2005). While the existing system includes a range of vessels commonly encountered in NSW, RVAWG requested that three additional wakeboarding vessels be added to the DSS vessel database prior to application of the DSS on the Clarence River. To this aim, a controlled full scale field testing program was conducted on the Clarence River near the Junction Hill Boat Ramp on 9 May 2014. This appendix details this boat wake wash monitoring program.

Section D.2 of this appendix outlines the methods undertaken to test the selected vessels. This includes descriptions of the site selection, tested vessels, data gathering equipment, the testing regime and data preparation. The data obtained is then analysed and a range of variables are discussed in Section D.3. Included within this analysis is a detailed description of the wake wave parameters for each vessel, which are subsequently quantitatively compared. The results of this testing program are compared with results from the existing DSS vessel database in Section D.4. Finally, the implications of the results on the Clarence River DSS investigation are outlined in Section D.5.

D.2 Experimental Design

D.2.1 Preamble

The objective of the field testing program was to accurately measure wake waves from three different wakeboarding vessels travelling at a range of speeds. The best practice methods applied in in Glamore and Hudson (2005) were again applied for measuring wake waves. These methods emphasise full scale testing of vessels using multiple wave probes deployed at distinct distances from a sailing line at a location without strong currents or wind energy with water sufficiently deep so that the waves are not depth affected. Importantly, this method is repeatable and allows for subsequent comparison of wake waves without external impeding factors and is enhanced by extensive quality assurance checks. This section outlines the methodology employed to measure the various vessels, the characteristics of the study site, the vessels tested and the quality assurance checks.

D.2.2 Site Location

The site location was approximately 250 m upstream of the Junction Hill Boat Ramp (see Figure D-1). This site was selected from a range of possible testing locations because:

(i) The river was moderately deep throughout (i.e. waves would not be depth affected but it was shallow enough for wave probe stations to be deployed);
(ii) The river bed at the site was very even (i.e. the water depth was spatially constant);
(iii) The river width was sufficient for deploying a sailing line and three wave probe stations;
(iv) The site is partially sheltered from wind and, as such, the measurements were not greatly influenced by background noise;
(v) During the test program, the site was not influenced by strong currents that would affect the measurements;

(vi) The sloping shoreline (composed of complex sediments and reeds) absorbed the majority of the wave energy, thereby eliminating wave reflection (which would be measured by the wave probes);

(vii) The site is located in a straight stretch of the river provided an optimal sailing line for the approaching vessels; and

(viii) At the time of the field testing program, erosion was observed at riverbank sections in the vicinity of the site location.

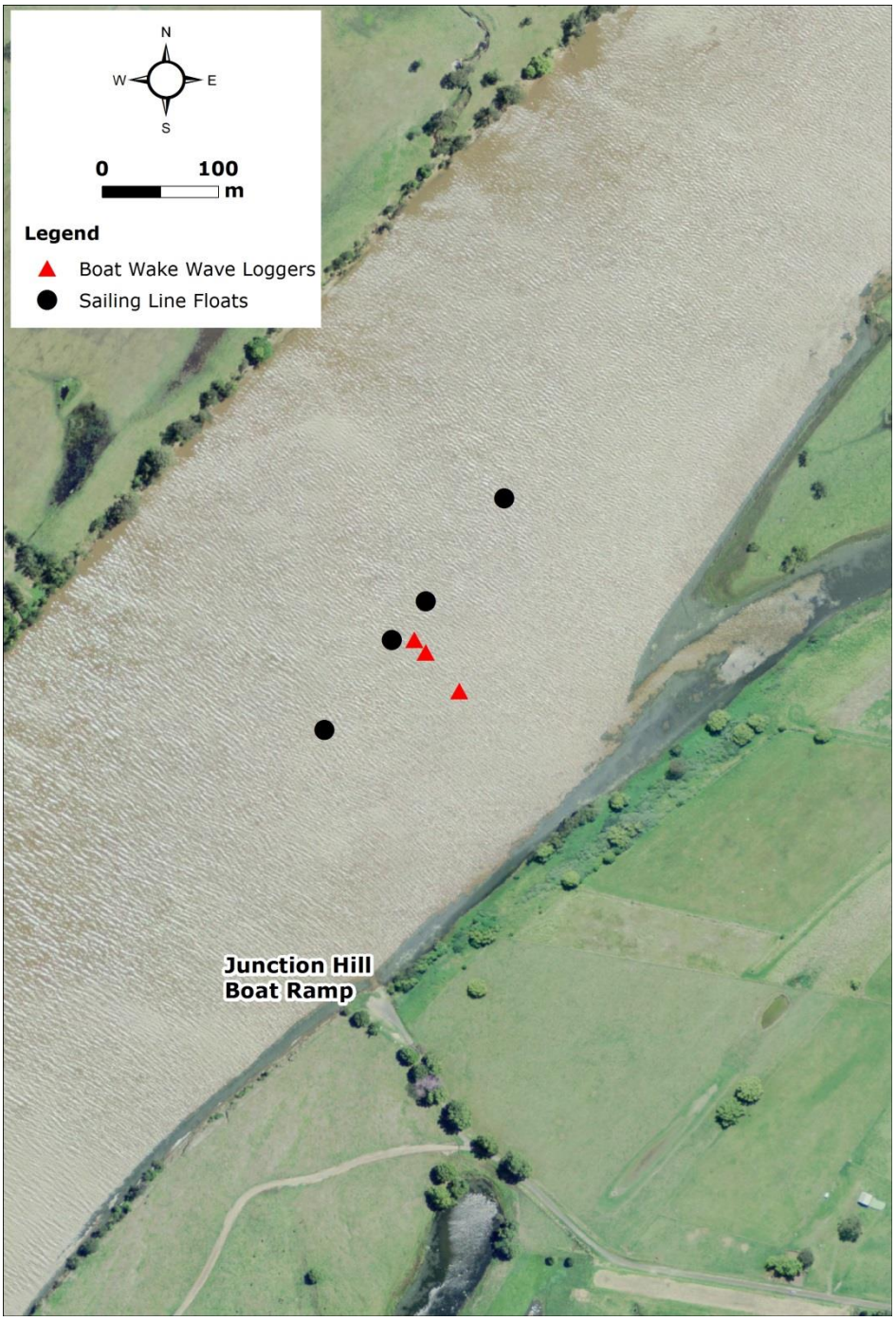


Figure D-1: Equipment Layout

D.2.3 Field Investigation

To measure the propagation of a wave train from a test vessel, an array of equipment was deployed across the site. A 250 m sailing line was set-up using four floating buoys. At distances of 22, 35 and 75 m from the sailing line, three submersible wave probes were deployed. Each probe was a battery powered RBRduo TD pressure transducer which logged data internally at 6 Hz (Figure D-2). These wave probes were secured to a portable mounting rig composed of modular pipe lengths and a "pod" (a large weight with stabilising feet) at its base (Figure D-3). Following deployment, GPS waymarks were taken at each sailing line float and each wave probe.

Figure D-2: RBRduo Wave Probe

Figure D-3: Wave Probe Deployment

During the testing program, two 'Control' vessels were anchored approximately 50 m downstream and upstream of the sailing line. The downstream 'Control' vessel used a calibrated radar gun to check the speed of an approaching/departing vessel prior to it passing the line of wave probes. Note that vessel testing was undertaken alternatively in both directions; upstream and downstream (except for wakesurf testing which was only undertaken in the downstream direction). A laser rangefinder was used to accurately calculate distance between the wave probes over water.

The weather conditions throughout the testing program were considered ideal. Winds at the site varied between calm and up to 5 knots in speed. There was no rain during the vessel tests. The testing program was undertaken on a falling tide; currents were slack at commencement (on approximately high tide) and directed weakly downstream at its conclusion.

D.2.4 Vessels Tested

For this investigation, three wakeboarding vessels were tested (Table D-1 and Figure D-4, D-5 and D-6). During testing, each boat was operated by an independent boat captain familiar with the vessel on one day (9 May 2014). Each boat was tested under a range of trim and ballasting arrangements.

Table D-1: Vessels Tested

Vessel ID	Make-Model	Engine (hp)	Length-beam (m)	Boat Type Wake/Ski	Speed (knots) at Critical Froude F_{nl}=0.5
Boat 1	Malibu Wakesetter VLX (2014)	Indmar 409	6.55/2.53	Wake	7.8
Boat 2	Tigé RZ2 Platinum Edition (2011)	PCM 450	6.71/2.59	Wake	7.9
Boat 3	Super Air Nautique G23 (2014)	PCM 409	7.01/2.59	Wake	8.1

Figure D-4: Boat 1 - Malibu Wakesetter VLX (2014)

Figure D-5: Boat 2 - Tigé RZ2 Platinum Edition (2011)

Figure D-6: Boat 3 - Super Air Nautique G23 (2014)

D.2.5 Testing Protocols

To obtain a statistically robust data set, a comprehensive testing program was developed. Each vessel was tested at a complete range of speeds including 4, 8, 10, 14, 19, 24 and 30 knots. For reference, these speeds are converted to miles/hr and km/hr in Table D-2. All vessels were tested with full ballasts (except 10 and 30 knots), without towing a rider and with 1 to 4 people onboard. Biased ballasting was used at 10 knots to undertake an examination of waves generated in association with wakesurfing (an alternative active to wakeboarding). Empty ballasting was used at 30 knots for comparison with waves generated by waterski vessels at their operational speed. For each testing protocol developed, the selected vessel was tested on at least six (6) replicate runs (except at 10 and 30 knots with only 3 runs each). This resulted in a total of 36 test runs per vessel.

Table D-2: Speeds Used During Field Testing Program

Knots	Miles/Hour	Kilometres/Hour
4	4.6	7.4
8	9.2	14.8
10	11.5	18.5
14	16.1	25.9
19	21.8	35.2
24	27.6	44.4
30	34.5	55.6

D.2.6 Data Preparation

Following the field testing program, the pressure sensor data from each wave probe was downloaded. Initially, a high-pass filter (>0.25 Hz) was applied to the raw pressure data to remove the tidal signal. Then the raw pressure data was converted to water surface elevation time series using the technique of Nielsen (1989), reproduced in Equation D-1.

$$\hat{\eta}_n = \frac{p_n}{\rho g} exp\left[A\left(\frac{y_p}{D}\right)\left(\frac{-p_{n-M}+2p_n-p_{n+M}}{p_n g(M\delta)^2}\right)\left(D+\frac{p_n}{\rho g}-y_p\right)\right] \quad \text{(D-1)}$$

where

$\hat{\eta}_n$ = water surface elevation corresponding to the *n*th central gauge pressure reading (m)
p_n = the *n*th central gauge pressure reading (Pa)
ρ = water density (998 kg/m^3)
g = acceleration due to gravity (9.81 m/s^2)
M $\approx \frac{\sqrt{\frac{D}{g}}}{\delta}$
= 3 (-)
δ = sampling period of the data (1/6 s ≈ 0.17 s)
$A\left(\frac{y_p}{D}\right)$ = $0.67 + 0.34\frac{y_p}{D}$ (-)
y_p = height of the pressure transducer above the river bed (m)
D = water depth (m)

Note that the water depth at each wave probe varied between 4.2 and 3.7 m on a falling tide during the field testing program. Similarly, the wave probes were located between 1.0 and 0.5 m below the water surface during this time.

The converted water surface elevation data was normalised to a distance off centreline and low-pass filtered (<2Hz) to remove high energy wind noise. A series of customised program codes were used to analyse the data for a range of wave parameters including maximum wave height (H_{max}), wave period of the H_{max} wave (T_{peak}), wave energy of the H_{max} wave (*Energy* H_{max}), total wave energy of the wave train (E_{tot}), number of waves and other variables. A total of 108 data sets (vessel runs) were obtained from the field trials. However, wave parameters were not able to be derived from the 18 vessel runs at 4 knots due to the very small wave wakes produced (i.e. it was not possible to differentiate between boat wake waves and small wind waves for these tests).

To remove the influence of small wind waves present in the boat wake data, the "significant" wave height was set to 0.04 m (as with Glamore and Hudson, 2005). That is, the minimum value considered in boat wake wave analysis was considered to be 0.04 m and waves with heights smaller than this were excluded from calculations.

D.3 Results

D.3.1 Data Visualisation

Time-history plots of wake waves were generated for each vessel run. The individual plots from each wave probe were stacked to provide a graphical representation of the wave train evolution over time and distance. From these plots, all the required wave characteristics including outlined in Section D.2.6 were determined. The resultant plots were catalogued by the test number with the first test of the day equating to Test 1 and the last as Test 108.

To help illustrate the findings from the study, a wave trace from each boat traveling at the same speed is shown in Figures D-7, D-8 and D-9. The stacking of slides in this manner provides an insight into the boat wake wave dynamics. In all cases, the top (red) line indicates the probe closest to the sailing line (22 m), while the middle (green) line indicates the wave by the time it reaches the middle probe (35 m) and the bottom (blue) line shows the wave at 75 m from the sailing line. Note that the wave traces from all tests (except the 18 vessel runs at 4 knots) are reproduced in full in Appendix E.

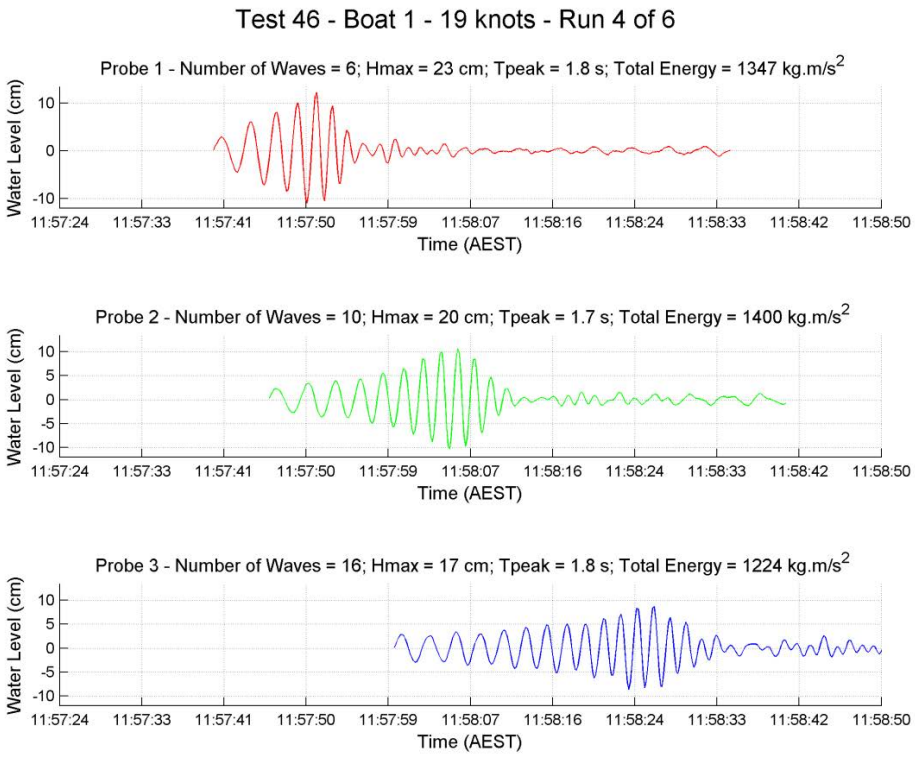


Figure D-7: Example Boat Wake Wave Trace - Boat 1 (19 knots)

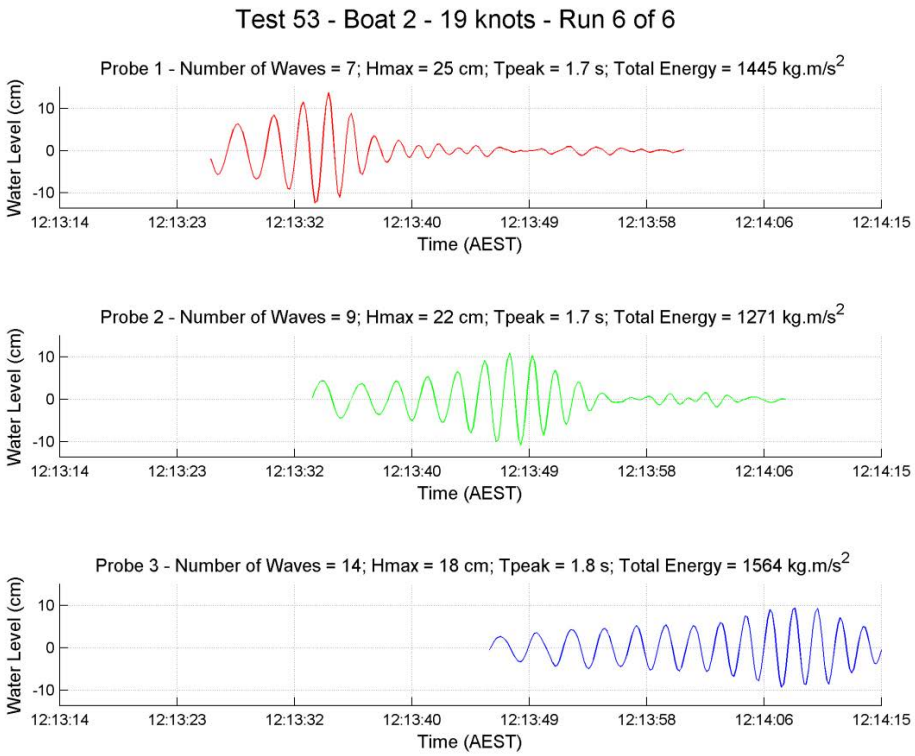


Figure D-8: Example Boat Wake Wave Trace - Boat 1 (19 knots)

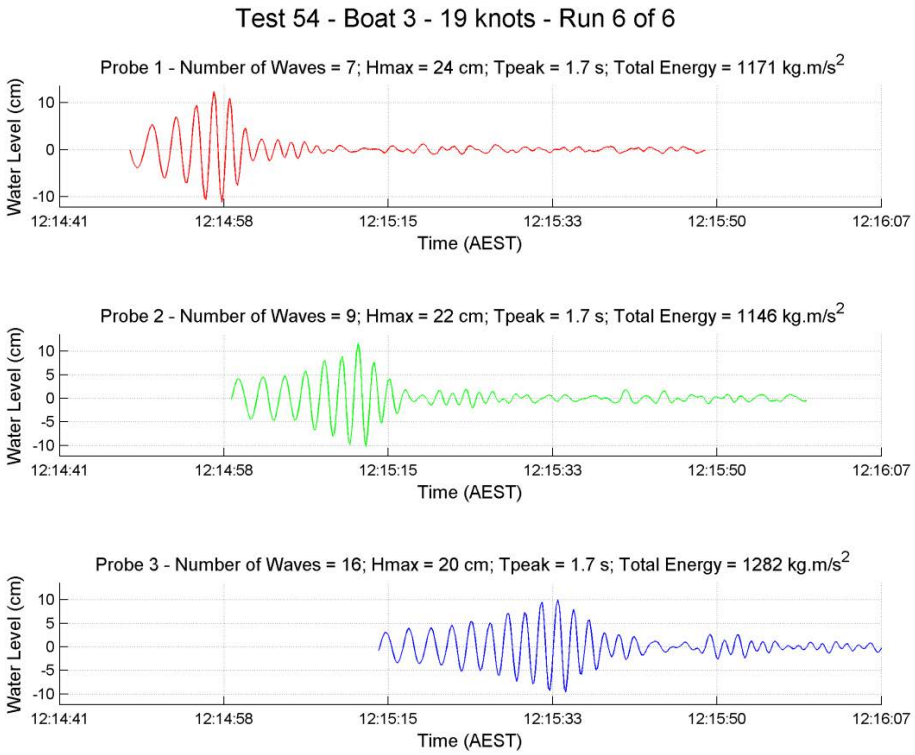


Figure D-9: Example Boat Wake Wave Trace - Boat 1 (19 knots)

It is apparent from Figures D-7, D-8 and D-9 that all boats tested, regardless of their specific design, generate a similar wave trace for a given speed. At 22 m the wave is typically characterised by a large H_{max}, with waves bunched in a tight wave train. As the wave train travels and disperses, generally the number of waves increases and the wave height attenuates. This becomes more apparent with increasing distance from its point of generation. By the final probe (approximately 11.0 boat lengths) the wave train is fully developed and, while further attenuation of the wave height is likely, the wave period should persist in deep water. The wave height, however, may again increase as the wave shoals onshore. The speed of the wave train, or celerity, and the shape of the wave as it travels from one probe to the next is difficult to compare from this figure as the time axis is slightly different for each vessel.

In general, Figures D-7, D-8 and D-9 illustrate that while wave height attenuates with distance, wave period remains fairly unchanged. The wave traces also indicate that the total wave train energy remains largely constant between probes.

D.3.2 Wave Analysis

Preamble

The characteristics of the individual wave trains (height, period, energy, etc.) were compared by grouping the individual runs from each wave probe and averaging the data. These averages provide a better indication of the expected conditions from a vessel than individual readings. All averages were based on a sample of at least 6 runs (except at 10 and 30 knots with only 3 runs each).

Maximum Wave Height

Maximum wave height is the height of the highest wave in the wave train. Since maximum wave height decreases with distance from the sailing line, the maximum wave height is measured at the wave probe closest to the sailing line (22 m). Table D-3 summarises the average maximum wave height (H_{max}) *measured at this probe* for the three boats tested. An average H_{max} across all three vessels tested is also included. The highest average H_{max} values were recorded at 8 knots for wakeboarding activities and 10 knots for wakesurfing activities.

Table D-3: Average Maximum Wave Height (H_{max})

Speed (knots)	No. of Tests per Boat	Boat 1	Boat 2	Boat 3	Average of Boats 1-3
		Malibu Wakesetter VLX (2014)	Tigé RZ2 Platinum Edition (2011)	Super Air Nautique G23 (2014)	
		Average Maximum Wave Height, H_{max} (m)			
8	6	0.26	0.27	0.29	**0.27**
10	3	0.32	0.43	0.40	**0.38**
14	6	0.24	0.24	0.24	**0.24**
19	6	0.20	0.23	0.23	**0.22**
24	6	0.16	0.21	0.20	**0.19**
30	3	0.11	0.17	0.12	**0.13**

Peak Wave Period

Peak wave period is used in this study to describe the wave period of the highest wave (H_{max}) in the wave train. The peak wave period remains relatively stable throughout the spreading of the wave train (i.e. the peak wave period at each wave probe is very similar). Table D-4 summarises the average peak wave period (T_{peak}) *measured at the wave probe closest to the sailing line (22 m)* for the three boats tested. An average T_{peak} across all three vessels tested is also included. The speeds (8 and 10 knots) at which the largest peak wave periods were recorded largely corresponded with the speed at which the highest waves were generated.

Table D-4: Average Peak Wave Period (T_{peak})

Speed (knots)	No. of Tests per Boat	Boat 1	Boat 2	Boat 3	Average of Boats 1-3
		Malibu Wakesetter VLX (2014)	Tigé RZ2 Platinum Edition (2011)	Super Air Nautique G23 (2014)	
		Average Peak Wave Period, T_{peak} (s)			
8	6	1.91	2.09	2.07	**2.02**
10	3	1.91	2.11	2.05	**2.02**
14	6	1.80	1.85	1.92	**1.85**
19	6	1.79	1.76	1.71	**1.75**
24	6	1.63	1.60	1.60	**1.61**
30	3	1.53	1.67	1.52	**1.57**

Energy of the Maximum Wave Height

The energy of the maximum wave height (*Energy* H_{max}) is a measure of the energy per unit length of the single highest wave in a wave train. Table D-5 summarises the average energy of the maximum wave height (*Energy* H_{max}) *measured at the wave probe closest to the sailing line (22 m)* for the three boats tested. An average *Energy* H_{max} across all three vessels tested is also included. The highest average *Energy* H_{max} values were recorded at 8 knots for wakeboarding activities and 10 knots for wakesurfing activities.

Table D-5: Average Energy of Maximum Wave Height (Energy H_{max})

Speed (knots)	No. of Tests per Boat	Boat 1	Boat 2	Boat 3	Average of Boats 1-3
		Malibu Wakesetter VLX (2014)	Tigé RZ2 Platinum Edition (2011)	Super Air Nautique G23 (2014)	
		Average Energy of Maximum Height, *Energy* H_{max} (kg.m/s^2)			
8	6	461	637	686	**595**
10	3	800	1,607	1,251	**1,219**
14	6	352	369	415	**379**
19	6	243	315	300	**286**
24	6	130	208	187	**175**
30	3	53	148	68	**90**

Total Wave Train Energy

The total wave train energy (E_{tot}) is a measure of the energy per unit length of wave train. The total wave train energy remains relatively stable throughout the spreading of the wave train (i.e. the total wave train energy at each wave probe is very similar). Table D-6 summarises the average total wave train energy (E_{tot}) *measured at the wave probe closest to the sailing line (22 m)* for the three boats tested. An average E_{tot} across all three vessels tested is also included. The speeds (8 and 10 knots) at which the largest total wave train energies were recorded largely corresponded with the speed at which the highest and longest waves were generated.

Table D-6: Average Energy of Maximum Wave Height (Energy H_{max})

Speed (knots)	No. of Tests per Boat	Boat 1	Boat 2	Boat 3	Average of Boats 1-3
		Malibu Wakesetter VLX (2014)	Tigé RZ2 Platinum Edition (2011)	Super Air Nautique G23 (2014)	
		Average Total Wave Train Energy, E_{tot} (kg.m/s^2)			
8	6	1,559	2,049	2,014	1,874
10	3	2,332	3,585	2,806	2,908
14	6	1,408	1,340	1,556	1,435
19	6	998	1,193	1,034	1,075
24	6	652	956	791	800
30	3	358	700	411	489

D.4 Comparison with Existing DSS Vessel Database

D.4.1 Wakeboarding Activities

The vessel generated wave energies presently included in the DSS are from controlled field tests conducted in 2004 and 2005. Two typical wave conditions associated with wakeboard activities are classified as "operating" and "maximum wave" conditions in the DSS. "Operating conditions" describe the waves generated when a vessel is towing a rider at operational speed (typically 19 knots for wakeboarding). However, maximum wave energy is not produced when wakeboarding vessels travel at "operating conditions", but rather at the slower velocity of approximately 8 knots. These are characterized in the DSS as "maximum wave" conditions and are experienced when a boat is accelerating, or slowing down from operational speed. The characteristic wave parameters for both of these typical wave conditions presently included in the DSS are reproduced in Table D-7.

Table D-7: Characteristic Boat Wake Wave Conditions Based on WRL Testing 2004-2005

Boat/Activity	Conditions	Speed (knots)	H_{max} (m)	T_{peak} (s)	Energy H_{max} (kg.m/s^2)	E_{tot} (kg.m/s^2)
Wakeboard	Maximum Wave	8	0.35	1.86	700	2,325
Wakeboard	Operating	19	0.25	1.57	293	1,138

Based on the results presented in Section D.3, the characteristic wave parameters for the three vessels tested are summarized in Table D-8.

Table D-8: Characteristic Boat Wake Wave Conditions Based on 2014 Clarence River Testing

Boat/Activity	Conditions	Speed (knots)	H_{max} (m)	T_{peak} (s)	Energy H_{max} (kg.m/s^2)	E_{tot} (kg.m/s^2)
Wakeboard	Maximum Wave	8	0.27	2.02	595	1,874
Wakeboard	Operating	19	0.22	1.75	286	1,075

The H_{max} and T_{peak} values from each of the Clarence River tests (excluding the wakesurfing runs at 10 knots) are plotted with the each of the same values from wakeboard vessel field tests conducted by WRL in 2004 and 2005 in Figure D-10.

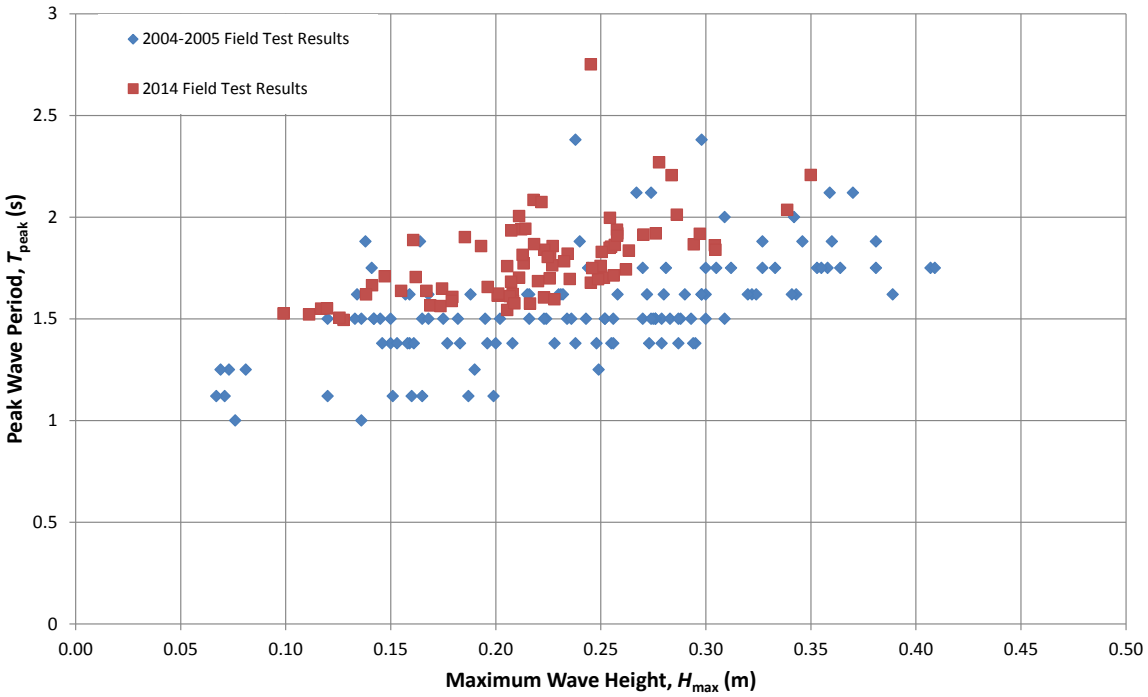


Figure D-10: Comparison of WRL 2004-05 and Clarence River 2014 Wakeboard Field Test Results

The key information used in a DSS assessment is the energy of the single highest wave in a wave train (*Energy* H_{max}) and the total wave train energy (E_{tot}). For the "maximum wave" conditions, the average wave energy values measured in the Clarence River field tests are slightly lower than those values presently included in the DSS. This appears to be because the wave energy of Boat 1 at 8 knots is lower than Boats 2 and 3 at the same speed. The *Energy* H_{max} and E_{tot} values for Boats 2 and 3 are approximately equivalent to the values presently included in the DSS. For the "operating conditions", the average wave energy values measured in the Clarence River field tests are approximately equivalent to the values presently included in the DSS. Note that the average H_{max} values in the 2014 tests are slightly lower than the 2004-2005 tests, but that the average T_{peak} values are slightly higher for both typical wave conditions.

D.4.2 Wakesurfing Activities

At the request of RVAWG, WRL undertook a preliminary examination of the Clarence River wakesurfing test results. *Prior to the commencement of this study, wave energies generated by vessels undertaking wakesurfing were not included in the DSS.*

Wakesurfing involves creating a large wake on one side of a boat that can be surfed without a tow rope. This creation of a large wake is assisted by placing the majority of the ballast near the aft corner on the side the vessel to be surfed (biased ballasting). Consequently, the wake generated off the opposite side of the boat is considerably smaller.

Wakesurfing was not intended to form a core part of the Clarence River field testing program. As such, only three (3) replicate runs at one speed (10 knots) were undertaken for each vessel. This provided a total of nine (9) measured wakesurfing results.

To expand this dataset and improve statistical robustness, seven (7) wakesurfing tests undertaken on Manly Dam by WRL between 2004 and 2005 (Glamore and Hudson, 2005), were incorporated in this study. These seven tests are comprised of three (3) runs by one boat and four (4) runs by a second vessel. Note that vessel speed was not recorded for the Manly Dam wakesurfing tests. For both the Clarence River and Manly Dam wakesurfing tests, biased ballasting was configured so that the larger wake on one side of the boat was directed towards the wave probes.

The average H_{max}, T_{peak}, *Energy* H_{max} and E_{tot} values from both wakesurfing datasets are summarized in Table D-9.

Table D-9: Average Wakesurf Boat Wake Wave Conditions

Testing Dataset	Year	Speed (knots)	No. of Tests	H_{max} (m)	T_{peak} (s)	Energy H_{max} (kg.m/s^2)	E_{tot} (kg.m/s^2)
Manly Dam	2004-05	Unknown	7	0.34	2.04	950	2,278
Clarence River	2014	10	9	0.38	2.02	1,219	2,908

The H_{max} and T_{peak} values from both wakesurfing datasets are plotted in Figure D-11. Note that the same scale as Figure D-10 has been used to emphasise the difference between the wakesurf and wakeboard test results.

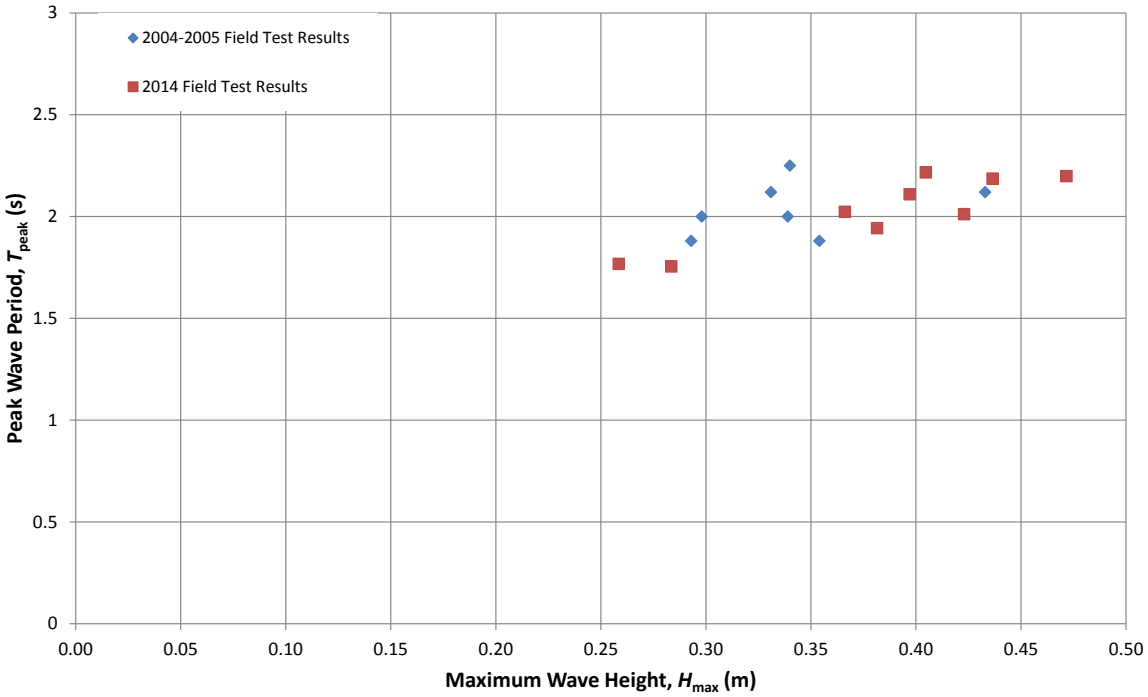


Figure D-11: Comparison of WRL 2004-05 and Clarence River 2014 Wakesurf Field Test Results

While it is acknowledged that there is a limited number of wakesurf field test results available, comparison of these two datasets indicates that the parameters of the large wake waves associated with wakesurfing are reproducible. *On a preliminary basis, a new vessel activity, wakesurf "operating conditions", was added to the DSS database.* The characteristic wave parameters for this wave condition are reproduced in Table D-10. Note that an empirical relationship fitted between the energy of the maximum wave height and the total energy of the wave train for the wakesurf activity (independent of wakeboard and waterski results) was also prepared for use in the DSS.

Table D-10: Characteristic Wakesurf Boat Wake Wave Conditions (Preliminary)

Boat/Activity	Conditions	Speed (knots)	H_{max} (m)	T_{peak} (s)	Energy H_{max} (kg.m/s^2)	E_{tot} (kg.m/s^2)
Wakesurf	Operating	10	0.36	2.03	1,102	2,575

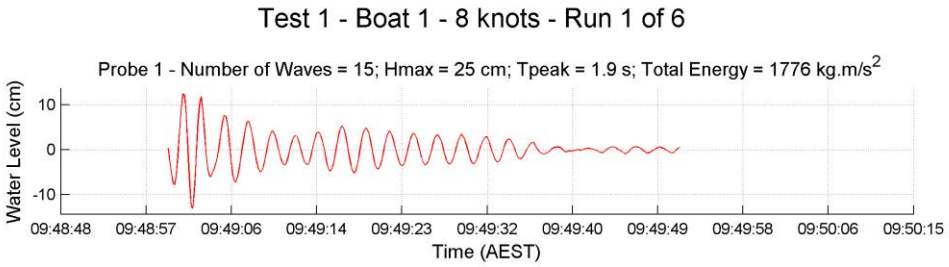
The wave energy associated with the single maximum wave height (*Energy* H_{max}) in the preliminary wakesurf "operating conditions" is approximately 3.8 times wakeboard "operating conditions" and 1.6 times wakeboard "maximum wave" conditions. However, the wakesurf wave conditions developed during this study remain preliminary and *it is recommended that additional wakesurfing field measurements be undertaken to improve statistical robustness.*

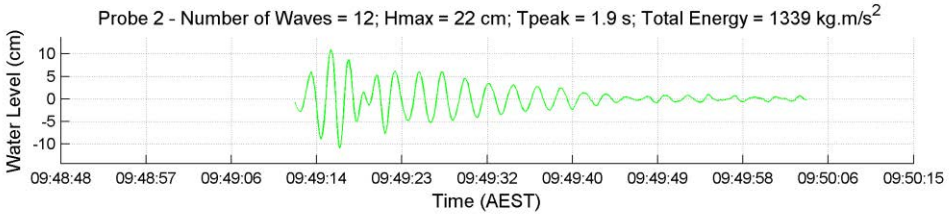
D.5 Implications for the Clarence River DSS Investigation

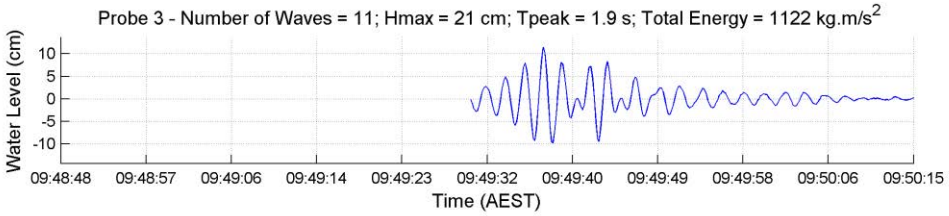
On the basis of the 2014 field testing program with three additional vessels, WRL adopted the following three resolutions prior to application of the DSS on the Clarence River:

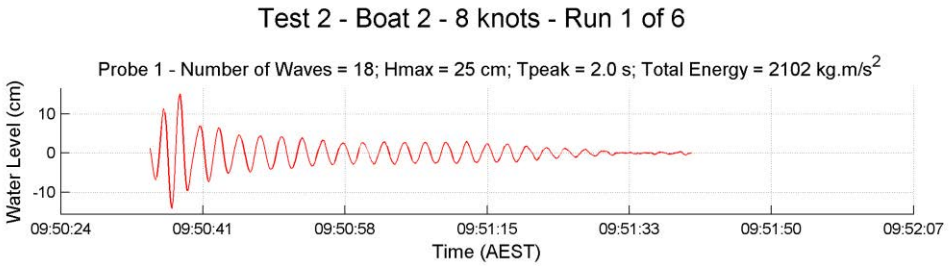
- **The characteristic "maximum wave" conditions for wakeboard vessels remain unchanged;**
- **The characteristic "operating conditions" for wakeboard vessels remain unchanged;**
- **The test results for the three additional vessels were added to the DSS vessel database** which slightly improved the correlation of the empirical relationship fitted between the energy of the maximum wave height and the total energy of the wave train; and
- **A new vessel activity, wakesurf "operating conditions", was added on a preliminary basis.**

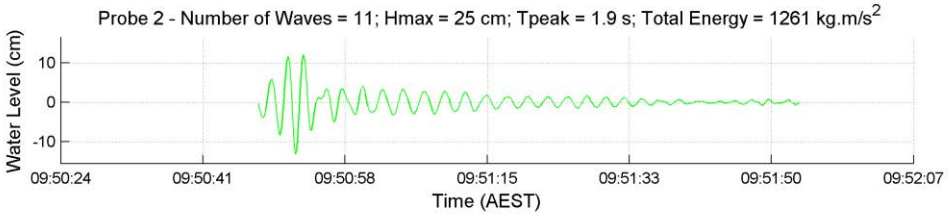
Appendix E - Controlled Full Scale Field Testing Program for Three Wakeboarding Vessels: Wave Traces

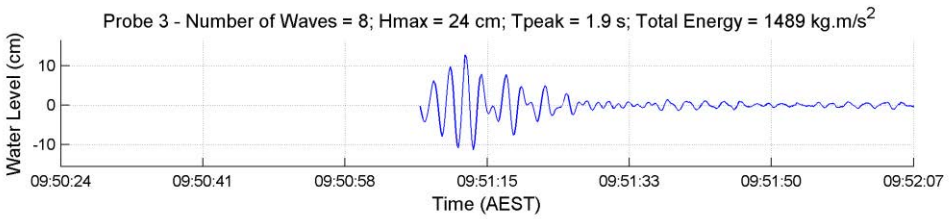


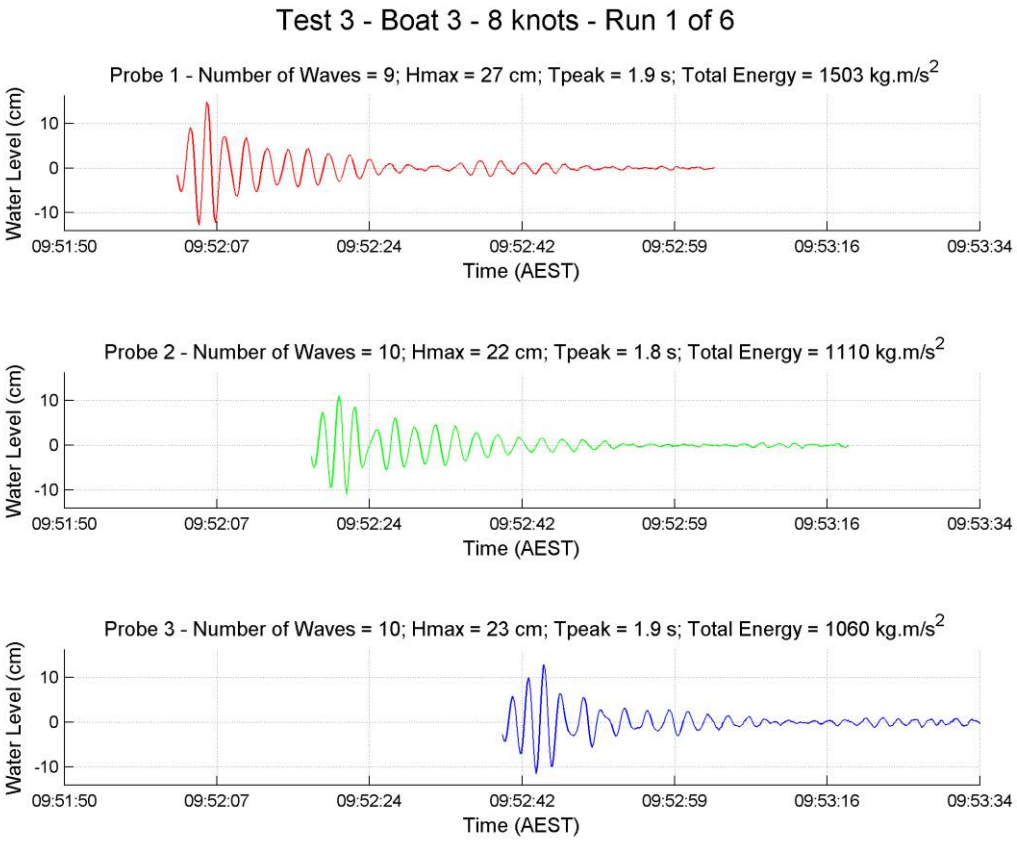


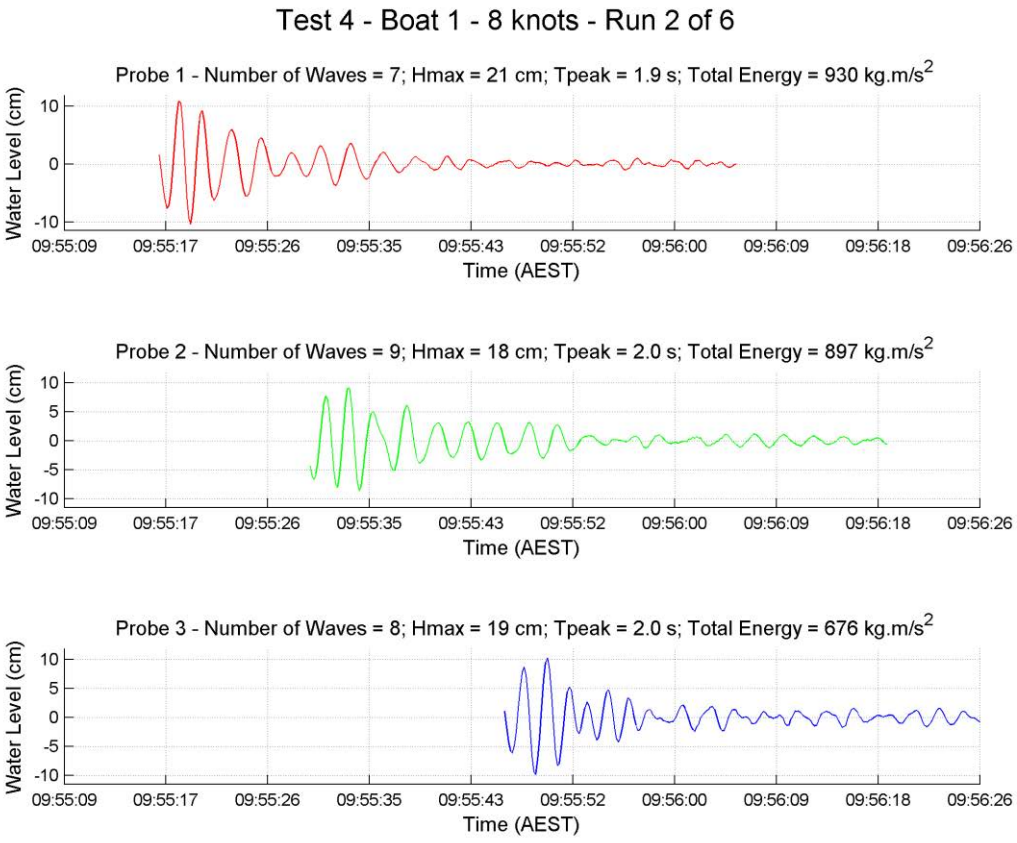




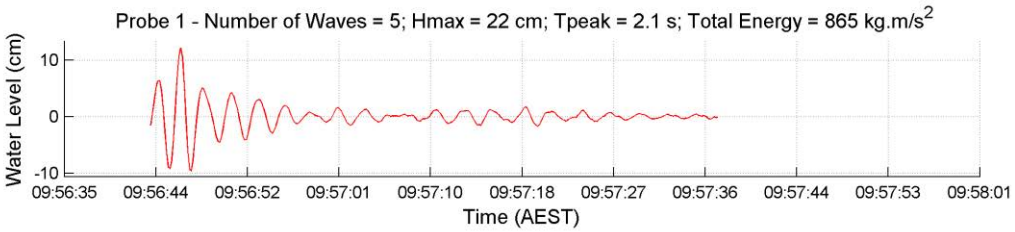


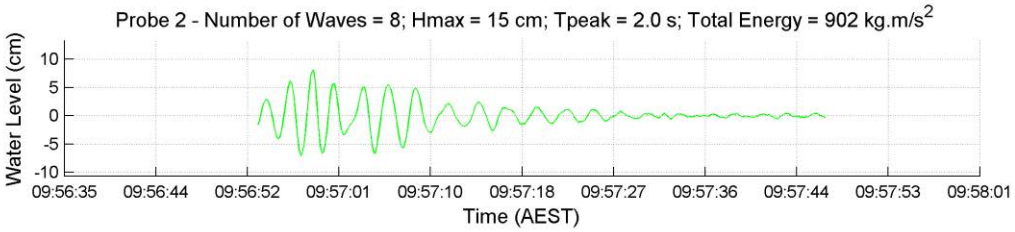


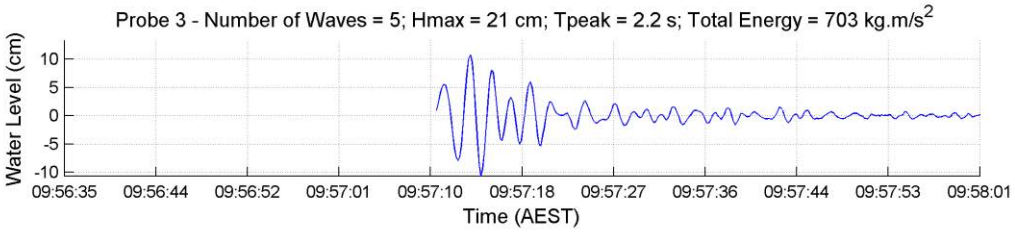

Test 3 - Boat 3 - 8 knots - Run 1 of 6
Probe 1 - Number of Waves = 9; Hmax = 27 cm; Tpeak = 1.9 s; Total Energy = 1503 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 22 cm; Tpeak = 1.8 s; Total Energy = 1110 kg.m/s2
Probe 3 - Number of Waves = 10; Hmax = 23 cm; Tpeak = 1.9 s; Total Energy = 1060 kg.m/s2
Water Level (cm)
10
0
-10
09:51:50
09:52:07
09:52:24
09:52:42
09:52:59
09:53:16
09:53:34
Time (AEST)


Test 4 - Boat 1 - 8 knots - Run 2 of 6
Probe 1 - Number of Waves = 7; Hmax = 21 cm; Tpeak = 1.9 s; Total Energy = 930 kg.m/s2
Probe 2 - Number of Waves = 9; Hmax = 18 cm; Tpeak = 2.0 s; Total Energy = 897 kg.m/s2
Probe 3 - Number of Waves = 8; Hmax = 19 cm; Tpeak = 2.0 s; Total Energy = 676 kg.m/s2
Water Level (cm)
10
5
0
-5
-10
09:55:09
09:55:17
09:55:26
09:55:35
09:55:43
09:55:52
09:56:00
09:56:09
09:56:18
09:56:26
Time (AEST)

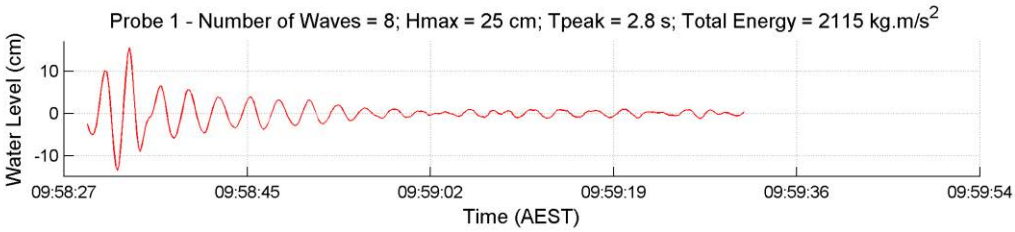
Test 5 - Boat 2 - 8 knots - Run 2 of 6

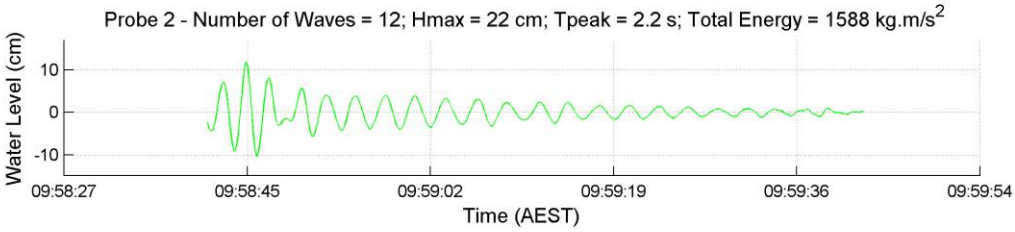


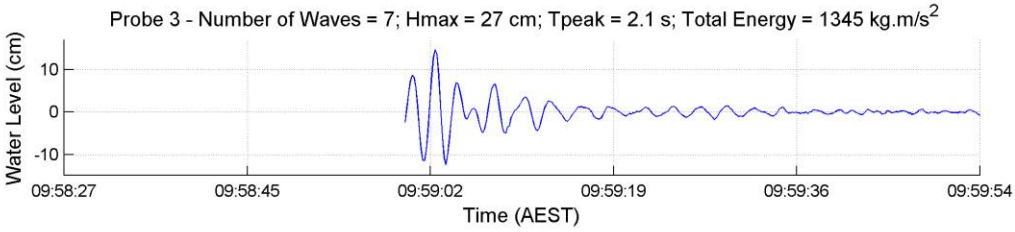




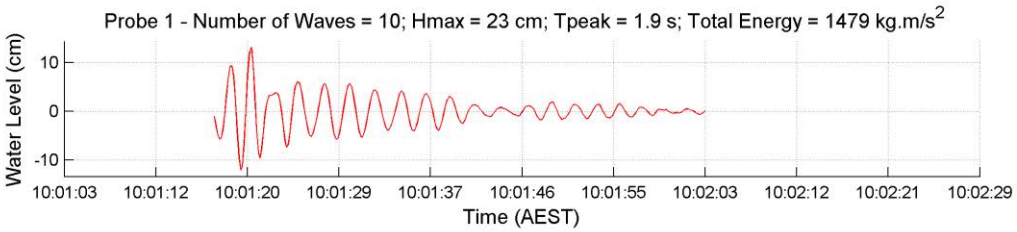
Test 6 - Boat 3 - 8 knots - Run 2 of 6

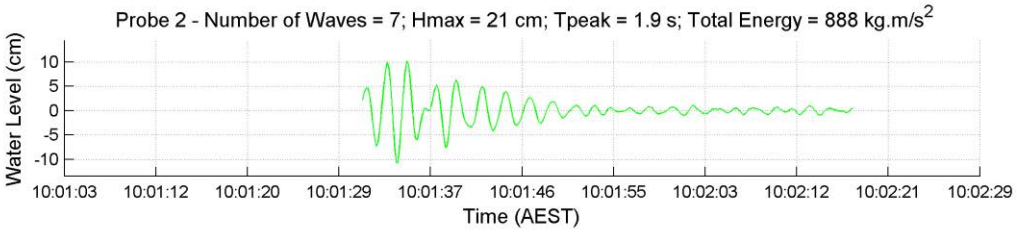


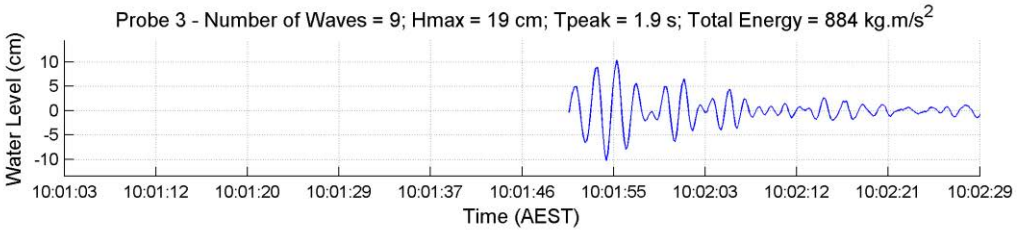




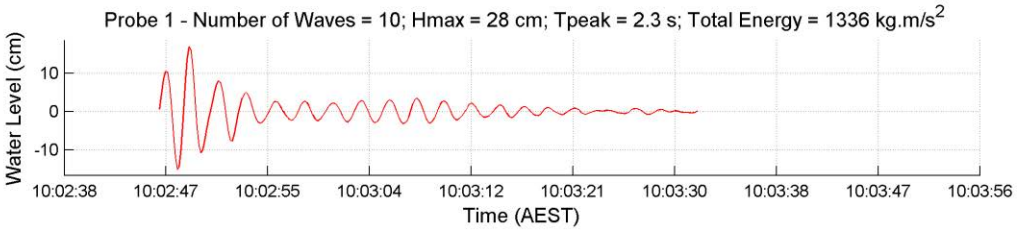
Test 7 - Boat 1 - 8 knots - Run 3 of 6

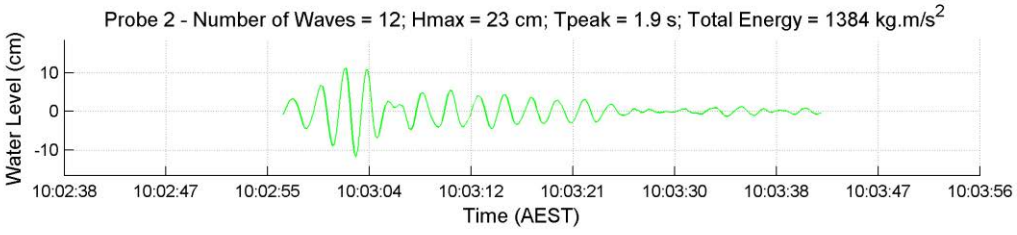


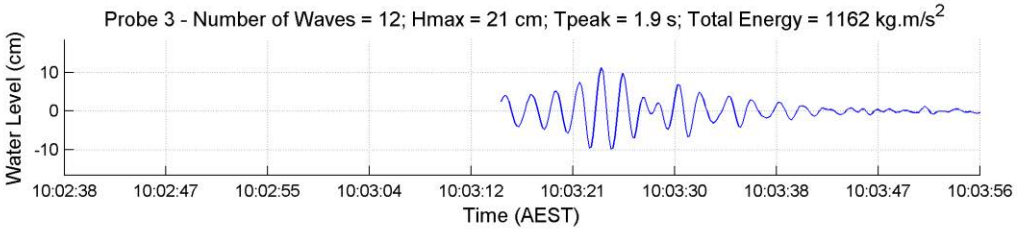




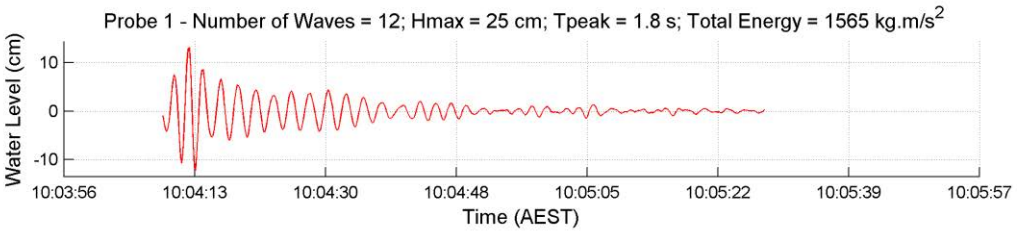
Test 8 - Boat 2 - 8 knots - Run 3 of 6

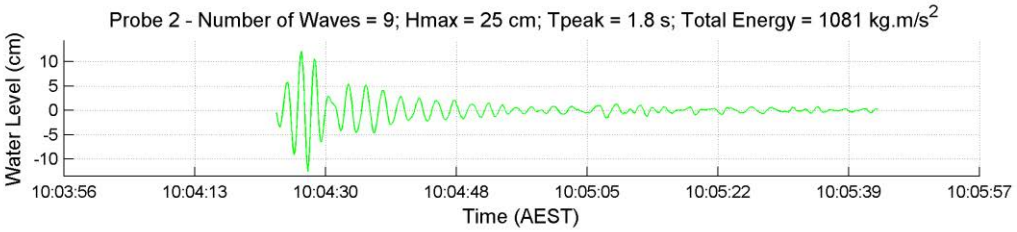


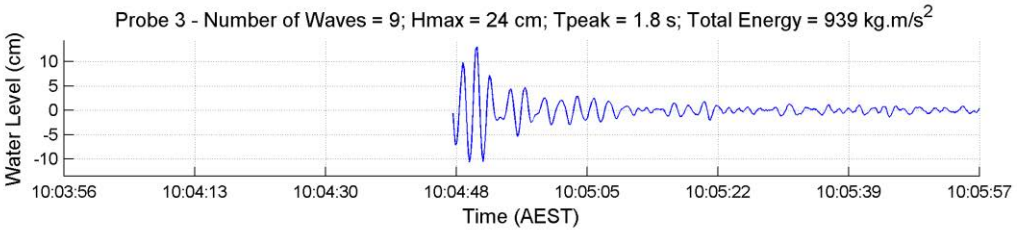




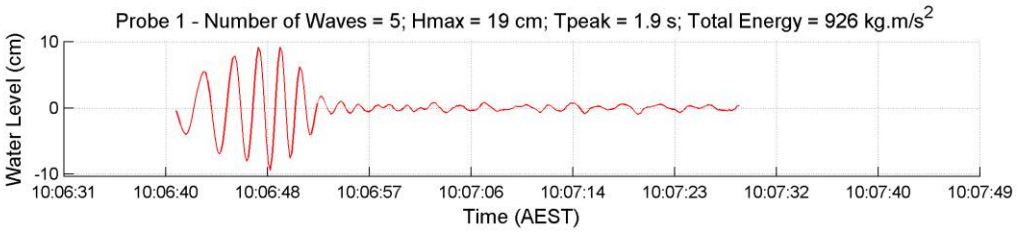
Test 9 - Boat 3 - 8 knots - Run 3 of 6

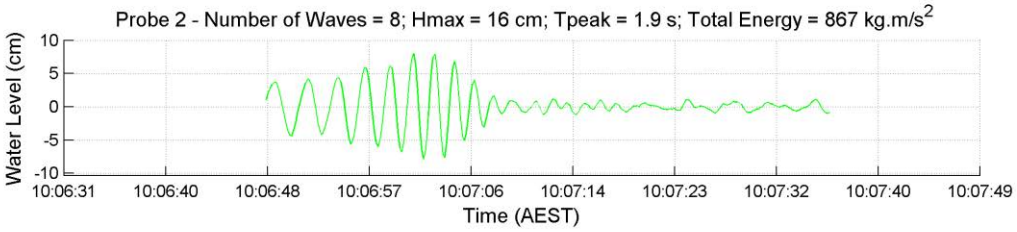


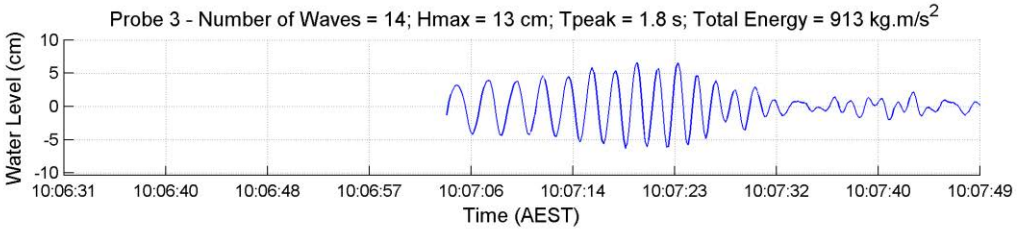




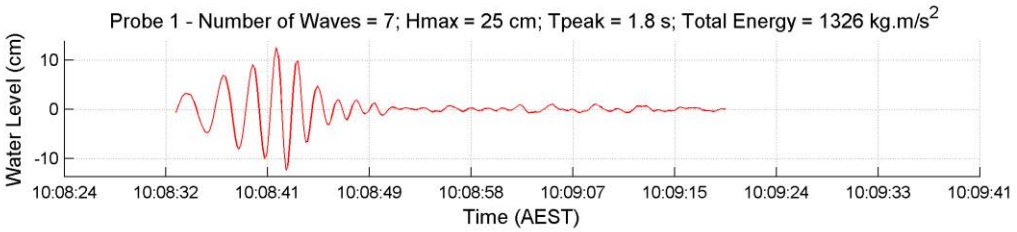
Test 10 - Boat 1 - 19 knots - Run 1 of 6

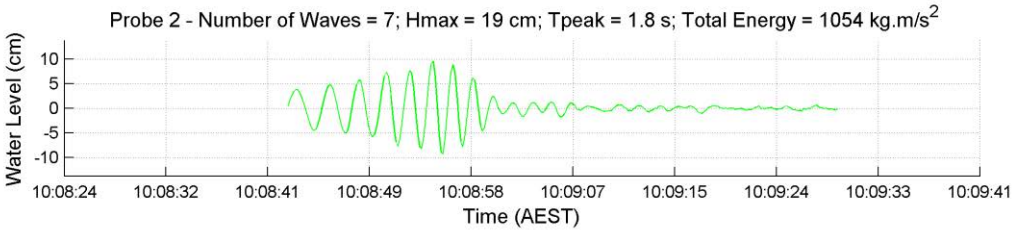


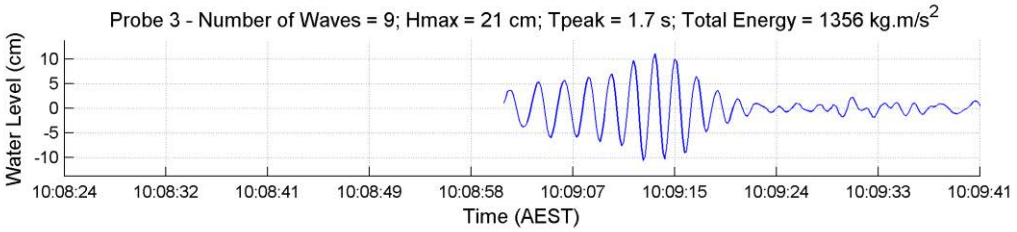




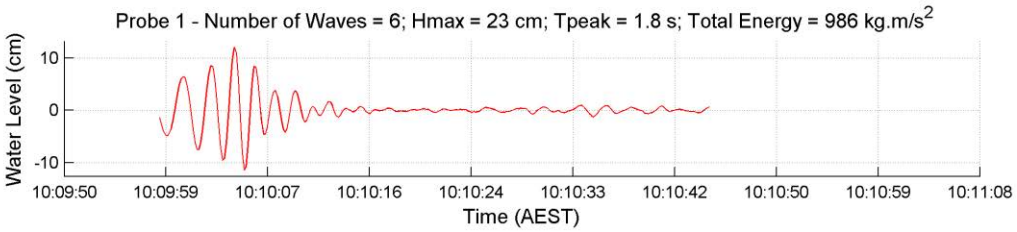
Test 11 - Boat 2 - 19 knots - Run 1 of 6

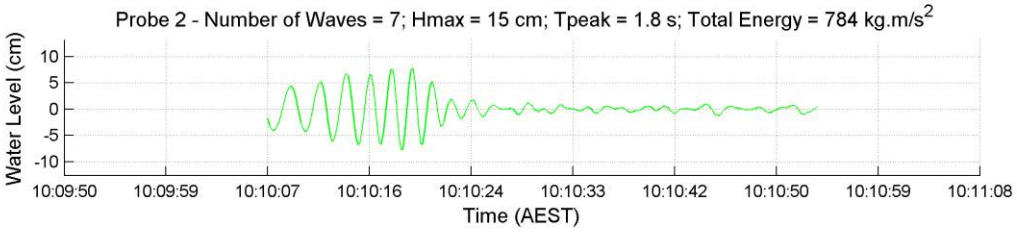


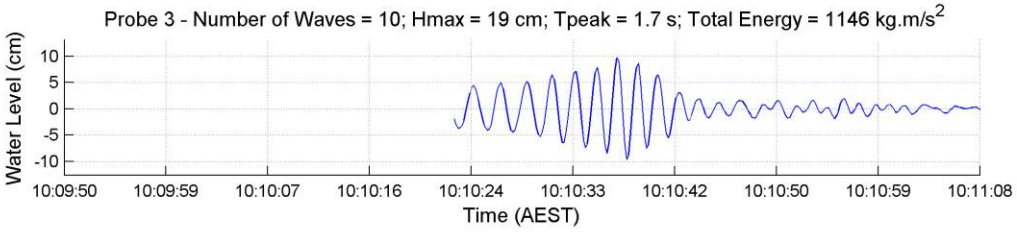




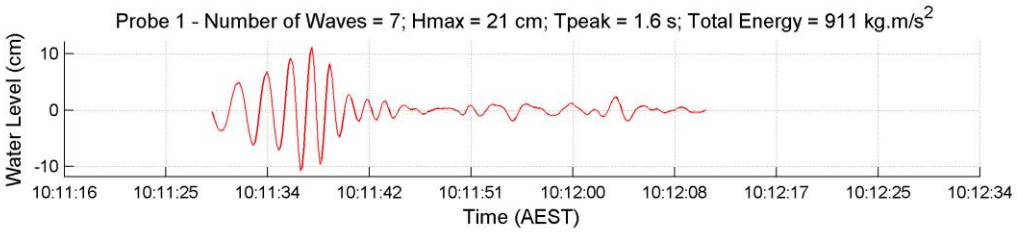
Test 12 - Boat 3 - 19 knots - Run 1 of 6

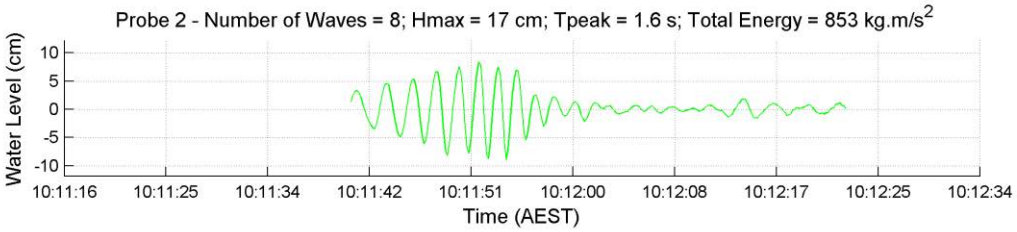


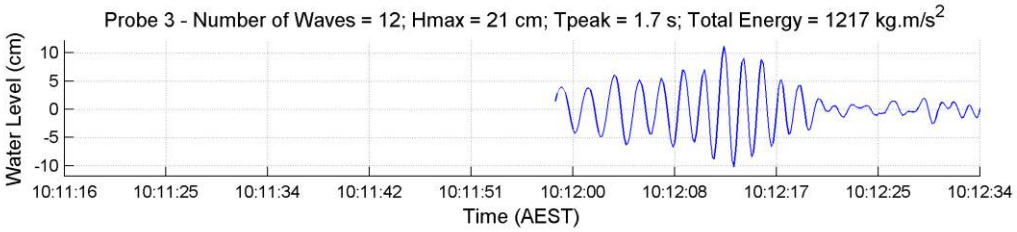




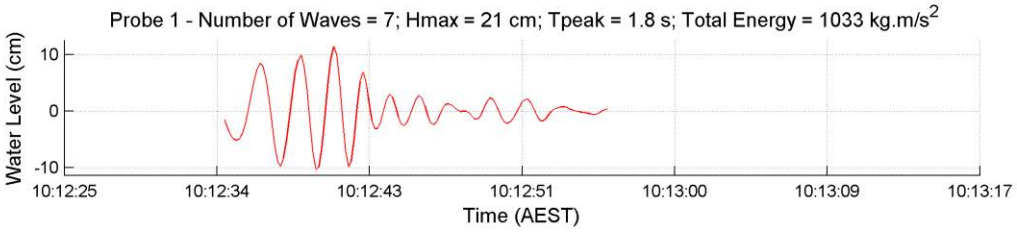
Test 13 - Boat 1 - 19 knots - Run 2 of 6

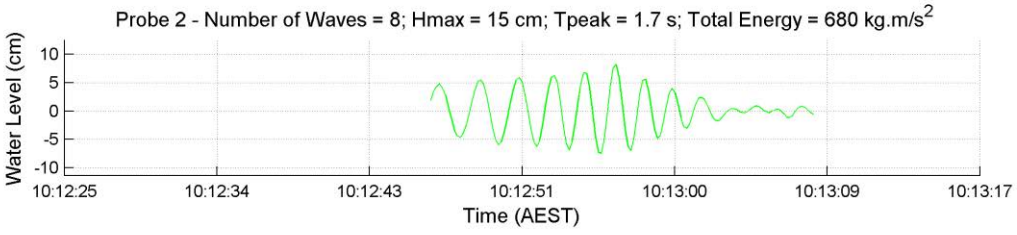


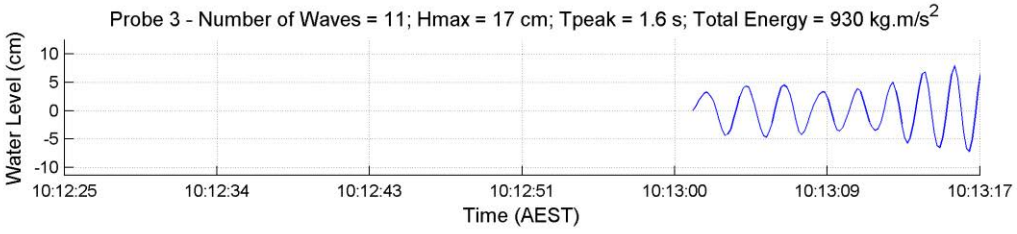




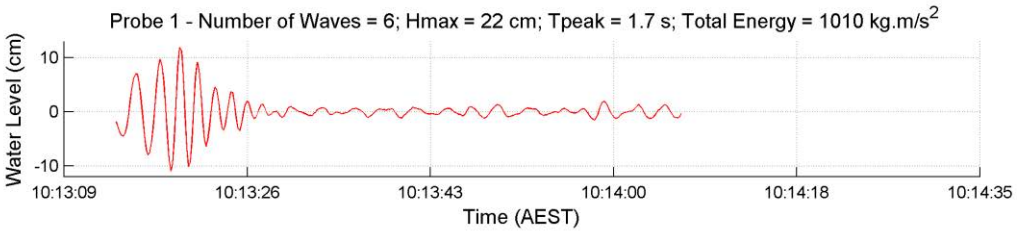
Test 14 - Boat 2 - 19 knots - Run 2 of 6

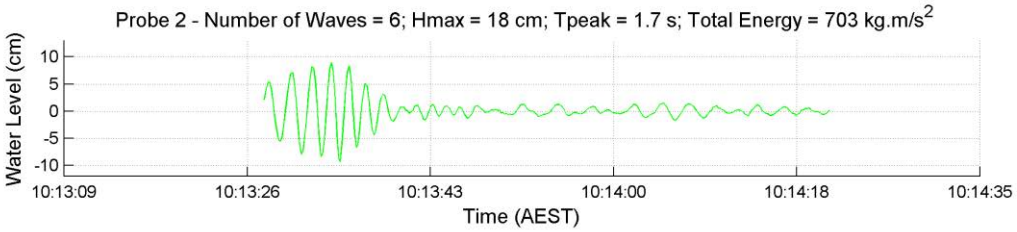


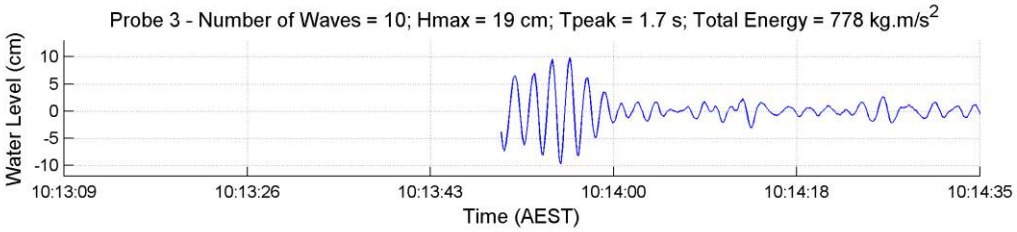




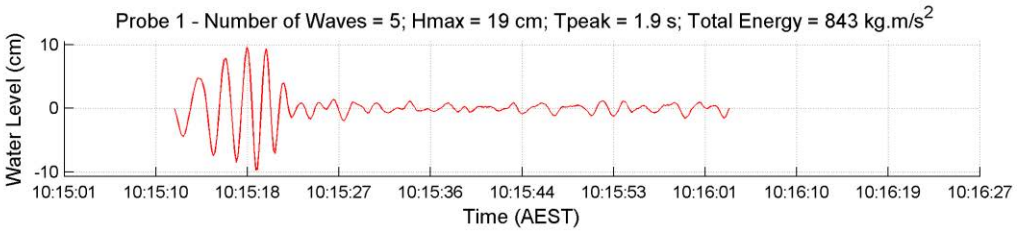
Test 15 - Boat 3 - 19 knots - Run 2 of 6

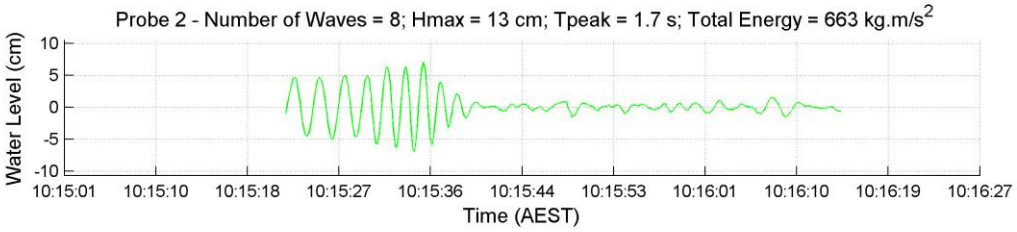


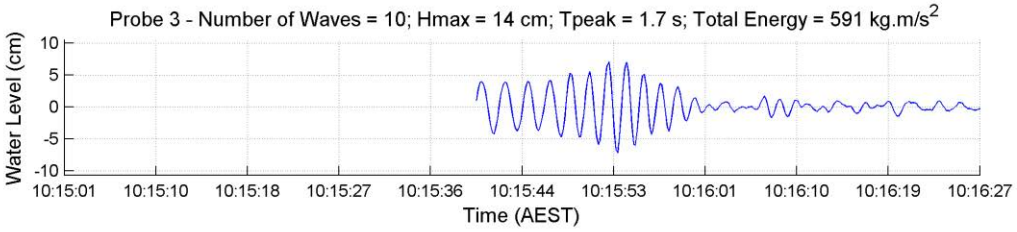




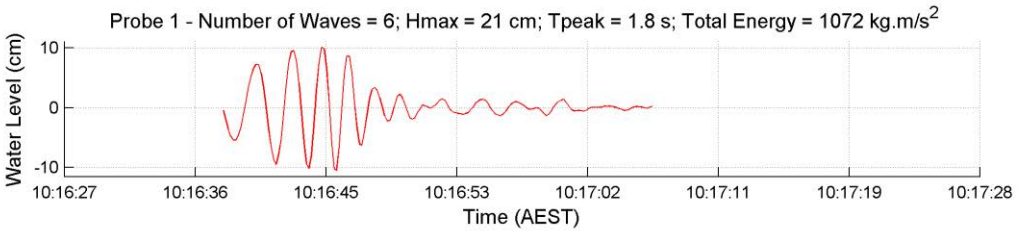
Test 16 - Boat 1 - 19 knots - Run 3 of 6

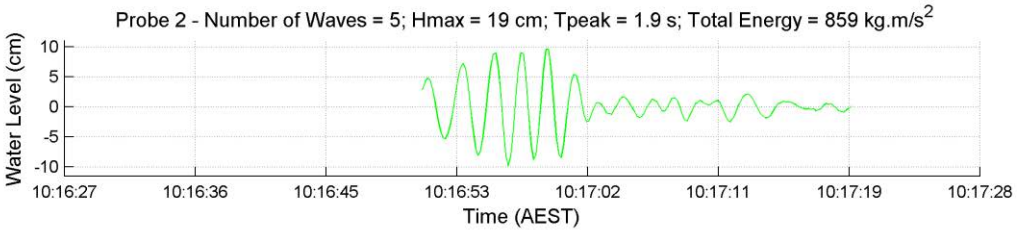


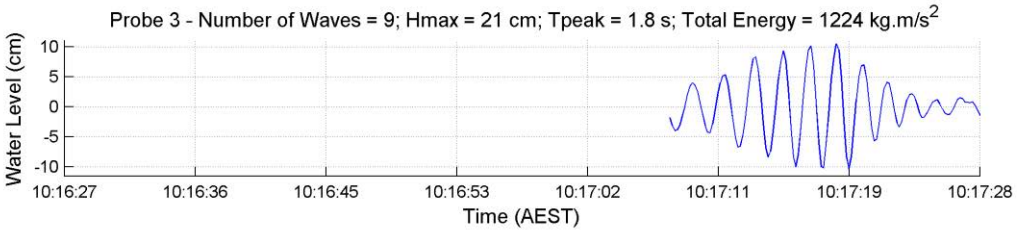




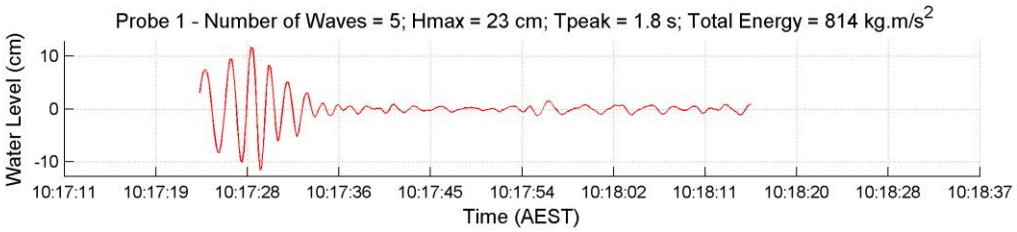
Test 17 - Boat 2 - 19 knots - Run 3 of 6

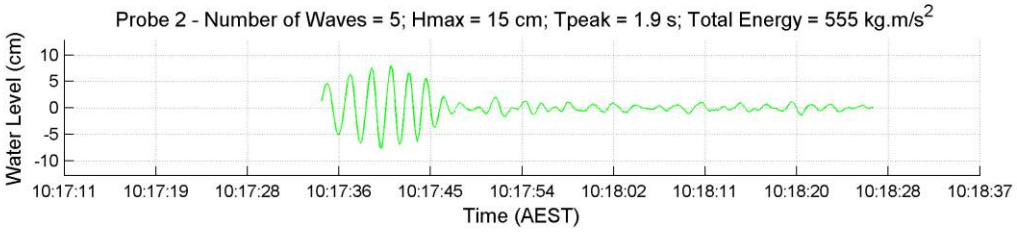


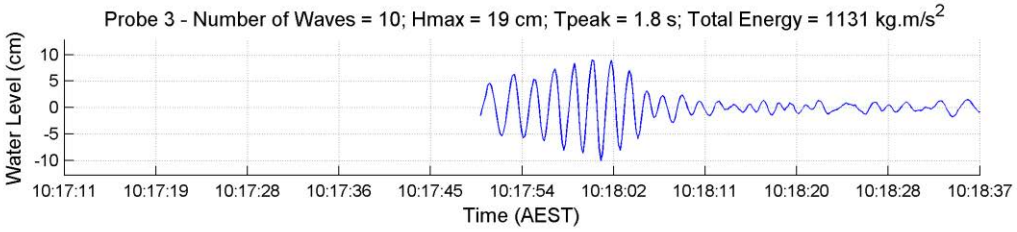




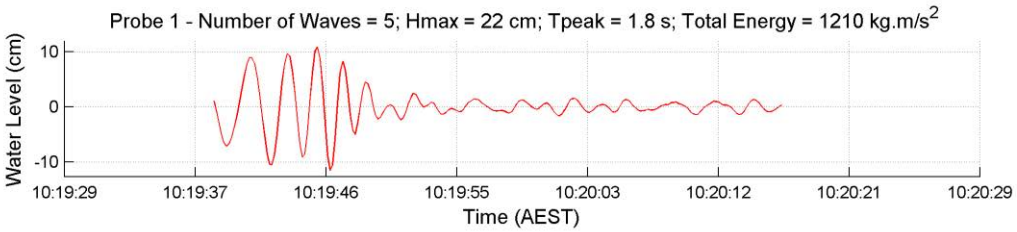
Test 18 - Boat 3 - 19 knots - Run 3 of 6

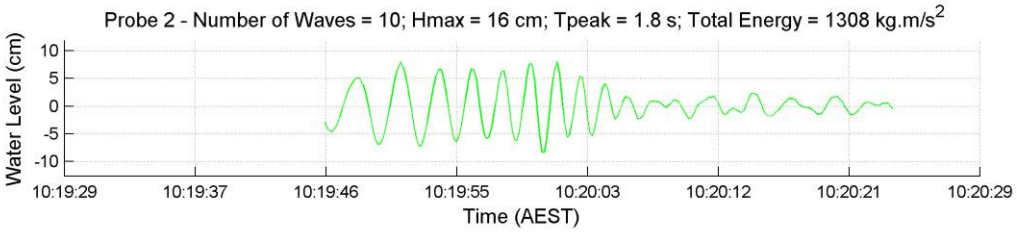


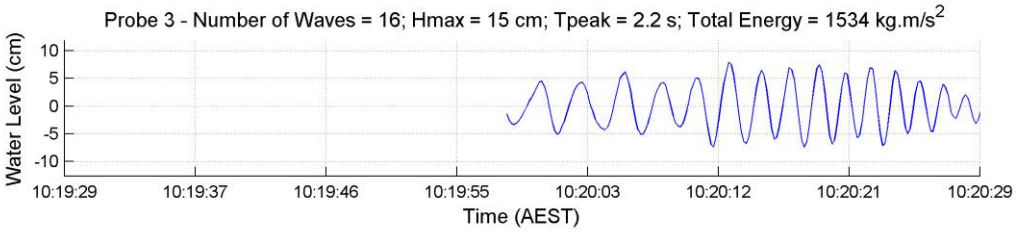




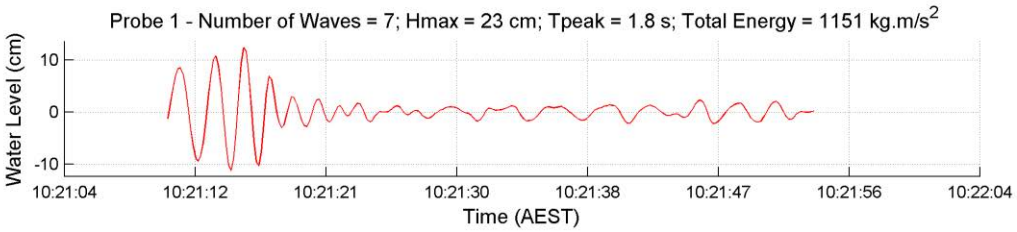
Test 19 - Boat 1 - 14 knots - Run 1 of 6

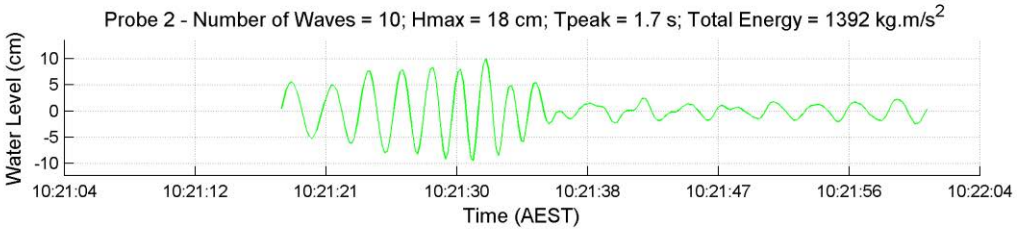


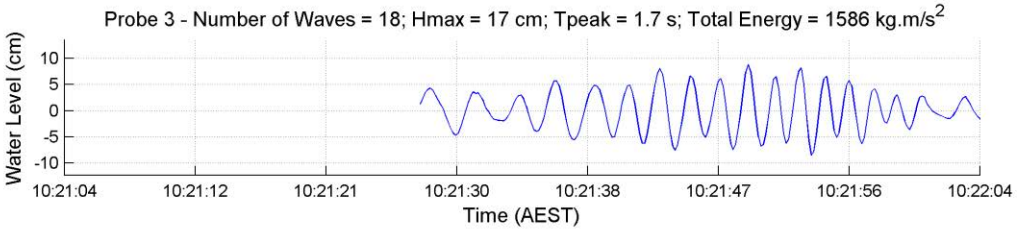




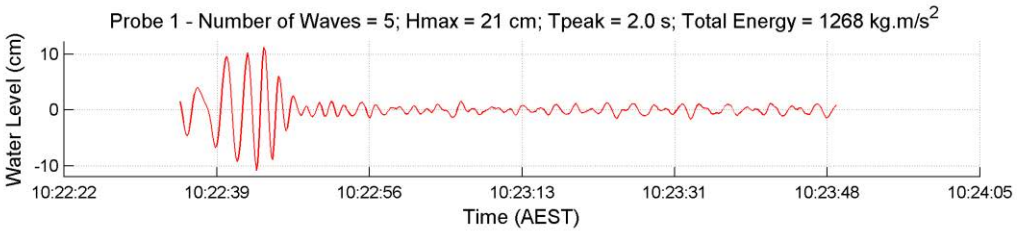
Test 20 - Boat 2 - 14 knots - Run 1 of 6

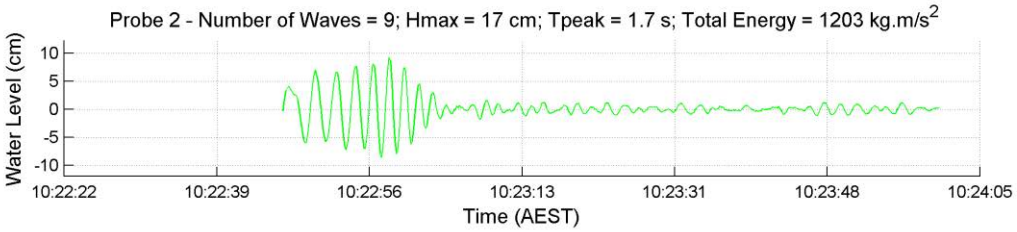


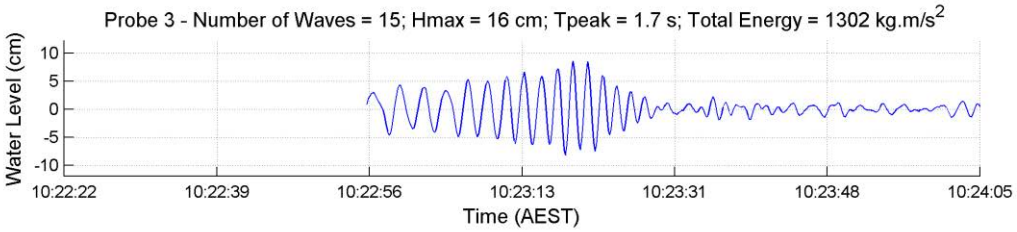




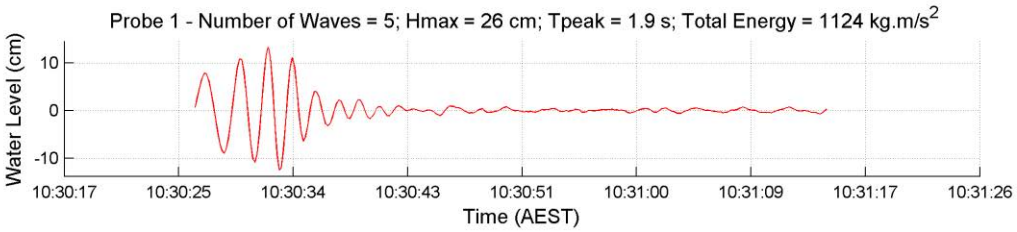
Test 21 - Boat 3 - 14 knots - Run 1 of 6

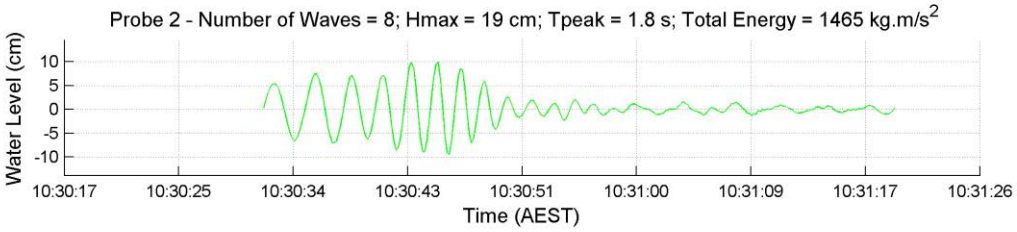


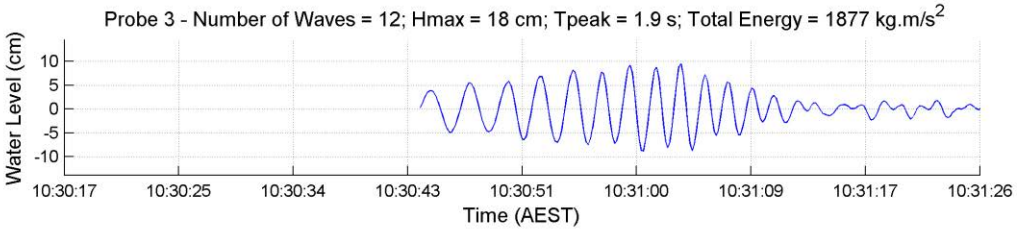




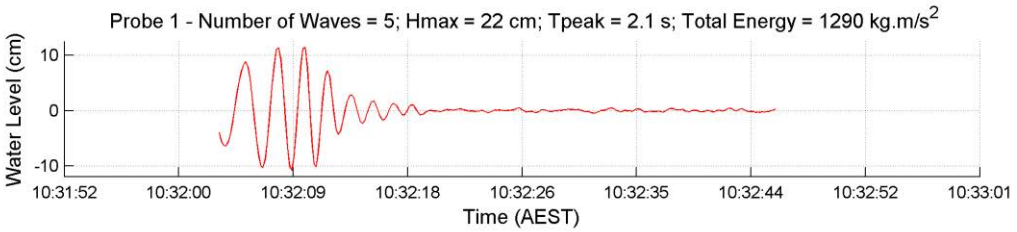
Test 22 - Boat 1 - 14 knots - Run 2 of 6

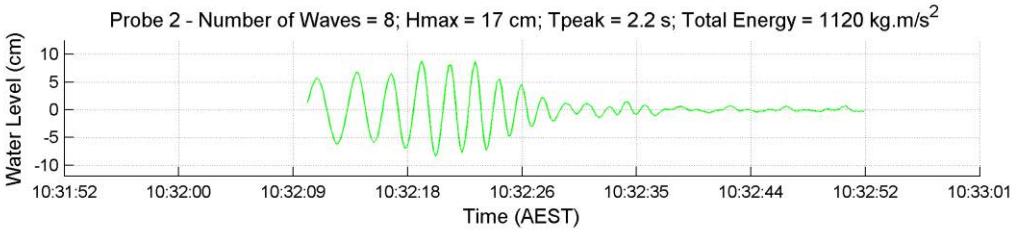


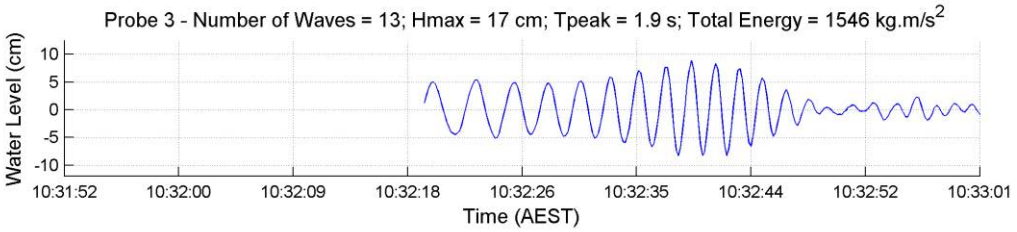




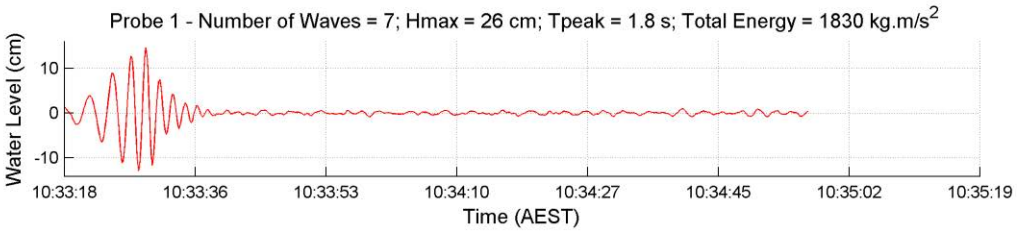
Test 23 - Boat 2 - 14 knots - Run 2 of 6

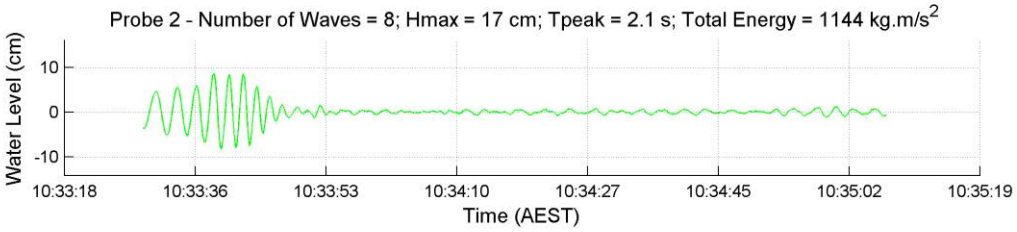


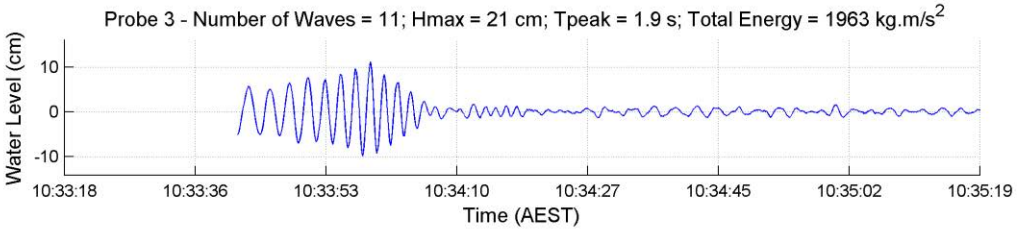




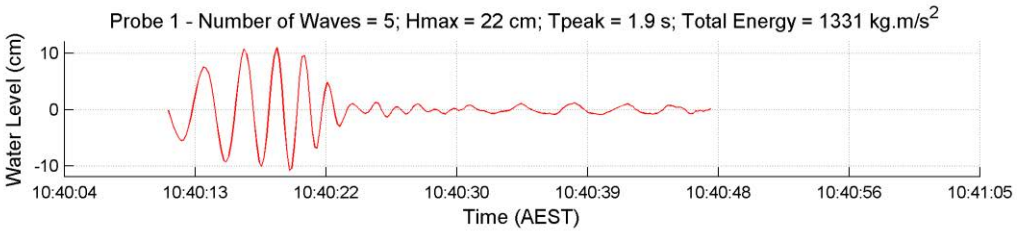
Test 24 - Boat 3 - 14 knots - Run 2 of 6

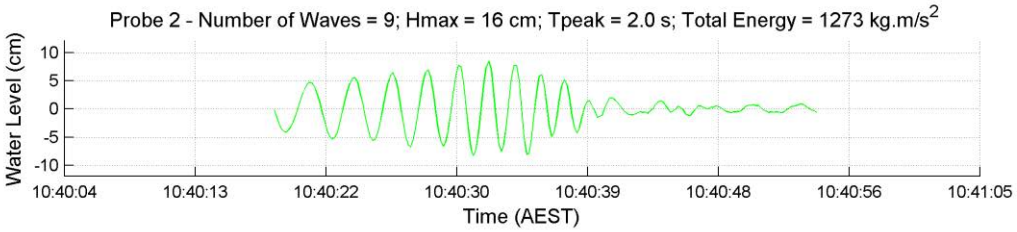


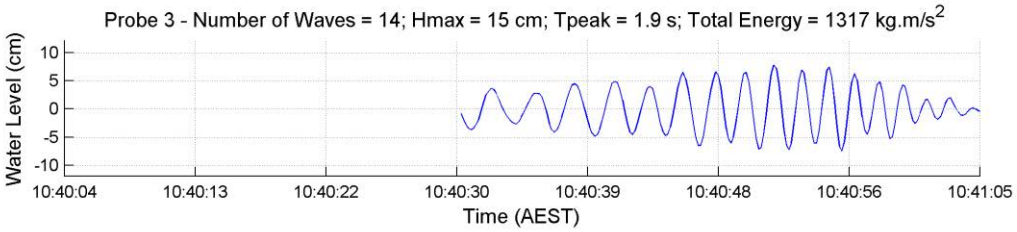




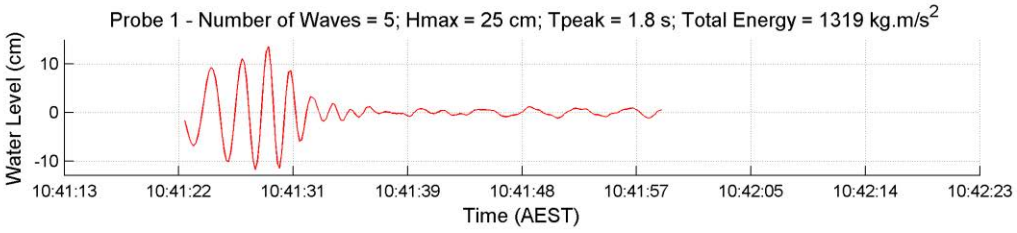
Test 25 - Boat 1 - 14 knots - Run 3 of 6

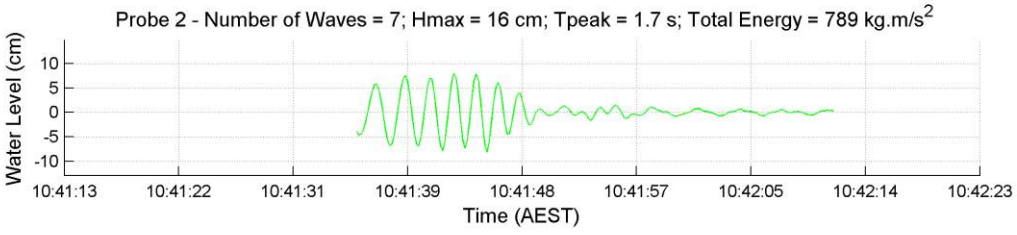


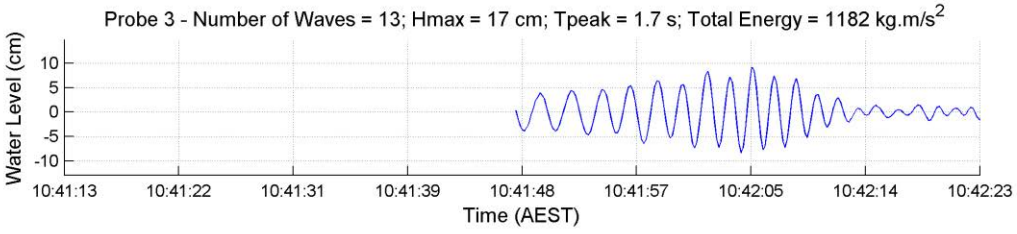




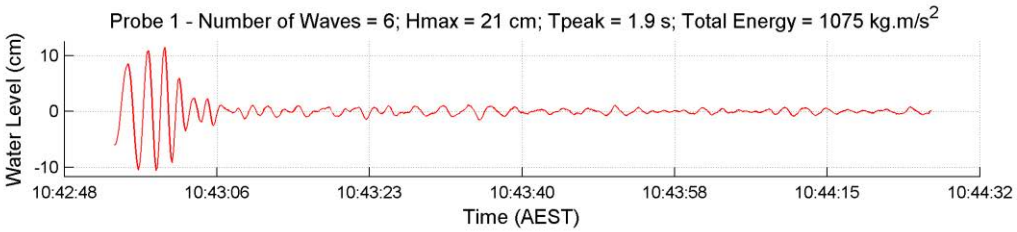
Test 26 - Boat 2 - 14 knots - Run 3 of 6

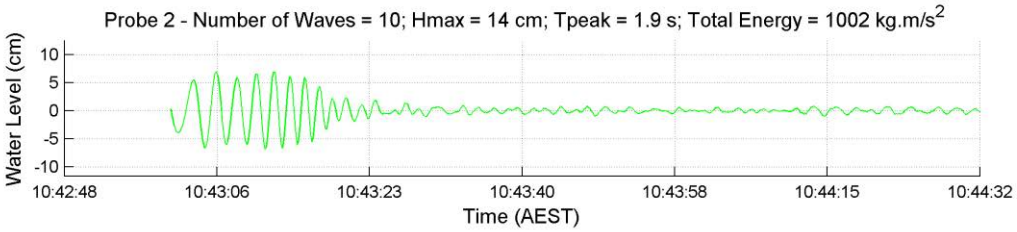


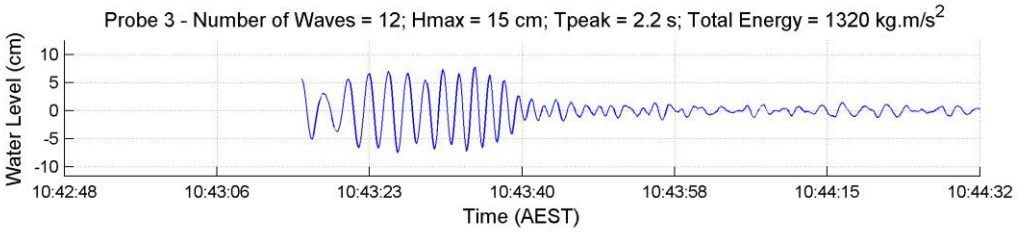




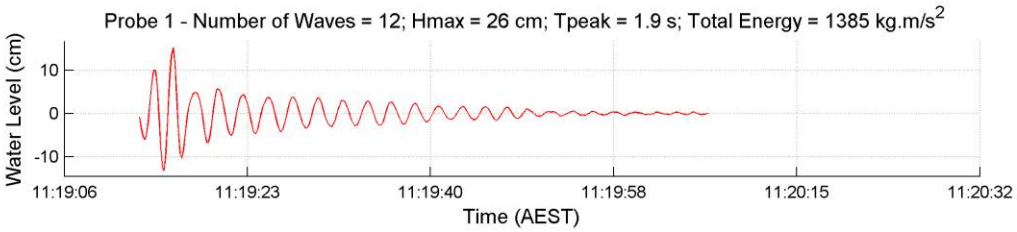
Test 27 - Boat 3 - 14 knots - Run 3 of 6

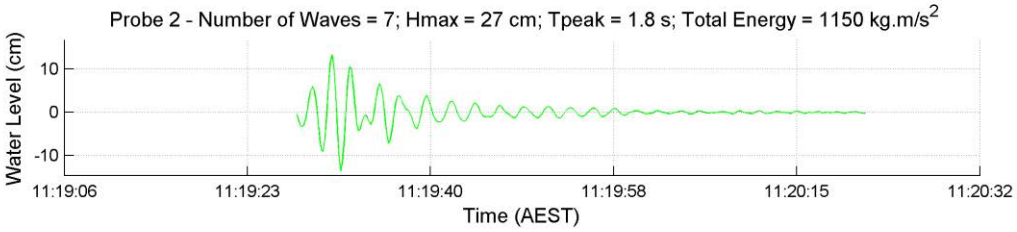


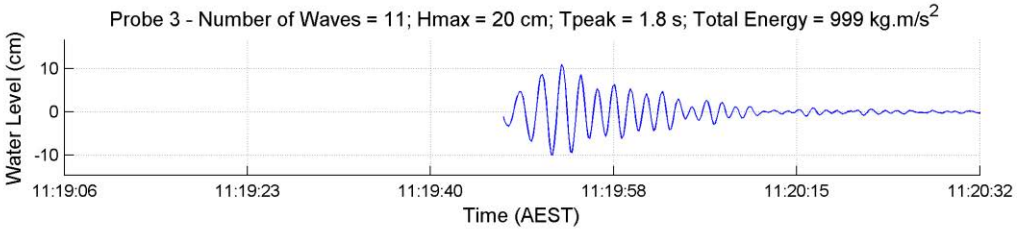


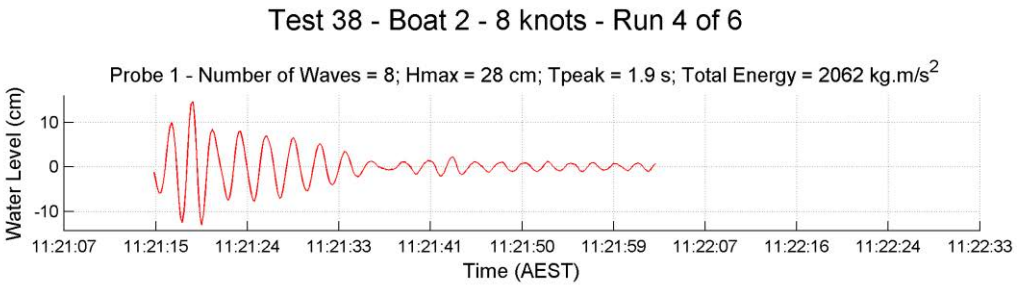


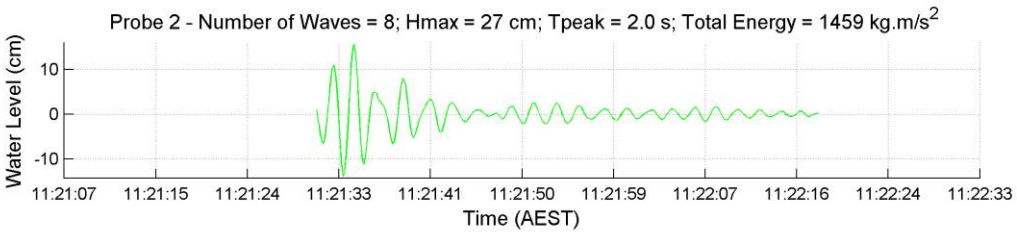
Test 37 - Boat 1 - 8 knots - Run 4 of 6

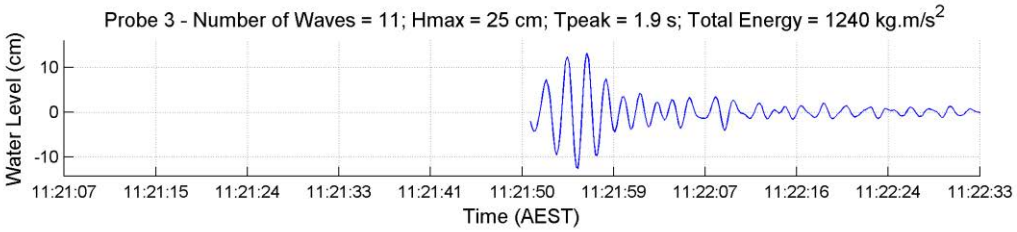


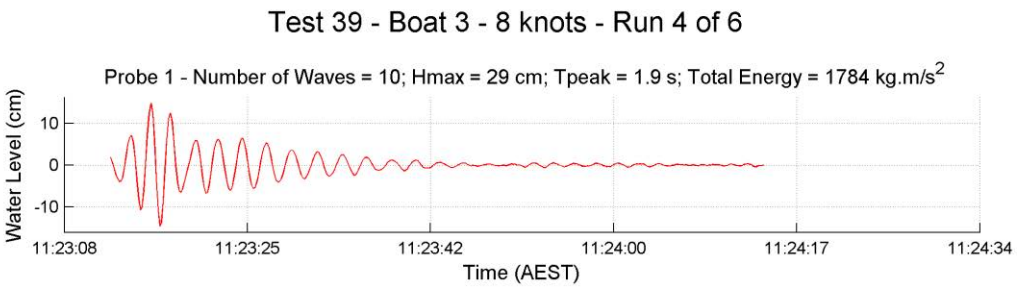


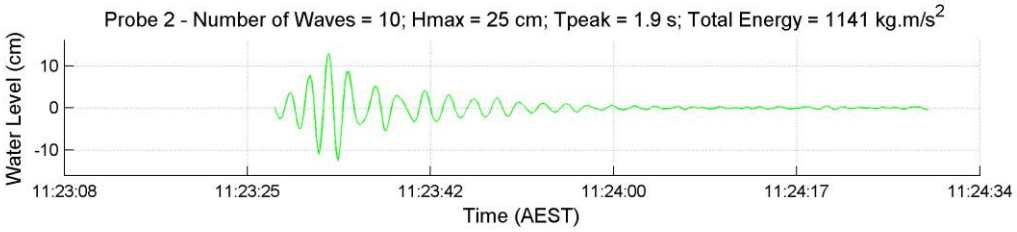


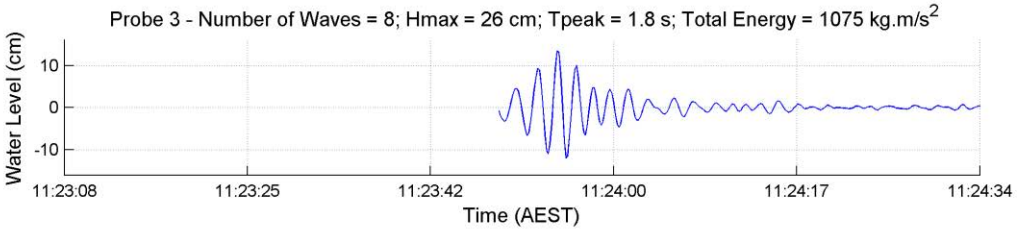

Test 38 - Boat 2 - 8 knots - Run 4 of 6
Probe 1 - Number of Waves = 8; Hmax = 28 cm; Tpeak = 1.9 s; Total Energy = 2062 kg.m/s2
Water Level (cm)
10
0
-10
11:21:07
11:21:15
11:21:24
11:21:33
11:21:41
11:21:50
11:21:59
11:22:07
11:22:16
11:22:24
11:22:33
Time (AEST)

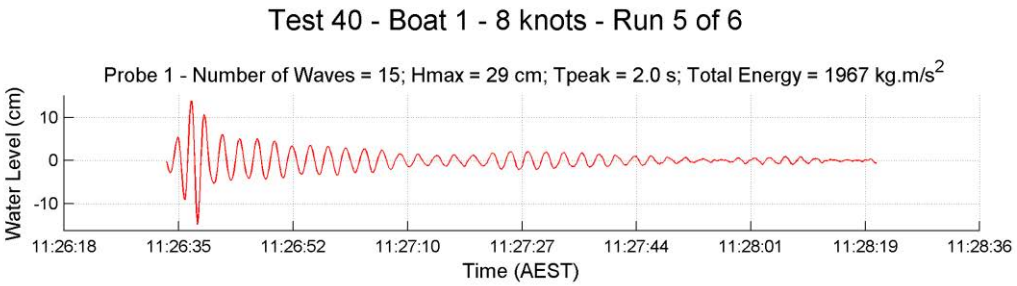

Probe 2 - Number of Waves = 8; Hmax = 27 cm; Tpeak = 2.0 s; Total Energy = 1459 kg.m/s2
Water Level (cm)
10
0
-10
11:21:07
11:21:15
11:21:24
11:21:33
11:21:41
11:21:50
11:21:59
11:22:07
11:22:16
11:22:24
11:22:33
Time (AEST)

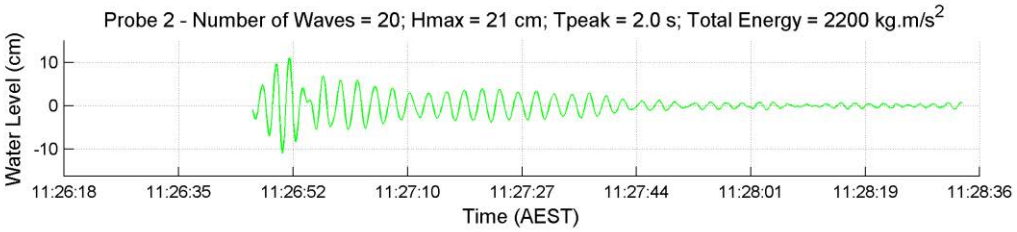

Probe 3 - Number of Waves = 11; Hmax = 25 cm; Tpeak = 1.9 s; Total Energy = 1240 kg.m/s2
Water Level (cm)
10
0
-10
11:21:07
11:21:15
11:21:24
11:21:33
11:21:41
11:21:50
11:21:59
11:22:07
11:22:16
11:22:24
11:22:33
Time (AEST)

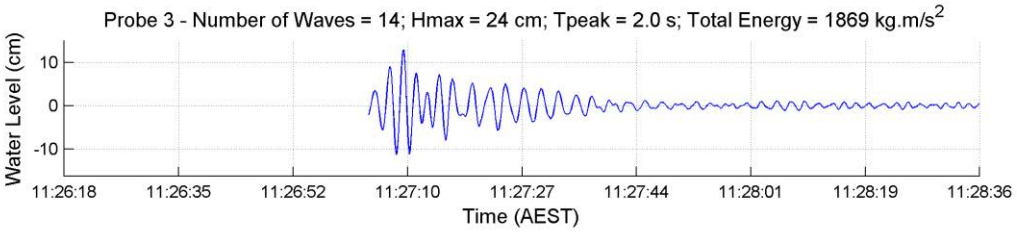

Test 39 - Boat 3 - 8 knots - Run 4 of 6
Probe 1 - Number of Waves = 10; Hmax = 29 cm; Tpeak = 1.9 s; Total Energy = 1784 kg.m/s2
Water Level (cm)
10
0
-10
11:23:08
11:23:25
11:23:42
11:24:00
11:24:17
11:24:34
Time (AEST)

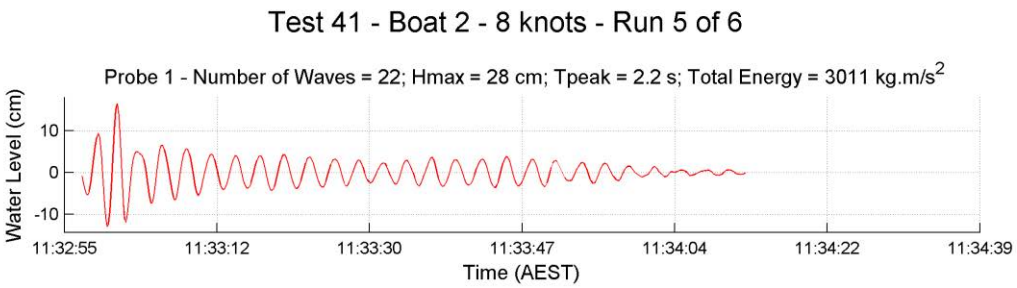

Probe 2 - Number of Waves = 10; Hmax = 25 cm; Tpeak = 1.9 s; Total Energy = 1141 kg.m/s2
Water Level (cm)
10
0
-10
11:23:08
11:23:25
11:23:42
11:24:00
11:24:17
11:24:34
Time (AEST)

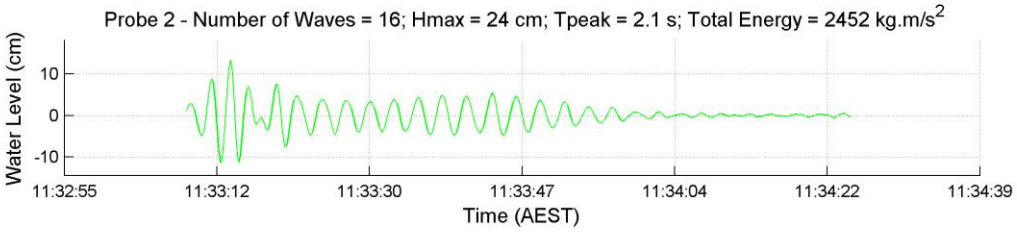

Probe 3 - Number of Waves = 8; Hmax = 26 cm; Tpeak = 1.8 s; Total Energy = 1075 kg.m/s2
Water Level (cm)
10
0
-10
11:23:08
11:23:25
11:23:42
11:24:00
11:24:17
11:24:34
Time (AEST)

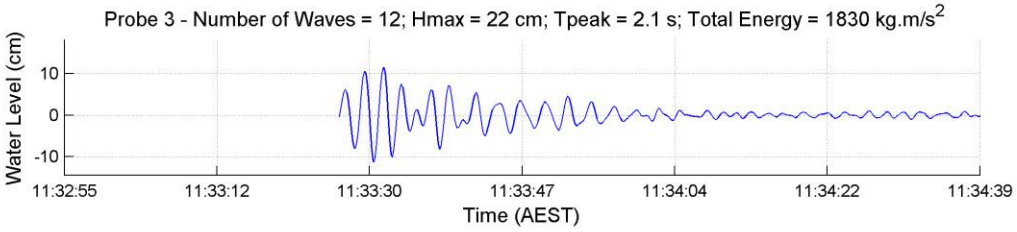

Test 40 - Boat 1 - 8 knots - Run 5 of 6
Probe 1 - Number of Waves = 15; Hmax = 29 cm; Tpeak = 2.0 s; Total Energy = 1967 kg.m/s2
Water Level (cm)
10
0
-10
11:26:18
11:26:35
11:26:52
11:27:10
11:27:27
11:27:44
11:28:01
11:28:19
11:28:36
Time (AEST)


Probe 2 - Number of Waves = 20; Hmax = 21 cm; Tpeak = 2.0 s; Total Energy = 2200 kg.m/s2
Water Level (cm)
10
0
-10
11:26:18
11:26:35
11:26:52
11:27:10
11:27:27
11:27:44
11:28:01
11:28:19
11:28:36
Time (AEST)

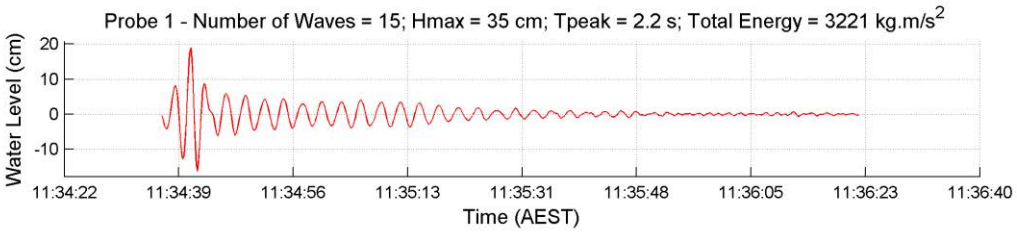

Probe 3 - Number of Waves = 14; Hmax = 24 cm; Tpeak = 2.0 s; Total Energy = 1869 kg.m/s2
Water Level (cm)
10
0
-10
11:26:18
11:26:35
11:26:52
11:27:10
11:27:27
11:27:44
11:28:01
11:28:19
11:28:36
Time (AEST)

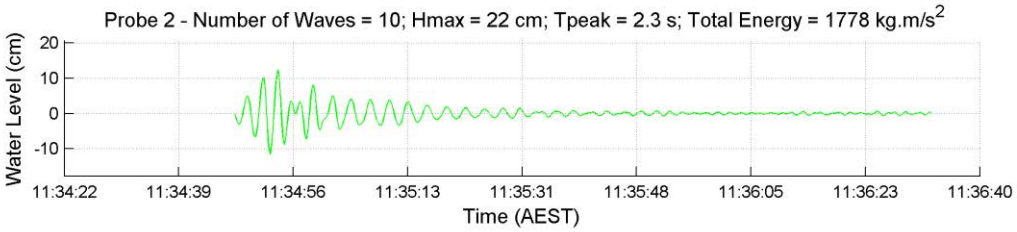

Test 41 - Boat 2 - 8 knots - Run 5 of 6
Probe 1 - Number of Waves = 22; Hmax = 28 cm; Tpeak = 2.2 s; Total Energy = 3011 kg.m/s2
Water Level (cm)
10
0
-10
11:32:55
11:33:12
11:33:30
11:33:47
11:34:04
11:34:22
11:34:39
Time (AEST)

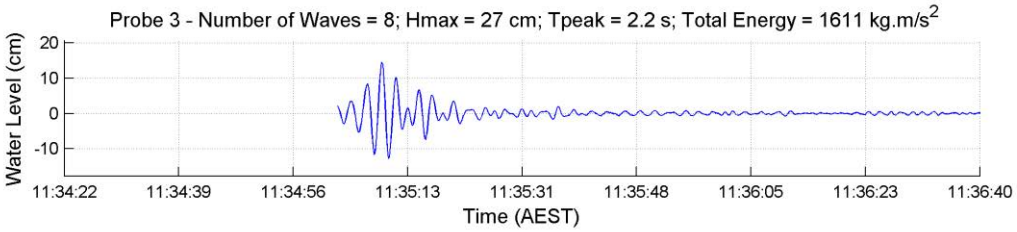

Probe 2 - Number of Waves = 16; Hmax = 24 cm; Tpeak = 2.1 s; Total Energy = 2452 kg.m/s2
Water Level (cm)
10
0
-10
11:32:55
11:33:12
11:33:30
11:33:47
11:34:04
11:34:22
11:34:39
Time (AEST)


Probe 3 - Number of Waves = 12; Hmax = 22 cm; Tpeak = 2.1 s; Total Energy = 1830 kg.m/s2
Water Level (cm)
10
0
-10
11:32:55
11:33:12
11:33:30
11:33:47
11:34:04
11:34:22
11:34:39
Time (AEST)

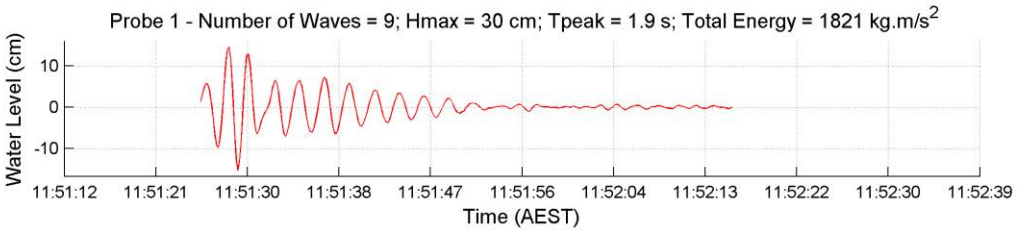
Test 42 - Boat 3 - 8 knots - Run 5 of 6

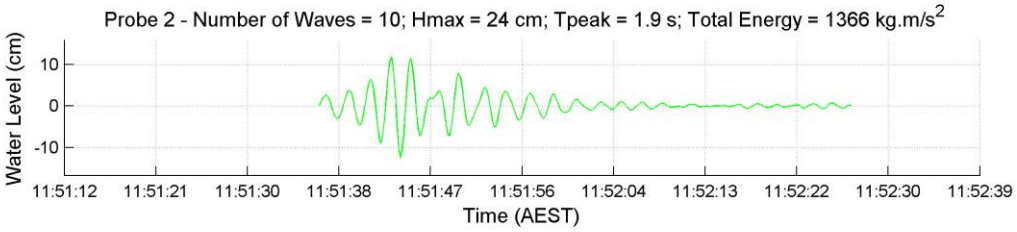


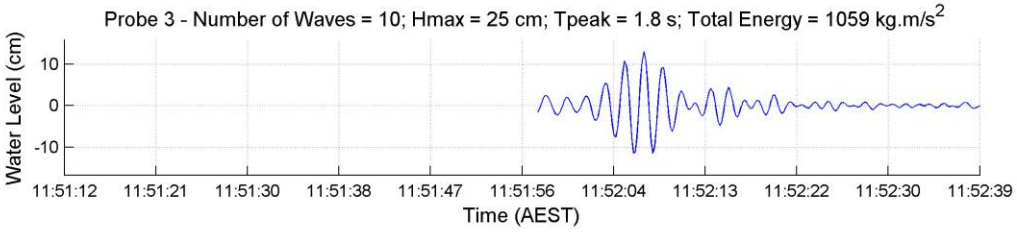




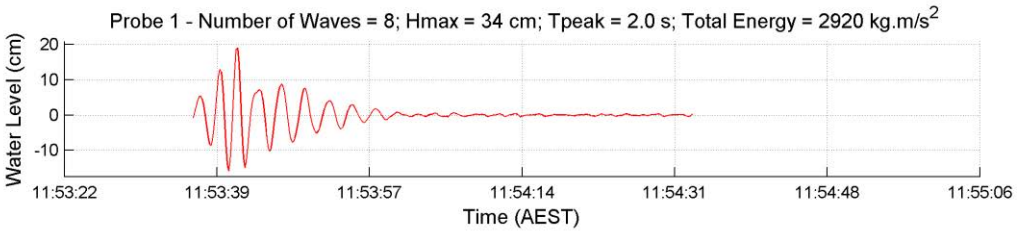
Test 43 - Boat 1 - 8 knots - Run 6 of 6

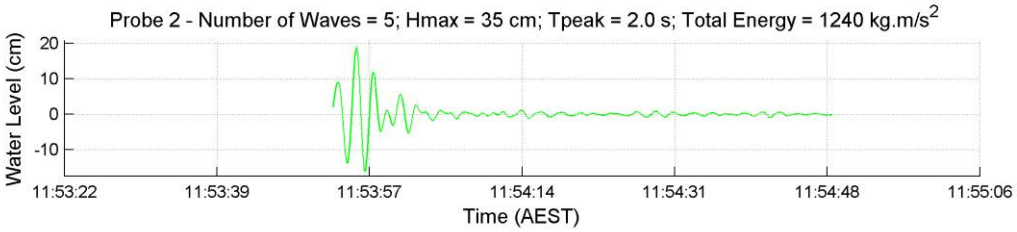


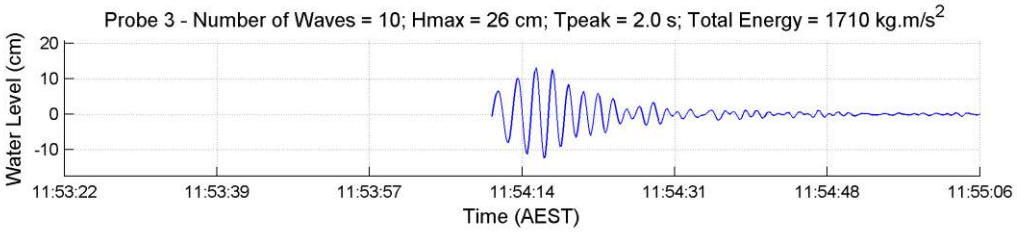




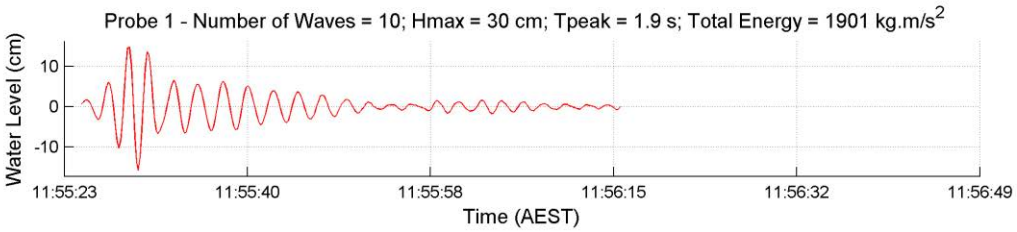
Test 44 - Boat 2 - 8 knots - Run 6 of 6

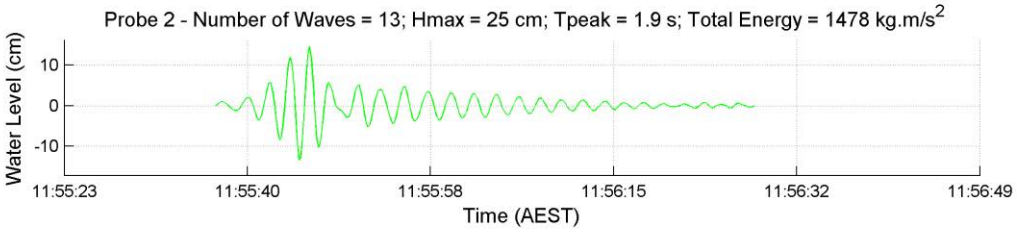


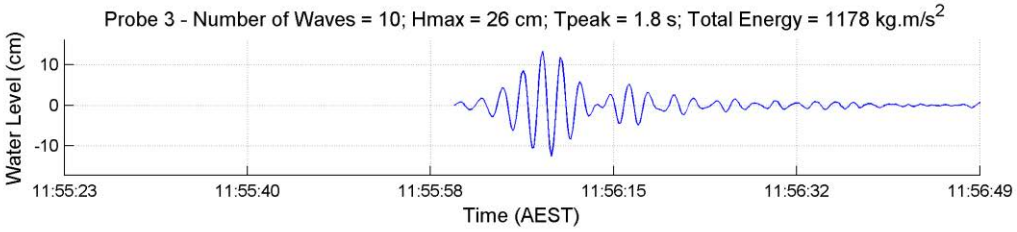




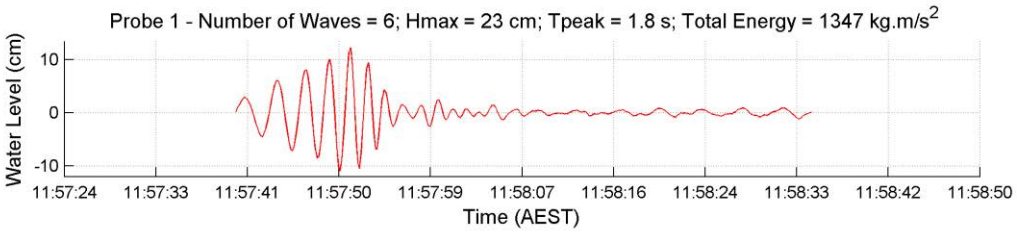
Test 45 - Boat 3 - 8 knots - Run 6 of 6

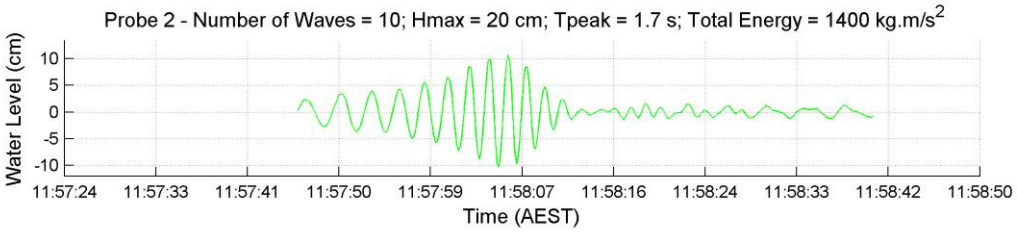


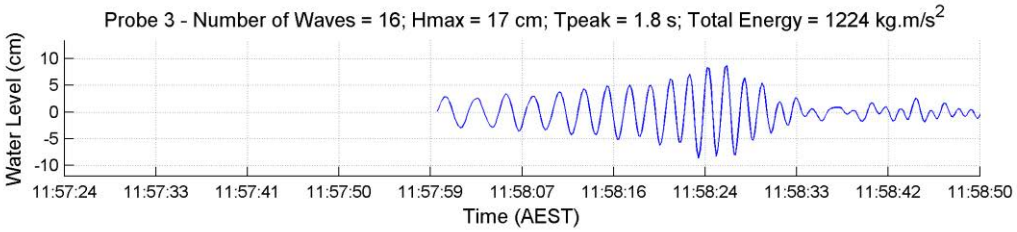




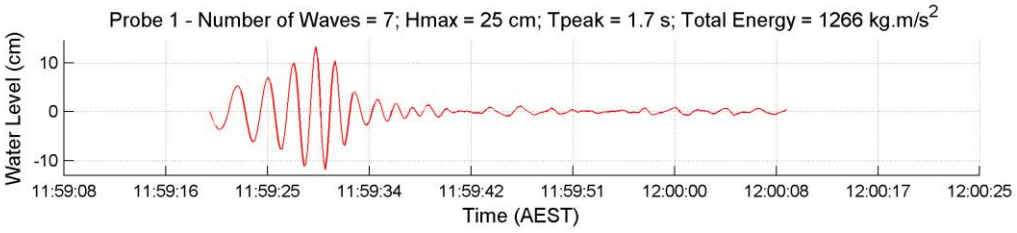
Test 46 - Boat 1 - 19 knots - Run 4 of 6

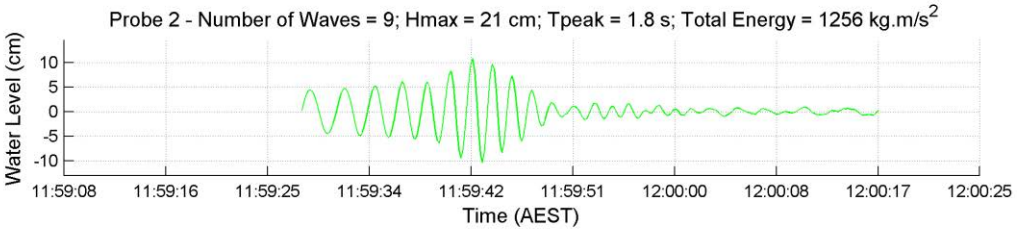


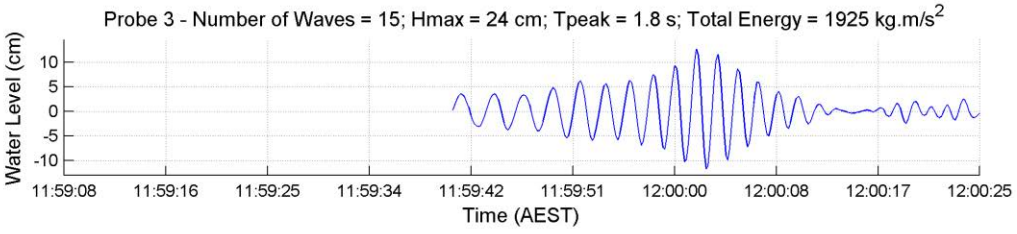




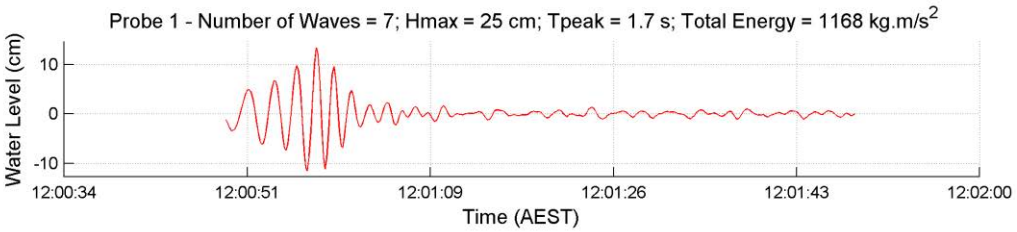
Test 47 - Boat 2 - 19 knots - Run 4 of 6

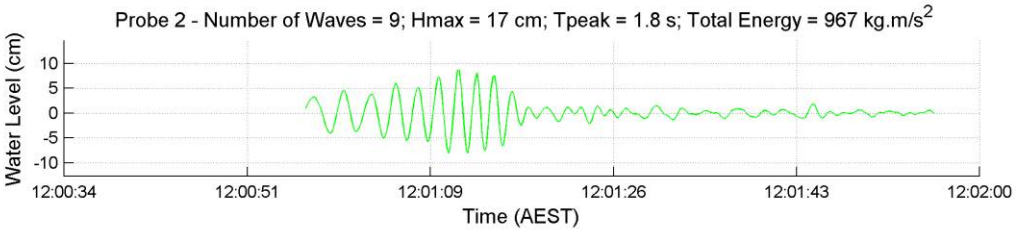


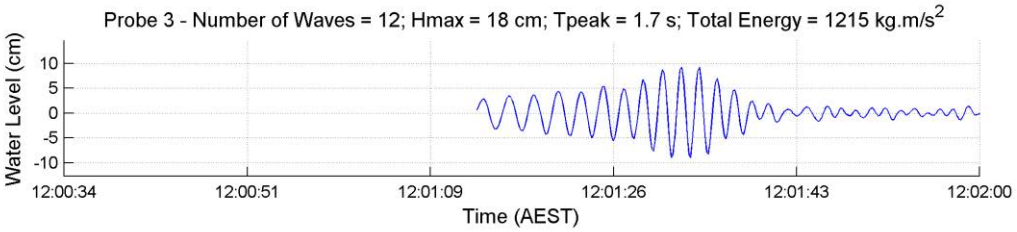




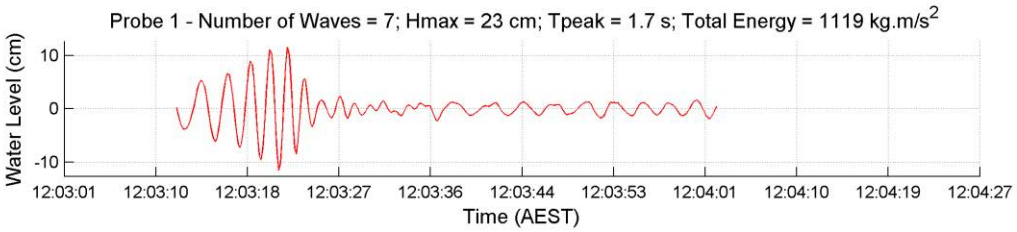
Test 48 - Boat 3 - 19 knots - Run 4 of 6

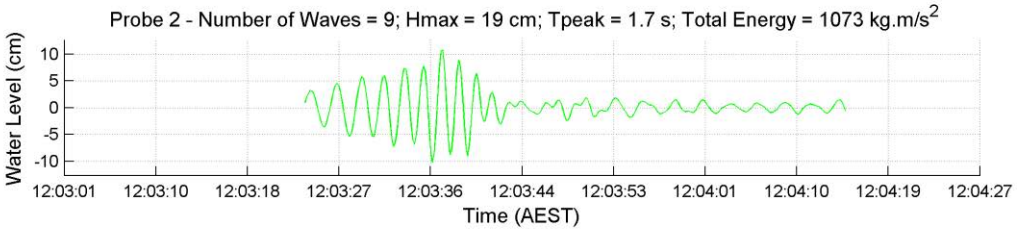


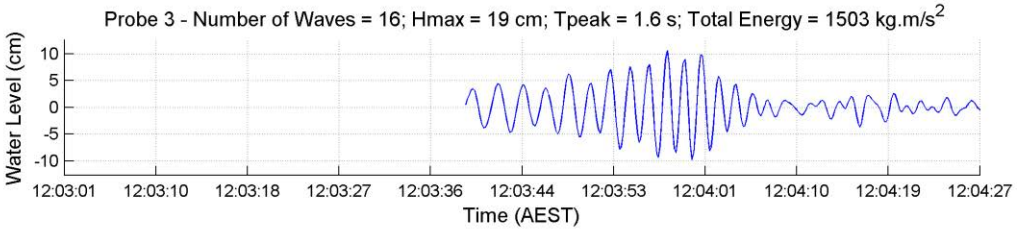




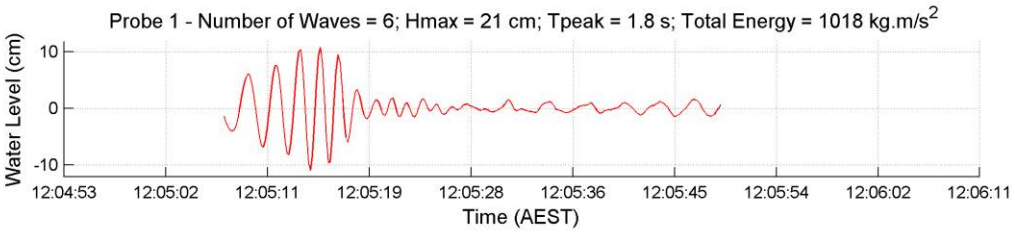
Test 49 - Boat 1 - 19 knots - Run 5 of 6

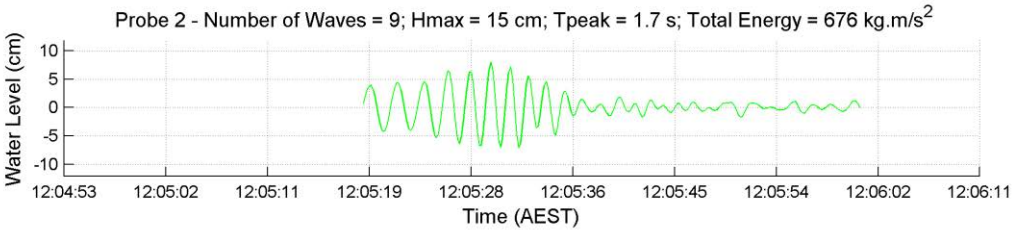


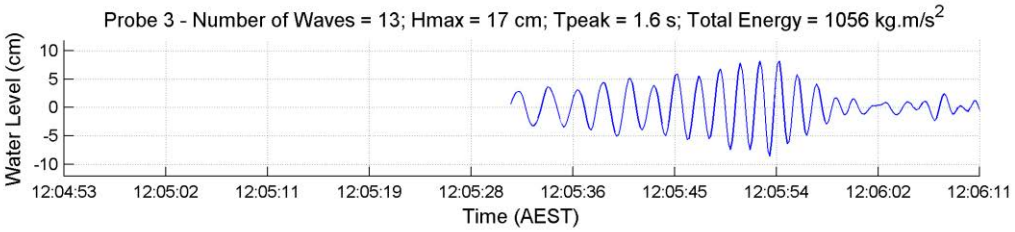




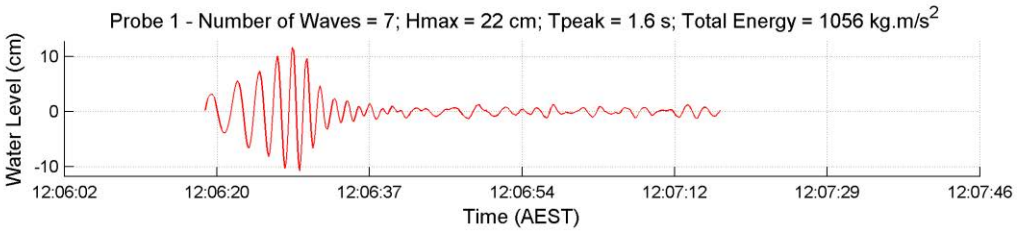
Test 50 - Boat 2 - 19 knots - Run 5 of 6

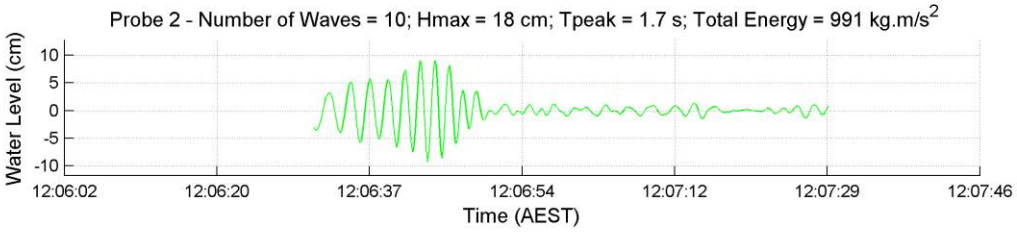


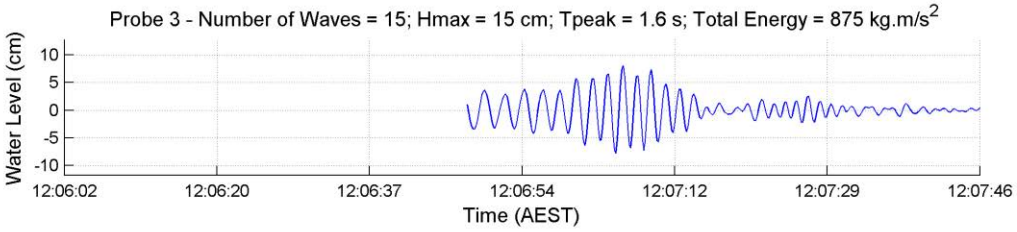


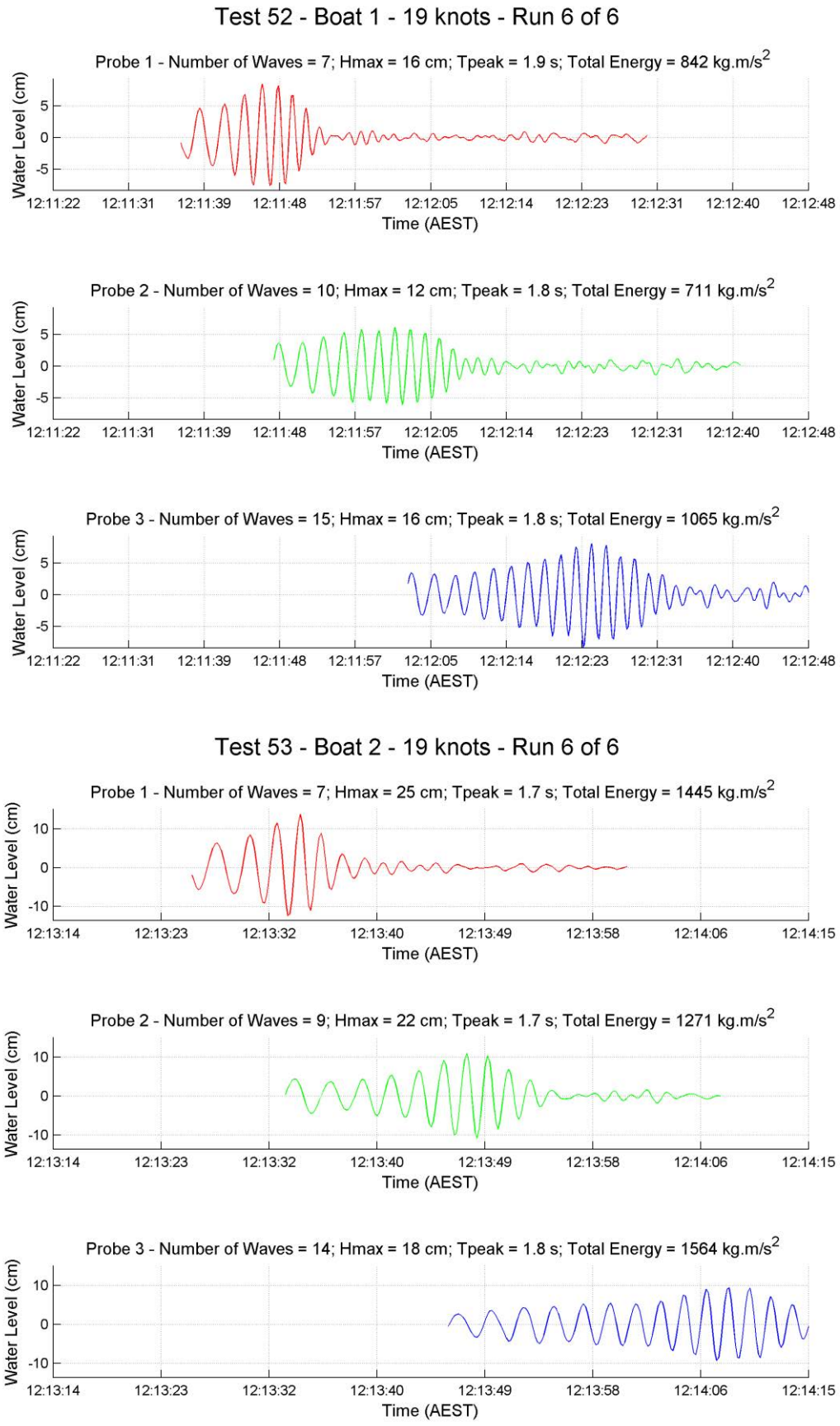


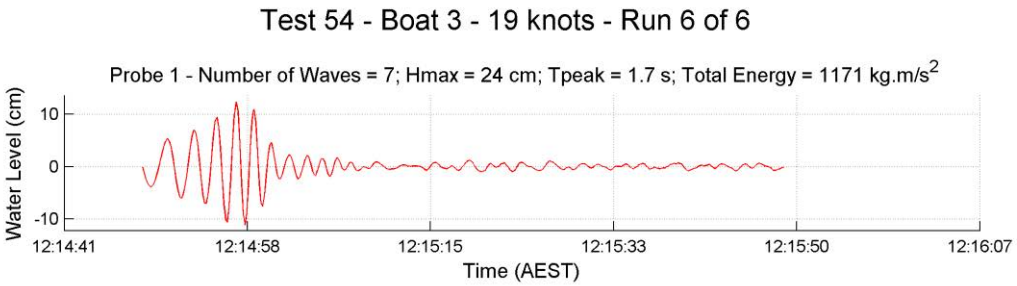
Test 51 - Boat 3 - 19 knots - Run 5 of 6

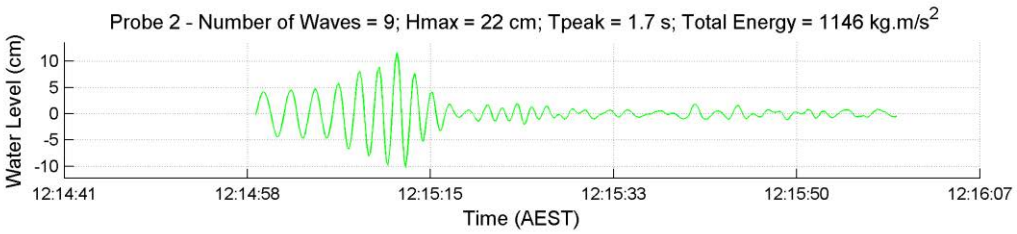


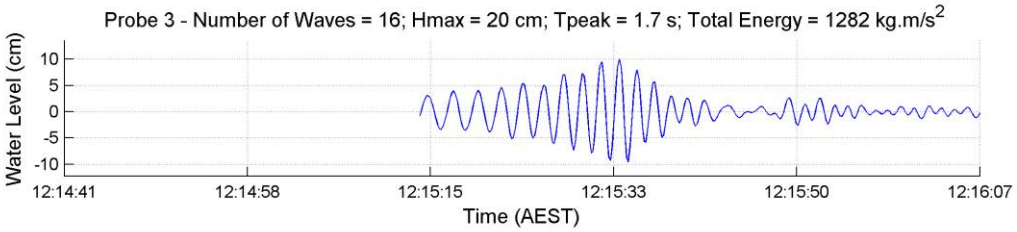


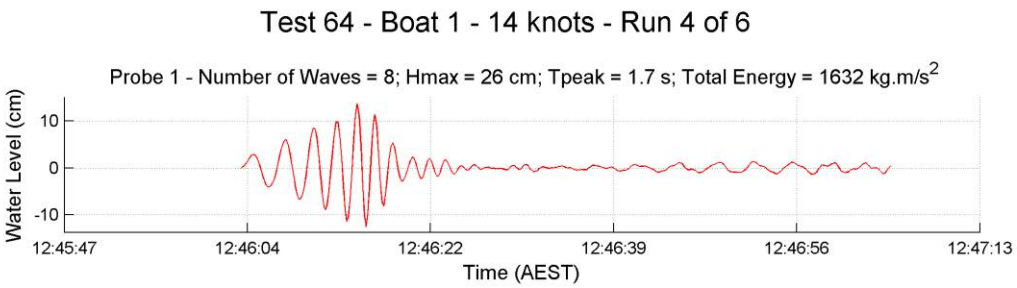


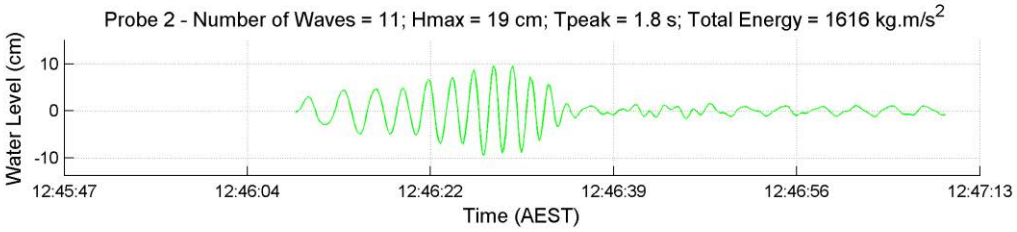

Test 52 - Boat 1 - 19 knots - Run 6 of 6
Probe 1 - Number of Waves = 7; Hmax = 16 cm; Tpeak = 1.9 s; Total Energy = 842 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 12 cm; Tpeak = 1.8 s; Total Energy = 711 kg.m/s2
Probe 3 - Number of Waves = 15; Hmax = 16 cm; Tpeak = 1.8 s; Total Energy = 1065 kg.m/s2
Test 53 - Boat 2 - 19 knots - Run 6 of 6
Probe 1 - Number of Waves = 7; Hmax = 25 cm; Tpeak = 1.7 s; Total Energy = 1445 kg.m/s2
Probe 2 - Number of Waves = 9; Hmax = 22 cm; Tpeak = 1.7 s; Total Energy = 1271 kg.m/s2
Probe 3 - Number of Waves = 14; Hmax = 18 cm; Tpeak = 1.8 s; Total Energy = 1564 kg.m/s2
Water Level (cm)
Time (AEST)

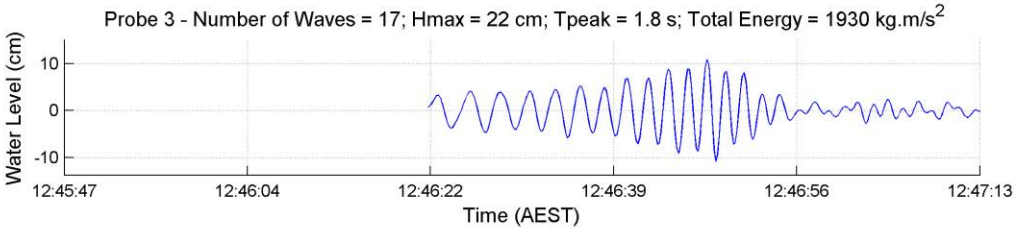

Test 54 - Boat 3 - 19 knots - Run 6 of 6
Probe 1 - Number of Waves = 7; Hmax = 24 cm; Tpeak = 1.7 s; Total Energy = 1171 kg.m/s2
Water Level (cm)
10
0
-10
12:14:41
12:14:58
12:15:15
12:15:33
12:15:50
12:16:07
Time (AEST)


Probe 2 - Number of Waves = 9; Hmax = 22 cm; Tpeak = 1.7 s; Total Energy = 1146 kg.m/s2
Water Level (cm)
10
5
0
-5
-10
12:14:41
12:14:58
12:15:15
12:15:33
12:15:50
12:16:07
Time (AEST)

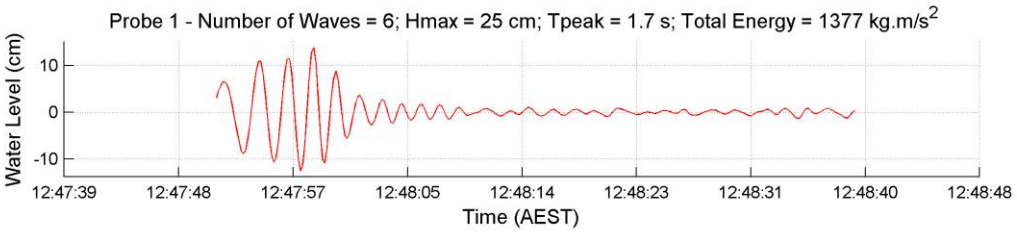

Probe 3 - Number of Waves = 16; Hmax = 20 cm; Tpeak = 1.7 s; Total Energy = 1282 kg.m/s2
Water Level (cm)
10
5
0
-5
-10
12:14:41
12:14:58
12:15:15
12:15:33
12:15:50
12:16:07
Time (AEST)

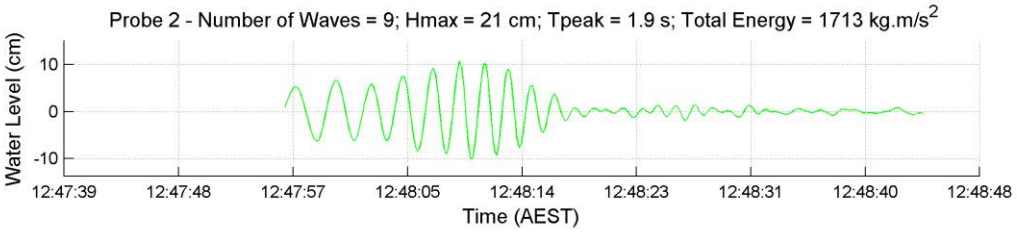

Test 64 - Boat 1 - 14 knots - Run 4 of 6
Probe 1 - Number of Waves = 8; Hmax = 26 cm; Tpeak = 1.7 s; Total Energy = 1632 kg.m/s2
Water Level (cm)
10
0
-10
12:45:47
12:46:04
12:46:22
12:46:39
12:46:56
12:47:13
Time (AEST)

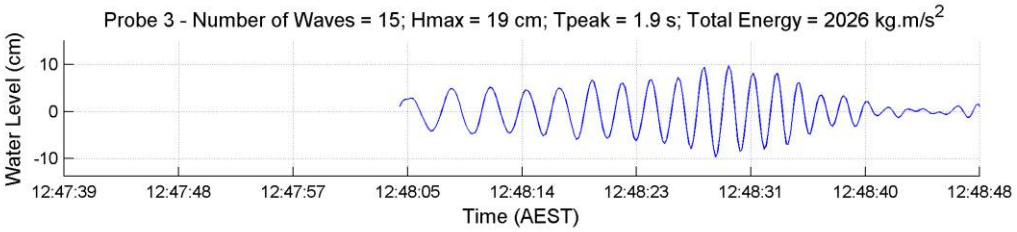

Probe 2 - Number of Waves = 11; Hmax = 19 cm; Tpeak = 1.8 s; Total Energy = 1616 kg.m/s2
Water Level (cm)
10
0
-10
12:45:47
12:46:04
12:46:22
12:46:39
12:46:56
12:47:13
Time (AEST)


Probe 3 - Number of Waves = 17; Hmax = 22 cm; Tpeak = 1.8 s; Total Energy = 1930 kg.m/s2
Water Level (cm)
10
0
-10
12:45:47
12:46:04
12:46:22
12:46:39
12:46:56
12:47:13
Time (AEST)

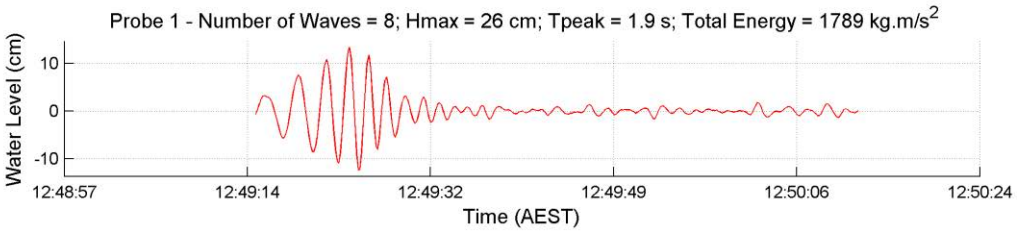
Test 65 - Boat 2 - 14 knots - Run 4 of 6

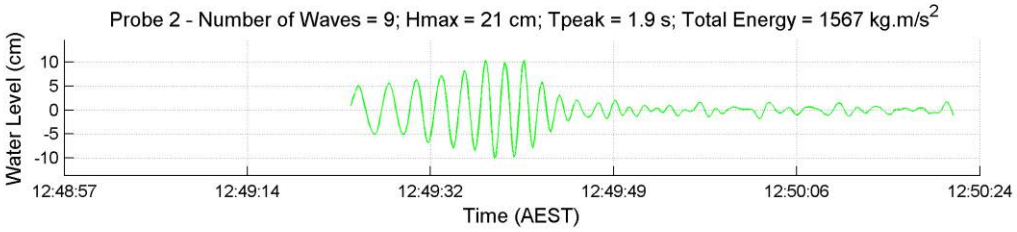


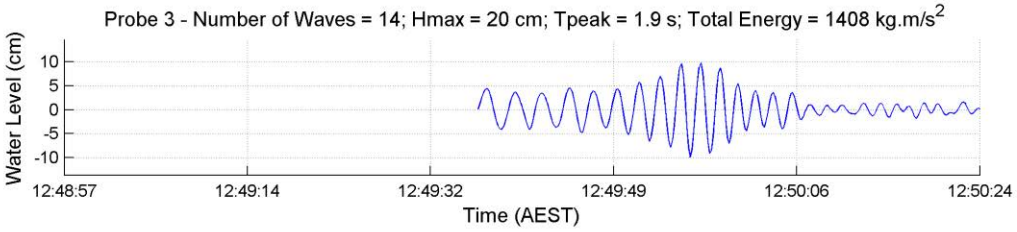




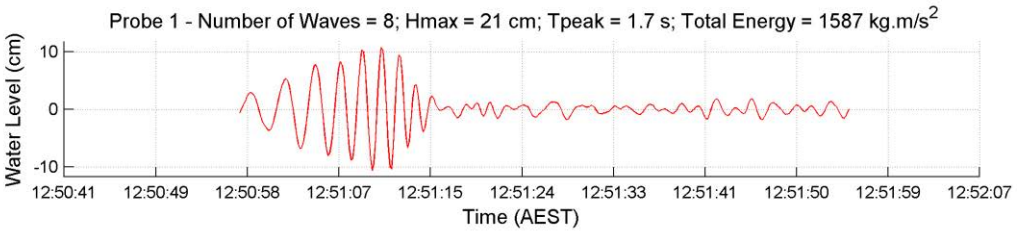
Test 66 - Boat 3 - 14 knots - Run 4 of 6

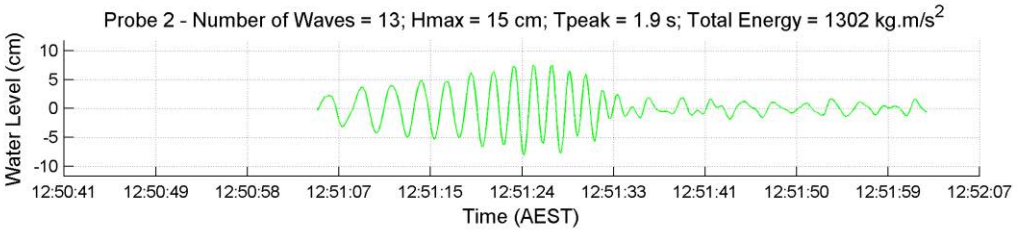


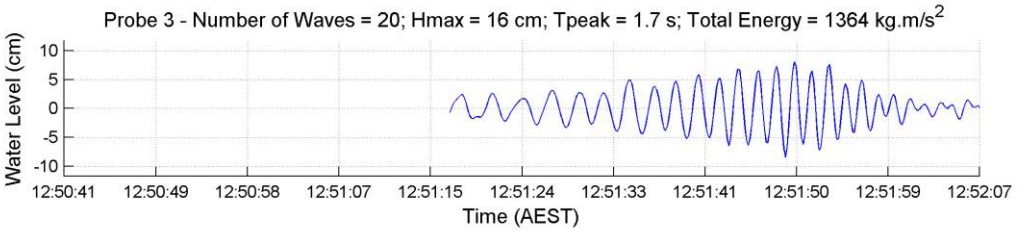




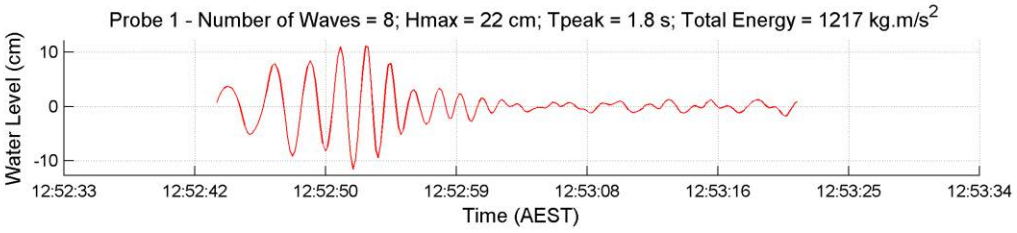
Test 67 - Boat 1 - 14 knots - Run 5 of 6

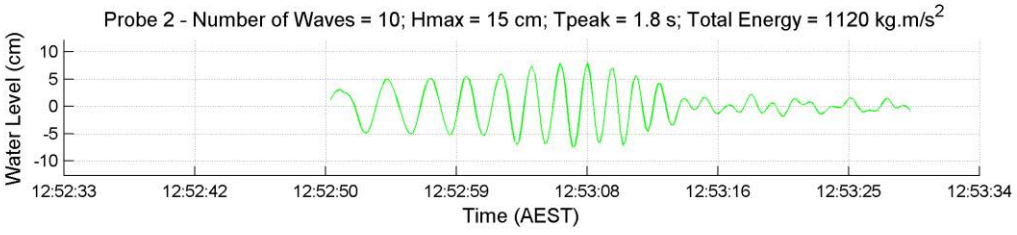


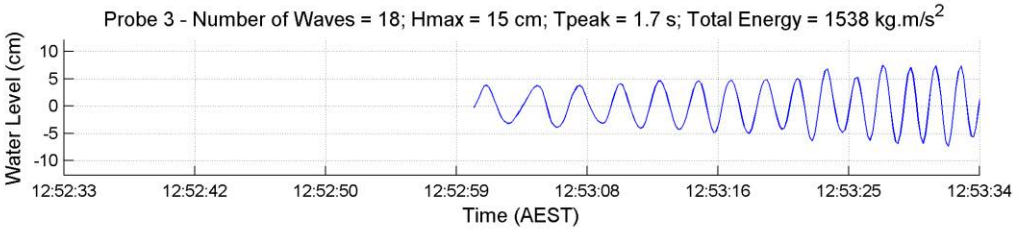




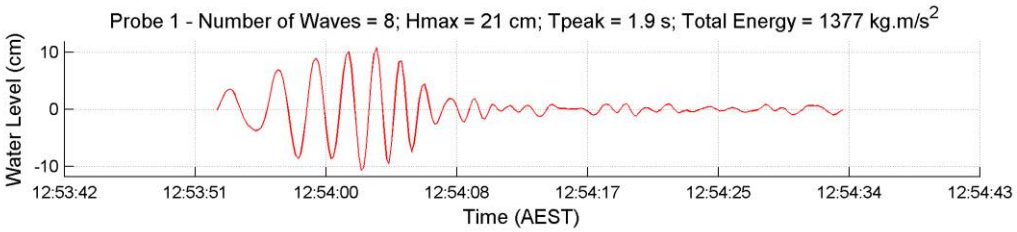
Test 68 - Boat 2 - 14 knots - Run 5 of 6

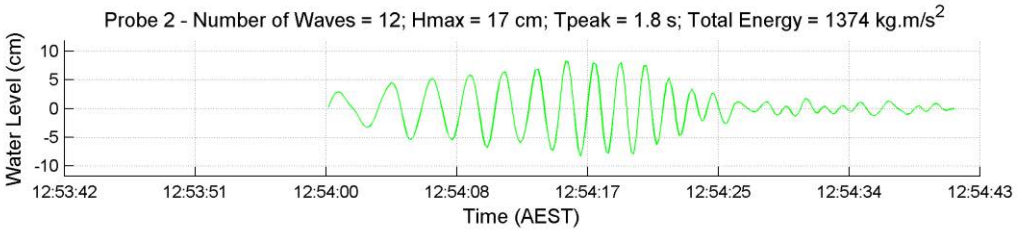


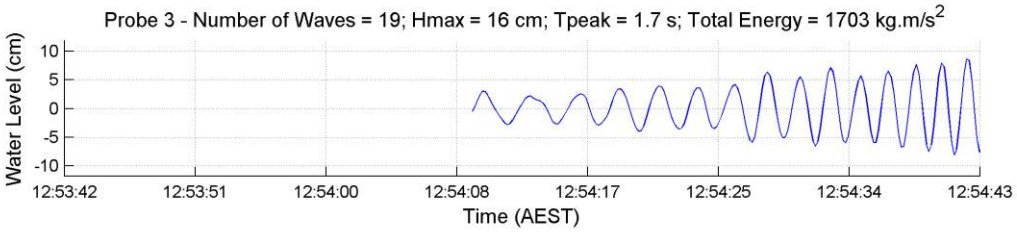




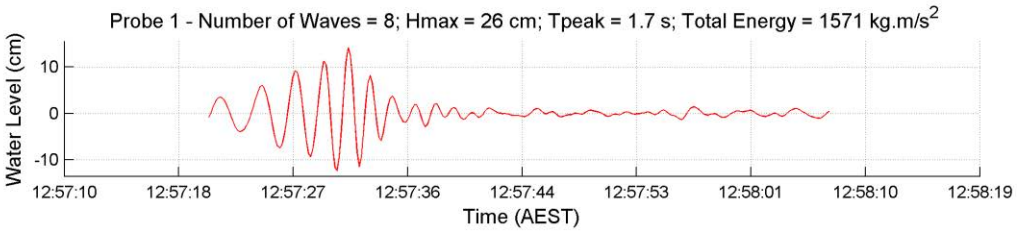
Test 69 - Boat 3 - 14 knots - Run 5 of 6

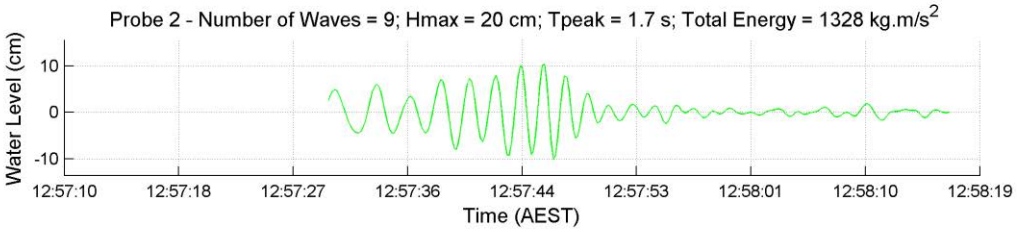


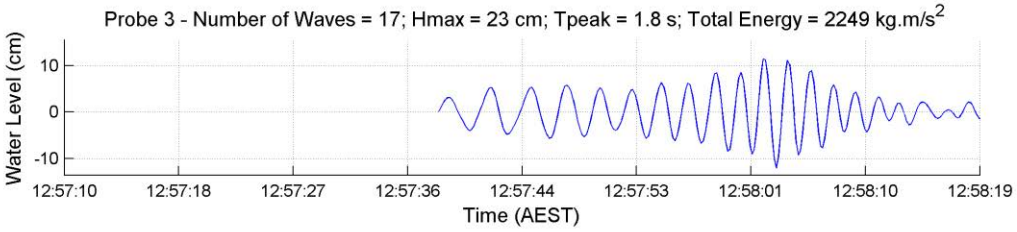




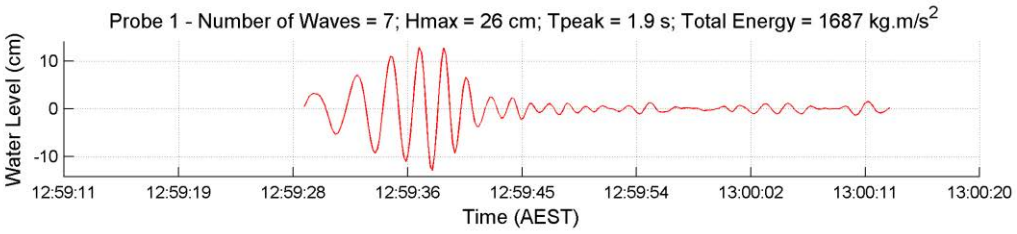
Test 70 - Boat 1 - 14 knots - Run 6 of 6

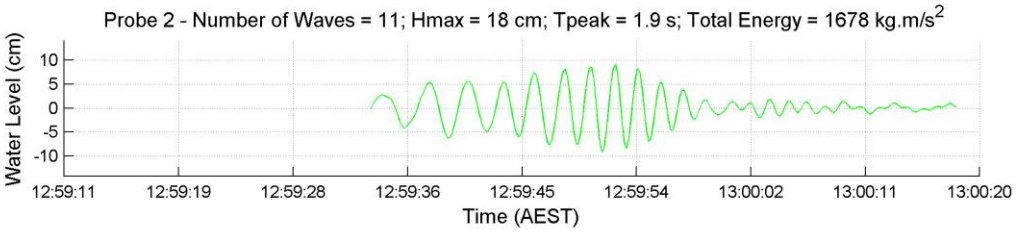


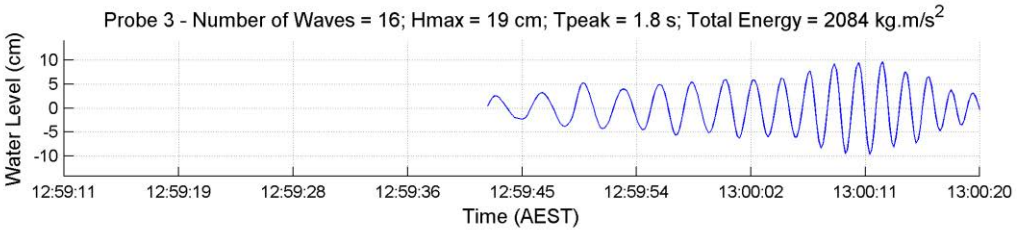




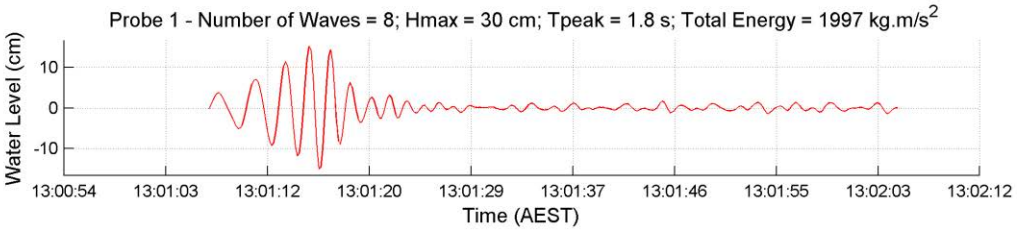
Test 71 - Boat 2 - 14 knots - Run 6 of 6

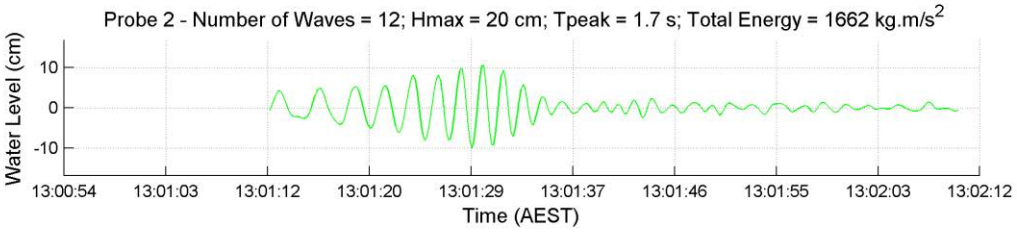


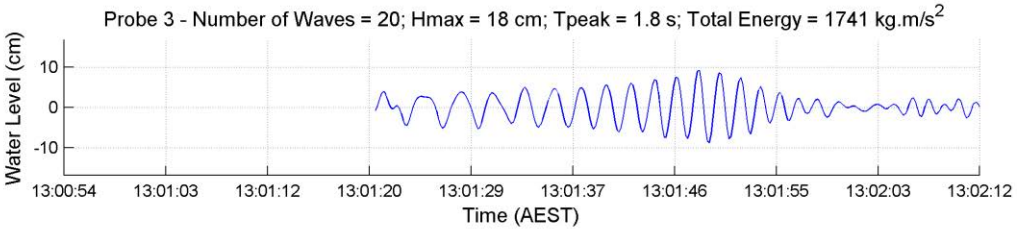


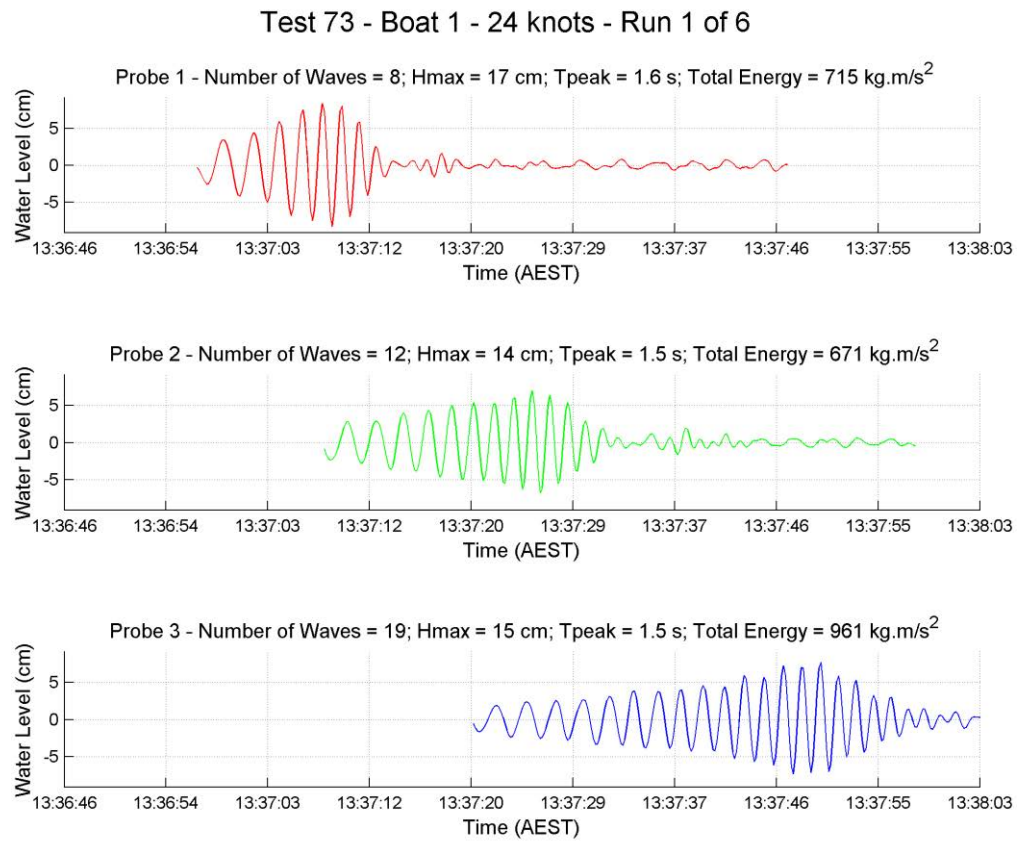


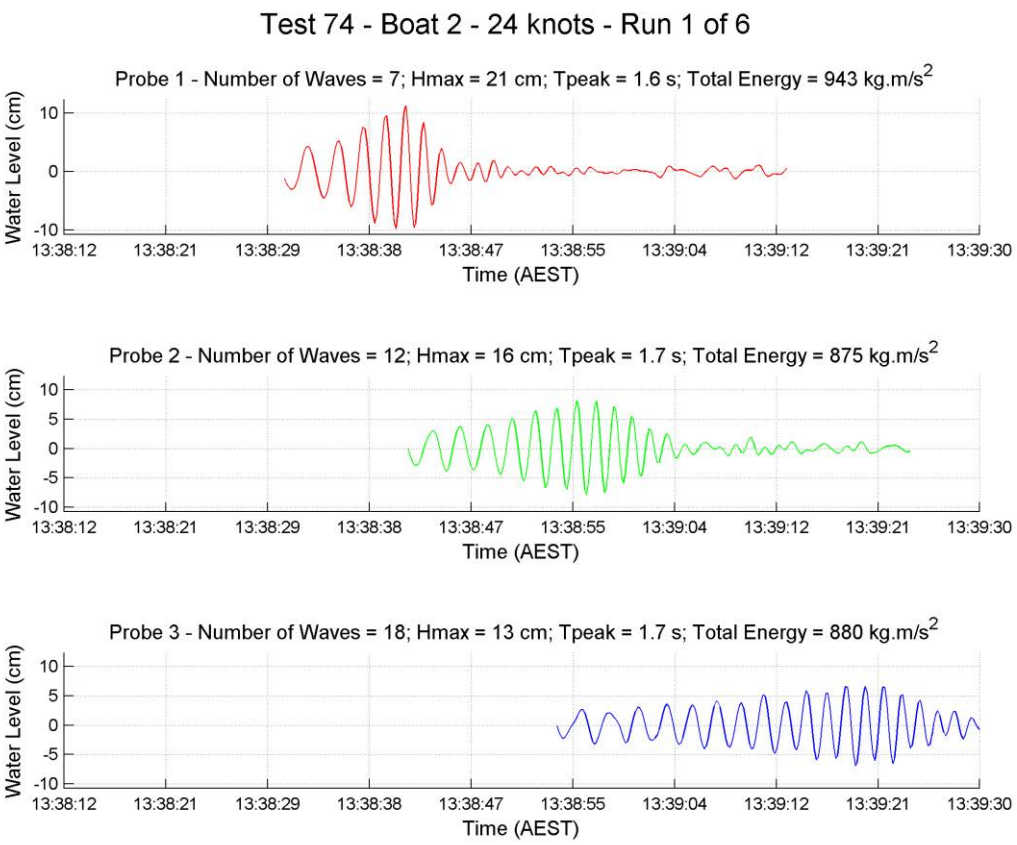
Test 72 - Boat 3 - 14 knots - Run 6 of 6

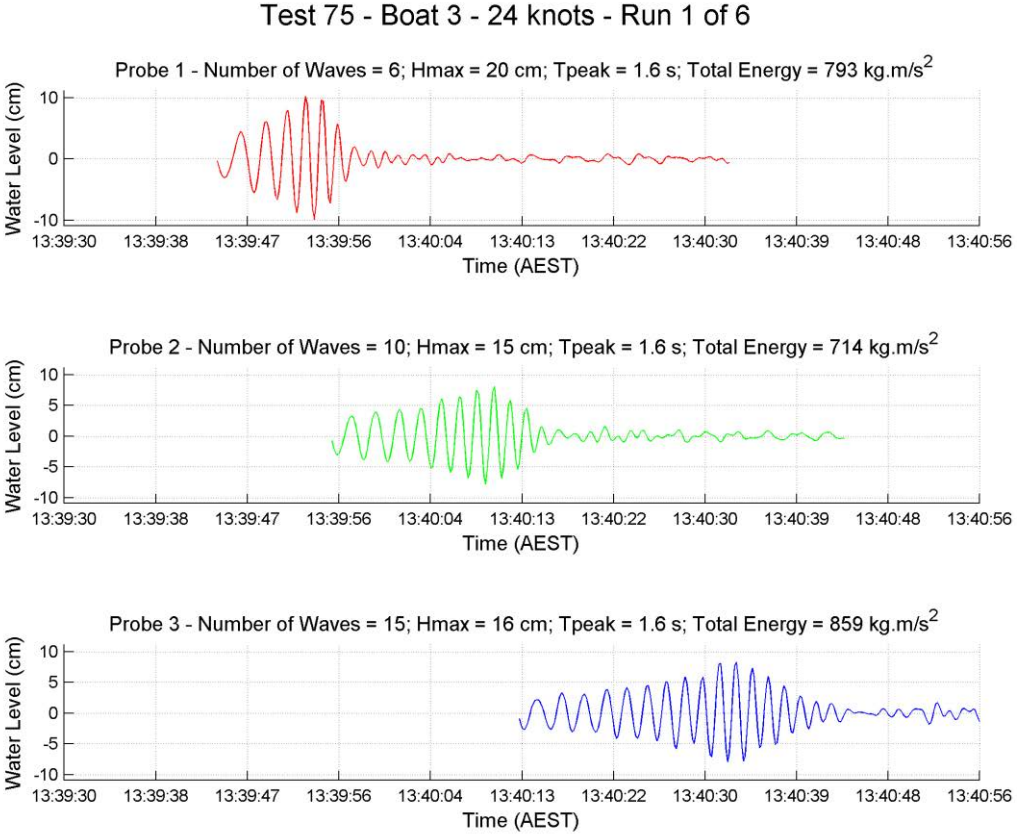


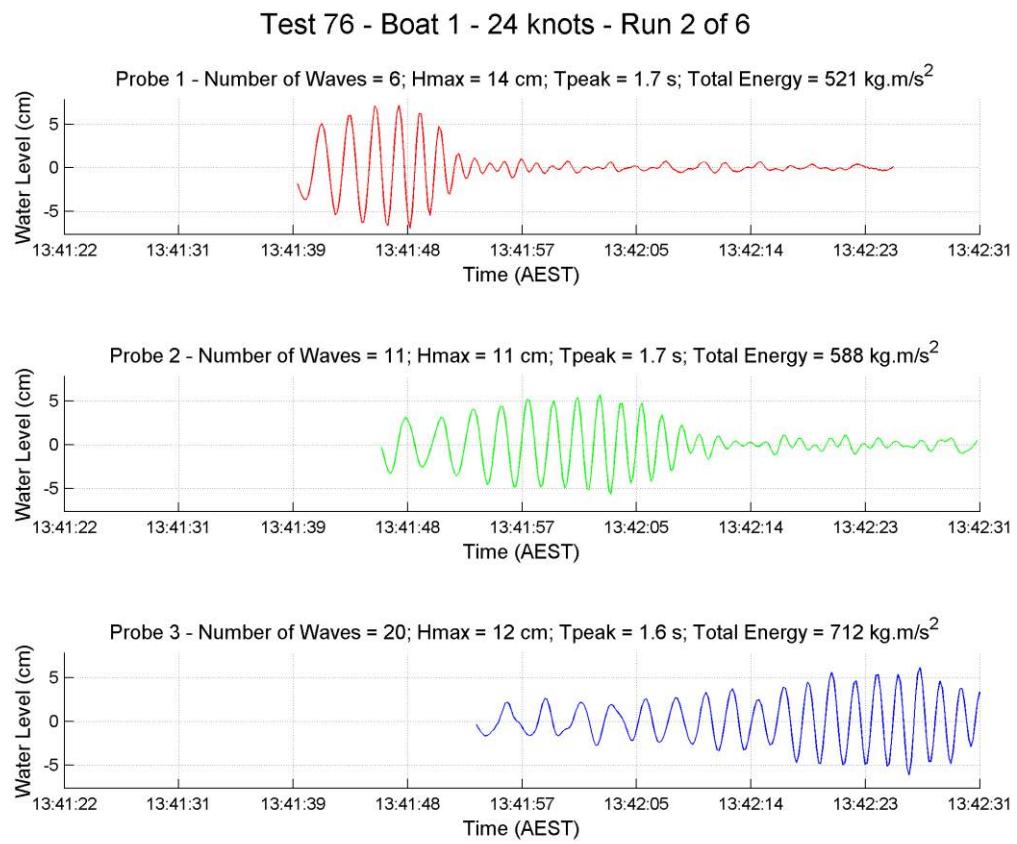


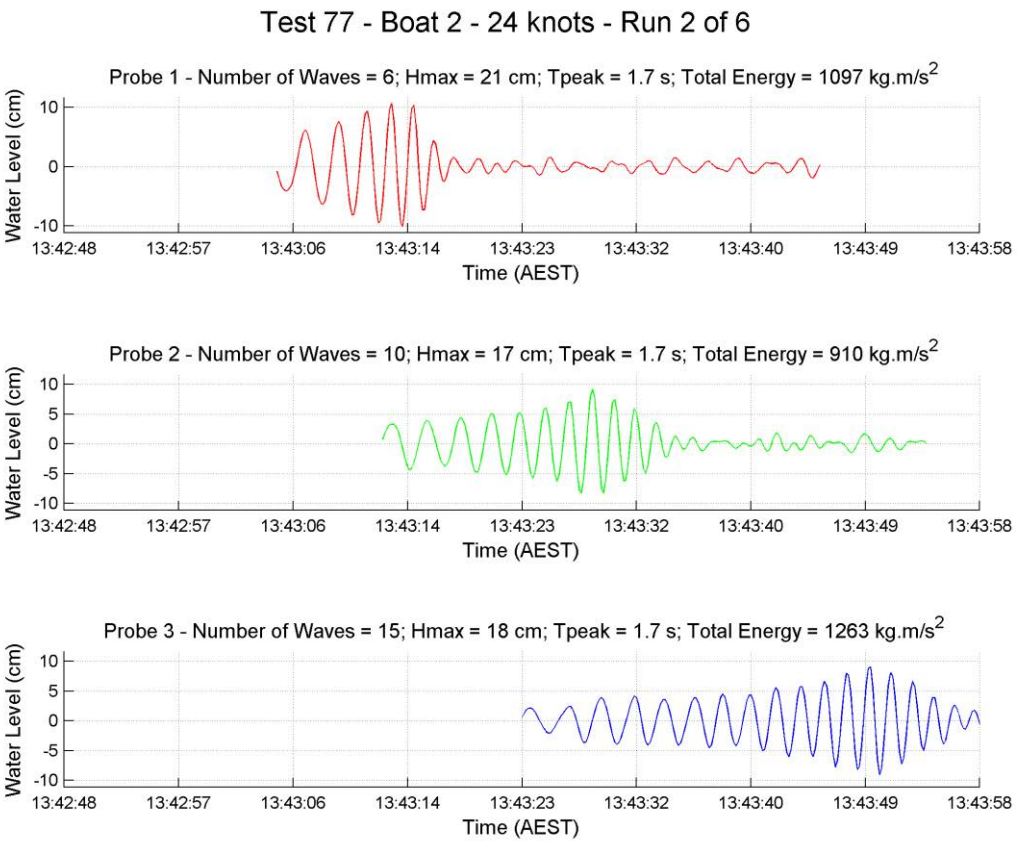


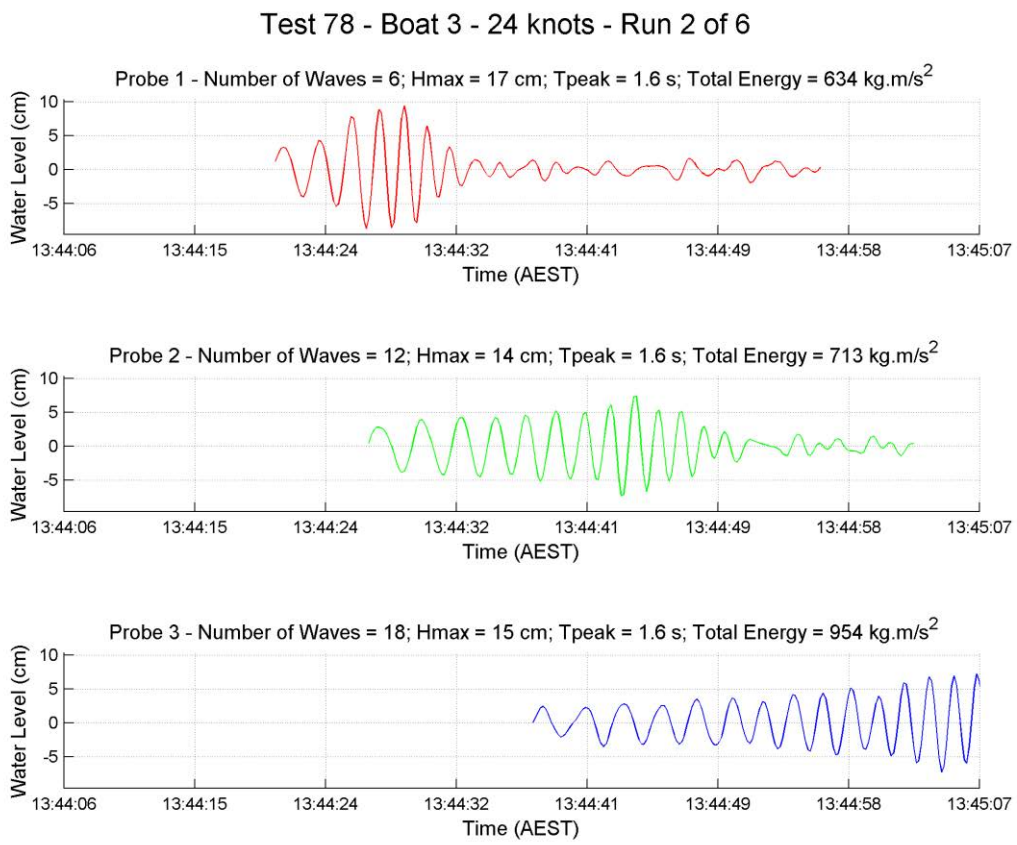

Test 73 - Boat 1 - 24 knots - Run 1 of 6
Probe 1 - Number of Waves = 8; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 715 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 14 cm; Tpeak = 1.5 s; Total Energy = 671 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 15 cm; Tpeak = 1.5 s; Total Energy = 961 kg.m/s2
Water Level (cm)
5
0
-5
13:36:46
13:36:54
13:37:03
13:37:12
13:37:20
13:37:29
13:37:37
13:37:46
13:37:55
13:38:03
Time (AEST)

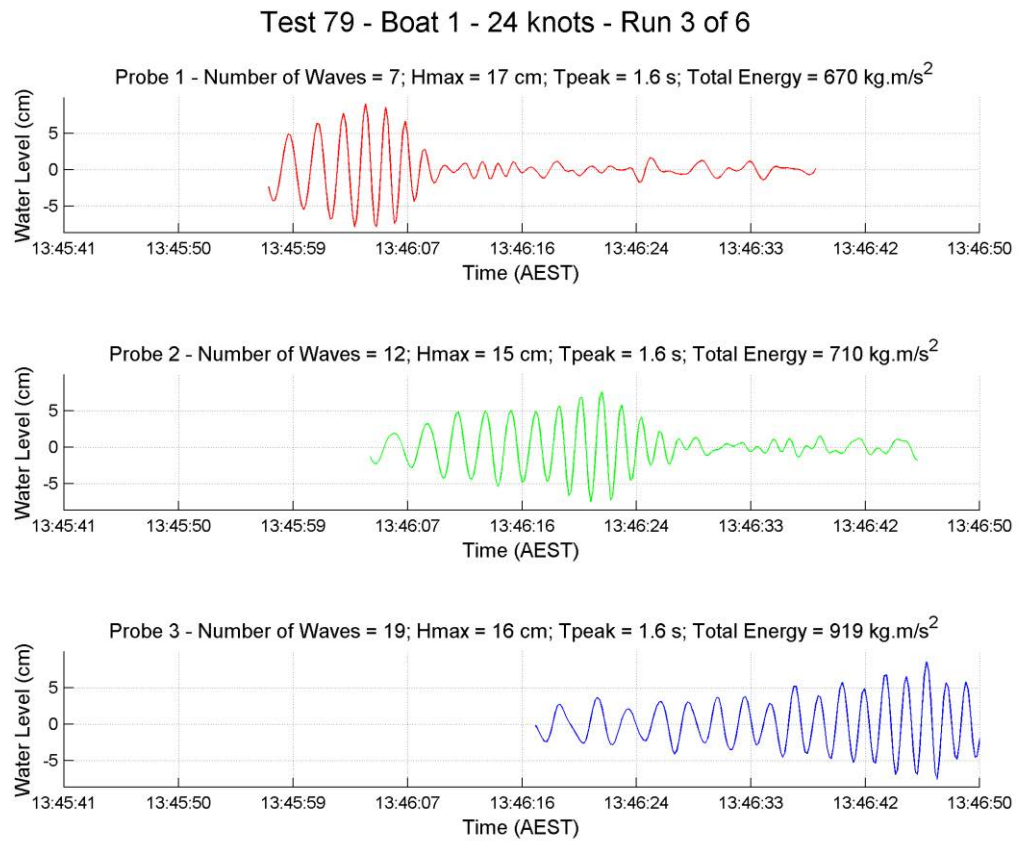

Test 74 - Boat 2 - 24 knots - Run 1 of 6
Probe 1 - Number of Waves = 7; Hmax = 21 cm; Tpeak = 1.6 s; Total Energy = 943 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 16 cm; Tpeak = 1.7 s; Total Energy = 875 kg.m/s2
Probe 3 - Number of Waves = 18; Hmax = 13 cm; Tpeak = 1.7 s; Total Energy = 880 kg.m/s2
Water Level (cm)
10
5
0
-5
-10
13:38:12
13:38:21
13:38:29
13:38:38
13:38:47
13:38:55
13:39:04
13:39:12
13:39:21
13:39:30
Time (AEST)

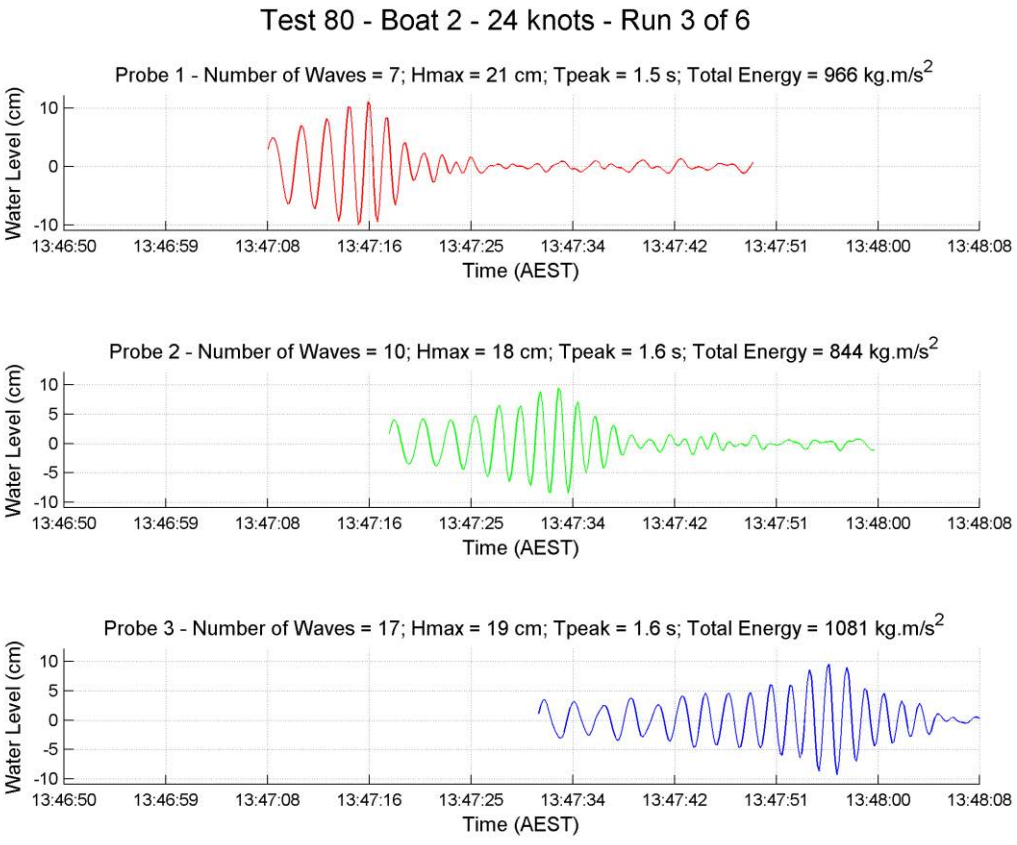

Test 75 - Boat 3 - 24 knots - Run 1 of 6
Probe 1 - Number of Waves = 6; Hmax = 20 cm; Tpeak = 1.6 s; Total Energy = 793 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 714 kg.m/s2
Probe 3 - Number of Waves = 15; Hmax = 16 cm; Tpeak = 1.6 s; Total Energy = 859 kg.m/s2
Water Level (cm)
Time (AEST)
13:39:30
13:39:38
13:39:47
13:39:56
13:40:04
13:40:13
13:40:22
13:40:30
13:40:39
13:40:48
13:40:56

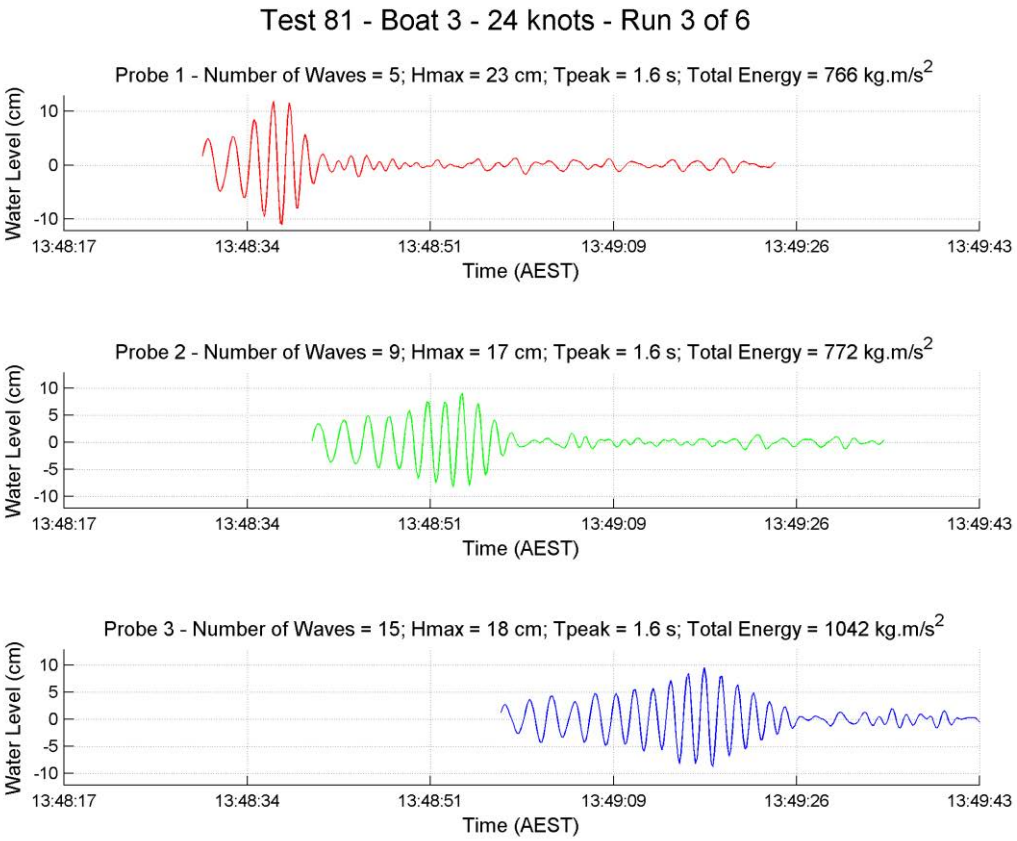

Test 76 - Boat 1 - 24 knots - Run 2 of 6
Probe 1 - Number of Waves = 6; Hmax = 14 cm; Tpeak = 1.7 s; Total Energy = 521 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 11 cm; Tpeak = 1.7 s; Total Energy = 588 kg.m/s2
Probe 3 - Number of Waves = 20; Hmax = 12 cm; Tpeak = 1.6 s; Total Energy = 712 kg.m/s2
Water Level (cm)
Time (AEST)
13:41:22
13:41:31
13:41:39
13:41:48
13:41:57
13:42:05
13:42:14
13:42:23
13:42:31

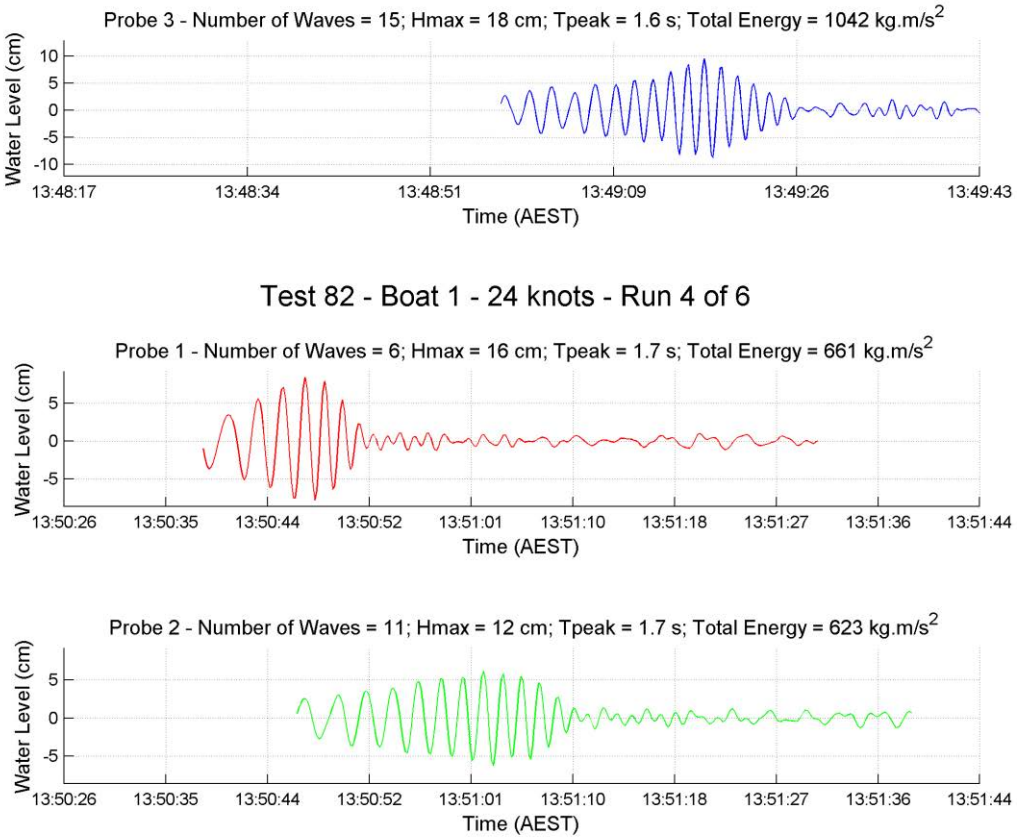

Test 77 - Boat 2 - 24 knots - Run 2 of 6
Probe 1 - Number of Waves = 6; Hmax = 21 cm; Tpeak = 1.7 s; Total Energy = 1097 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 17 cm; Tpeak = 1.7 s; Total Energy = 910 kg.m/s2
Probe 3 - Number of Waves = 15; Hmax = 18 cm; Tpeak = 1.7 s; Total Energy = 1263 kg.m/s2
Water Level (cm)
Time (AEST)
13:42:48
13:42:57
13:43:06
13:43:14
13:43:23
13:43:32
13:43:40
13:43:49
13:43:58

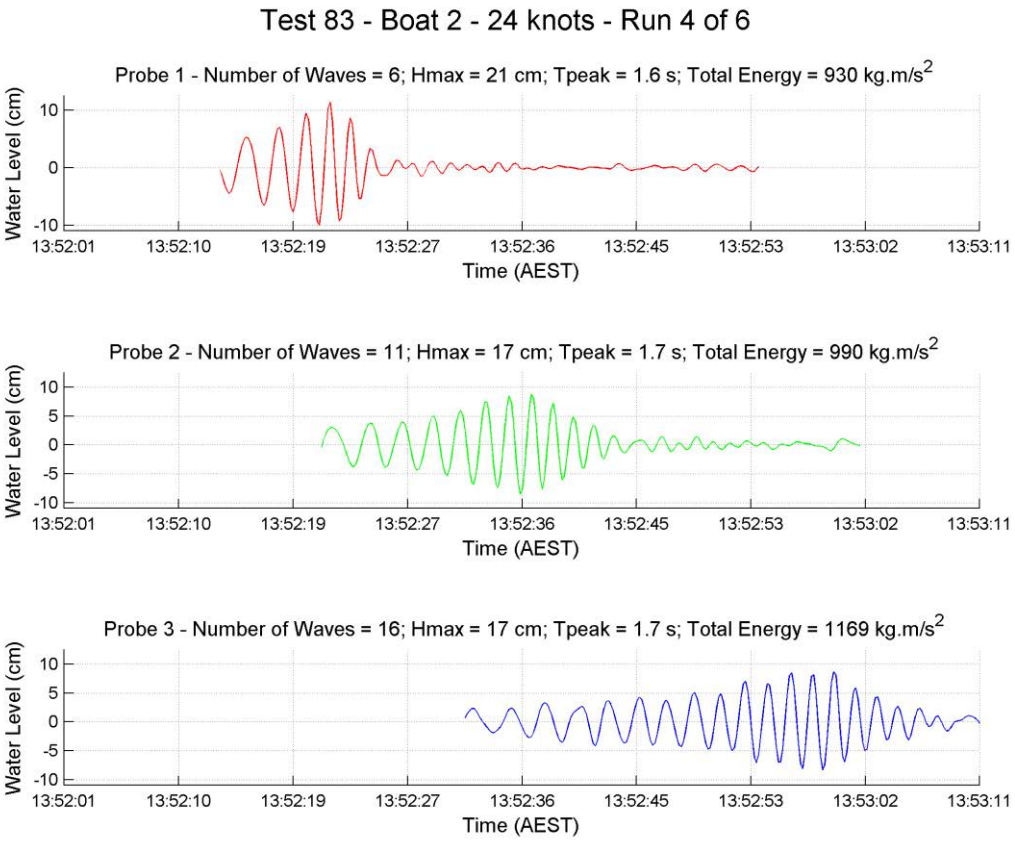

Test 78 - Boat 3 - 24 knots - Run 2 of 6
Probe 1 - Number of Waves = 6; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 634 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 14 cm; Tpeak = 1.6 s; Total Energy = 713 kg.m/s2
Probe 3 - Number of Waves = 18; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 954 kg.m/s2
Water Level (cm)
Time (AEST)
13:44:06
13:44:15
13:44:24
13:44:32
13:44:41
13:44:49
13:44:58
13:45:07

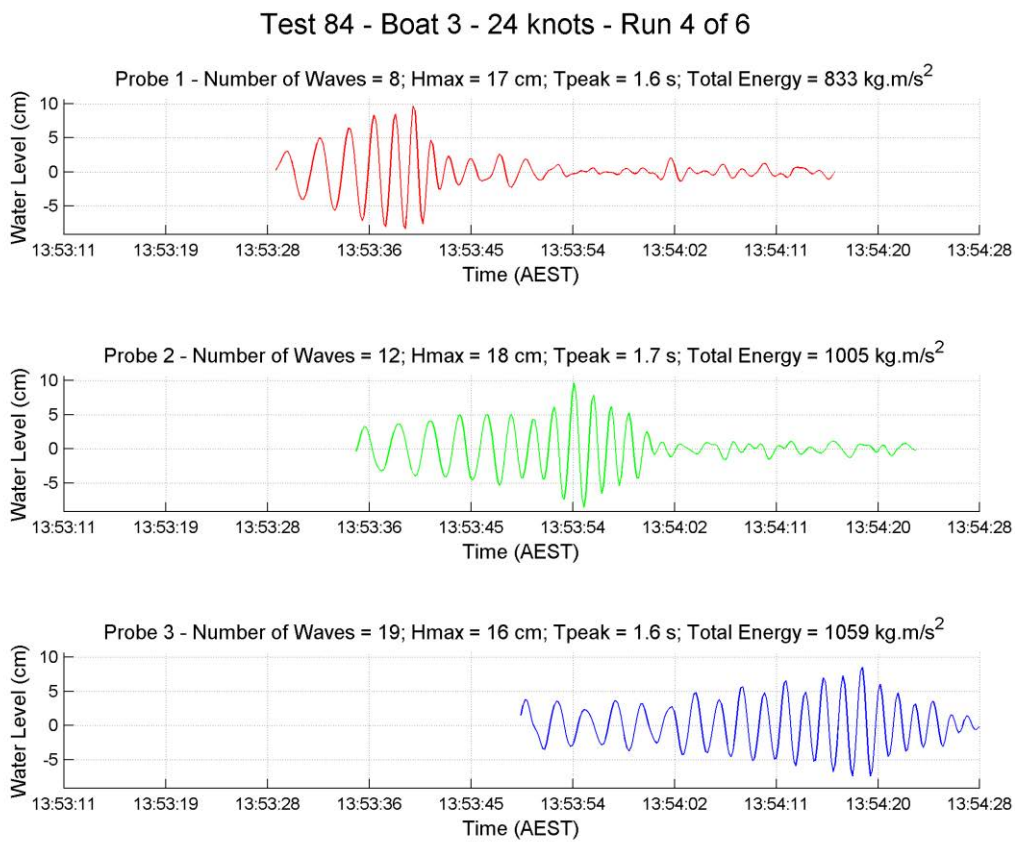

Test 79 - Boat 1 - 24 knots - Run 3 of 6
Probe 1 - Number of Waves = 7; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 670 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 710 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 16 cm; Tpeak = 1.6 s; Total Energy = 919 kg.m/s2
Water Level (cm)
Time (AEST)
13:45:41
13:45:50
13:45:59
13:46:07
13:46:16
13:46:24
13:46:33
13:46:42
13:46:50

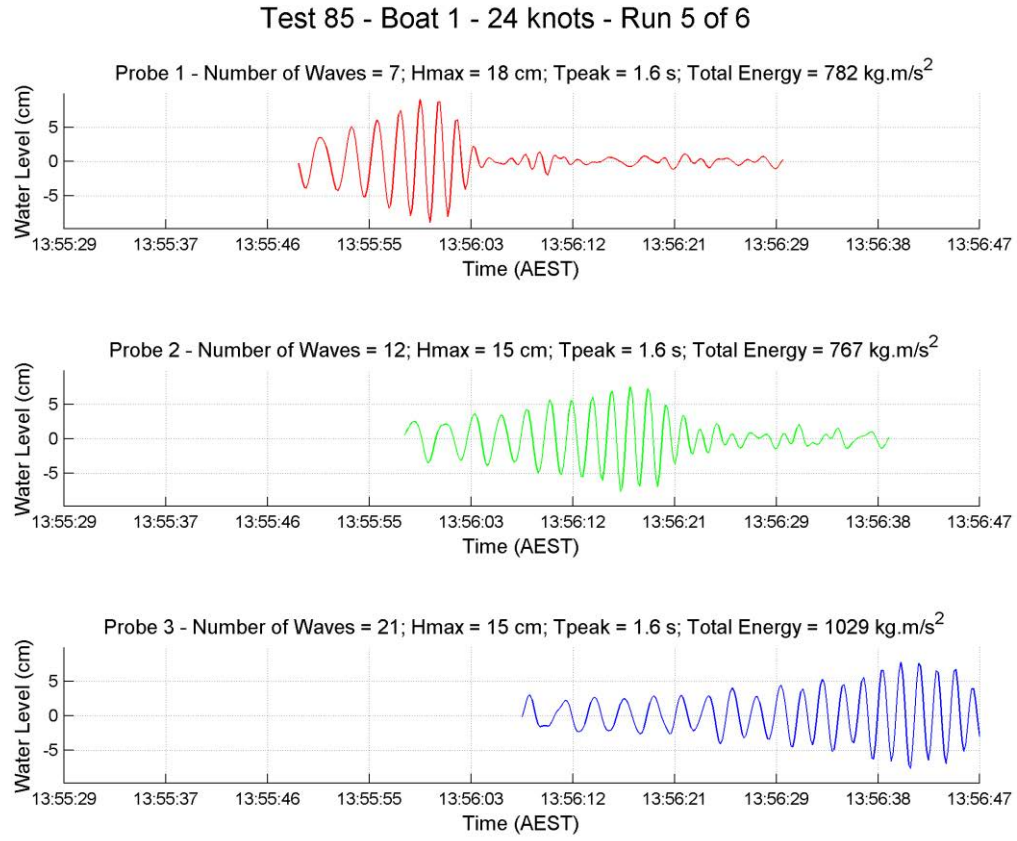

Test 80 - Boat 2 - 24 knots - Run 3 of 6
Probe 1 - Number of Waves = 7; Hmax = 21 cm; Tpeak = 1.5 s; Total Energy = 966 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 18 cm; Tpeak = 1.6 s; Total Energy = 844 kg.m/s2
Probe 3 - Number of Waves = 17; Hmax = 19 cm; Tpeak = 1.6 s; Total Energy = 1081 kg.m/s2
Water Level (cm)
Time (AEST)
13:46:50
13:46:59
13:47:08
13:47:16
13:47:25
13:47:34
13:47:42
13:47:51
13:48:00
13:48:08

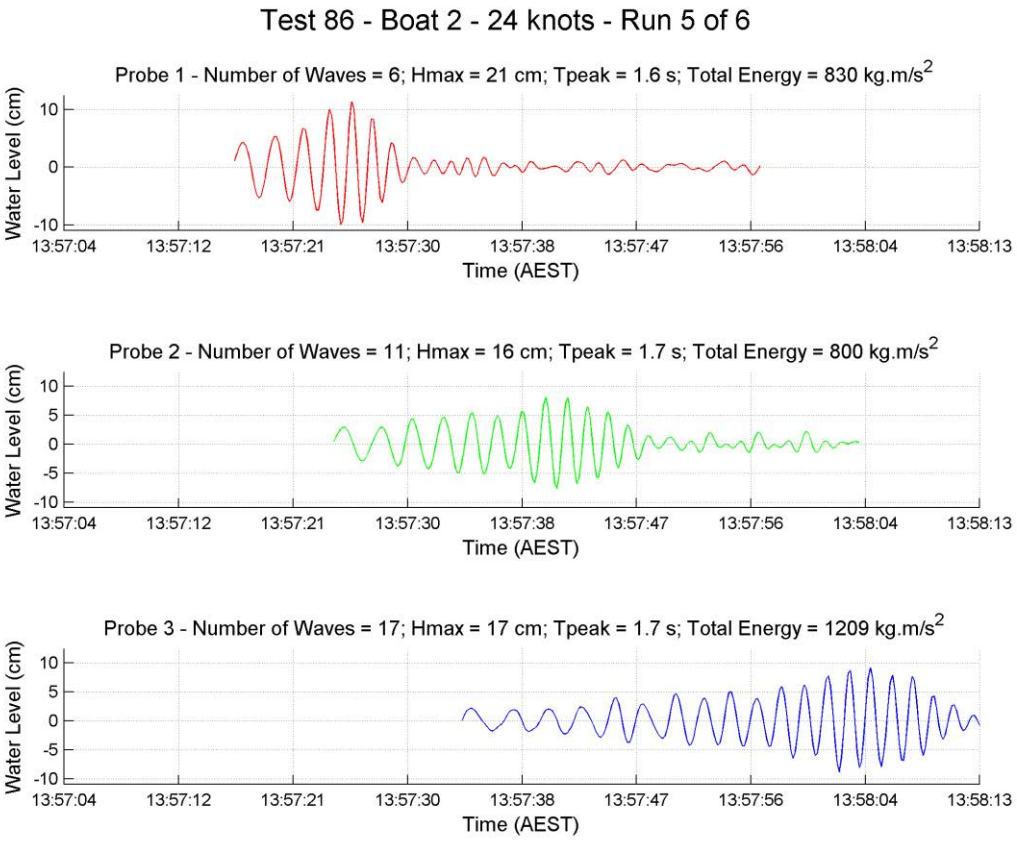

Test 81 - Boat 3 - 24 knots - Run 3 of 6
Probe 1 - Number of Waves = 5; Hmax = 23 cm; Tpeak = 1.6 s; Total Energy = 766 kg.m/s2
Probe 2 - Number of Waves = 9; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 772 kg.m/s2
Probe 3 - Number of Waves = 15; Hmax = 18 cm; Tpeak = 1.6 s; Total Energy = 1042 kg.m/s2
Water Level (cm)
Time (AEST)
13:48:17
13:48:34
13:48:51
13:49:09
13:49:26
13:49:43

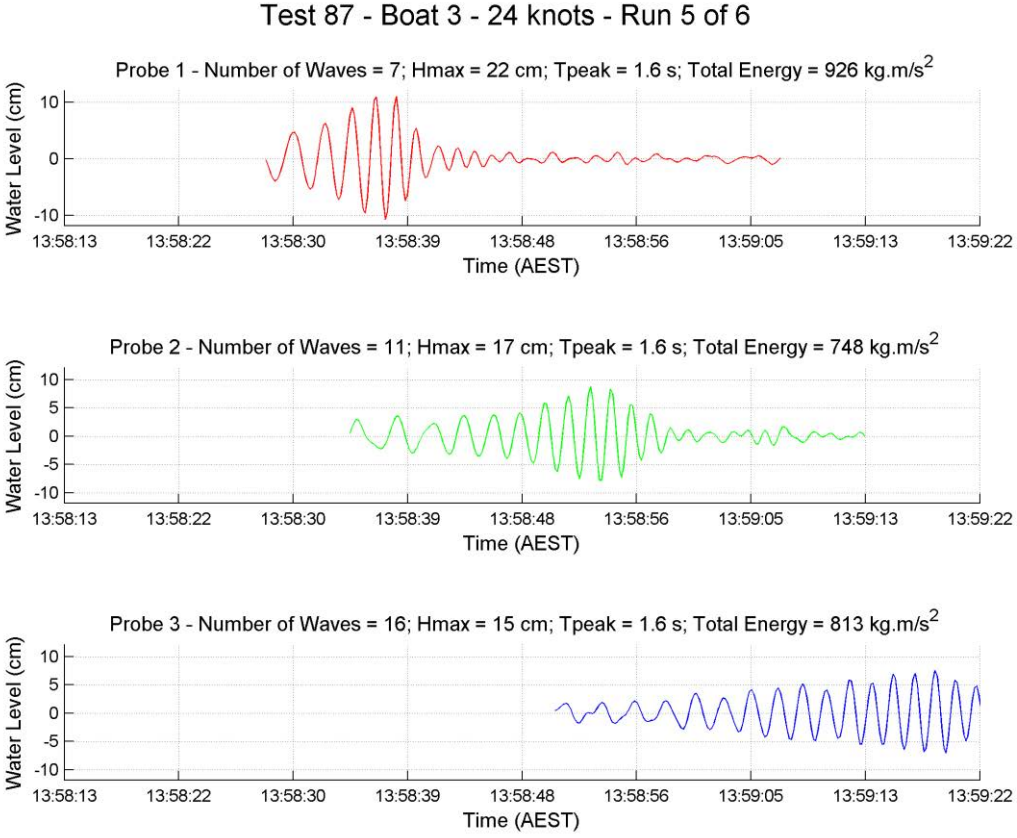

Test 82 - Boat 1 - 24 knots - Run 4 of 6
Probe 1 - Number of Waves = 6; Hmax = 16 cm; Tpeak = 1.7 s; Total Energy = 661 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 12 cm; Tpeak = 1.7 s; Total Energy = 623 kg.m/s2
Probe 3 - Number of Waves = 20; Hmax = 12 cm; Tpeak = 1.6 s; Total Energy = 706 kg.m/s2
Water Level (cm)
Time (AEST)
13:50:26
13:50:35
13:50:44
13:50:52
13:51:01
13:51:10
13:51:18
13:51:27
13:51:36
13:51:44

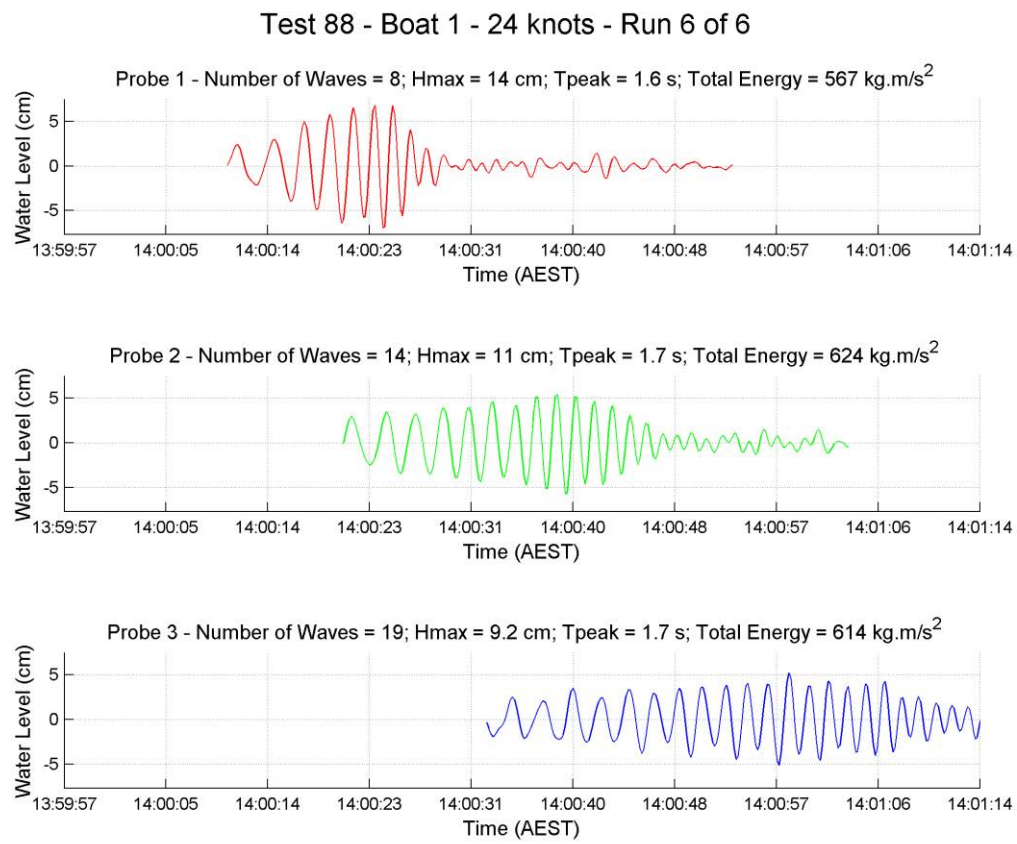

Test 83 - Boat 2 - 24 knots - Run 4 of 6
Probe 1 - Number of Waves = 6; Hmax = 21 cm; Tpeak = 1.6 s; Total Energy = 930 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 17 cm; Tpeak = 1.7 s; Total Energy = 990 kg.m/s2
Probe 3 - Number of Waves = 16; Hmax = 17 cm; Tpeak = 1.7 s; Total Energy = 1169 kg.m/s2
Water Level (cm)
Time (AEST)
13:52:01
13:52:10
13:52:19
13:52:27
13:52:36
13:52:45
13:52:53
13:53:02
13:53:11

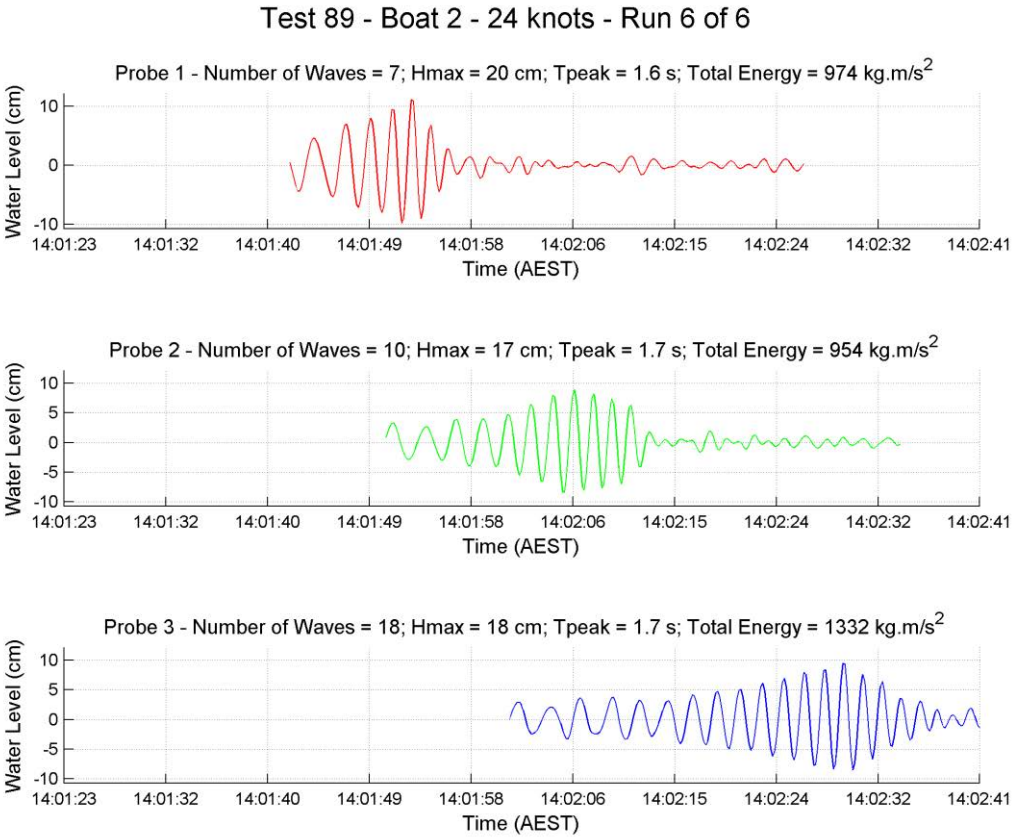

Test 84 - Boat 3 - 24 knots - Run 4 of 6
Probe 1 - Number of Waves = 8; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 833 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 18 cm; Tpeak = 1.7 s; Total Energy = 1005 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 16 cm; Tpeak = 1.6 s; Total Energy = 1059 kg.m/s2
Water Level (cm)
Time (AEST)
13:53:11
13:53:19
13:53:28
13:53:36
13:53:45
13:53:54
13:54:02
13:54:11
13:54:20
13:54:28

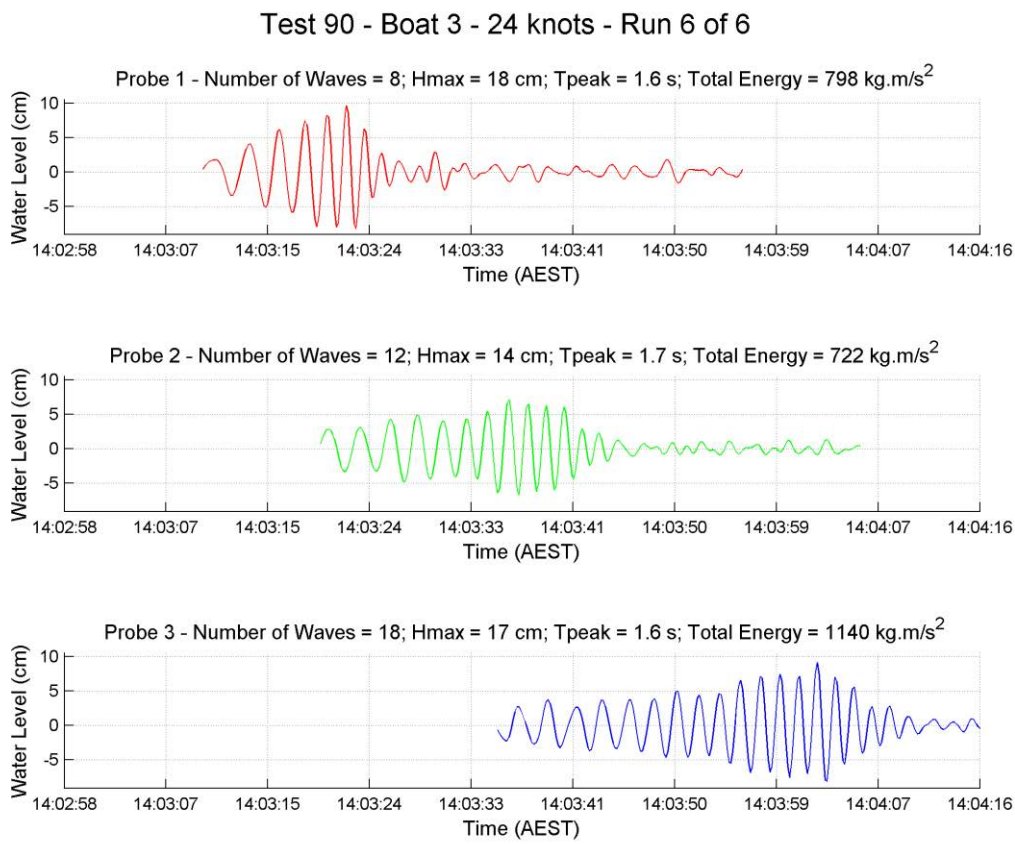

Test 85 - Boat 1 - 24 knots - Run 5 of 6
Probe 1 - Number of Waves = 7; Hmax = 18 cm; Tpeak = 1.6 s; Total Energy = 782 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 767 kg.m/s2
Probe 3 - Number of Waves = 21; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 1029 kg.m/s2
Water Level (cm)
5
0
-5
13:55:29
13:55:37
13:55:46
13:55:55
13:56:03
13:56:12
13:56:21
13:56:29
13:56:38
13:56:47
Time (AEST)

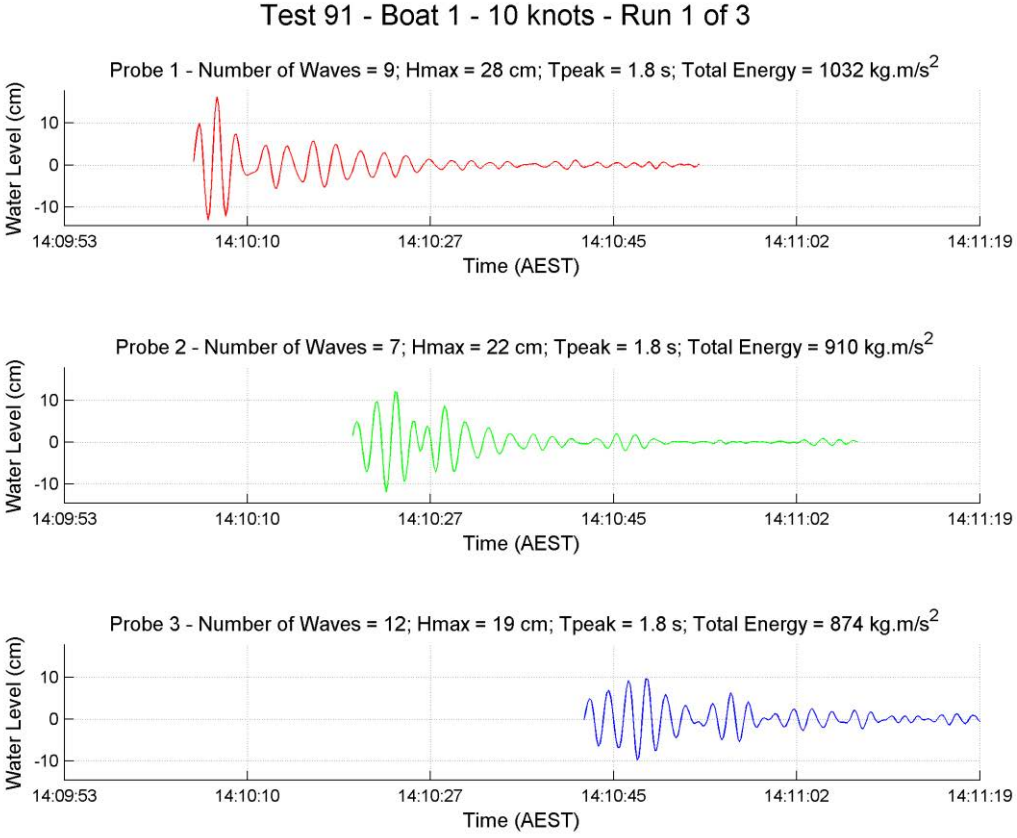

Test 86 - Boat 2 - 24 knots - Run 5 of 6
Probe 1 - Number of Waves = 6; Hmax = 21 cm; Tpeak = 1.6 s; Total Energy = 830 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 16 cm; Tpeak = 1.7 s; Total Energy = 800 kg.m/s2
Probe 3 - Number of Waves = 17; Hmax = 17 cm; Tpeak = 1.7 s; Total Energy = 1209 kg.m/s2
Water Level (cm)
10
5
0
-5
-10
13:57:04
13:57:12
13:57:21
13:57:30
13:57:38
13:57:47
13:57:56
13:58:04
13:58:13
Time (AEST)

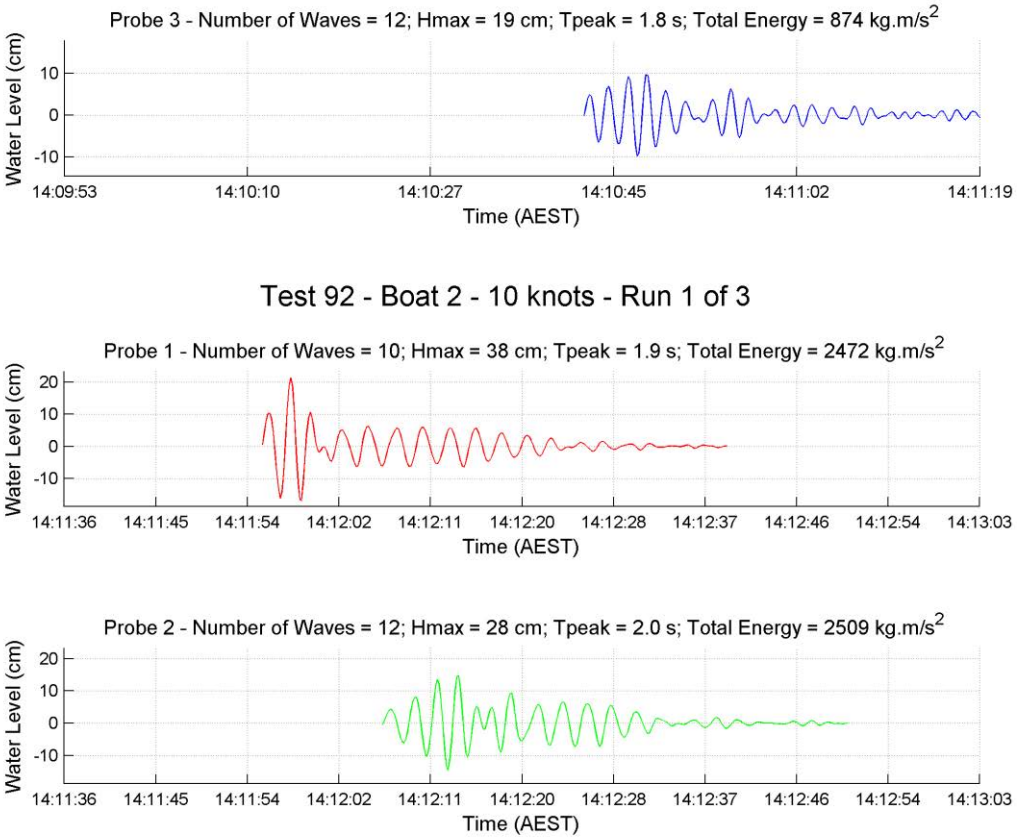

Test 87 - Boat 3 - 24 knots - Run 5 of 6
Probe 1 - Number of Waves = 7; Hmax = 22 cm; Tpeak = 1.6 s; Total Energy = 926 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 748 kg.m/s2
Probe 3 - Number of Waves = 16; Hmax = 15 cm; Tpeak = 1.6 s; Total Energy = 813 kg.m/s2
Water Level (cm)
Time (AEST)
13:58:13
13:58:22
13:58:30
13:58:39
13:58:48
13:58:56
13:59:05
13:59:13
13:59:22

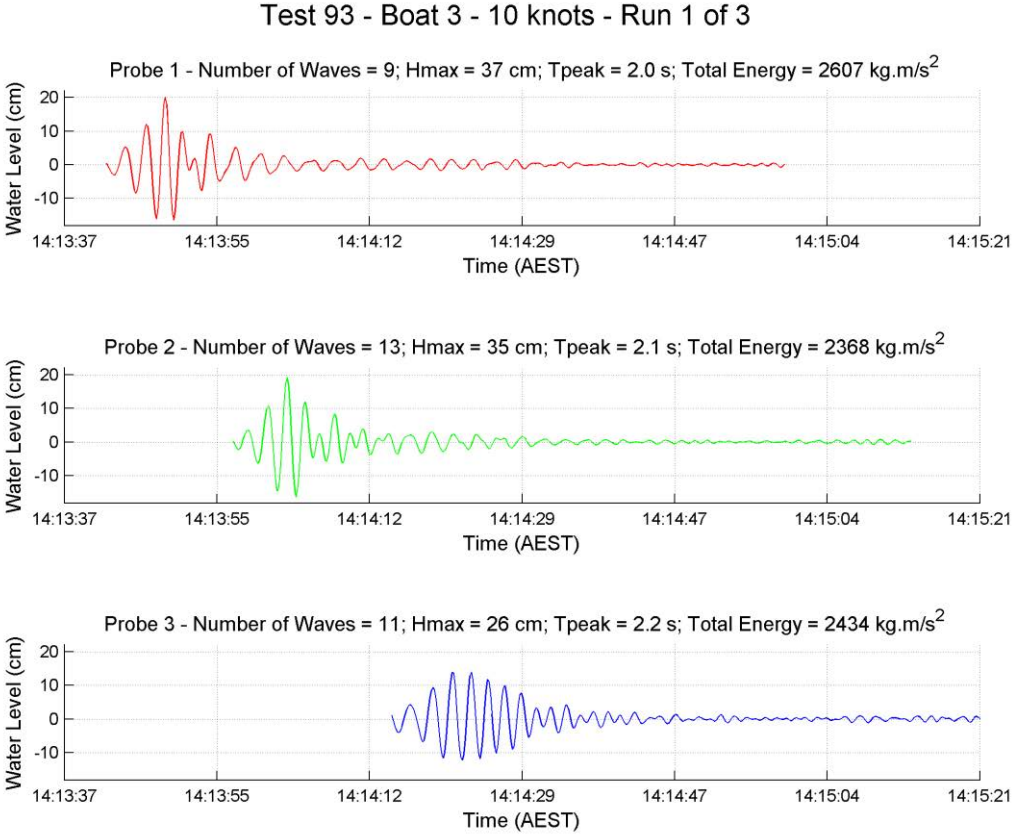

Test 88 - Boat 1 - 24 knots - Run 6 of 6
Probe 1 - Number of Waves = 8; Hmax = 14 cm; Tpeak = 1.6 s; Total Energy = 567 kg.m/s2
Probe 2 - Number of Waves = 14; Hmax = 11 cm; Tpeak = 1.7 s; Total Energy = 624 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 9.2 cm; Tpeak = 1.7 s; Total Energy = 614 kg.m/s2
Water Level (cm)
Time (AEST)
13:59:57
14:00:05
14:00:14
14:00:23
14:00:31
14:00:40
14:00:48
14:00:57
14:01:06
14:01:14

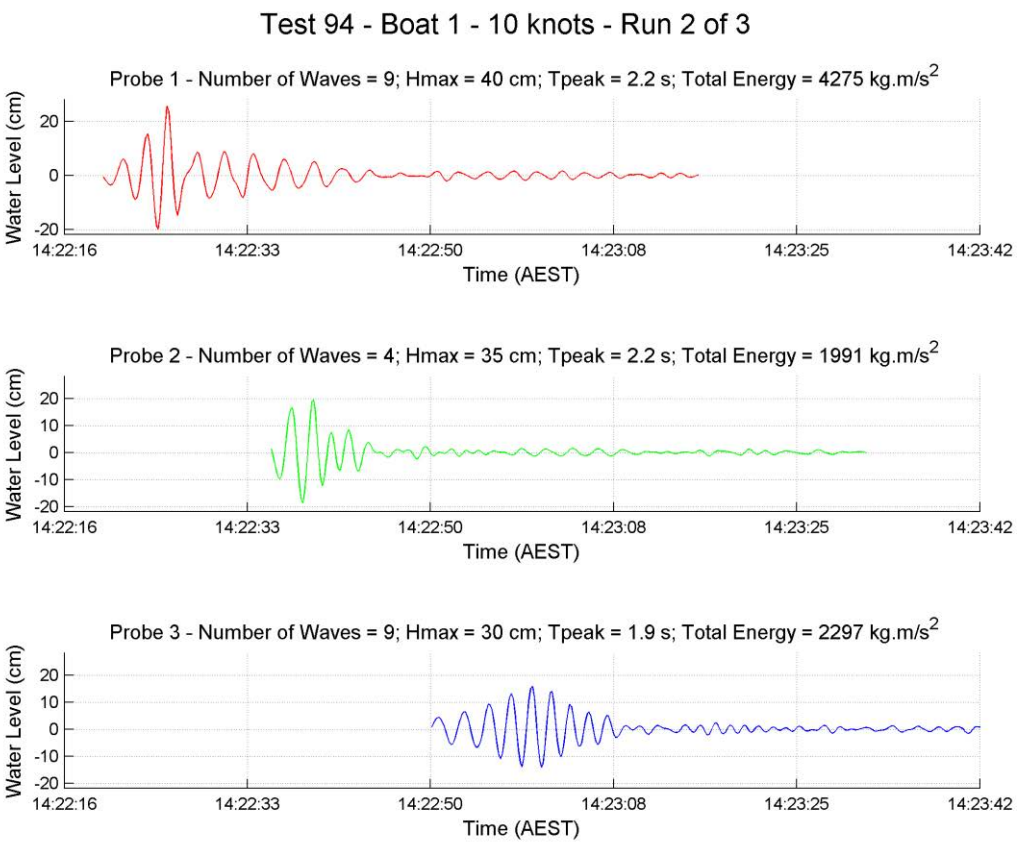

Test 89 - Boat 2 - 24 knots - Run 6 of 6
Probe 1 - Number of Waves = 7; Hmax = 20 cm; Tpeak = 1.6 s; Total Energy = 974 kg.m/s2
Probe 2 - Number of Waves = 10; Hmax = 17 cm; Tpeak = 1.7 s; Total Energy = 954 kg.m/s2
Probe 3 - Number of Waves = 18; Hmax = 18 cm; Tpeak = 1.7 s; Total Energy = 1332 kg.m/s2
Water Level (cm)
Time (AEST)
14:01:23
14:01:32
14:01:40
14:01:49
14:01:58
14:02:06
14:02:15
14:02:24
14:02:32
14:02:41

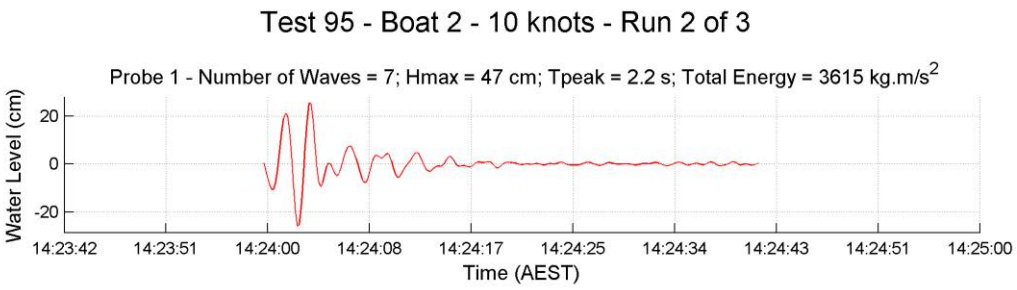

Test 90 - Boat 3 - 24 knots - Run 6 of 6
Probe 1 - Number of Waves = 8; Hmax = 18 cm; Tpeak = 1.6 s; Total Energy = 798 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 14 cm; Tpeak = 1.7 s; Total Energy = 722 kg.m/s2
Probe 3 - Number of Waves = 18; Hmax = 17 cm; Tpeak = 1.6 s; Total Energy = 1140 kg.m/s2
Water Level (cm)
Time (AEST)
14:02:58
14:03:07
14:03:15
14:03:24
14:03:33
14:03:41
14:03:50
14:03:59
14:04:07
14:04:16

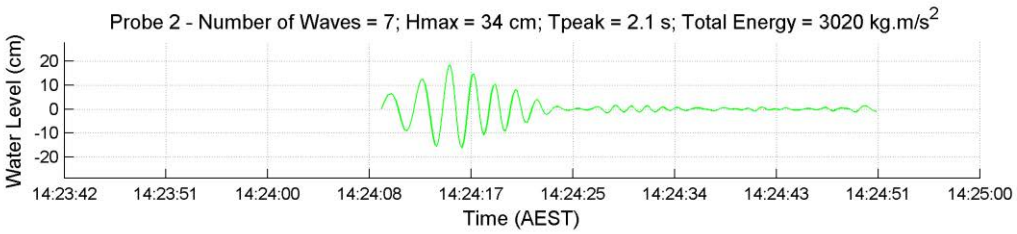

Test 91 - Boat 1 - 10 knots - Run 1 of 3
Probe 1 - Number of Waves = 9; Hmax = 28 cm; Tpeak = 1.8 s; Total Energy = 1032 kg.m/s2
Probe 2 - Number of Waves = 7; Hmax = 22 cm; Tpeak = 1.8 s; Total Energy = 910 kg.m/s2
Probe 3 - Number of Waves = 12; Hmax = 19 cm; Tpeak = 1.8 s; Total Energy = 874 kg.m/s2
Water Level (cm)
10
0
-10
14:09:53
14:10:10
14:10:27
14:10:45
14:11:02
14:11:19
Time (AEST)

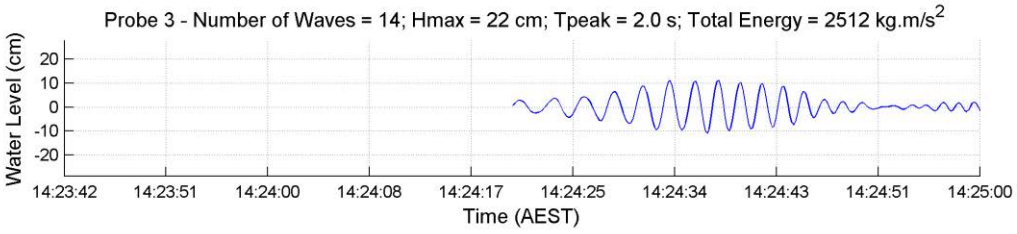

Test 92 - Boat 2 - 10 knots - Run 1 of 3
Probe 1 - Number of Waves = 10; Hmax = 38 cm; Tpeak = 1.9 s; Total Energy = 2472 kg.m/s2
Probe 2 - Number of Waves = 12; Hmax = 28 cm; Tpeak = 2.0 s; Total Energy = 2509 kg.m/s2
Probe 3 - Number of Waves = 15; Hmax = 25 cm; Tpeak = 2.0 s; Total Energy = 2108 kg.m/s2
Water Level (cm)
20
10
0
-10
14:11:36
14:11:45
14:11:54
14:12:02
14:12:11
14:12:20
14:12:28
14:12:37
14:12:46
14:12:54
14:13:03
Time (AEST)

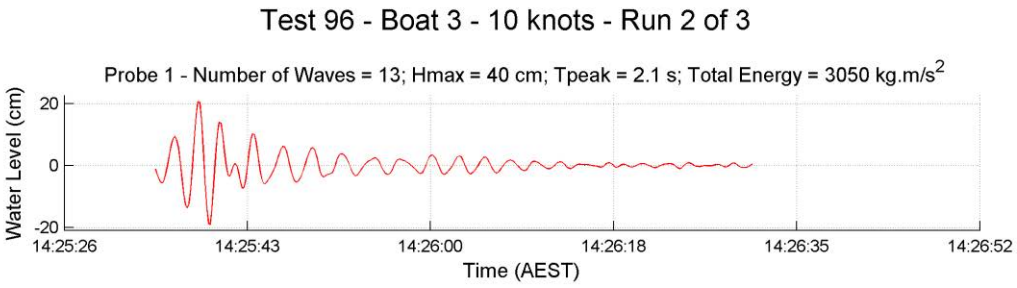

Test 93 - Boat 3 - 10 knots - Run 1 of 3
Probe 1 - Number of Waves = 9; Hmax = 37 cm; Tpeak = 2.0 s; Total Energy = 2607 kg.m/s2
Probe 2 - Number of Waves = 13; Hmax = 35 cm; Tpeak = 2.1 s; Total Energy = 2368 kg.m/s2
Probe 3 - Number of Waves = 11; Hmax = 26 cm; Tpeak = 2.2 s; Total Energy = 2434 kg.m/s2
Water Level (cm)
20
10
0
-10
14:13:37
14:13:55
14:14:12
14:14:29
14:14:47
14:15:04
14:15:21
Time (AEST)

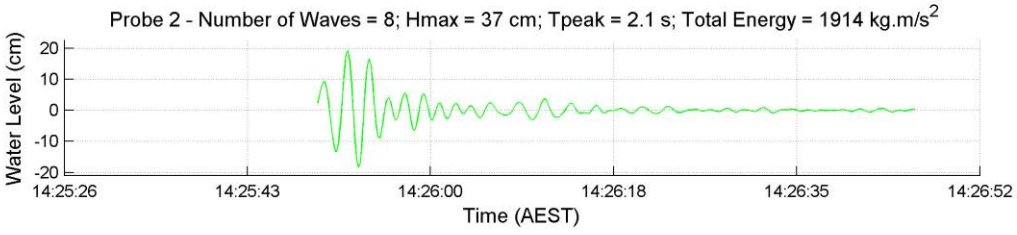

Test 94 - Boat 1 - 10 knots - Run 2 of 3
Probe 1 - Number of Waves = 9; Hmax = 40 cm; Tpeak = 2.2 s; Total Energy = 4275 kg.m/s2
Probe 2 - Number of Waves = 4; Hmax = 35 cm; Tpeak = 2.2 s; Total Energy = 1991 kg.m/s2
Probe 3 - Number of Waves = 9; Hmax = 30 cm; Tpeak = 1.9 s; Total Energy = 2297 kg.m/s2
Water Level (cm)
20
0
-20
14:22:16
14:22:33
14:22:50
14:23:08
14:23:25
14:23:42
Time (AEST)

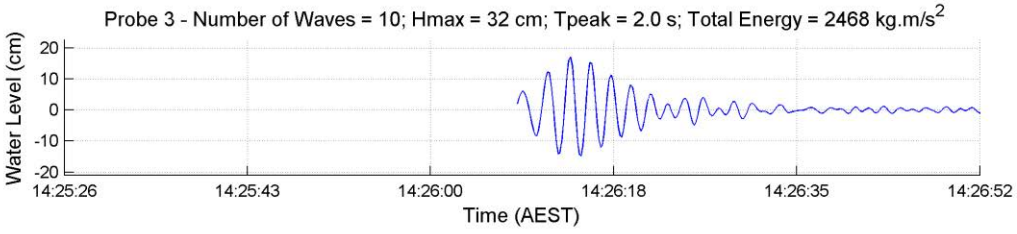

Test 95 - Boat 2 - 10 knots - Run 2 of 3
Probe 1 - Number of Waves = 7; Hmax = 47 cm; Tpeak = 2.2 s; Total Energy = 3615 kg.m/s2
Water Level (cm)
20
0
-20
14:23:42
14:23:51
14:24:00
14:24:08
14:24:17
14:24:25
14:24:34
14:24:43
14:24:51
14:25:00
Time (AEST)

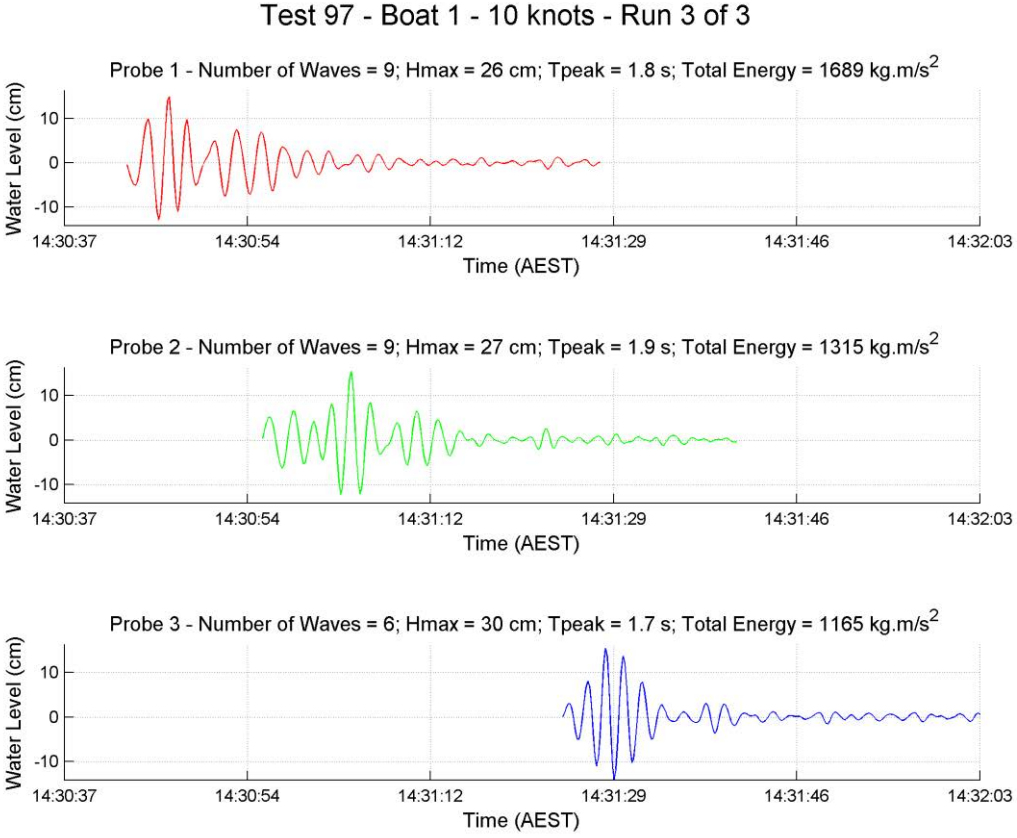

Probe 2 - Number of Waves = 7; Hmax = 34 cm; Tpeak = 2.1 s; Total Energy = 3020 kg.m/s2
Water Level (cm)
20
10
0
-10
-20
14:23:42
14:23:51
14:24:00
14:24:08
14:24:17
14:24:25
14:24:34
14:24:43
14:24:51
14:25:00
Time (AEST)

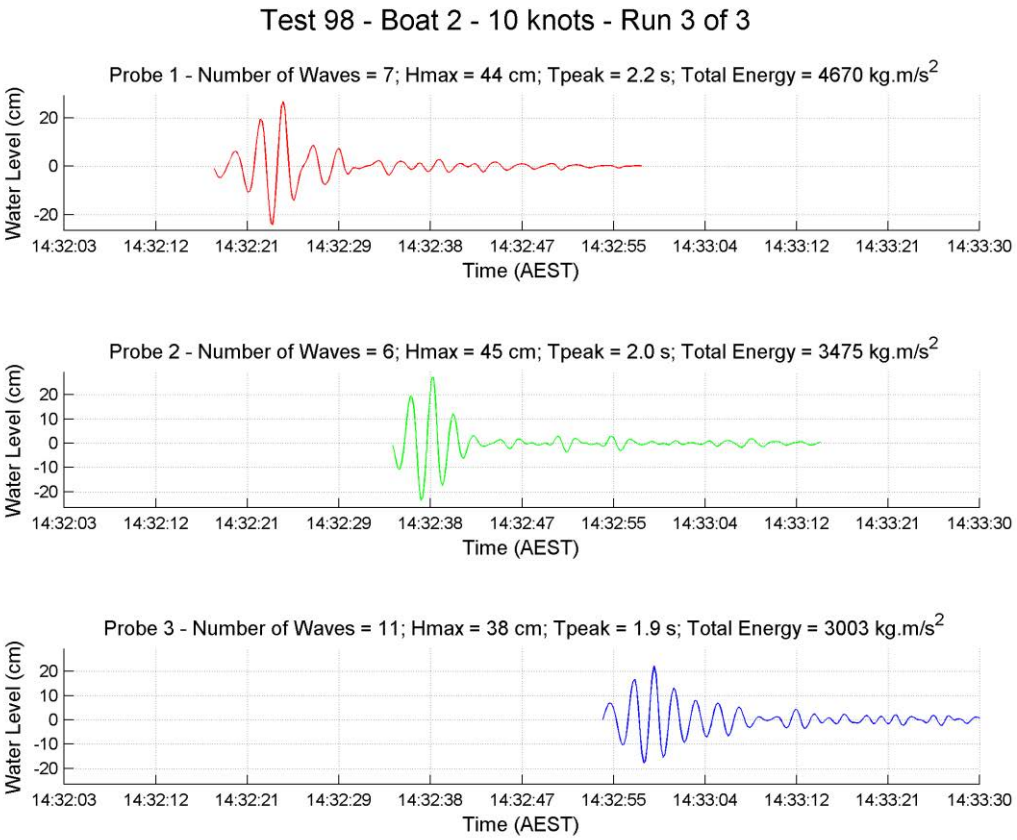

Probe 3 - Number of Waves = 14; Hmax = 22 cm; Tpeak = 2.0 s; Total Energy = 2512 kg.m/s2
Water Level (cm)
20
10
0
-10
-20
14:23:42
14:23:51
14:24:00
14:24:08
14:24:17
14:24:25
14:24:34
14:24:43
14:24:51
14:25:00
Time (AEST)


Test 96 - Boat 3 - 10 knots - Run 2 of 3
Probe 1 - Number of Waves = 13; Hmax = 40 cm; Tpeak = 2.1 s; Total Energy = 3050 kg.m/s2
Water Level (cm)
20
0
-20
14:25:26
14:25:43
14:26:00
14:26:18
14:26:35
14:26:52
Time (AEST)

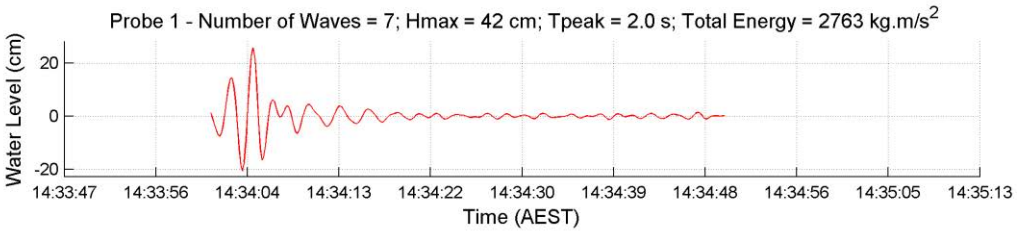

Probe 2 - Number of Waves = 8; Hmax = 37 cm; Tpeak = 2.1 s; Total Energy = 1914 kg.m/s2
Water Level (cm)
20
10
0
-10
-20
14:25:26
14:25:43
14:26:00
14:26:18
14:26:35
14:26:52
Time (AEST)

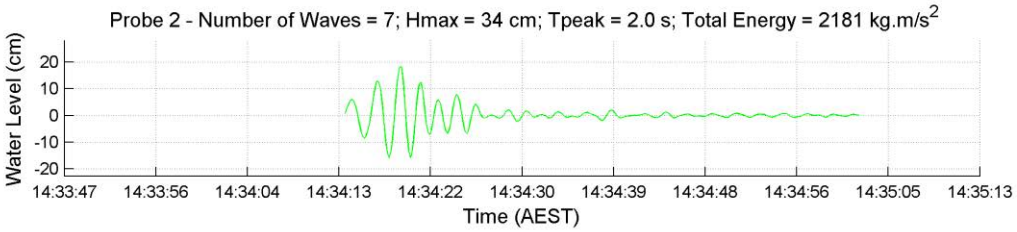

Probe 3 - Number of Waves = 10; Hmax = 32 cm; Tpeak = 2.0 s; Total Energy = 2468 kg.m/s2
Water Level (cm)
20
10
0
-10
-20
14:25:26
14:25:43
14:26:00
14:26:18
14:26:35
14:26:52
Time (AEST)

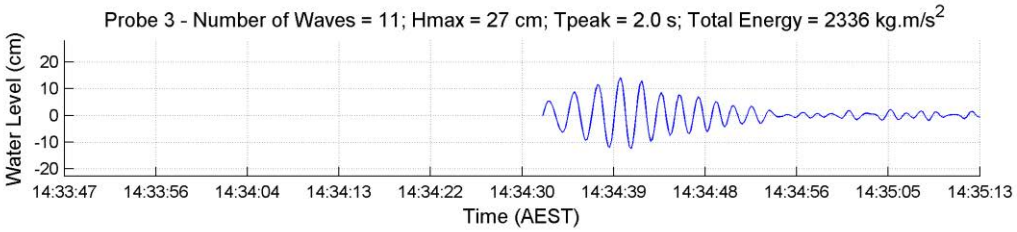

Test 97 - Boat 1 - 10 knots - Run 3 of 3
Probe 1 - Number of Waves = 9; Hmax = 26 cm; Tpeak = 1.8 s; Total Energy = 1689 kg.m/s2
Probe 2 - Number of Waves = 9; Hmax = 27 cm; Tpeak = 1.9 s; Total Energy = 1315 kg.m/s2
Probe 3 - Number of Waves = 6; Hmax = 30 cm; Tpeak = 1.7 s; Total Energy = 1165 kg.m/s2
Water Level (cm)
10
0
-10
14:30:37
14:30:54
14:31:12
14:31:29
14:31:46
14:32:03
Time (AEST)


Test 98 - Boat 2 - 10 knots - Run 3 of 3
Probe 1 - Number of Waves = 7; Hmax = 44 cm; Tpeak = 2.2 s; Total Energy = 4670 kg.m/s2
Probe 2 - Number of Waves = 6; Hmax = 45 cm; Tpeak = 2.0 s; Total Energy = 3475 kg.m/s2
Probe 3 - Number of Waves = 11; Hmax = 38 cm; Tpeak = 1.9 s; Total Energy = 3003 kg.m/s2
Water Level (cm)
20
10
0
-10
-20
14:32:03
14:32:12
14:32:21
14:32:29
14:32:38
14:32:47
14:32:55
14:33:04
14:33:12
14:33:21
14:33:30
Time (AEST)

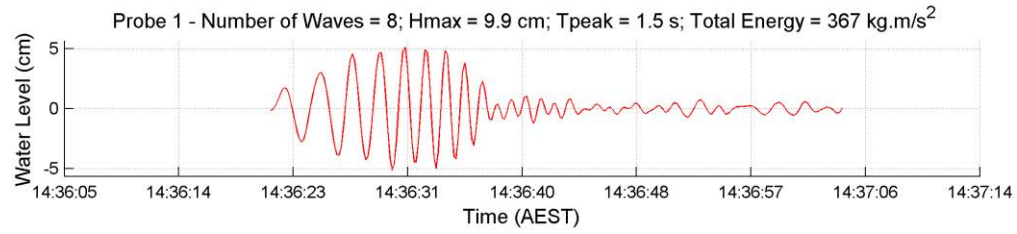
Test 99 - Boat 3 - 10 knots - Run 3 of 3

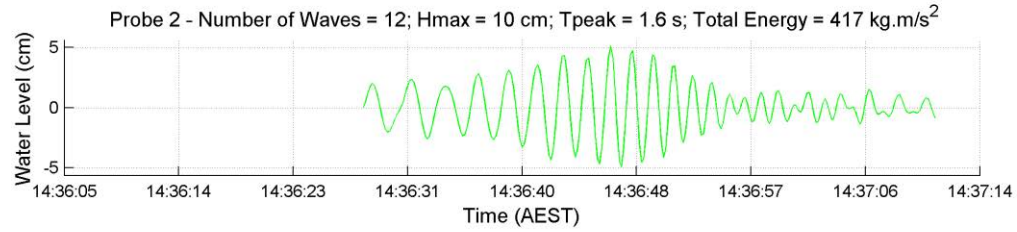


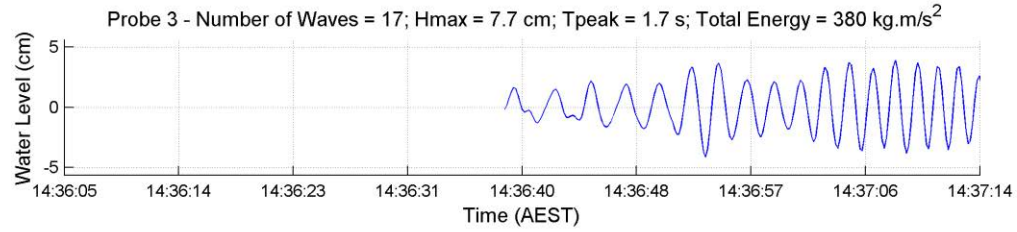


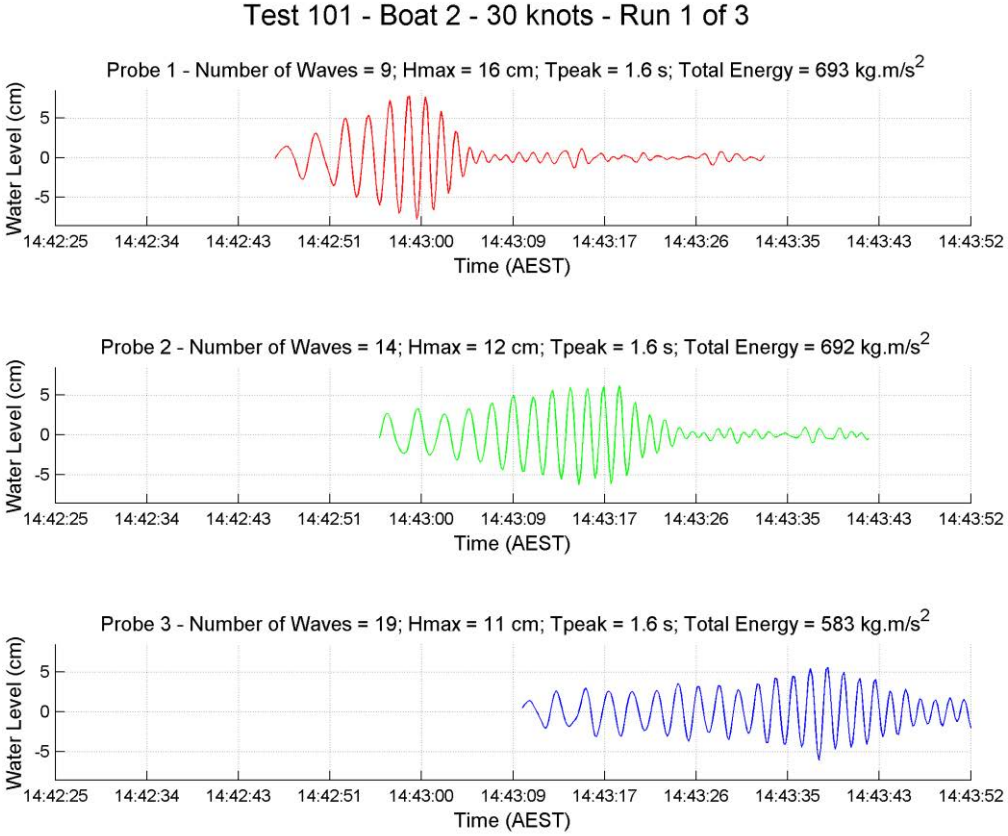


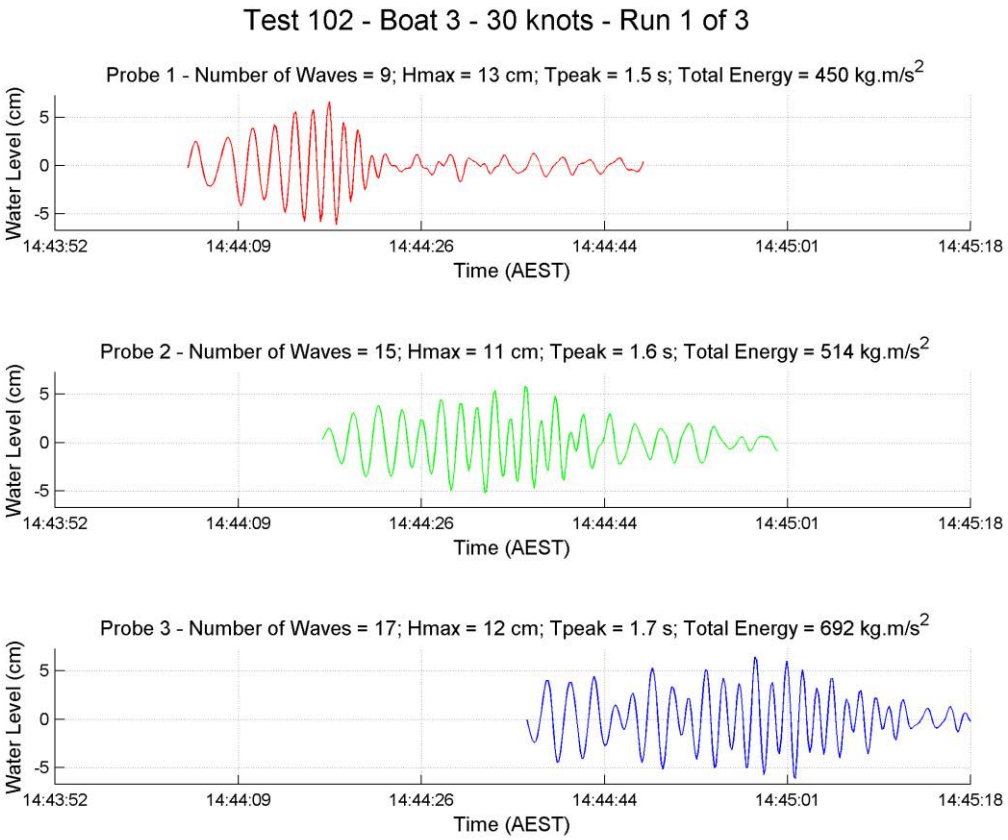
Test 100 - Boat 1 - 30 knots - Run 1 of 3



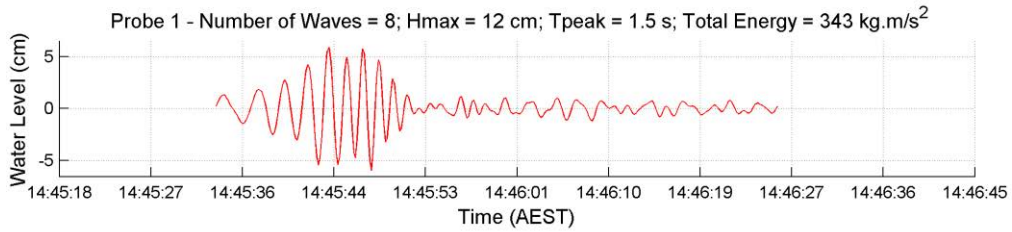


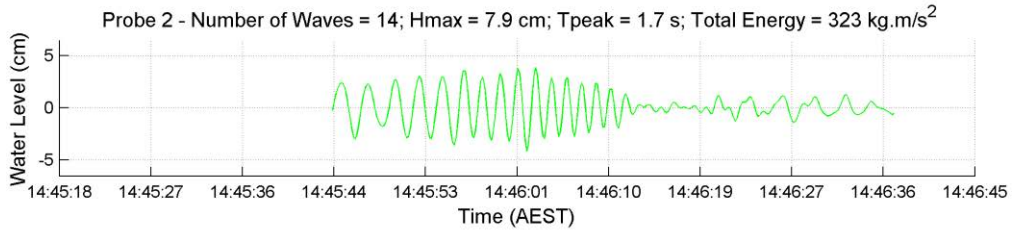


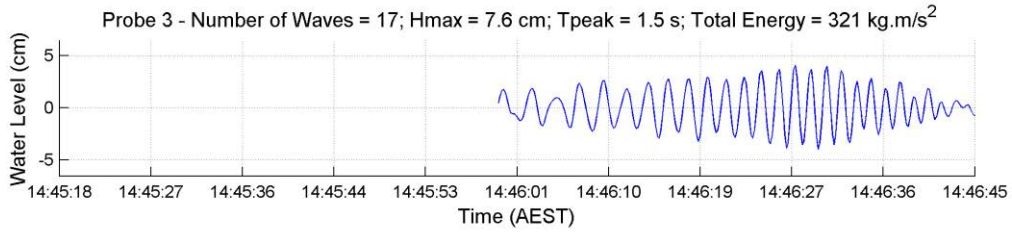

Test 101 - Boat 2 - 30 knots - Run 1 of 3
Probe 1 - Number of Waves = 9; Hmax = 16 cm; Tpeak = 1.6 s; Total Energy = 693 kg.m/s2
Probe 2 - Number of Waves = 14; Hmax = 12 cm; Tpeak = 1.6 s; Total Energy = 692 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 11 cm; Tpeak = 1.6 s; Total Energy = 583 kg.m/s2
Water Level (cm)
5
0
-5
14:42:25
14:42:34
14:42:43
14:42:51
14:43:00
14:43:09
14:43:17
14:43:26
14:43:35
14:43:43
14:43:52
Time (AEST)


Test 102 - Boat 3 - 30 knots - Run 1 of 3
Probe 1 - Number of Waves = 9; Hmax = 13 cm; Tpeak = 1.5 s; Total Energy = 450 kg.m/s2
Probe 2 - Number of Waves = 15; Hmax = 11 cm; Tpeak = 1.6 s; Total Energy = 514 kg.m/s2
Probe 3 - Number of Waves = 17; Hmax = 12 cm; Tpeak = 1.7 s; Total Energy = 692 kg.m/s2
Water Level (cm)
5
0
-5
14:43:52
14:44:09
14:44:26
14:44:44
14:45:01
14:45:18
Time (AEST)

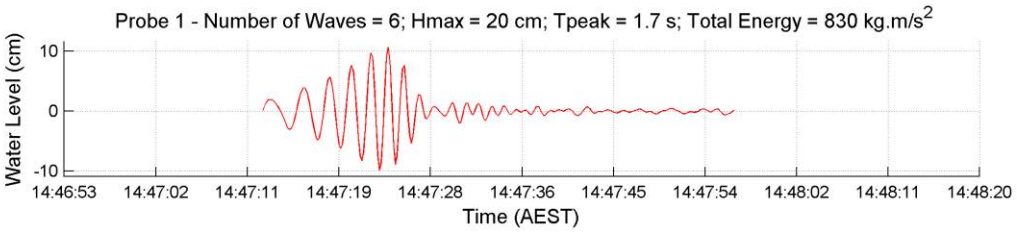
Test 103 - Boat 1 - 30 knots - Run 2 of 3

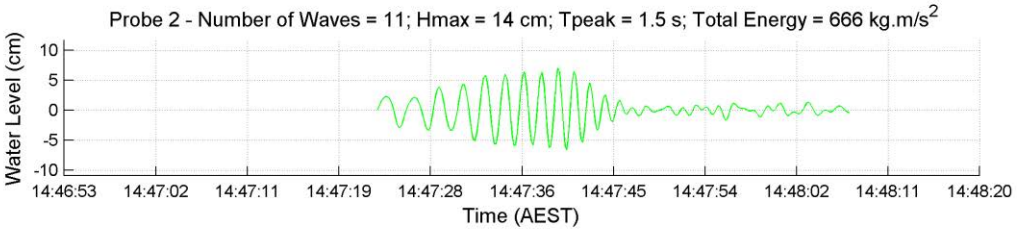


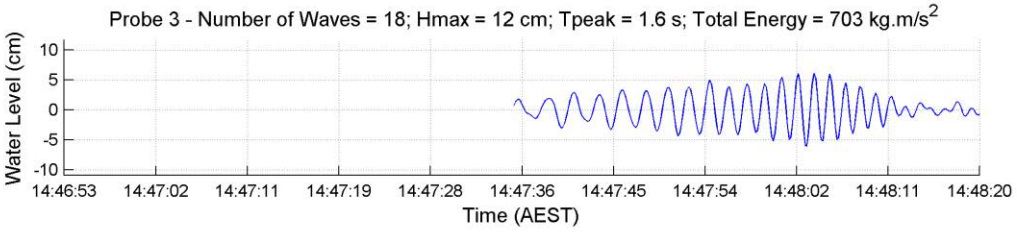




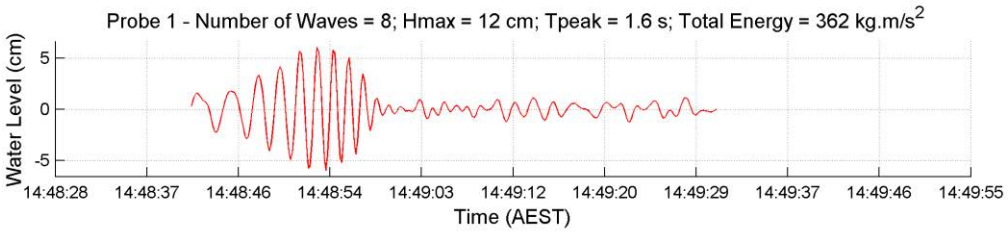
Test 104 - Boat 2 - 30 knots - Run 2 of 3

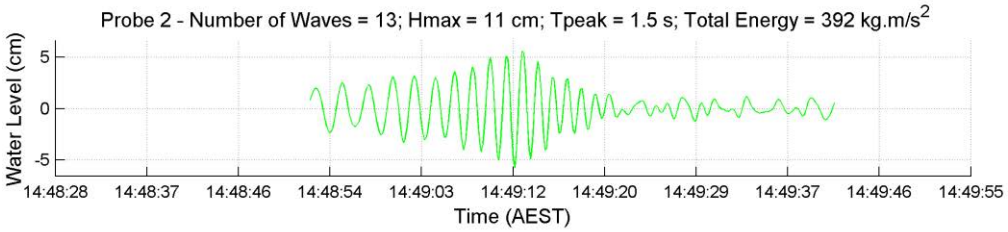


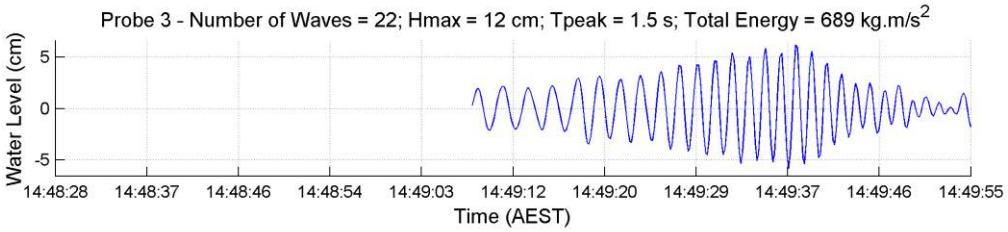




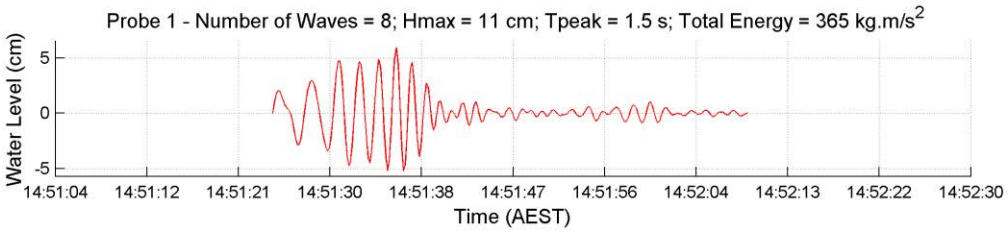
Test 105 - Boat 3 - 30 knots - Run 2 of 3

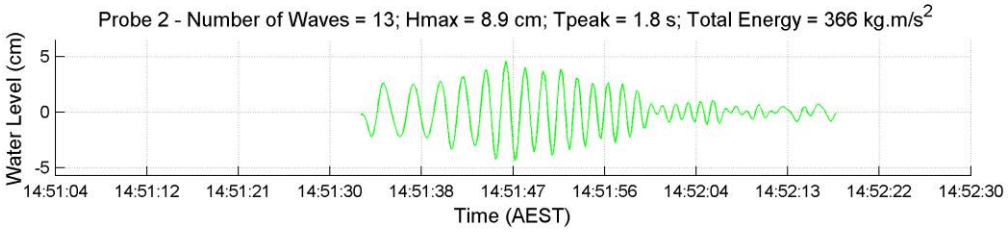


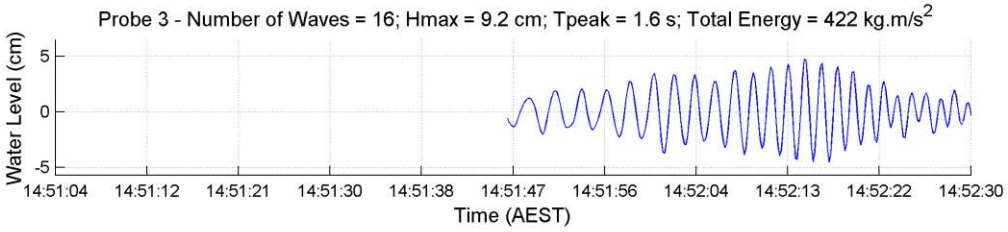


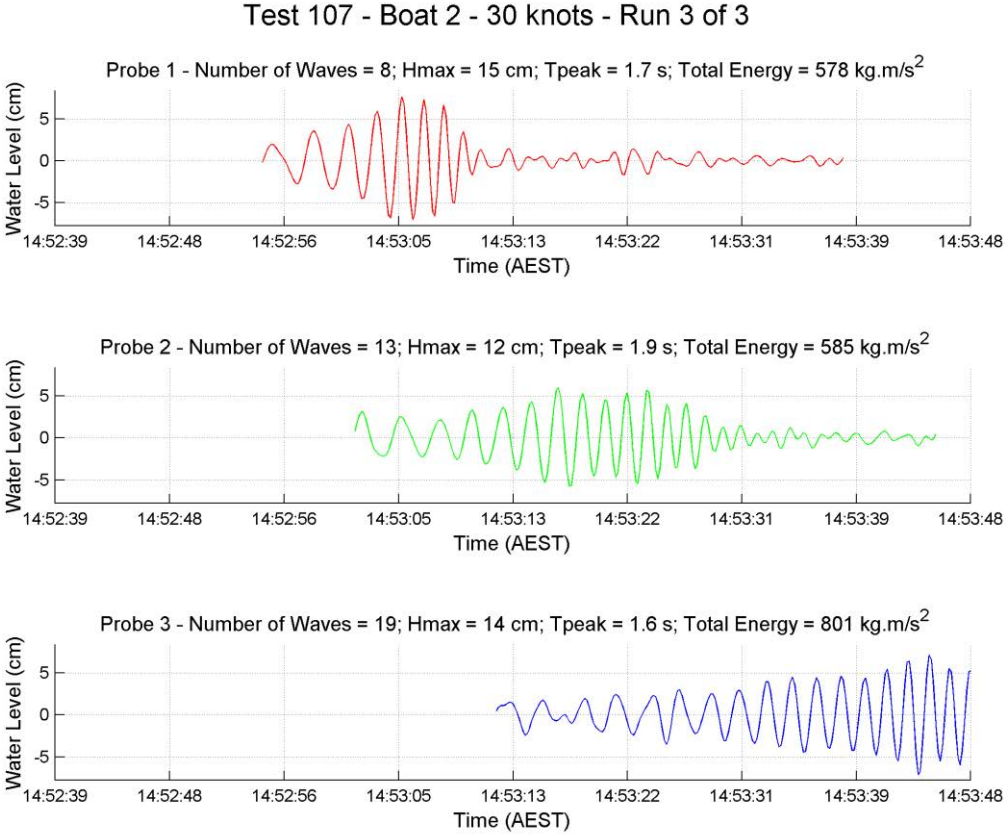


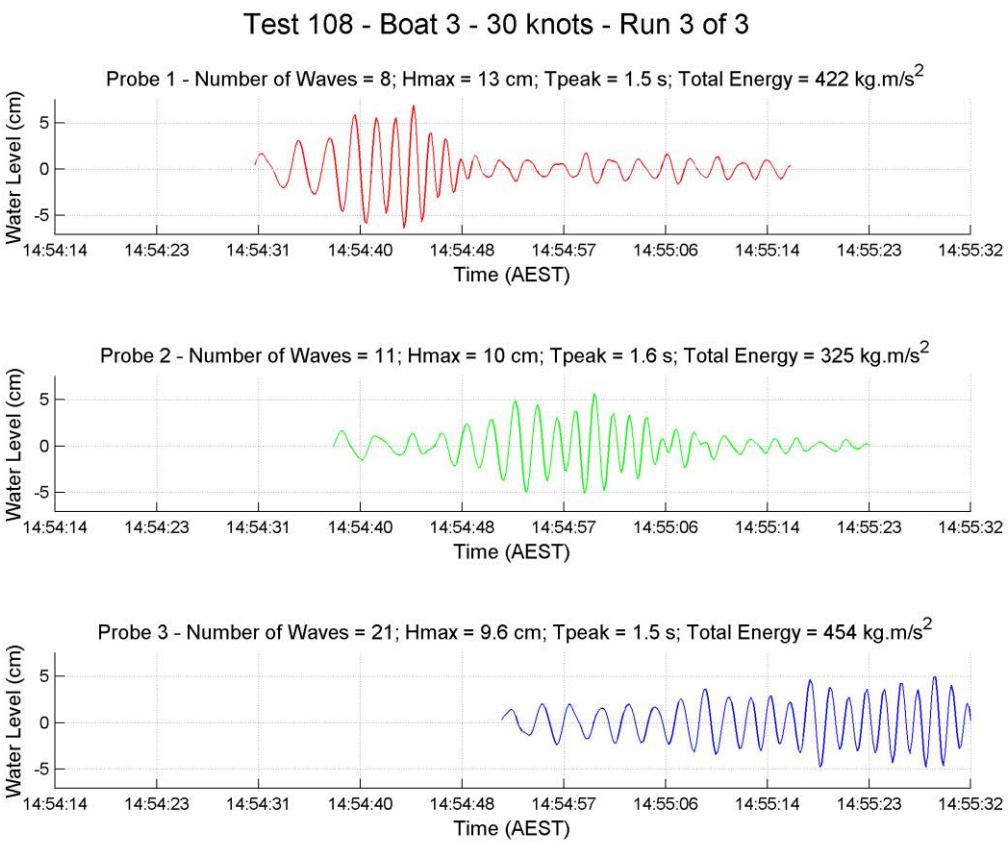
Test 106 - Boat 1 - 30 knots - Run 3 of 3







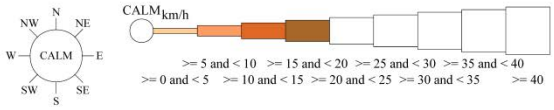

Test 107 - Boat 2 - 30 knots - Run 3 of 3
Probe 1 - Number of Waves = 8; Hmax = 15 cm; Tpeak = 1.7 s; Total Energy = 578 kg.m/s2
Probe 2 - Number of Waves = 13; Hmax = 12 cm; Tpeak = 1.9 s; Total Energy = 585 kg.m/s2
Probe 3 - Number of Waves = 19; Hmax = 14 cm; Tpeak = 1.6 s; Total Energy = 801 kg.m/s2
Water Level (cm)
5
0
-5
14:52:39
14:52:48
14:52:56
14:53:05
14:53:13
14:53:22
14:53:31
14:53:39
14:53:48
Time (AEST)


Test 108 - Boat 3 - 30 knots - Run 3 of 3
Probe 1 - Number of Waves = 8; Hmax = 13 cm; Tpeak = 1.5 s; Total Energy = 422 kg.m/s2
Probe 2 - Number of Waves = 11; Hmax = 10 cm; Tpeak = 1.6 s; Total Energy = 325 kg.m/s2
Probe 3 - Number of Waves = 21; Hmax = 9.6 cm; Tpeak = 1.5 s; Total Energy = 454 kg.m/s2
Water Level (cm)
5
0
-5
14:54:14
14:54:23
14:54:31
14:54:40
14:54:48
14:54:57
14:55:06
14:55:14
14:55:23
14:55:32
Time (AEST)

Appendix F - Wind Rose and Frequency Data

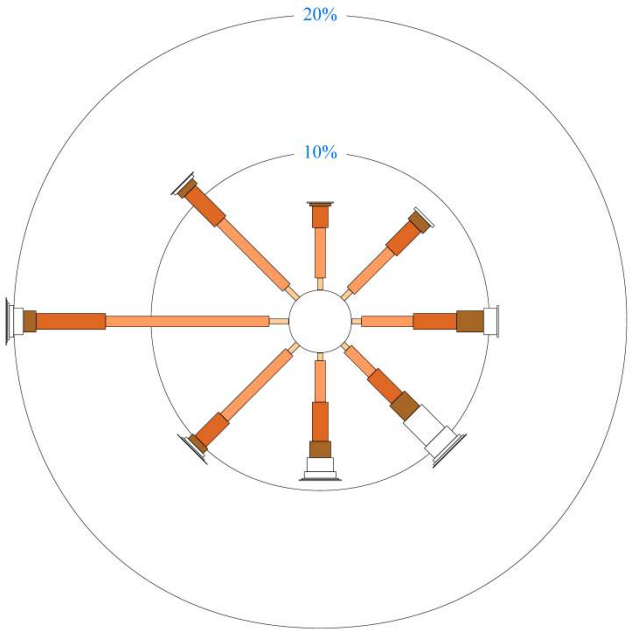
Rose of Wind direction versus Wind speed in km/h (01 Sep 2002 to 30 Apr 2014)
GRAFTON RESEARCH STN
Site No: 058077 • Opened Jan 1917 • Still Open • Latitude: -29.6224° • Longitude: 152.9605° • Elevation 25m

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



All Data
32314 Total Observations

Calm 11%



Frequency Analysis of Wind direction versus Wind speed in km/h (01 Sep 2002 to 30 Apr 2014)
Custom times selected, refer to attached note for details

GRAFTON RESEARCH STN
Site Number 058077 • Opened Jan 1917 • Still Open • Latitude: -29.6224° • Longitude: 152.9605° • Elevation 25m

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

All Data **32314 Total Observations**

Wind speed in km/h	Wind direction									
	N	NE	E	SE	S	SW	W	NW	Calm	ALL
>= 0 and < 5	274	273	228	168	176	281	454	376		**5899**
>= 5 and < 10	1177	1335	1211	821	972	2166	3841	2192		**13715**
>= 10 and < 15	501	803	1014	813	914	783	1629	1009		**7466**
>= 15 and < 20	69	253	630	504	379	154	295	166		**2450**
>= 20 and < 25	23	62	313	768	327	67	224	73		**1857**
>= 25 and < 30	1	1	31	337	151	27	99	14		**661**
>= 30 and < 35	1	0	0	71	28	4	37	4		**145**
>= 35 and < 40	0	0	1	40	20	9	21	2		**93**
>= 40	2	1	0	11	3	1	9	1		**28**
All	**2048**	**2728**	**3428**	**3533**	**2970**	**3492**	**6609**	**3837**	**3669**	**32314**

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

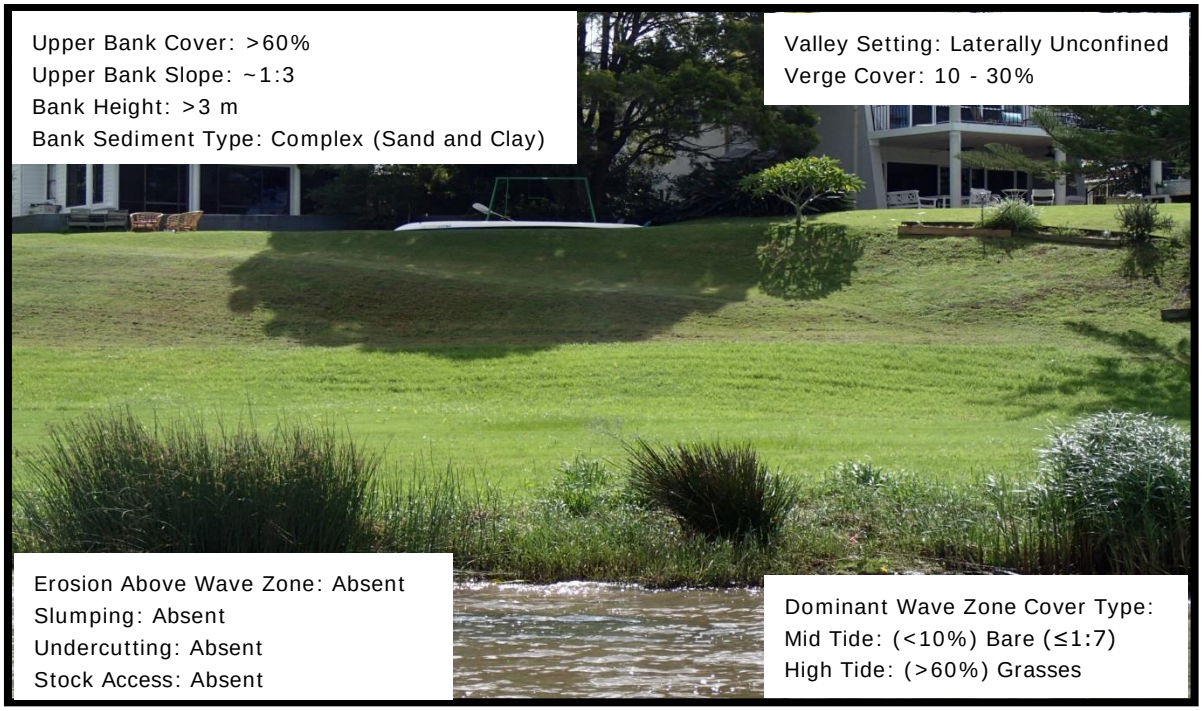
Desnagging:	☐ None	☐ Conducted in last previous year
Excavation:	☐ Present	☐ Absent
Extraction:	☐ None	☐ Water ☐ Sediment
Stock Access:	☐ Absent	☐ Present

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

Appendix H – Field Examples of Erosion Potential Categories

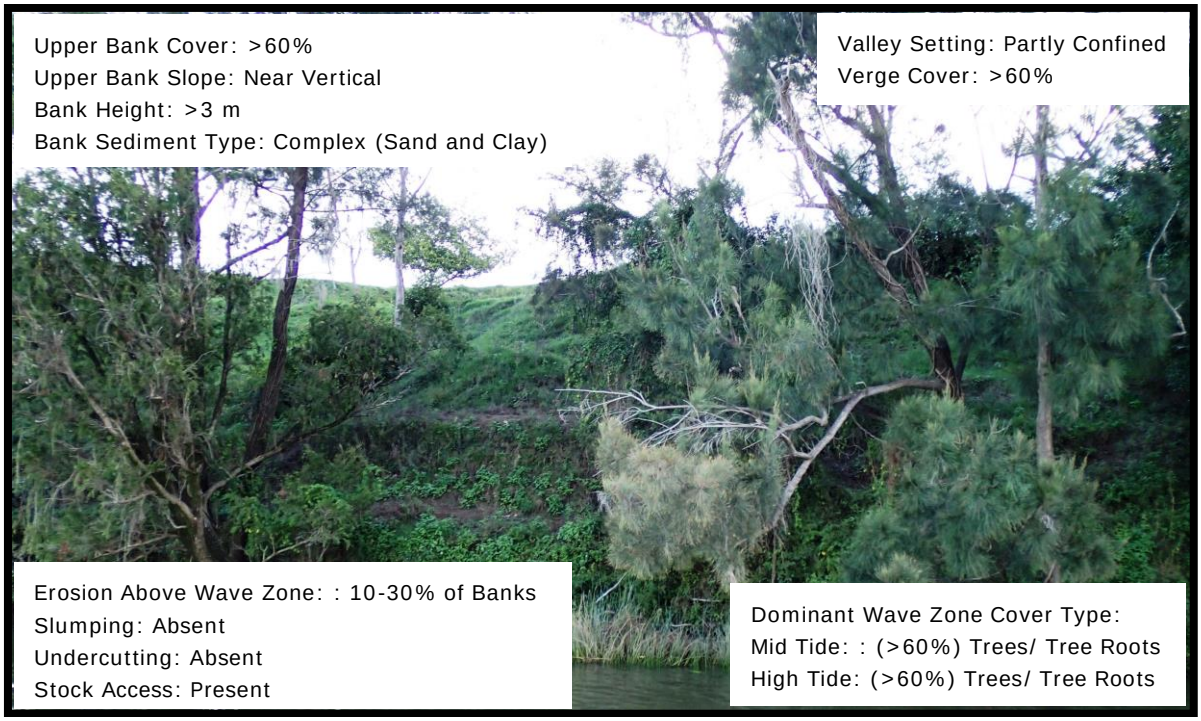
Highly Resistant – R5A

Highly Resistant – L73C



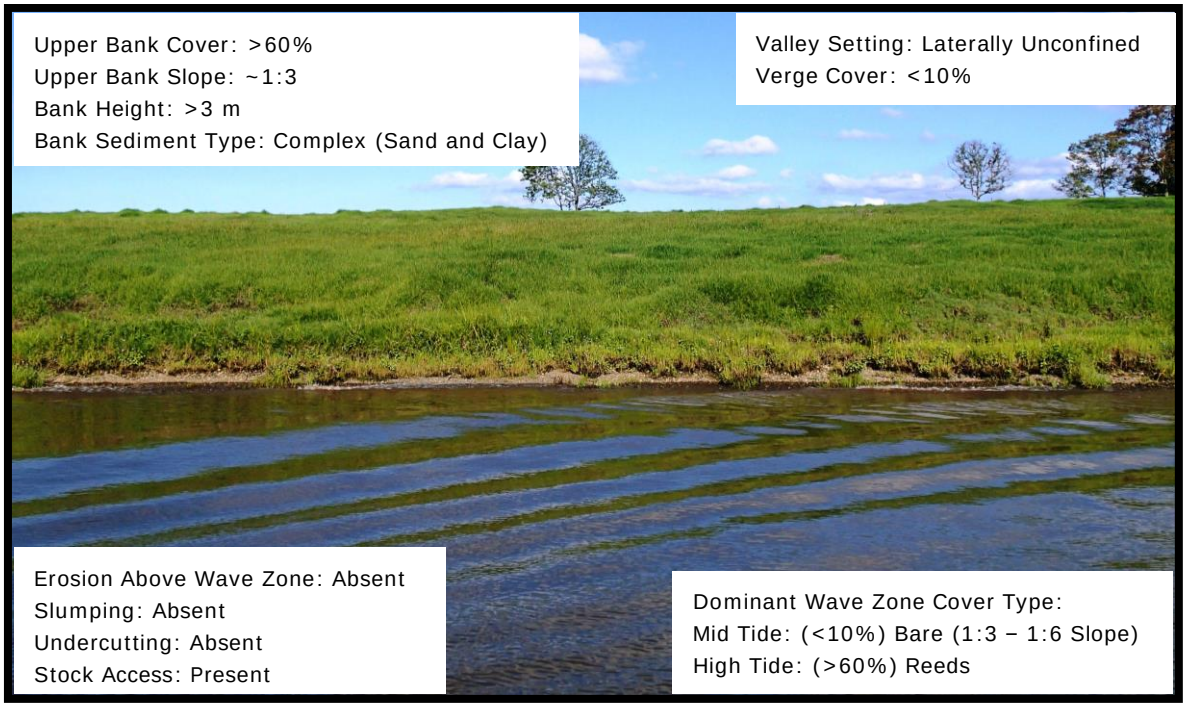
Moderately Resistant – L51A

Moderately Resistant – L67A



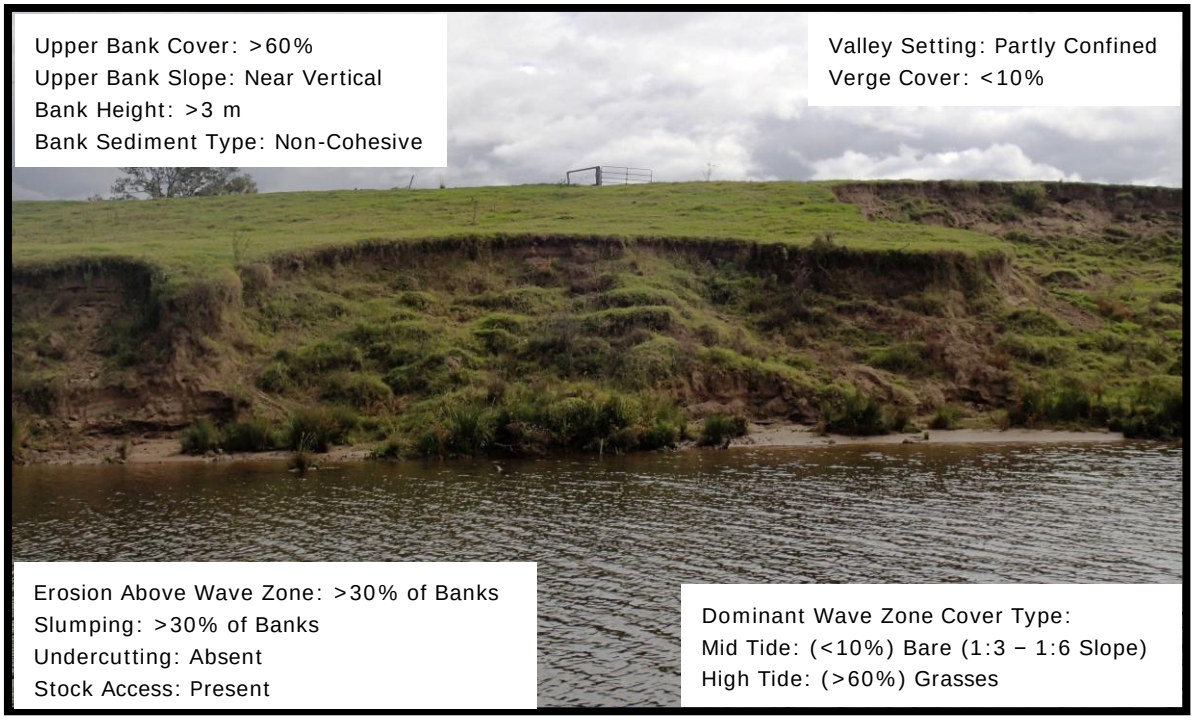
Mildly Resistant – R21B

Mildly Resistant – RE58A

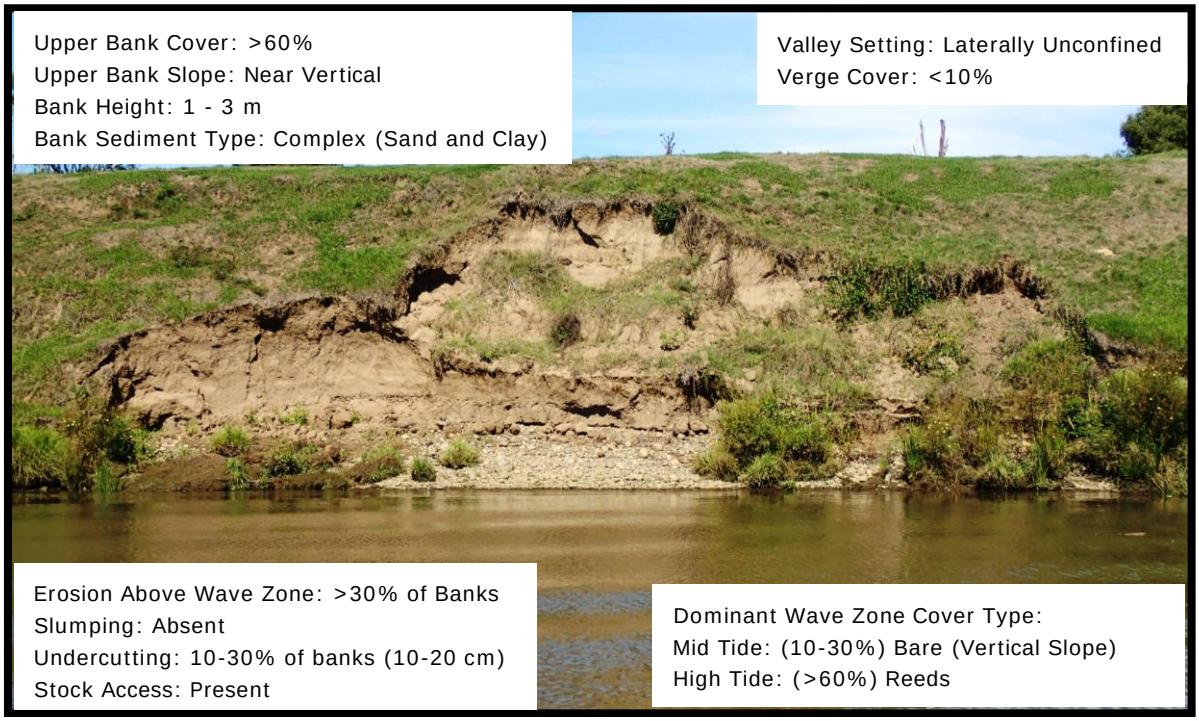


Moderately Erosive – L32C

Moderately Erosive – RS43A



Highly Erosive – L5C



Highly Erosive – L29B

Appendix I - Example Wind Wave vs Boat Wave Comparison

I.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.

I.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 I-1 and I-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 (R22 and L22).

Table I-1 – Wave Energies and Associated ARI (R22)

Energy of maximum wave ($kg.m/s^2$)	Total Wind Wave Energy for the Extended Duration ($kg.m/s^2$)	ARI (years)
0.67	24,170	1.87×10^{-3}
1.33	42,604	2.50×10^{-3}
1.54	48,089	3.85×10^{-3}
2.76	81,349	5.51×10^{-3}
2.94	85,728	6.44×10^{-3}
5.82	151,112	2.03×10^{-2}
6.74	170,565	2.41×10^{-2}
7.52	191,245	2.57×10^{-2}
8.00	201,540	2.58×10^{-2}
11.27	270,015	2.58×10^{-2}
15.80	355,251	2.11×10^{-1}
17.22	386,898	2.14×10^{-1}
18.28	400,984	2.22×10^{-1}
23.66	501,572	8.57×10^{-1}
33.91	681,977	4
39.22	769,772	12

Table I-2 – Wave Energies and Associated ARI (L22)

Energy of maximum wave ($kg.m/s^2$)	Total Wind Wave Energy for the Extended Duration ($kg.m/s^2$)	ARI (years)
5.67	147,828	3.68×10^{-3}
7.94	200,212	3.71×10^{-3}
10.31	227,024	8.92×10^{-3}
11.22	259,774	1.08×10^{-2}
11.91	282,675	1.09×10^{-2}
15.38	347,530	1.25×10^{-2}
17.09	384,348	1.25×10^{-2}
23.04	490,672	1.28×10^{-2}
30.38	610,707	1.30×10^{-2}
33.03	667,157	1.32×10^{-2}
44.64	805,219	5.83×10^{-2}
45.46	862,246	5.88×10^{-2}
65.11	1,172,379	5.91×10^{-2}
120.48	1,893,002	5.00×10^{-1}
179.97	2,672,693	3
257.39	3,634,009	12

I.3 Wake Wave Data

Wake wave data from previous studies is included in the DSS. Table I-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 I-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
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.

I.4 Comparison of Wave Energies

The wake wave energy is then compared to the ARI of the wind energy. Table I-4 provides some examples of a wakeboarding vessel under operating conditions, for 8 hours with 300 boat passes at distance of 177 m from the shore in the study stretch 22. 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 I-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)
R22	Maximum Wave	176	12	757	378,587	2.58×10^{-2}	C
	Operating	72	12	370	185,192	1.18×10^{-2}	C
L22	Maximum Wave	176	2.83	757	378,587	8.93×10^{-3}	B
	Operating	72	1.14×10^{-1}	370	185,192	3.38×10^{-3}	B

Appendix J – DSS Sensitivity Test for High Tide Conditions

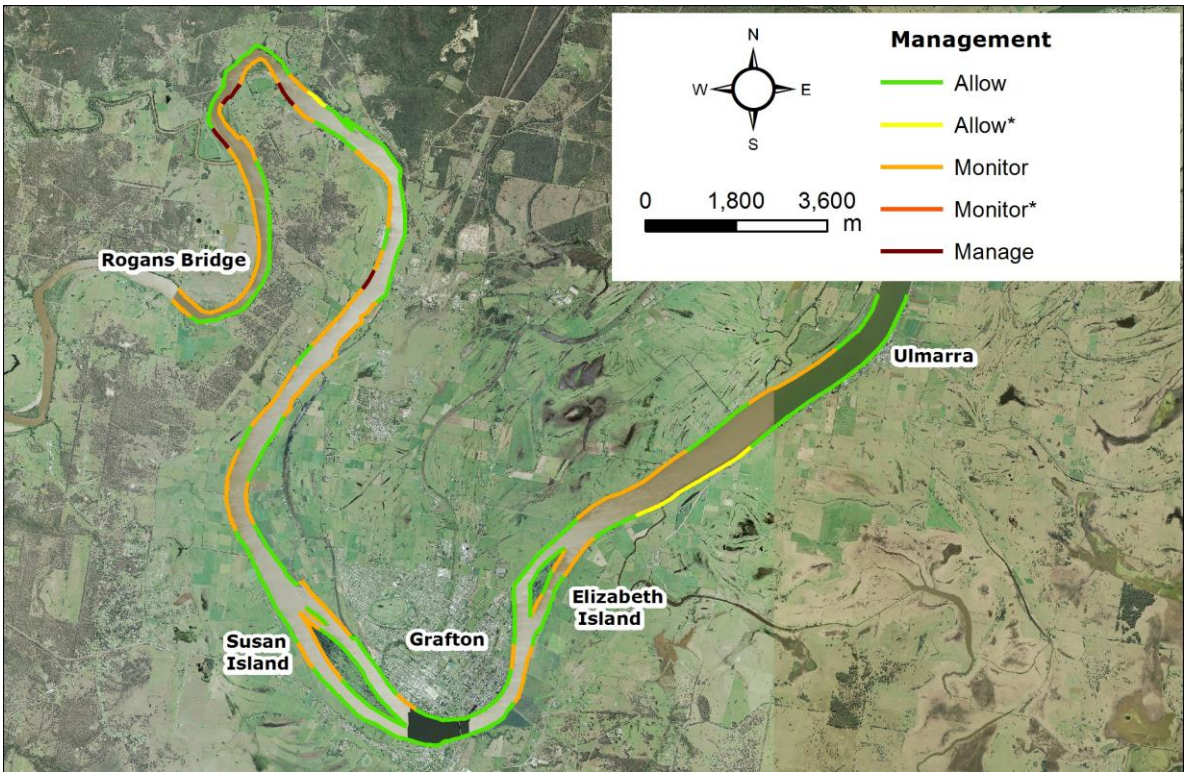


Figure J-1: DSS Management Recommendations – Wakeboard Operating - 10 Boat Passes – 8 hour Duration (High Tide Conditions)

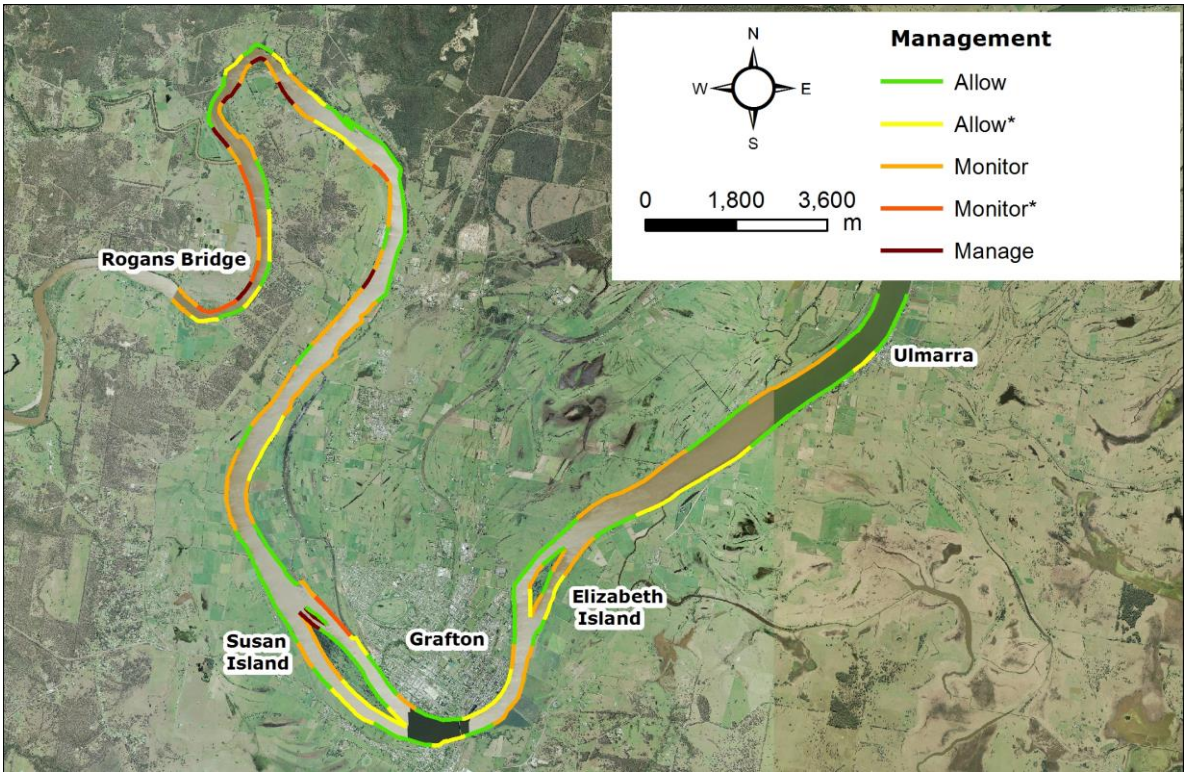


Figure J-2: DSS Management Recommendations – Wakeboard Operating - 150 Boat Passes – 8 hour Duration (High Tide Conditions)

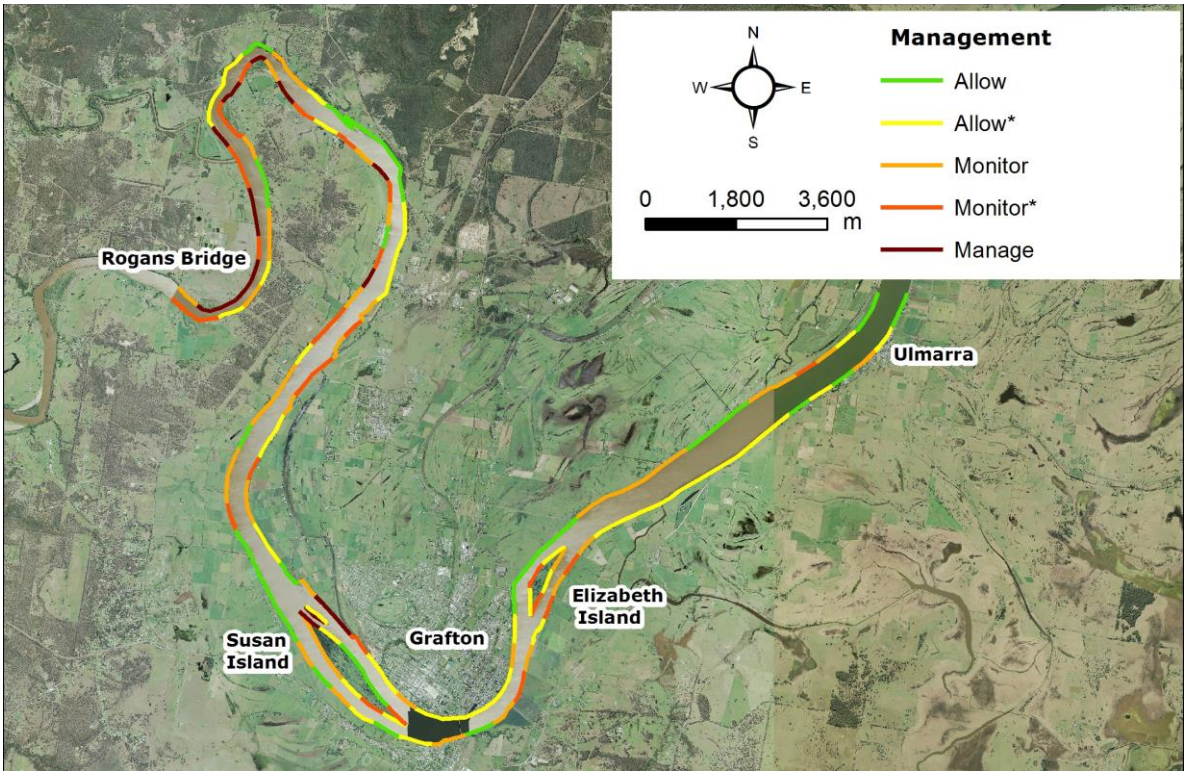


Figure J-3: DSS Management Recommendations – Wakeboard Operating - 300 Boat Passes – 8 hour Duration (High Tide Conditions)

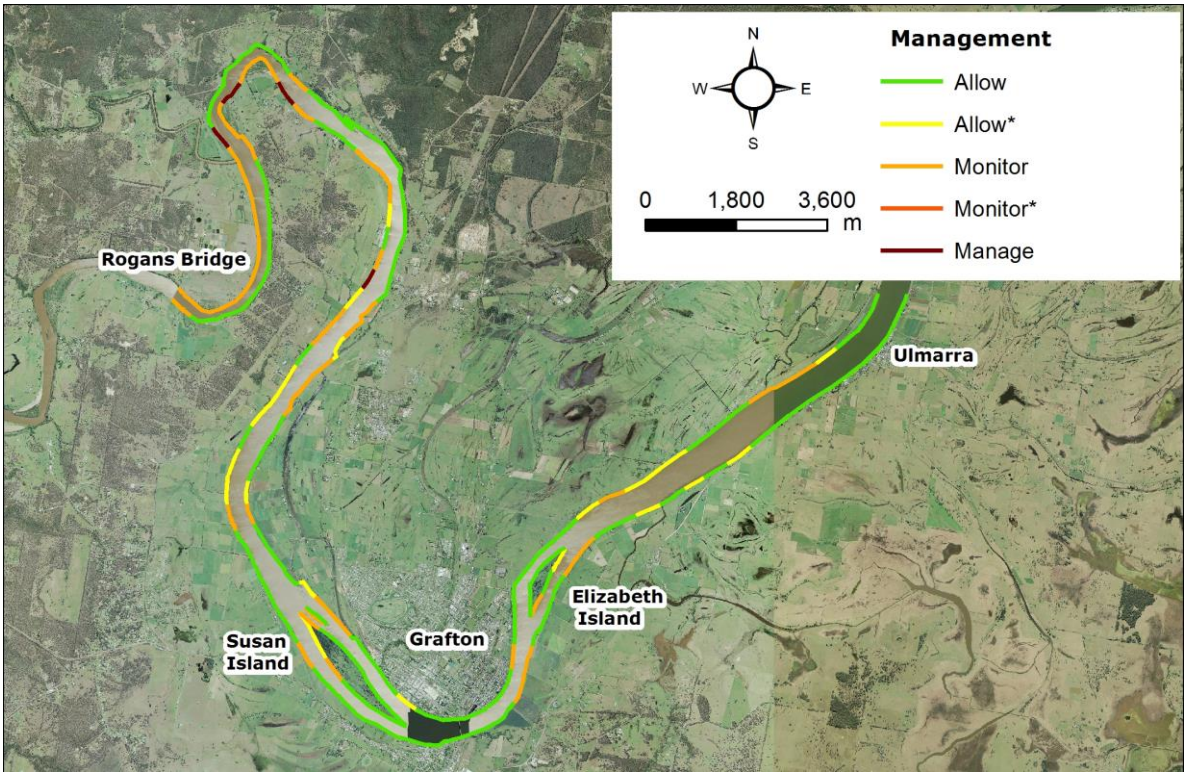


Figure J-4: DSS Management Recommendations – Waterski Operating - 10 Boat Passes – 8 hour Duration (High Tide Conditions)

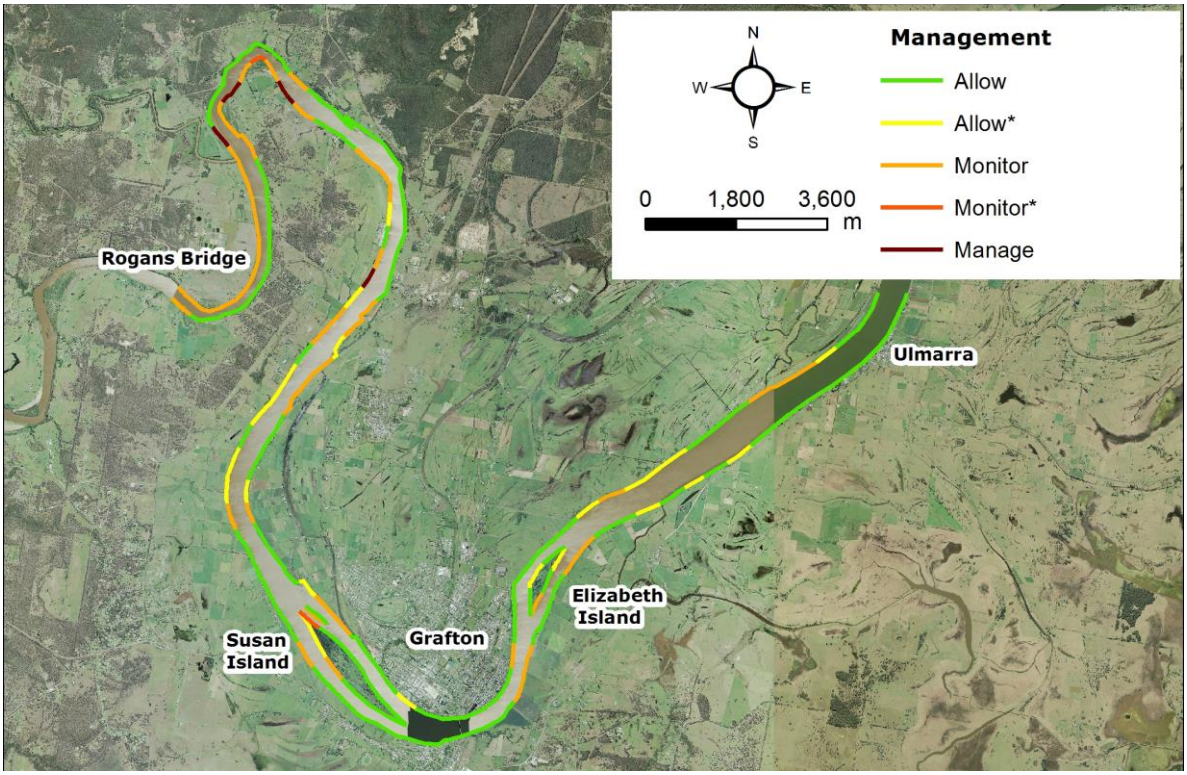


Figure J-5: DSS Management Recommendations – Waterski Operating - 150 Boat Passes – 8 hour Duration (High Tide Conditions)

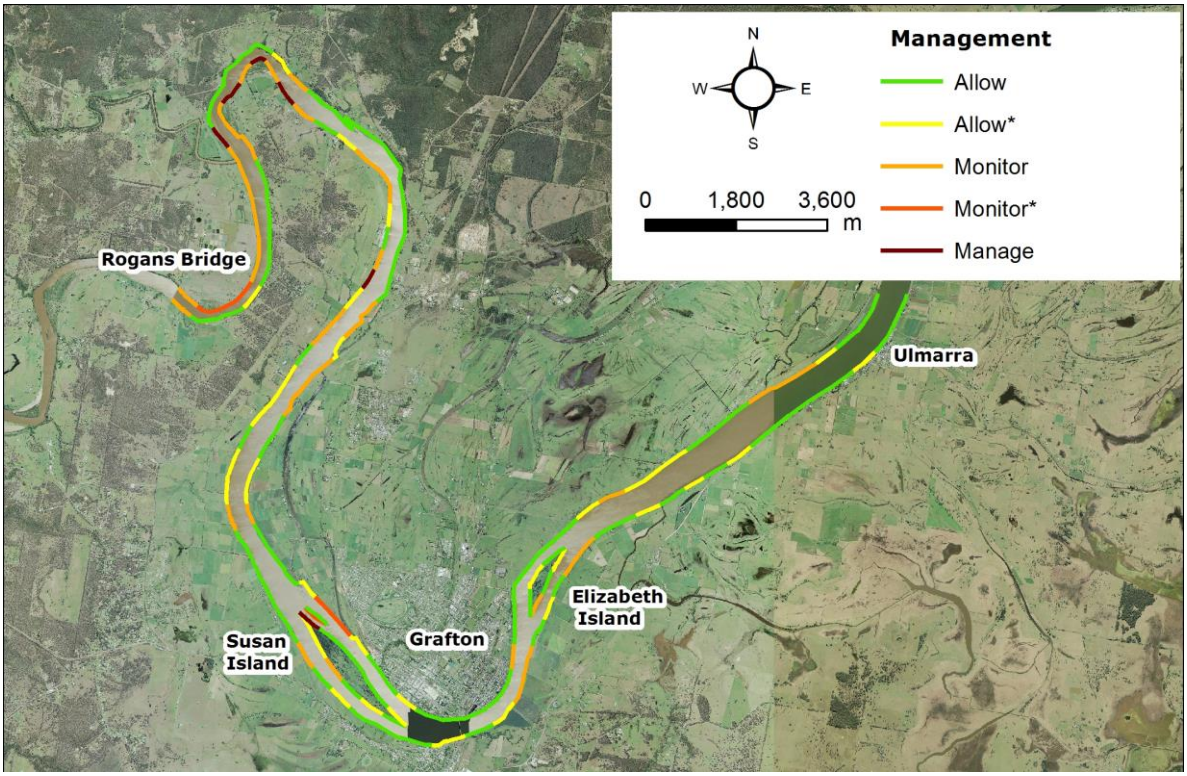


Figure J-6: DSS Management Recommendations – Waterski Operating - 300 Boat Passes – 8 hour Duration (High Tide Conditions)

Appendix K – DSS Sensitivity Test – High Boat Passes

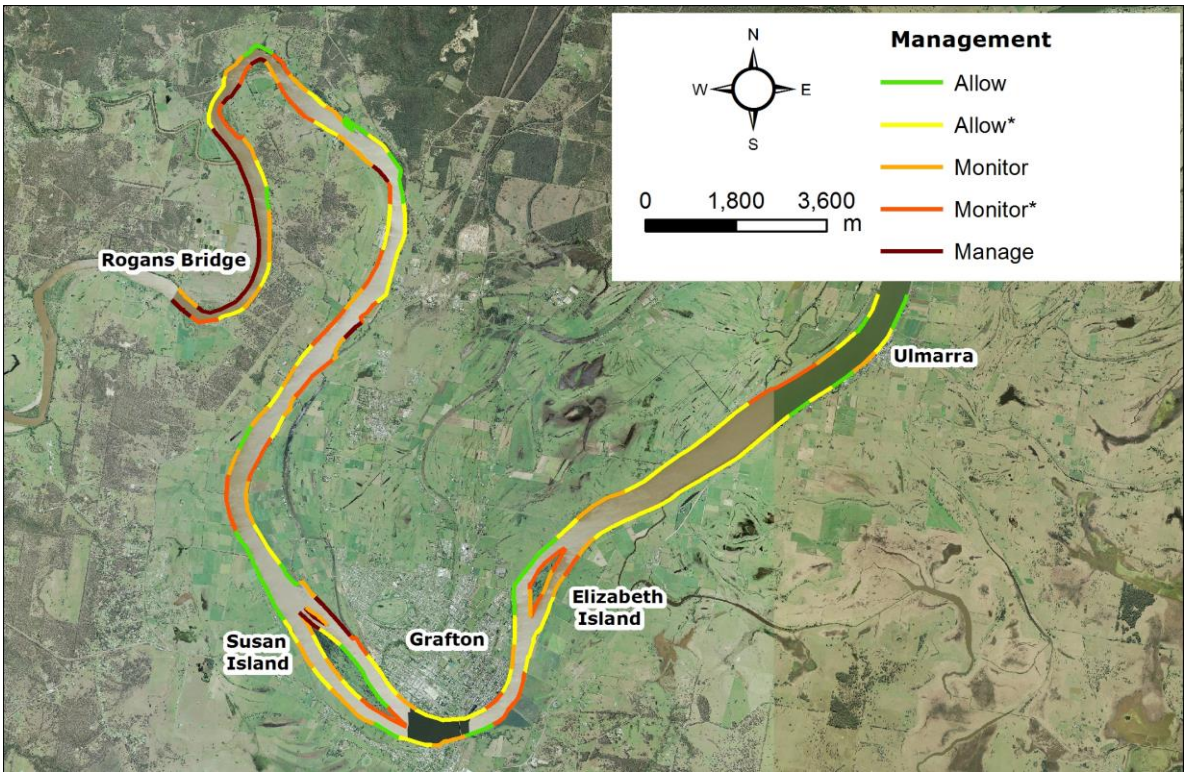


Figure K-1: DSS Management Recommendations – Wakeboard Operating – 500 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

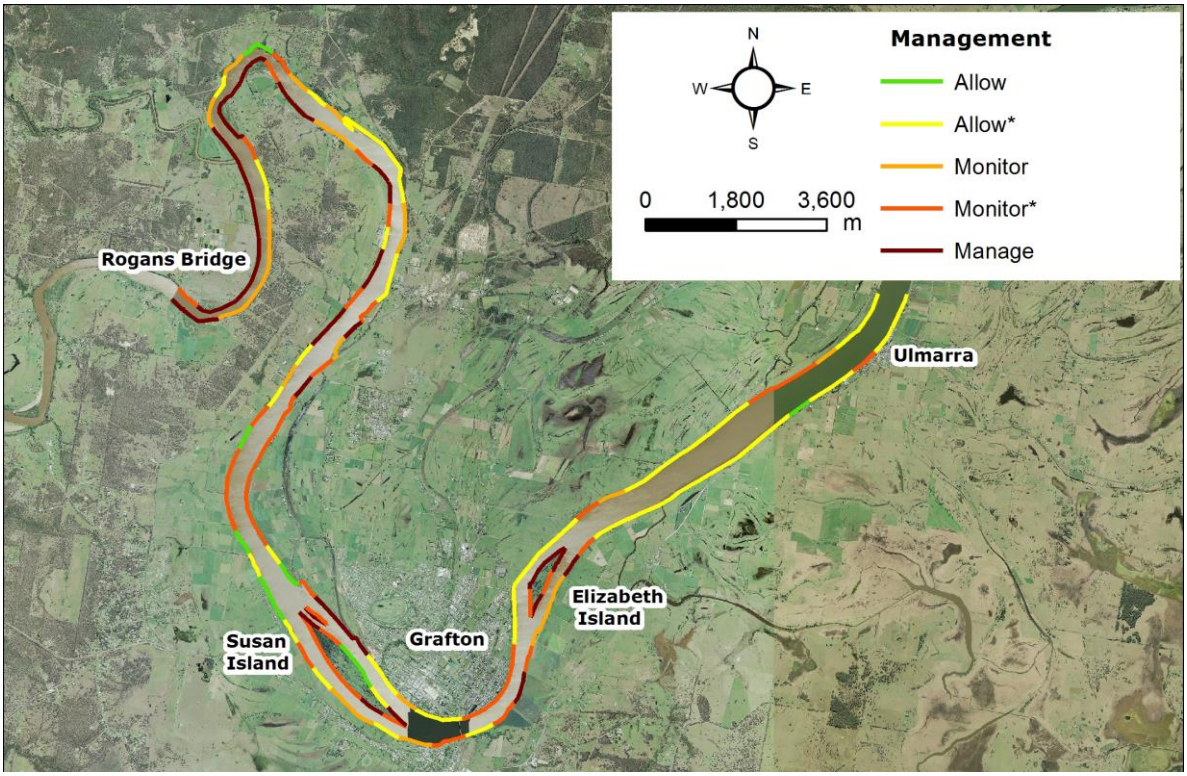


Figure K-2: DSS Management Recommendations – Wakeboard Operating – 1,000 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

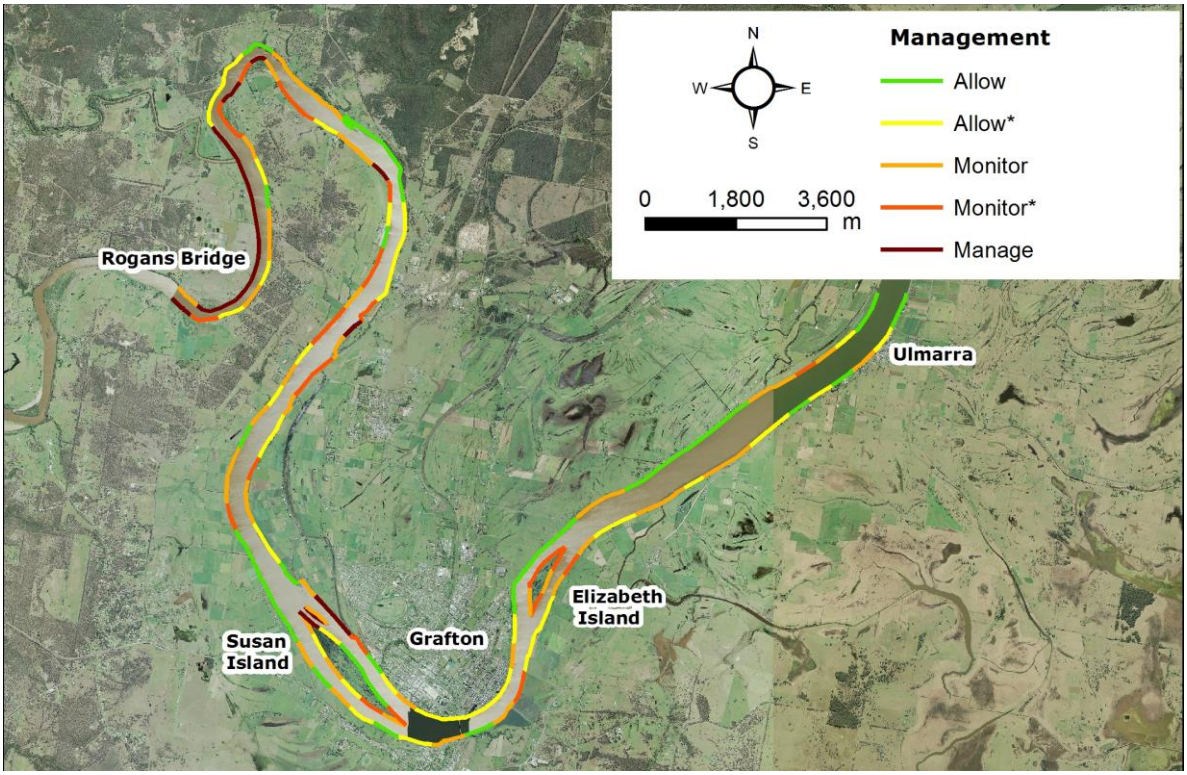


Figure K-3: DSS Management Recommendations – Wakeboard Maximum Wave - 150 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

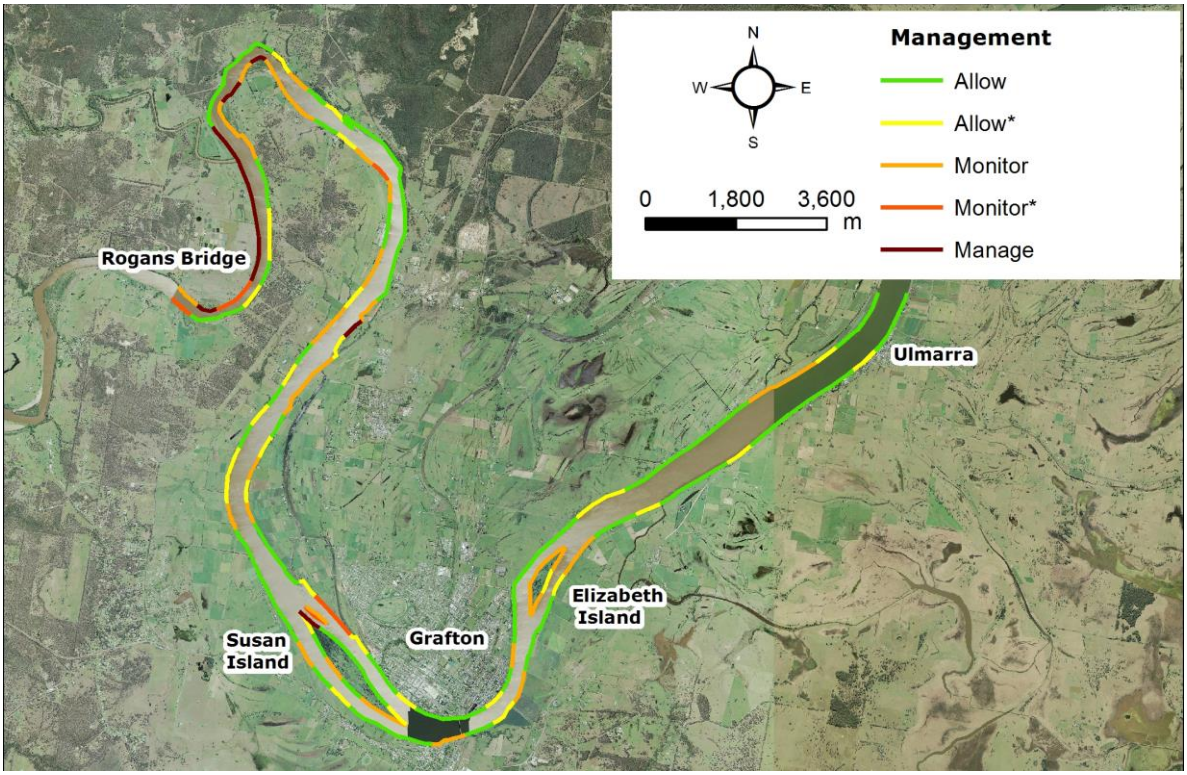


Figure K-4: DSS Management Recommendations – Waterski Operating – 500 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

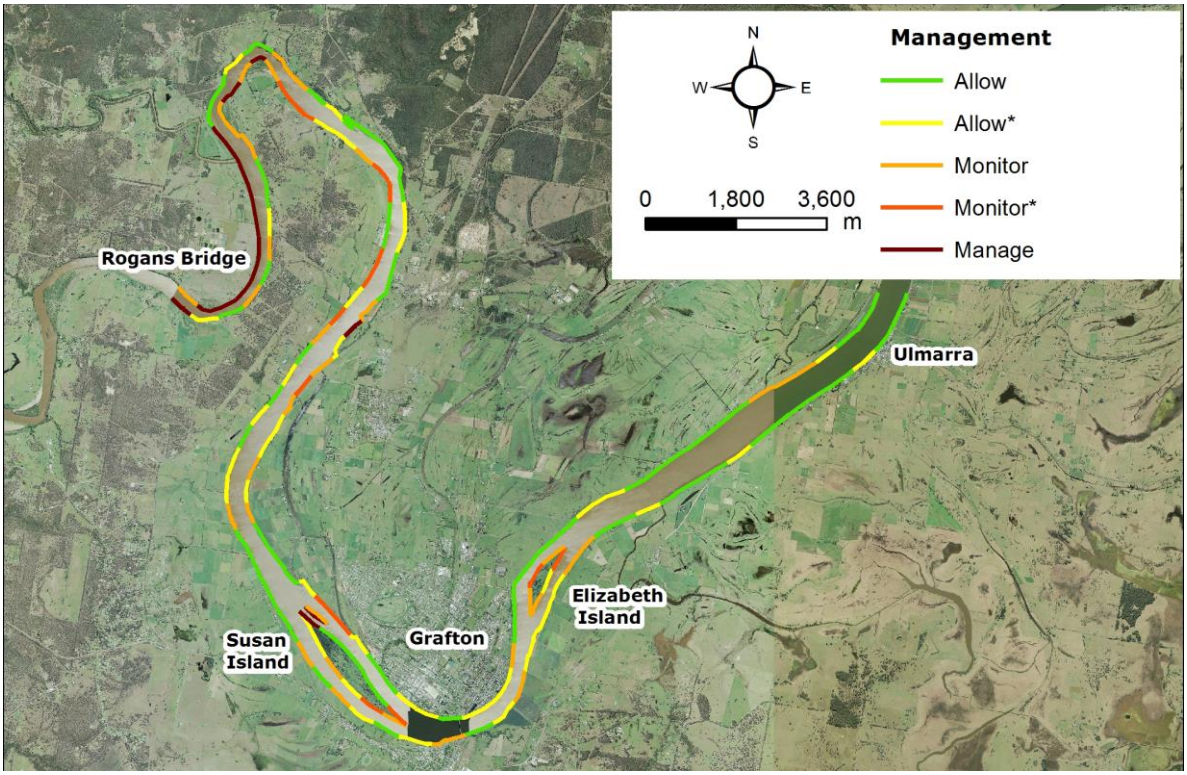


Figure K-5: DSS Management Recommendations – Waterski Operating – 1,000 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

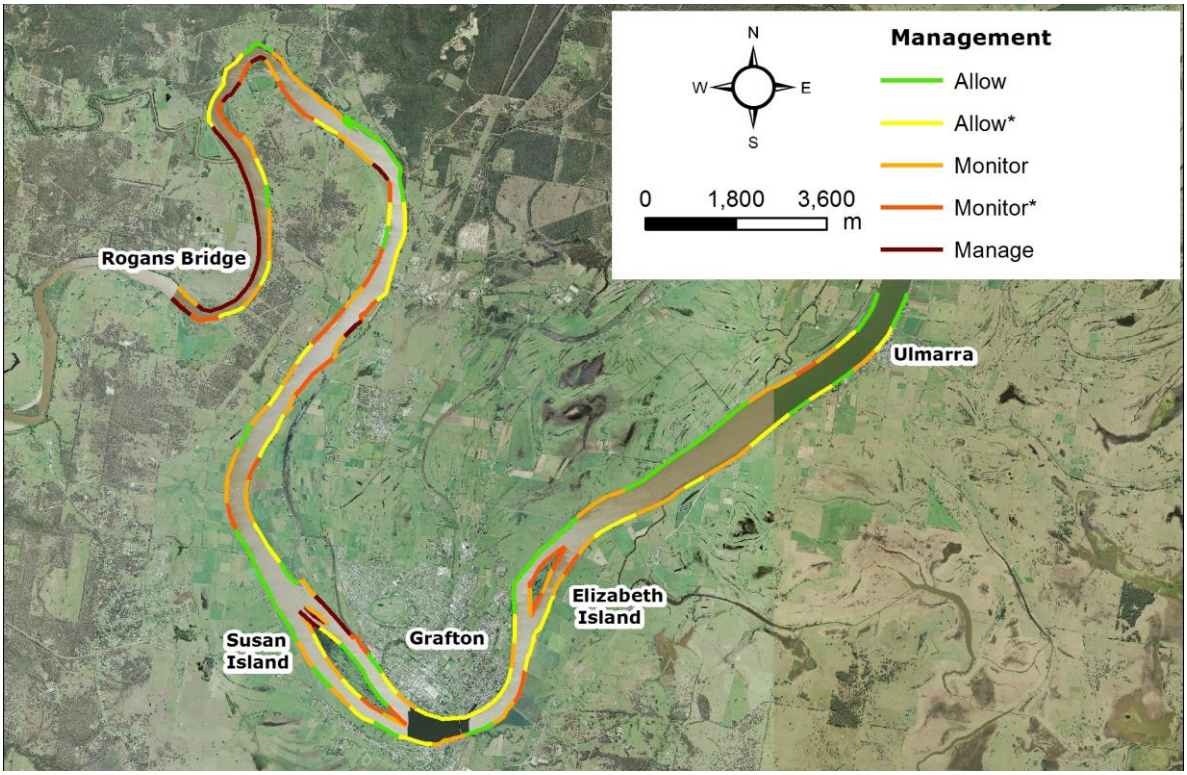


Figure K-6: DSS Management Recommendations – Waterski Maximum Wave - 150 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

Appendix L – DSS Sensitivity Test – Adjusted Local Winds

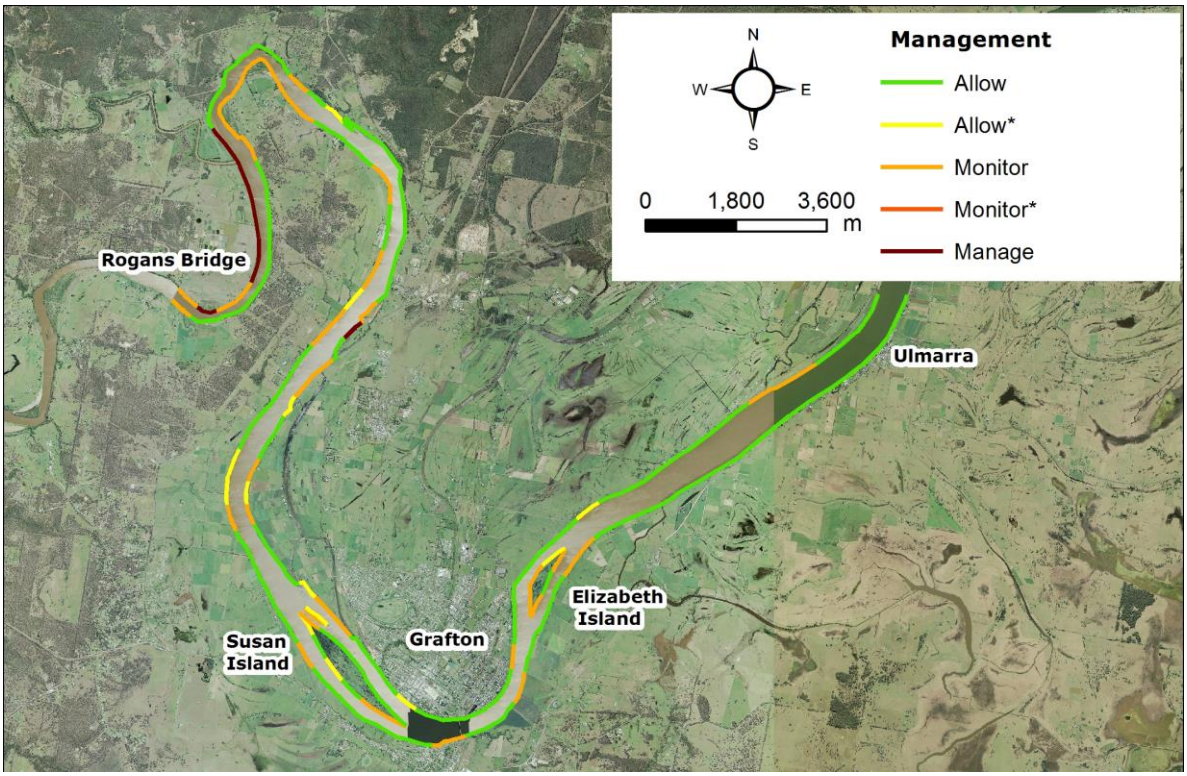


Figure L-1: DSS Management Recommendations – Wakeboard Operating – Adjusted Local Winds – 10 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

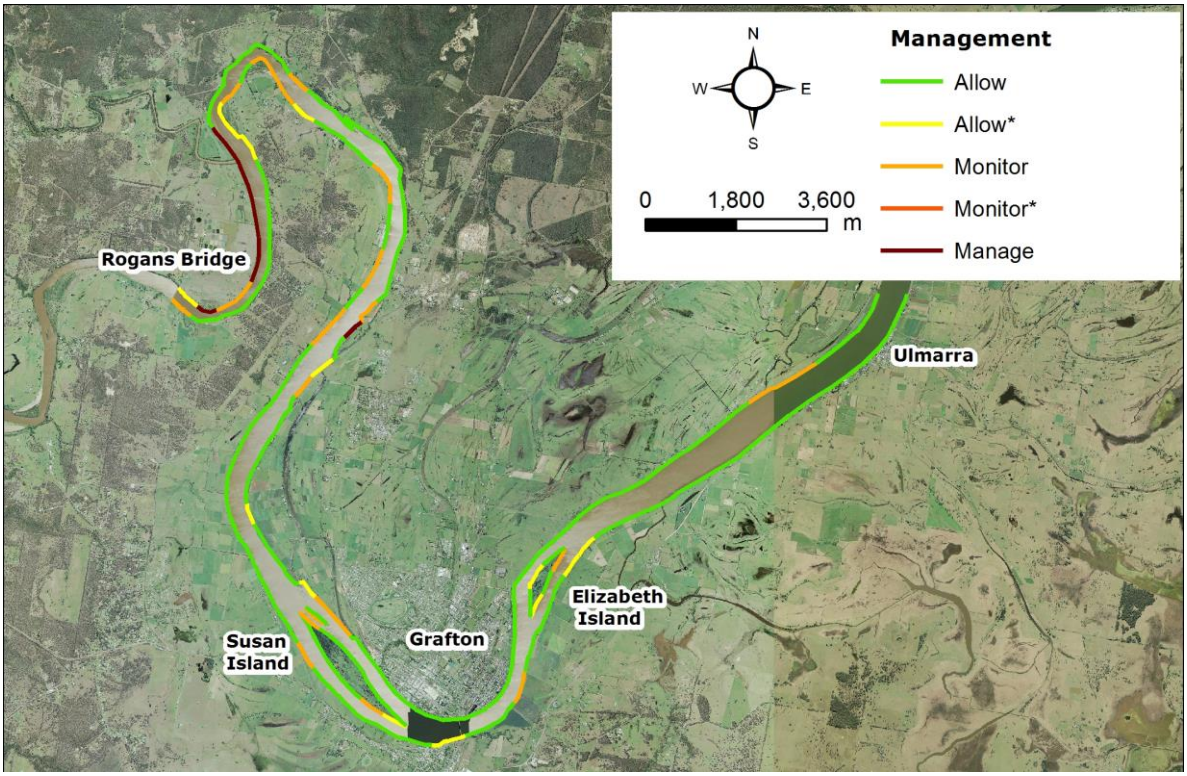


Figure L-2: DSS Management Recommendations – Wakeboard Operating – Adjusted Local Winds – 150 Boat Passes - 8 hour Duration (Mid - Low Tide Conditions)

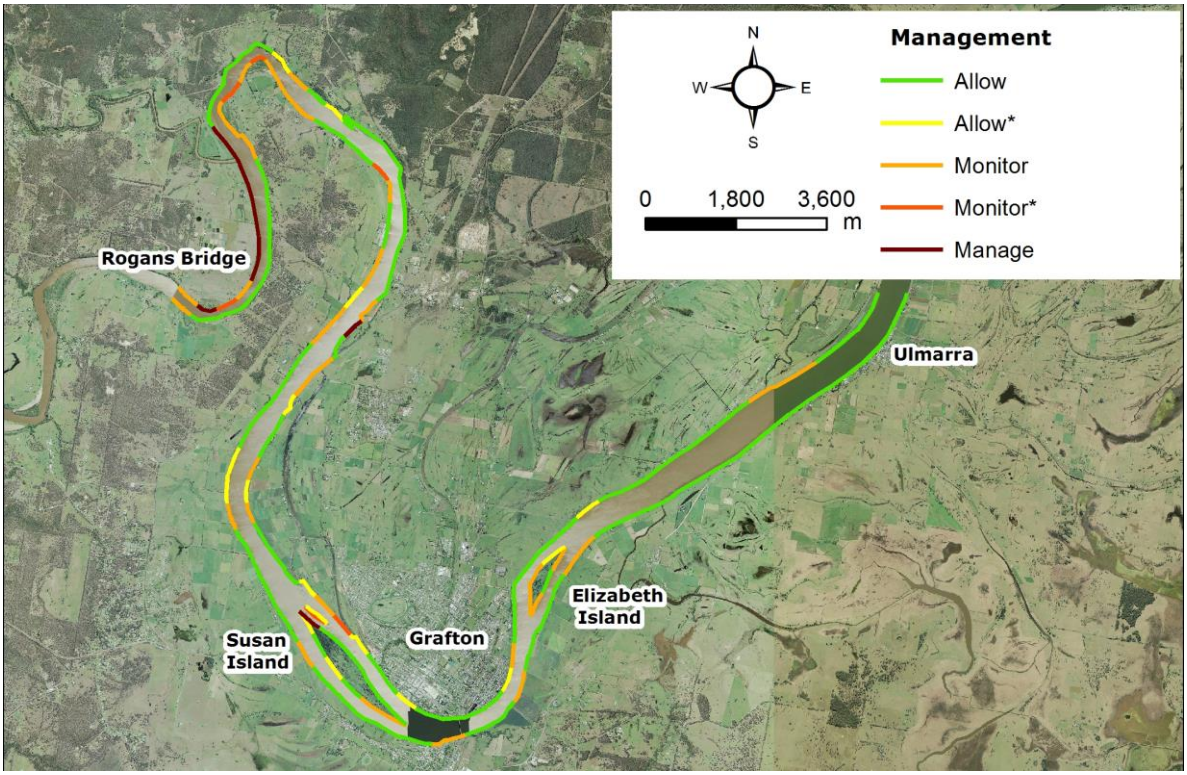


Figure L-3: DSS Management Recommendations – Wakeboard Operating – Adjusted Local Winds – 300 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

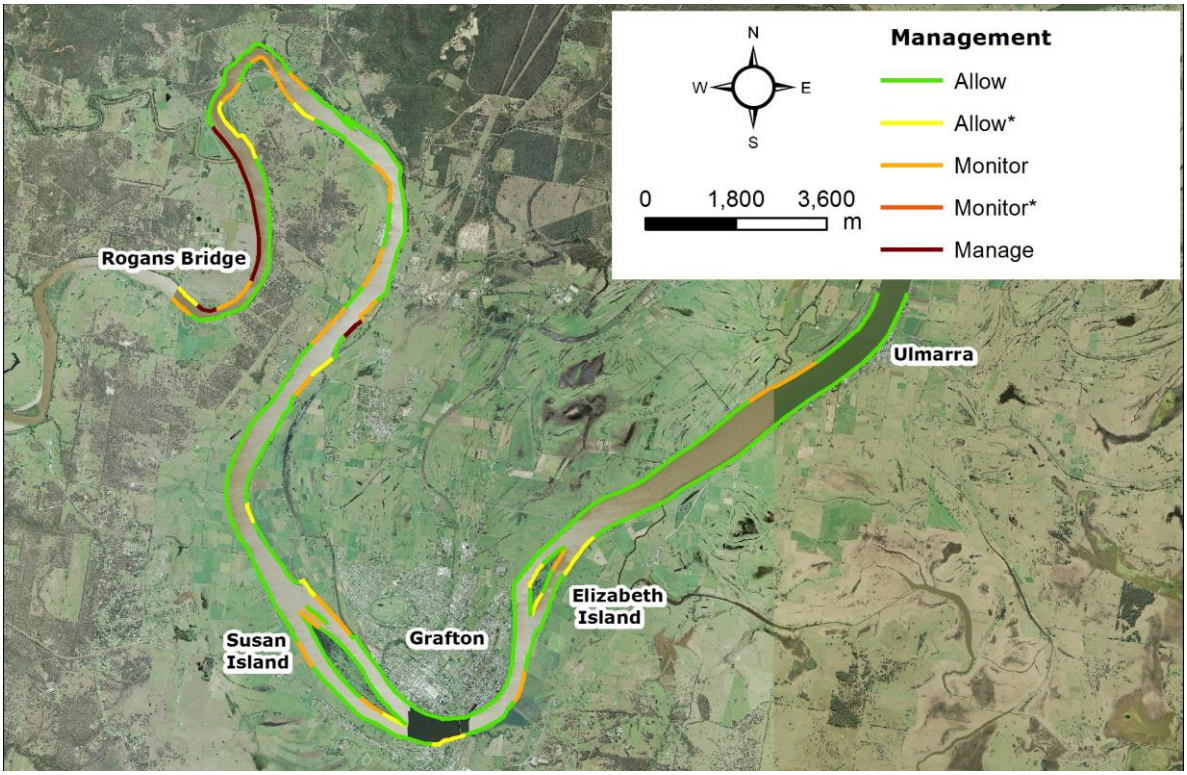


Figure L-4: DSS Management Recommendations – Waterski Operating – Adjusted Local Winds – 10 Boat Passes - 8 hour Duration (Mid - Low Tide Conditions)

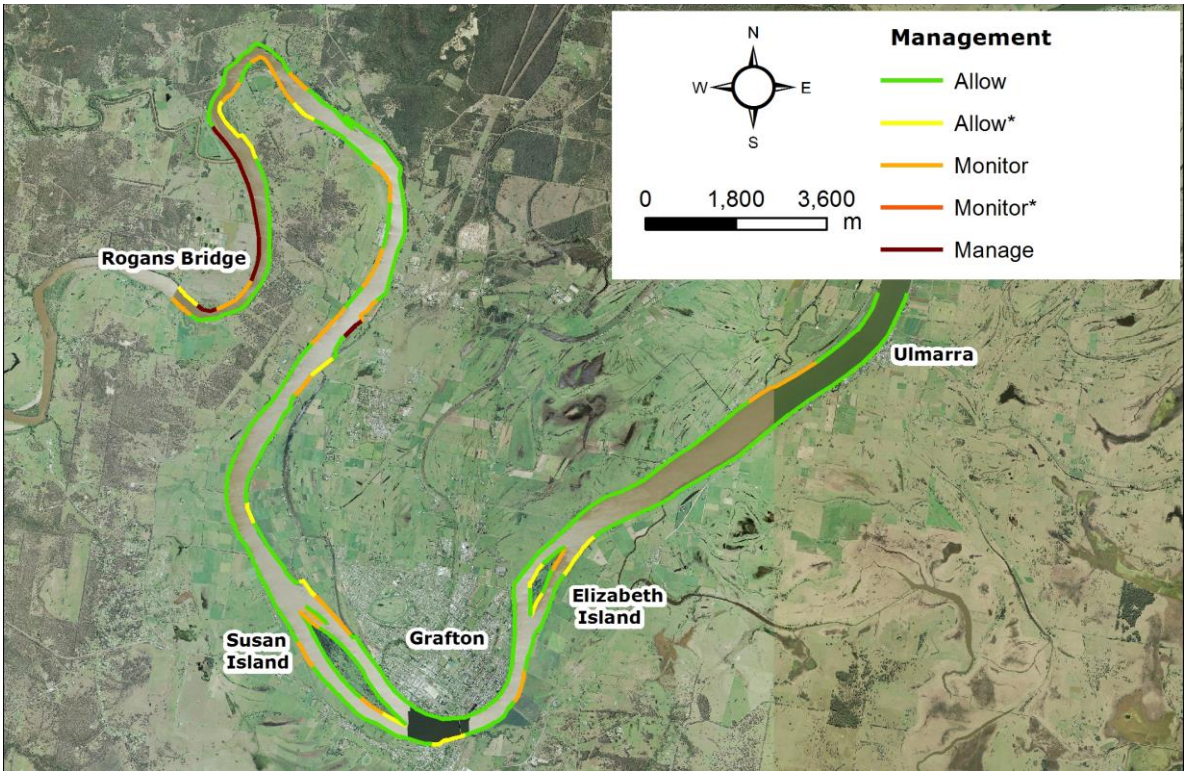


Figure L-5: DSS Management Recommendations – Waterski Operating – Adjusted Local Winds – 150 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

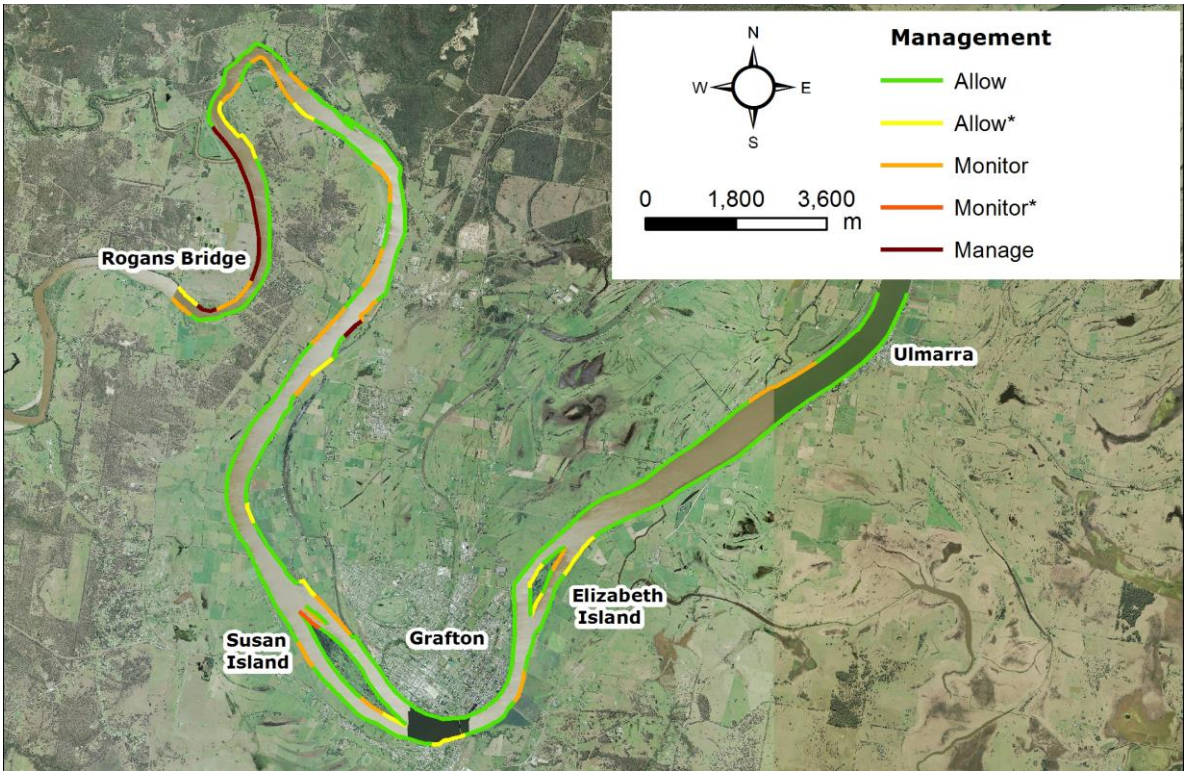


Figure L-6: DSS Management Recommendations – Waterski Operating – Adjusted Local Winds - 300 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

Appendix M – DSS Sensitivity Test – Boat Wave Attenuation

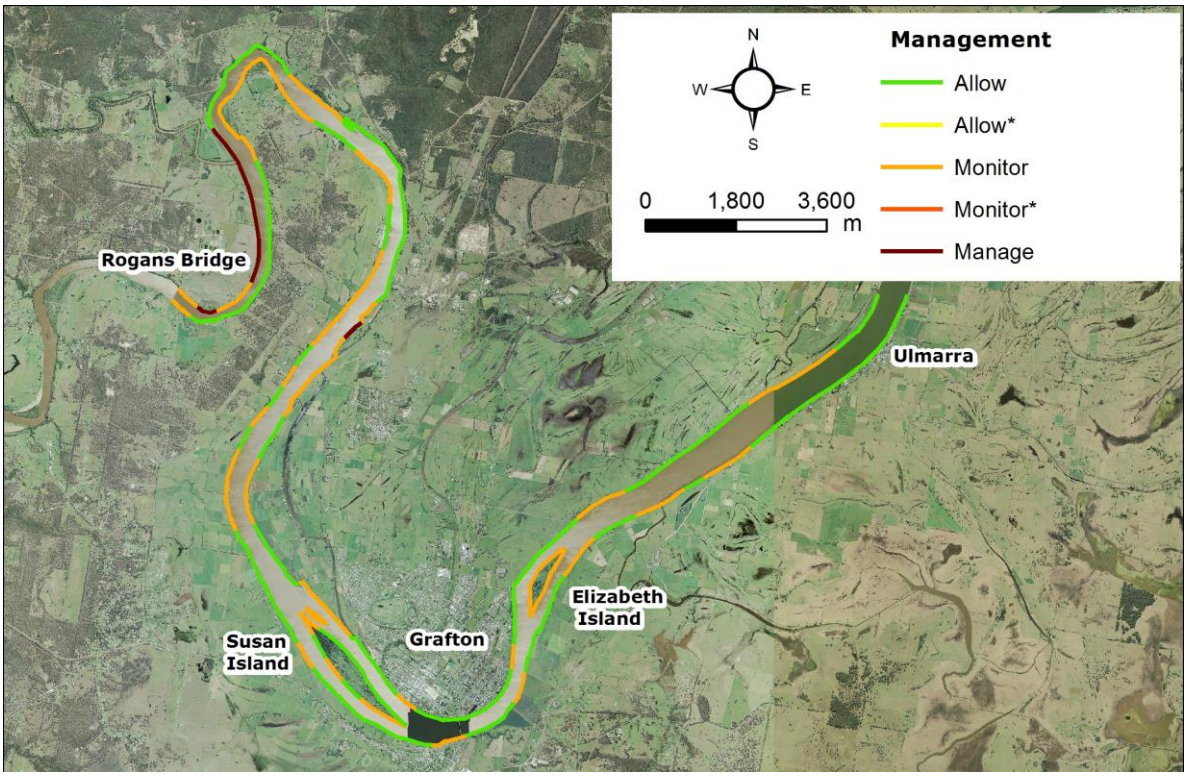


Figure M-1: DSS Management Recommendations – Wakeboard Operating – Boat Wave Attenuation – 10 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

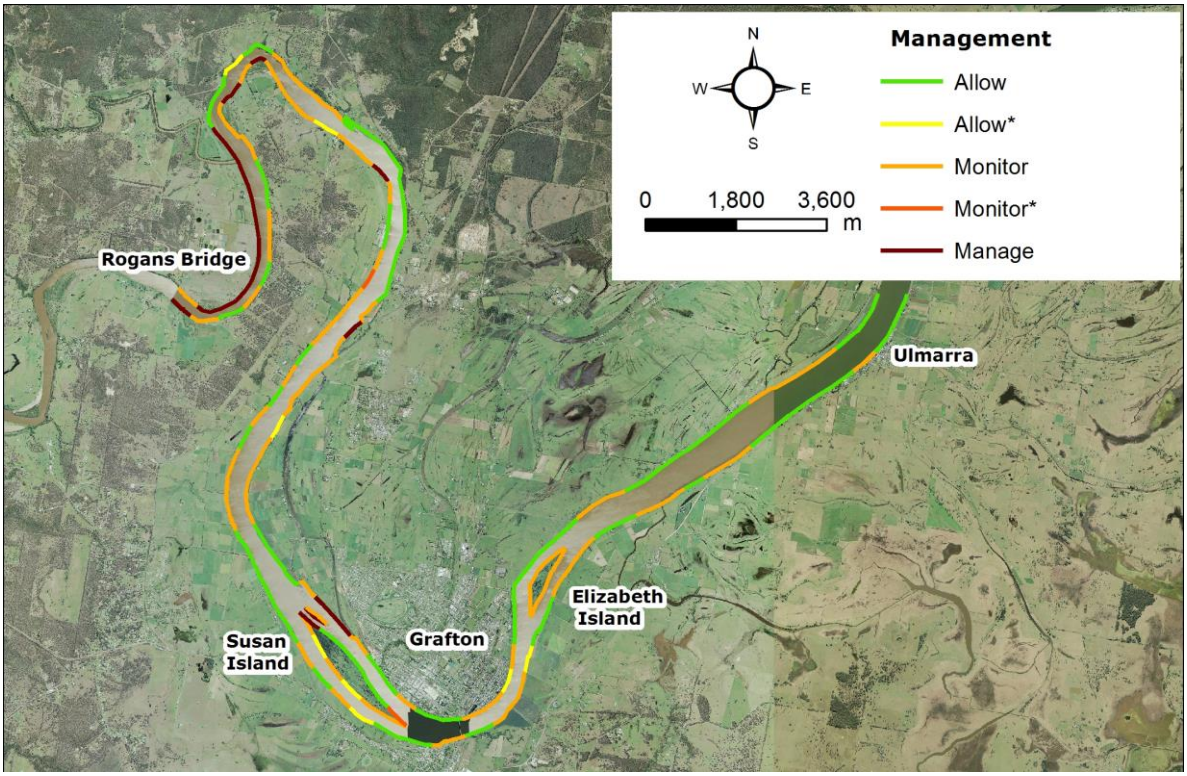


Figure M-2: DSS Management Recommendations – Wakeboard Operating – Boat Wave Attenuation – 150 Boat Passes - 8 hour Duration (Mid - Low Tide Conditions)

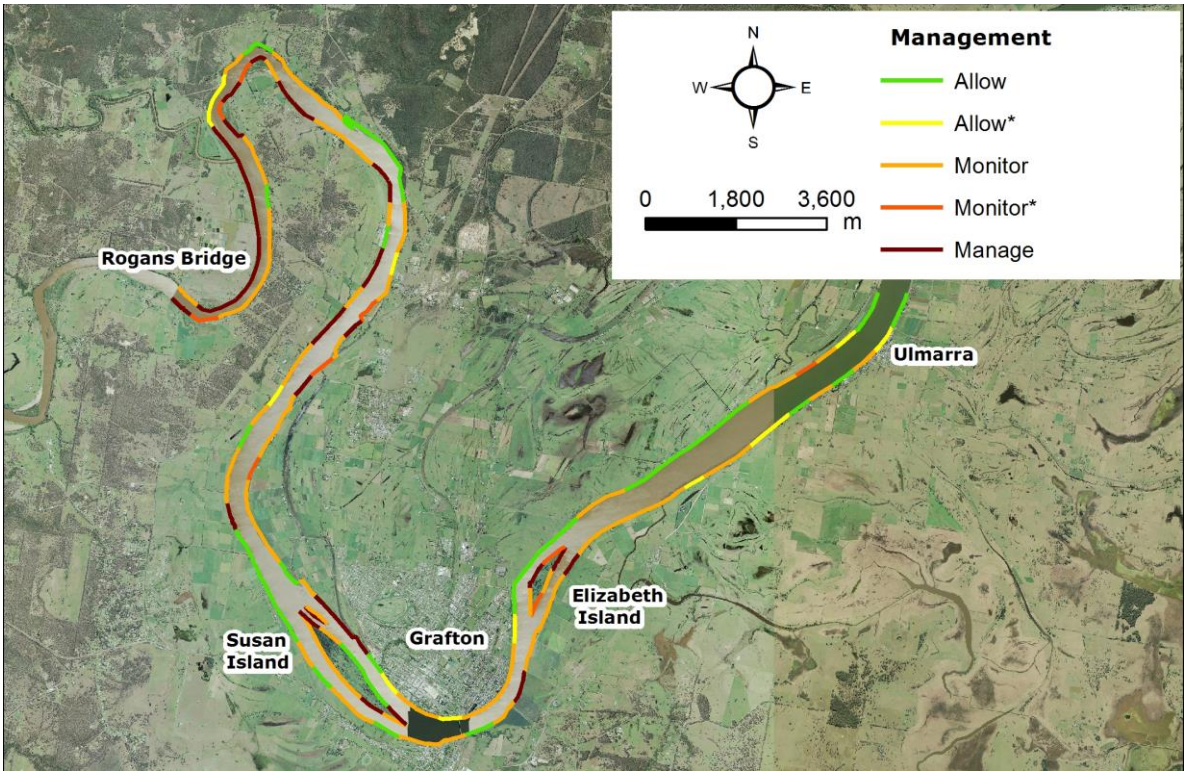


Figure M-3: DSS Management Recommendations – Wakeboard Operating – Boat Wave Attenuation – 300 Boat Passes – 8 hour Duration (Mid – Low Tide Conditions)

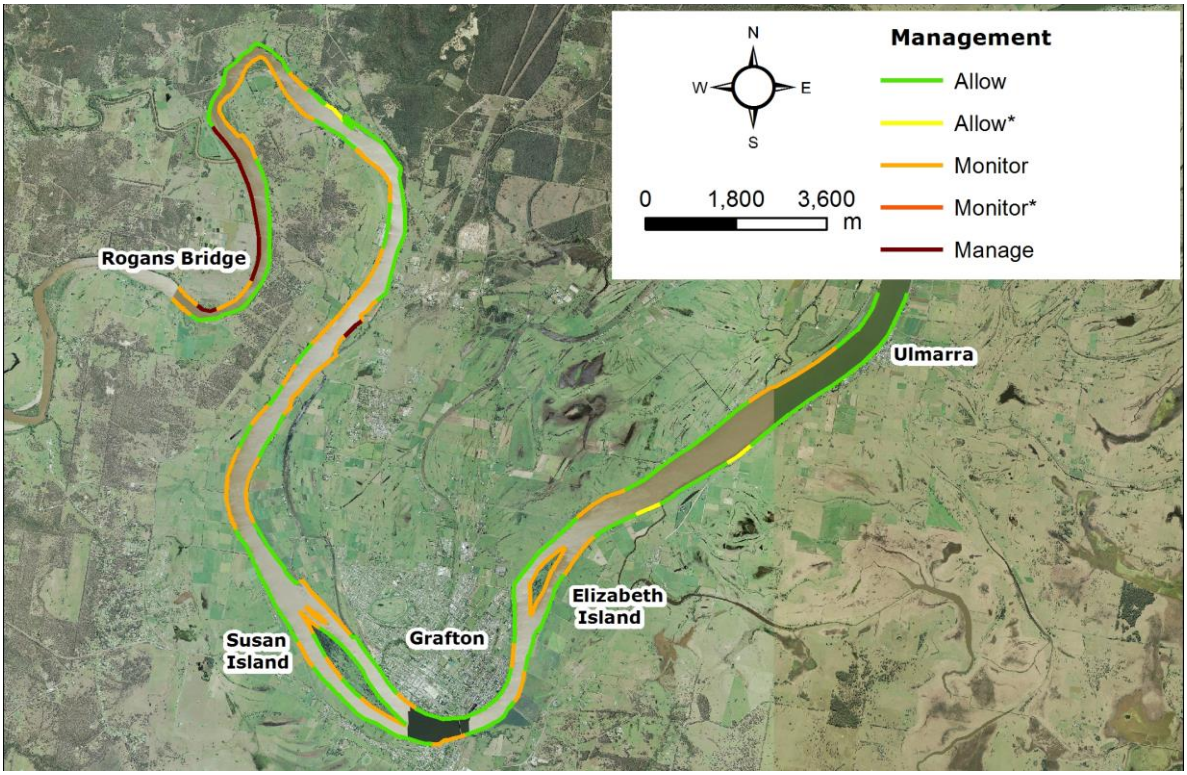


Figure M-4: DSS Management Recommendations – Waterski Operating – Boat Wave Attenuation – 10 Boat Passes - 8 hour Duration (Mid - Low Tide Conditions)

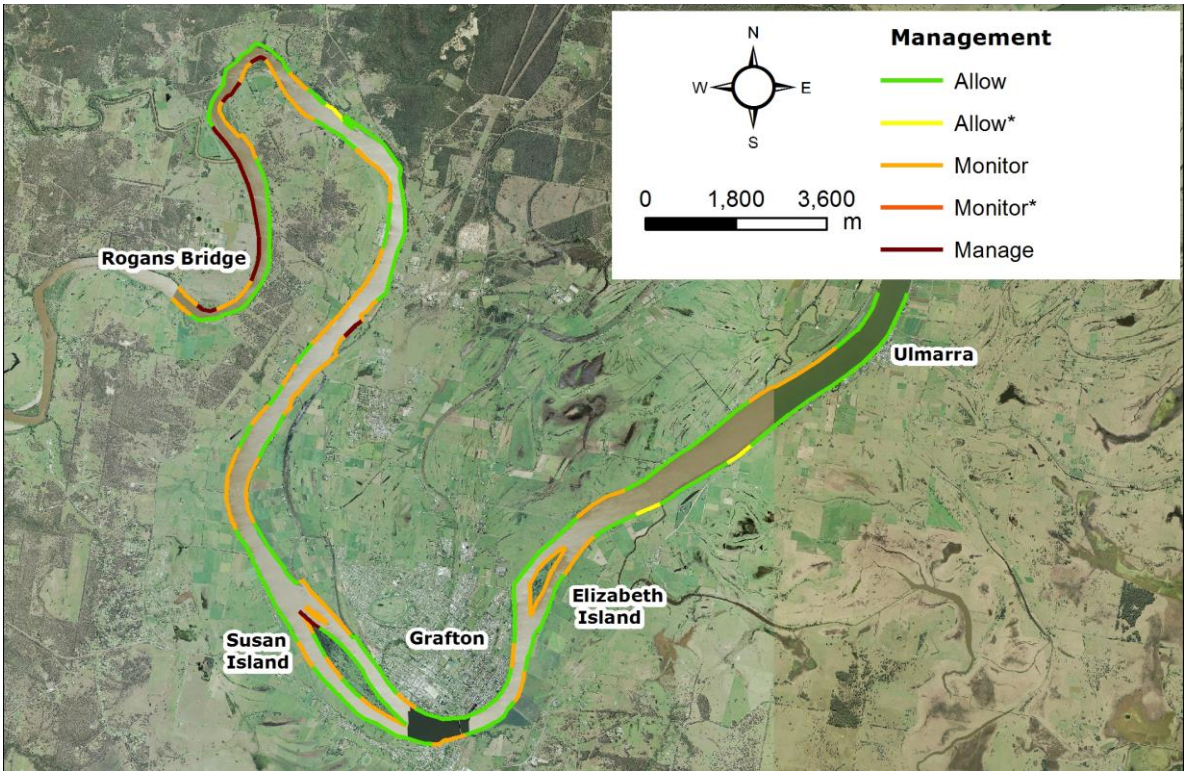


Figure M-5: DSS Management Recommendations – Waterski Operating – Boat Wave Attenuation – 150 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

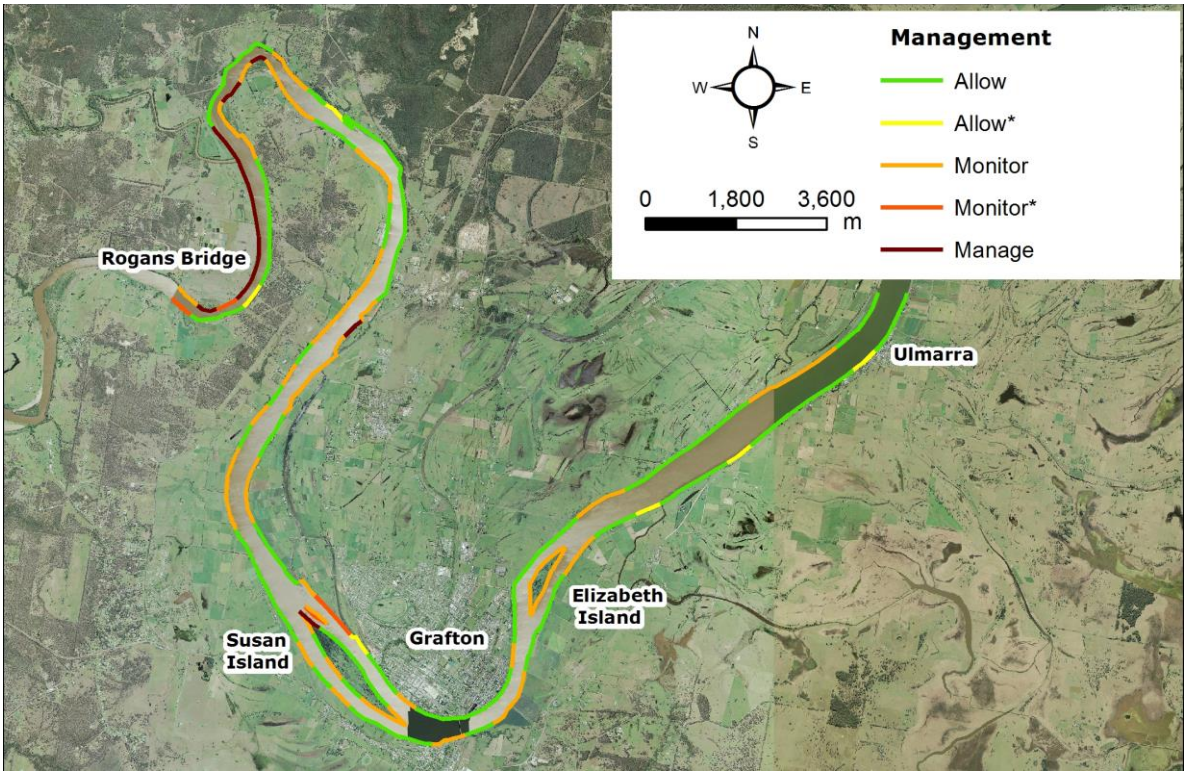
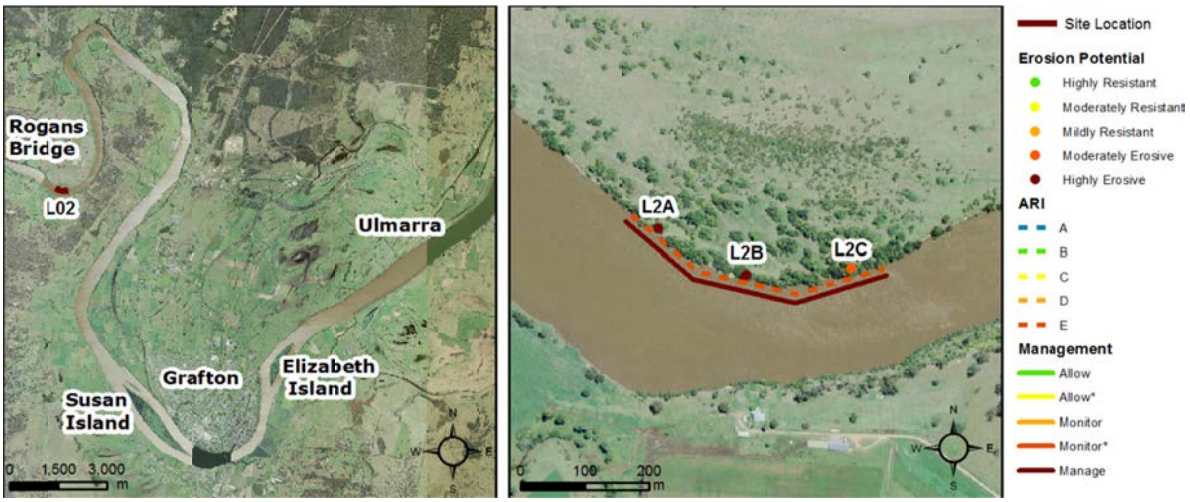


Figure M-6: DSS Management Recommendations – Waterski Operating – Boat Wave Attenuation - 300 Boat Passes – 8 hour Duration (Mid - Low Tide Conditions)

Appendix N – Riverbank Management Program

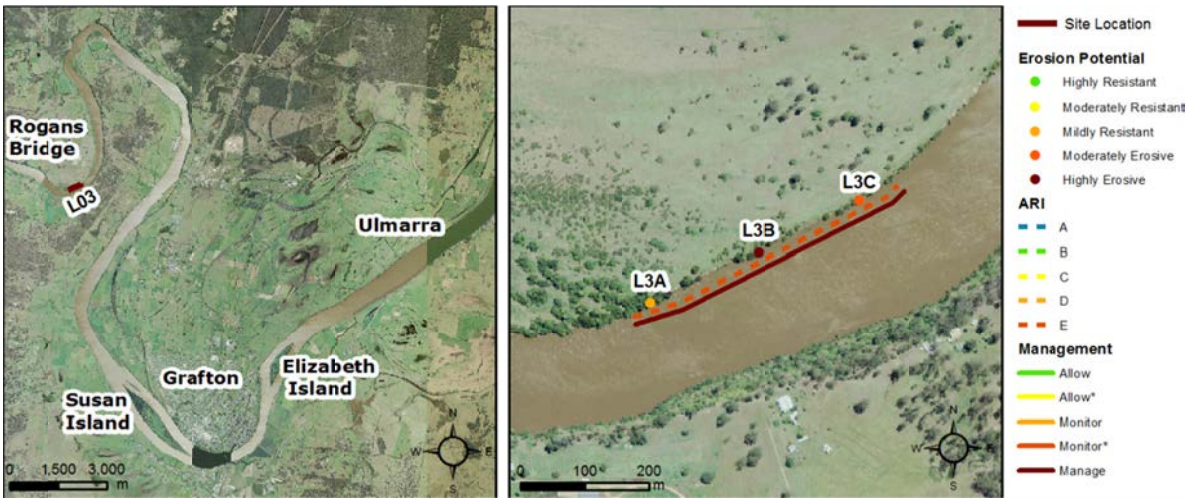


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from west/south-west directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and little to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion was observed across all three transects.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), reshaping and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with reshaping and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment where necessary. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing bank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise bank sediments by generating a network of roots and partially absorbing wave attack. Reshaping can be used to remove near-vertical erosion scarps. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

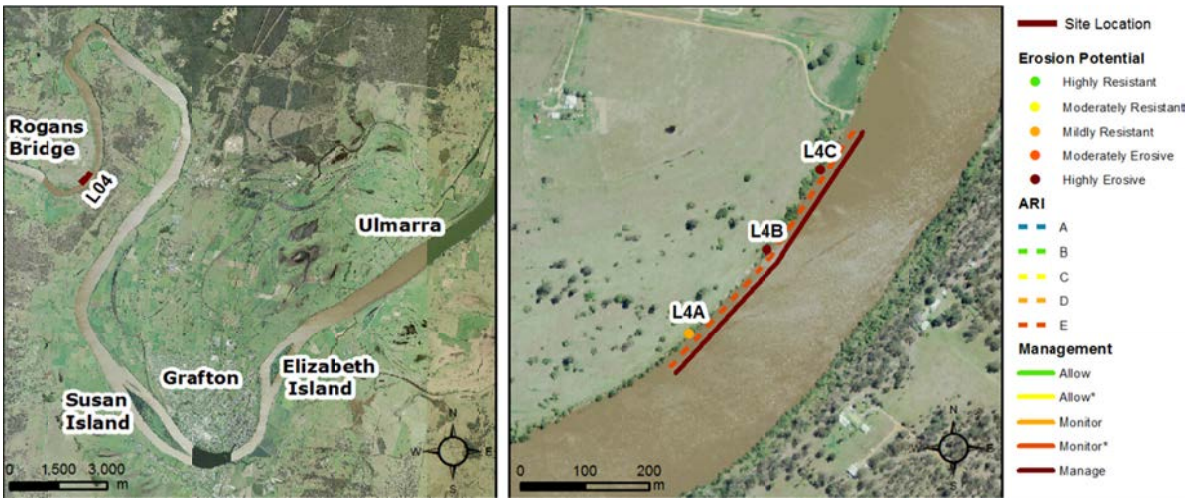


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from east/south-west directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and little to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion was observed across all three transects.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing bank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise bank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

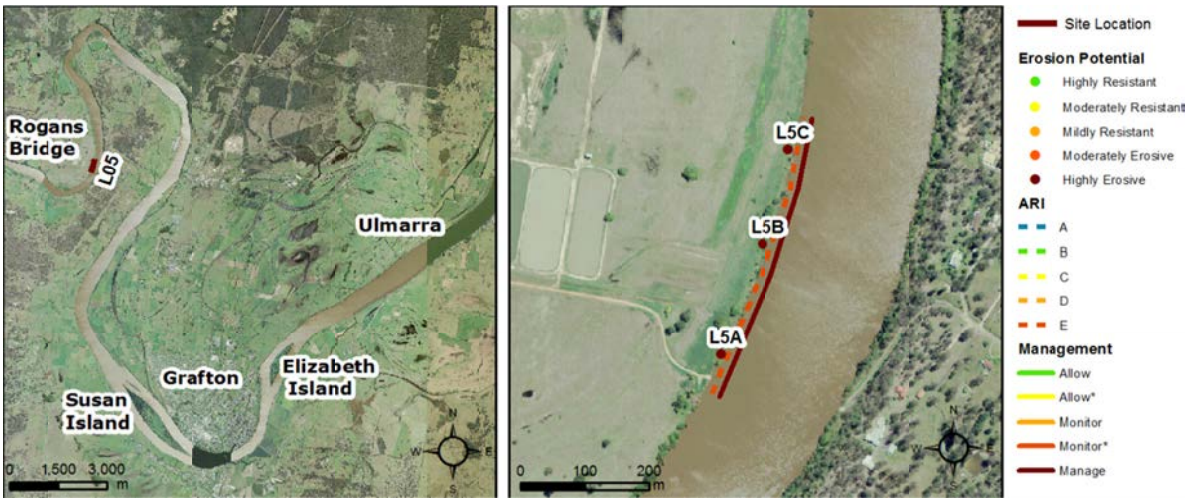


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-west directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion across all three transects, and vegetation undercutting at transect 'B' and transect 'C', was observed during the site inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this section. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

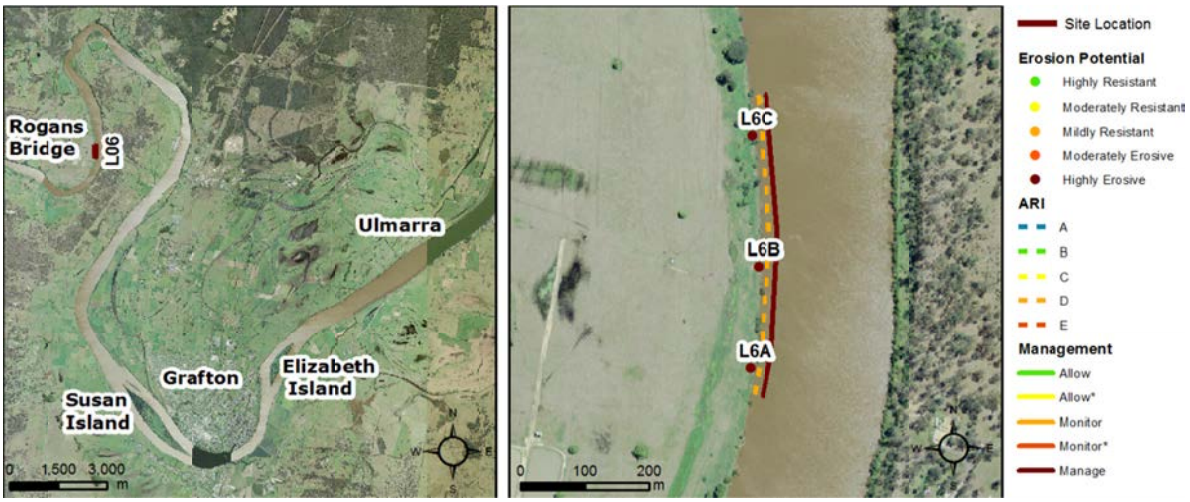


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south directions. The site was poorly vegetated in the riparian zone and contained no native understorey regeneration at the time of the inspection. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion across all three transects, vegetation undercutting at transect 'A' and slumping at transect 'B' and transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, toe protection and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering of the upper bank to create terraces with a back-slope of 1H:3V, toe protection, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge, should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

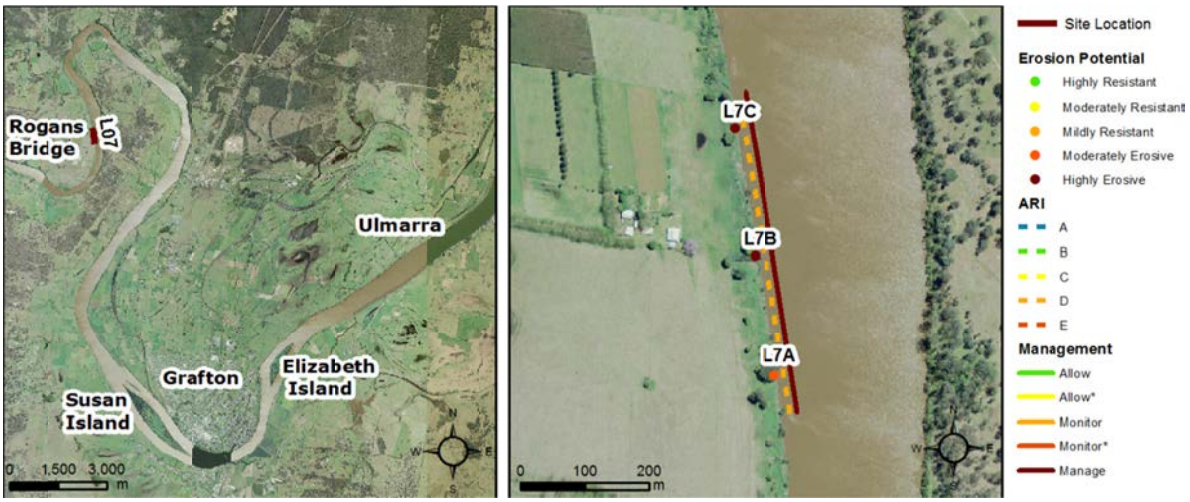


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-east directions. The site was poorly vegetated in the riparian zone and contained no native understorey regeneration at the time of the inspection. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion across all three transects, slumping at transect 'A' and transect 'B' and vegetation undercutting at transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, toe protection and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering of the upper bank to create terraces with a back-slope of 1H:3V, toe protection, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge, should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

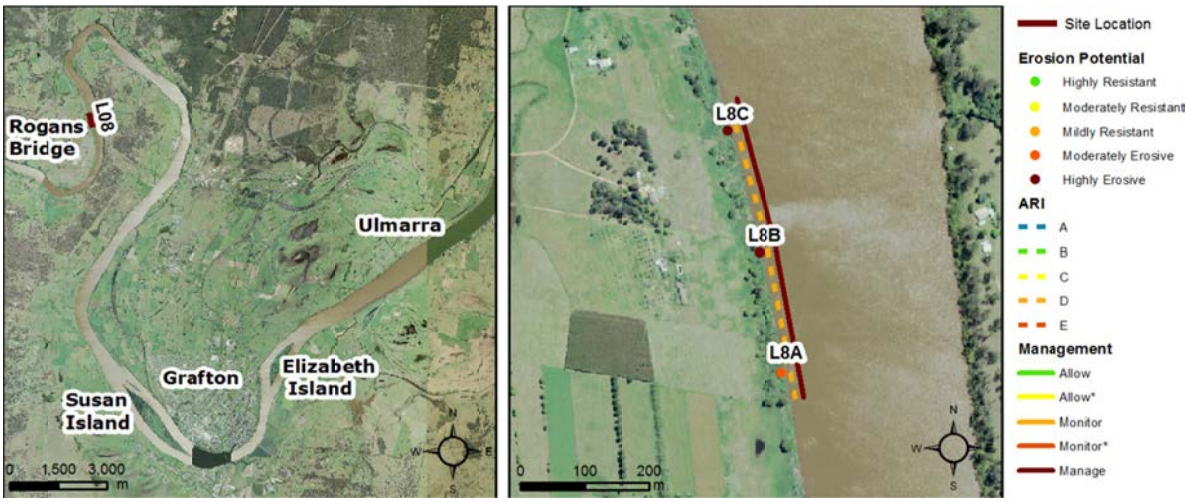


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and exposed to moderate fetch lengths from north-east/south-east directions. The site was poorly vegetated in the riparian zone and contained no native understorey regeneration at the time of the inspection. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion across all three transects, and slumping at transect 'B' and transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, toe protection and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering of the upper bank to create terraces with a back-slope of 1H:3V, toe protection, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge, should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

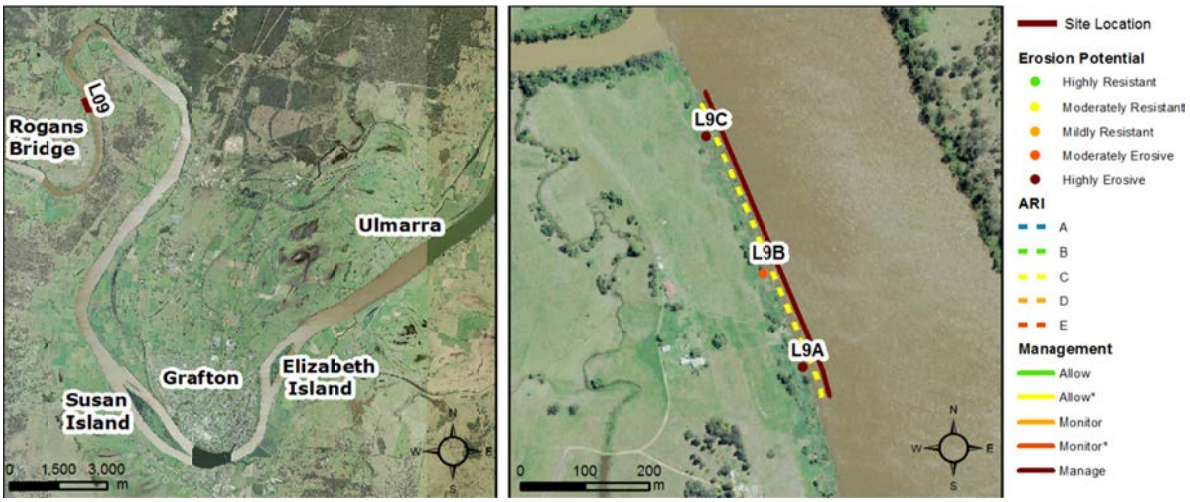


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and exposed to moderate fetch lengths from north-east/south-east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion and slumping at transect 'B' and transect 'C' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this site. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge, should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

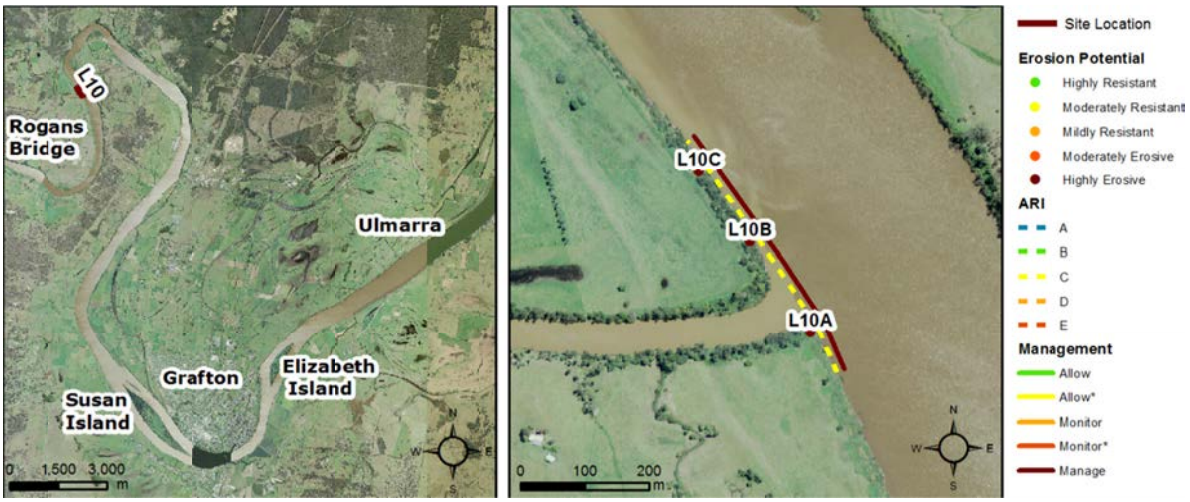


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant slumping at all three transects, with erosion at transect 'A', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge, should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

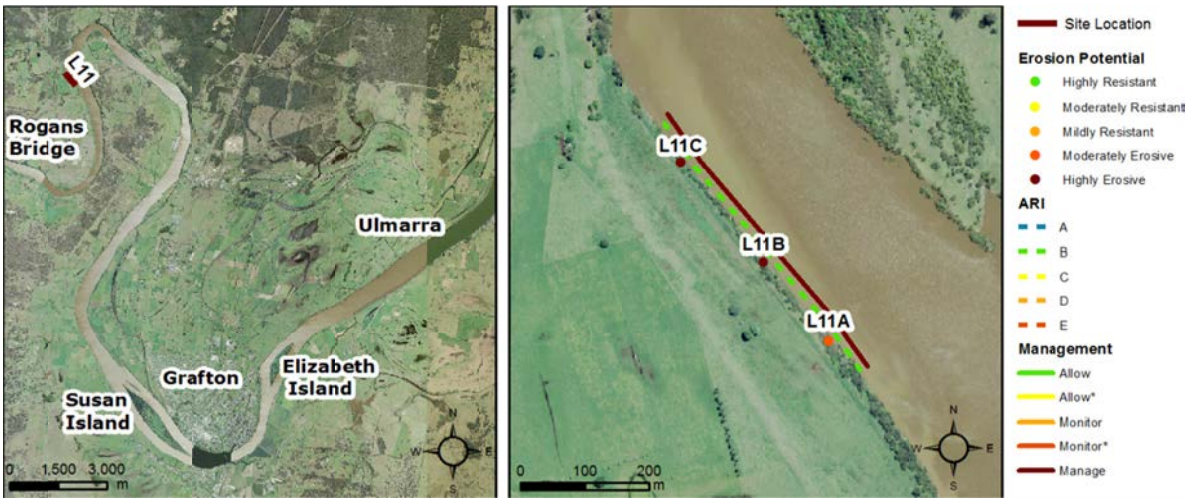


Site Description: The site is located on the left bank of the Clarence River downstream of Rogans Bridge at the entrance to Whiteman Creek. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north /south-east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Slumping at transect 'A' and erosion at transect 'B' and transect 'C' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

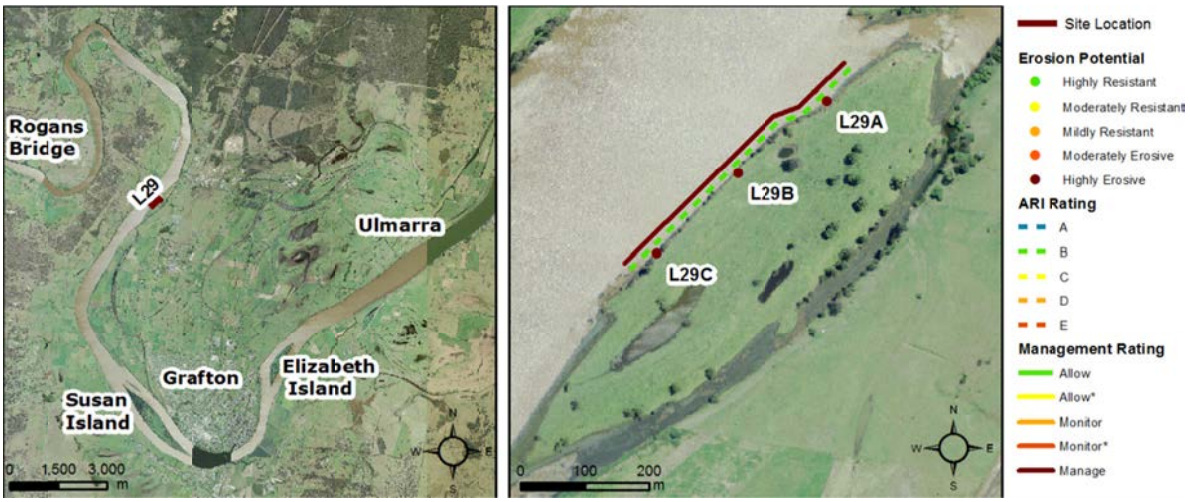


Site Description: The site is located on the left bank of the Clarence River downstream of Whiteman Creek. The site is located on a straight section of the river and exposed to moderate fetch lengths from north/east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion due to poor land management practices was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this site. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

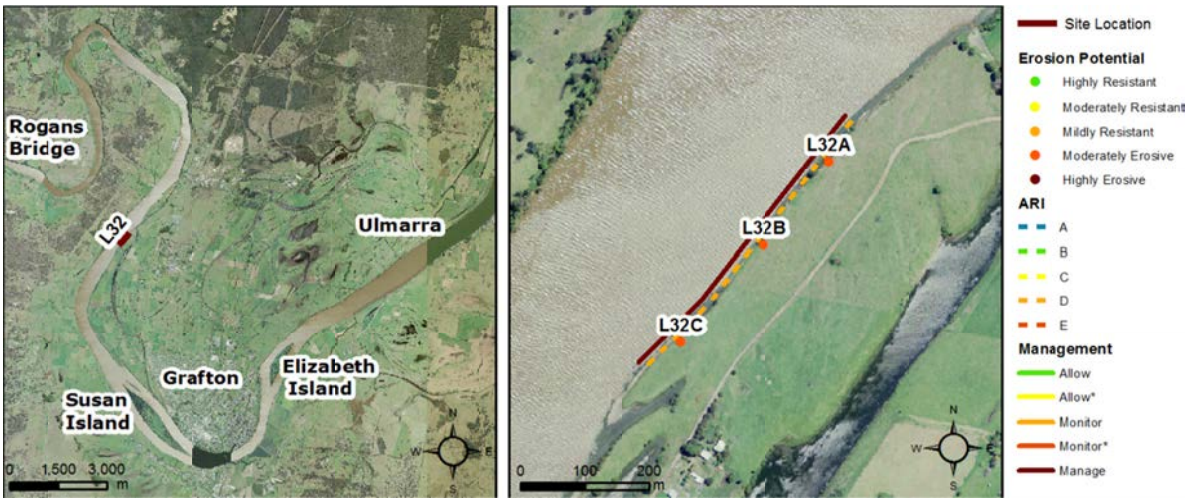


Site Description: The site is located on the left bank of the Clarence River upstream of the Junction Hill boat ramp on a small, unnamed island. The site is exposed to moderate fetch lengths from west/north-west directions. The site was well vegetated in the wave zone but poorly vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion across all three transects, with vegetation undercutting at transect 'B' and transect 'C' and slumping at transect 'C', was observed at the time of the inspection.

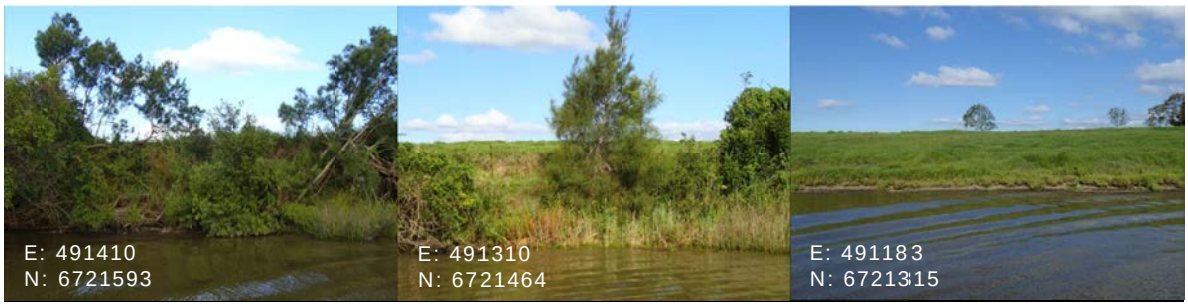
Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include native revegetation (with bioengineering where possible), bank reshaping and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend immediate stabilisation of the riverbank in the riparian zone through stock management, in combination with reshaping to remove near-vertical erosion scarps, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge across the entire stretch. Cut riverbank material should be used for toe renourishment.

Justification: Stock management is required to prevent ongoing bank destabilisation and damage caused by stock access. Riverbank stabilisation could also be improved through battering or rock fillets. However, battering or rock fillets are not considered a feasible option for stretch L29 due to the limited access of machinery onto the island and since there are no adjacent assets on the island under threat. Note that buoys are not sufficient as a stand-alone management option for this stretch.



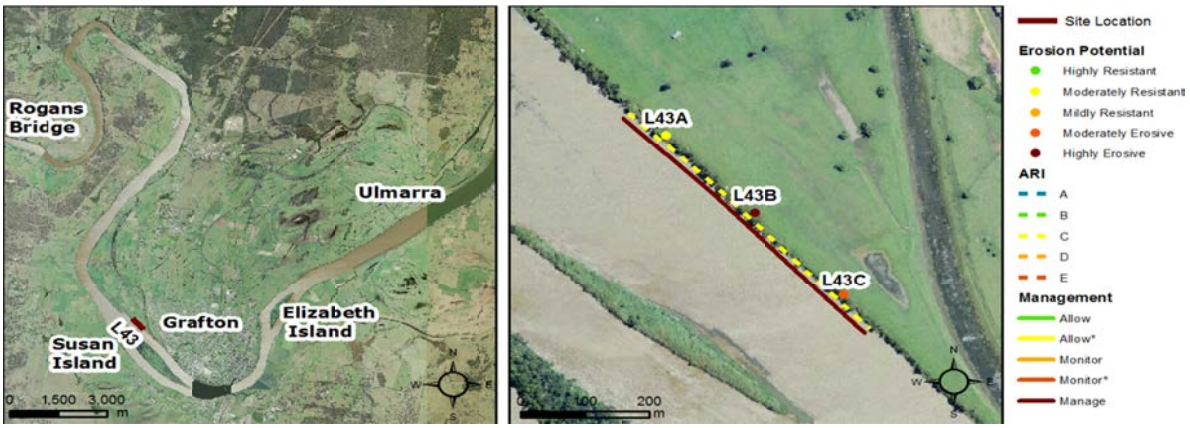
Site Description: The site is located on the left bank of the Clarence River downstream of the Junction Hill boat ramp on a small, unnamed island. The site is exposed to moderate fetch lengths from west/north-west directions. The site was relatively well vegetated in the wave zone but poorly vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Vegetation undercutting at transect 'A' and significant erosion and slumping at transect 'B' was observed at the time of the inspection.



Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are satisfactory as a stand-alone management option for this stretch.

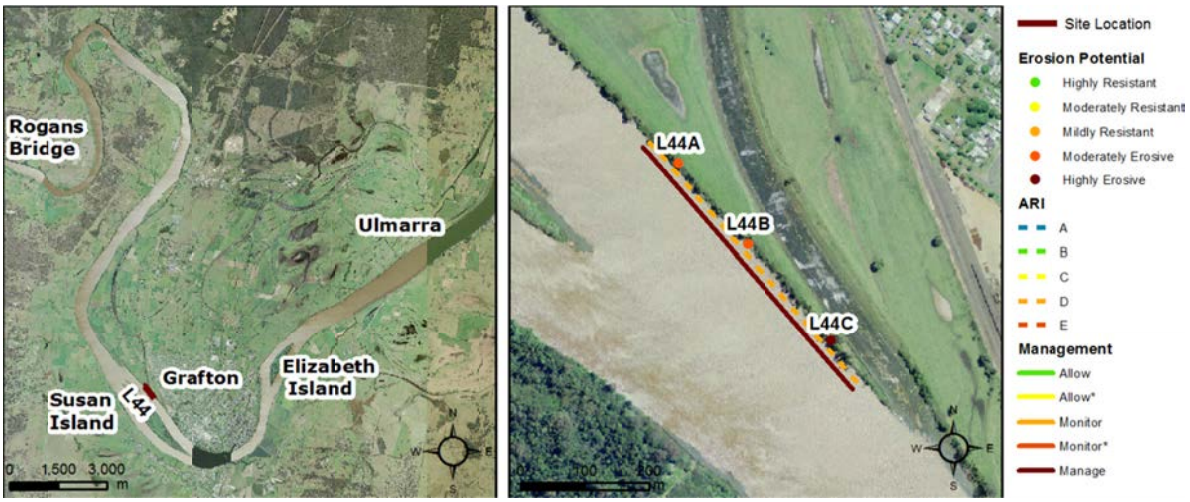


Site Description: The site is located on the left bank of the Clarence River directly opposite Peanut and Susan Island. The site is located on a straight section of the river and is exposed to moderate fetch lengths from west/south-west directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion at transect 'A' and transect 'C', with vegetation undercutting at transect 'B' and transect 'C' and slumping at transect 'A', was observed at the time of the inspection. Rock protection has been used at transect 'A' without sufficient engineering design.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, stock management, armouring and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Existing rock protection at transect 'A' should be removed and the upper bank battered to create terraces with a back-slope of 1H:3V. Investigate the potential for rock fillets in conjunction with toe armouring to encourage phragmites growth. A 'no wash' zone should be implemented inside Peanut Island.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

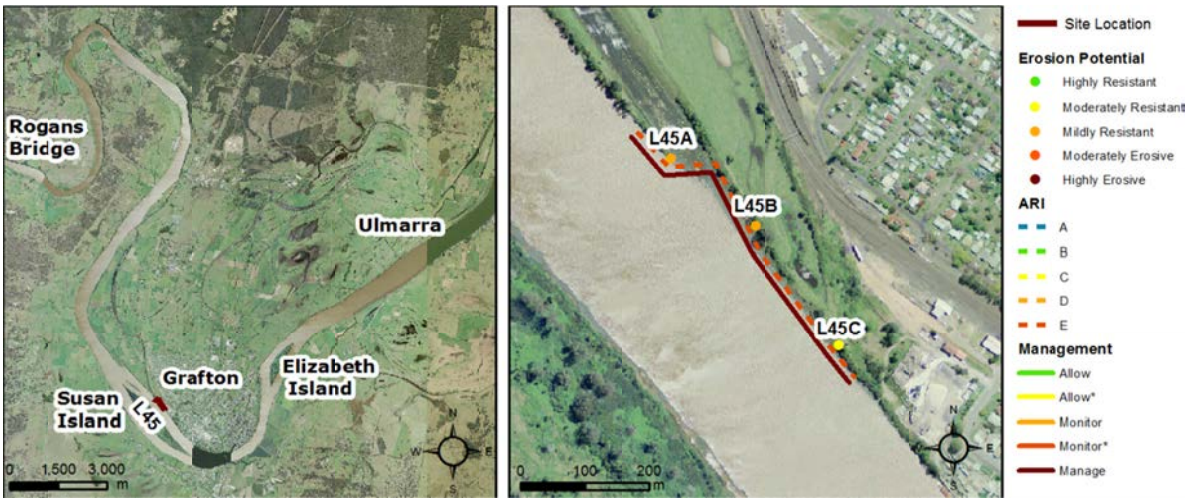


Site Description: The site is located on the left bank of the Clarence River directly opposite Susan Island and upstream of the entrance to Carrs Creek. The site is located on a straight section of the river and is exposed to moderate fetch lengths from west/south-west directions. The site was relatively well vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion at all three transects, with slumping at transect 'B' and transect 'C' and vegetation undercutting at transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, stock management and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend stock management, in combination with the removal of exotic vegetation, battering of the upper bank at transect 'A' to create terraces with a back-slope of 1H:3V, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Investigate the potential for rock fillets in conjunction with toe armouring to encourage phragmites growth across the entire stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

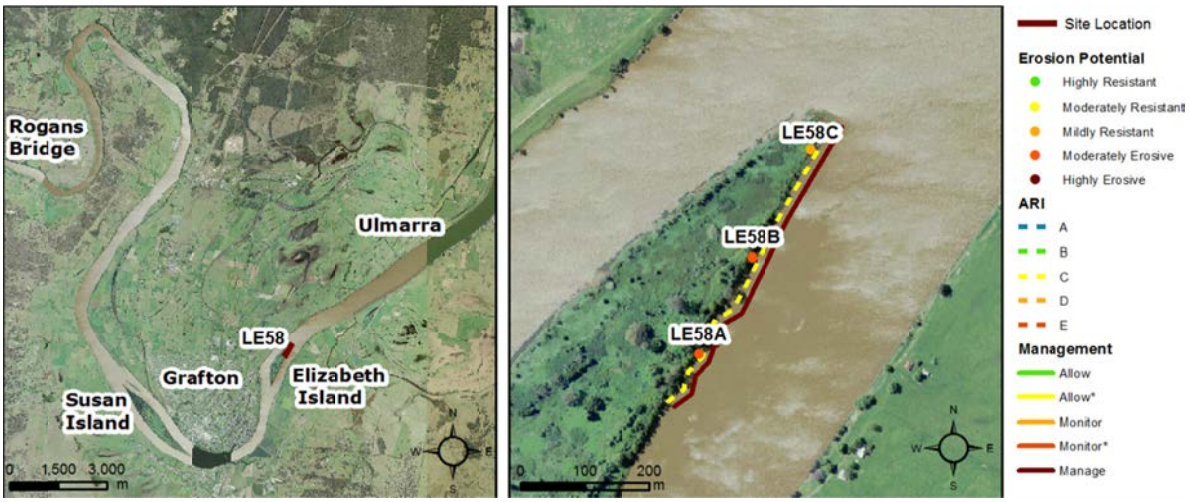


Site Description: The site is located on the left bank of the Clarence River at the entrance to Carrs Creek, directly opposite Susan Island. The site is located on a straight section of the river and is exposed to moderate fetch lengths from west/south-west directions. The site was relatively well vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. No significant erosion, slumping or vegetation undercutting was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are satisfactory as a stand-alone management option for this stretch.

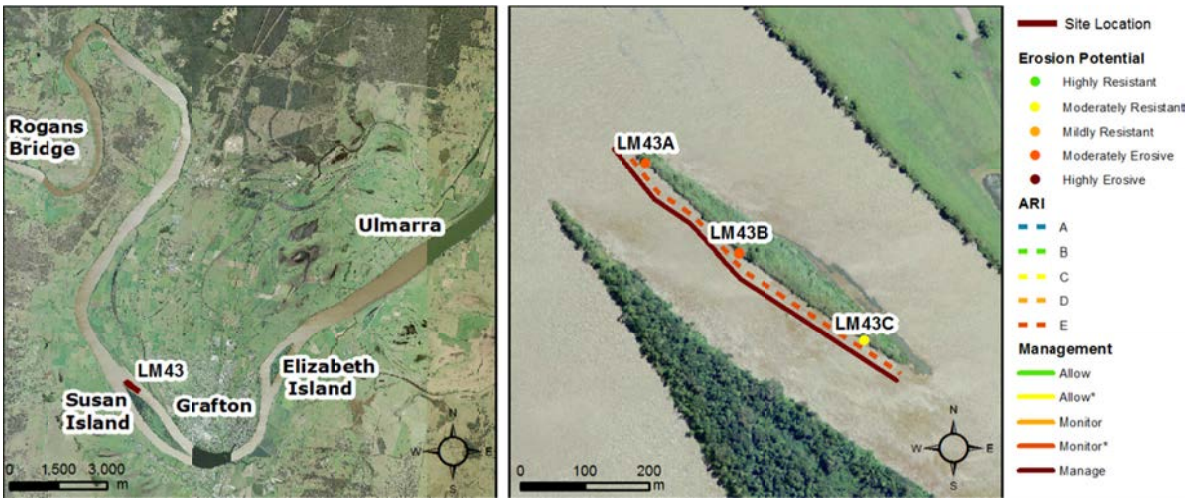


Site Description: The site is located on the left bank of Elizabeth Island on the Clarence River. The site is exposed to moderate fetch lengths from north-east/south-east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Moderate erosion at transect 'A', with significant vegetation undercutting at transect 'A' and transect 'B' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and native revegetation. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Planting of native trees in combination with the removal of exotic vegetation should be used to stabilise the riverbank on the island across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this river stretch while revegetation is established.

Justification: Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are satisfactory as a stand-alone management option for this stretch.

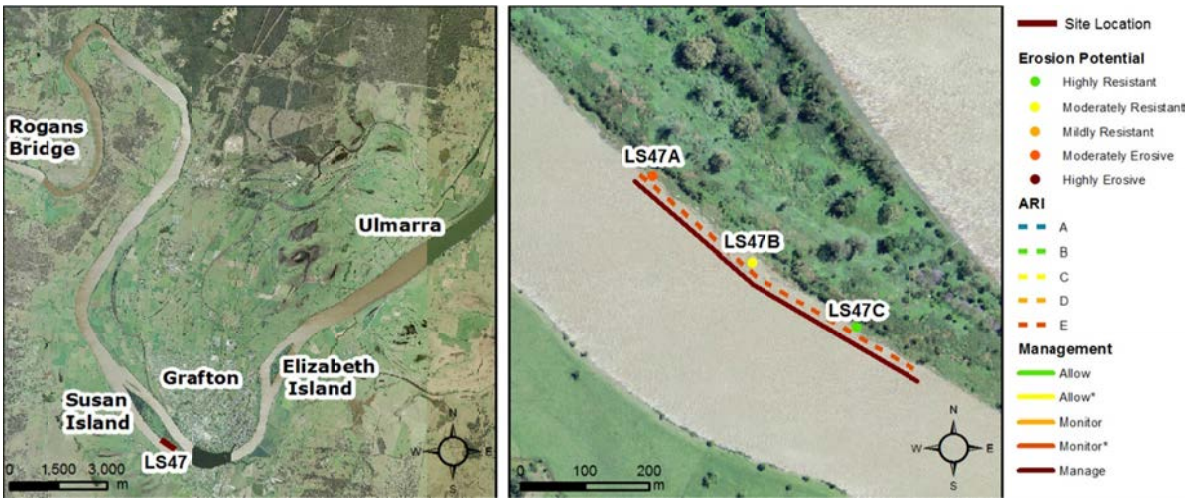


Site Description: The site is located on the left bank of Peanut Island on the Clarence River. The site is exposed to moderate fetch lengths from north-west/south directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Minor vegetation undercutting at transect 'A' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation, native revegetation and managed retreat. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a managed retreat (or 'do-nothing' option) for this stretch. Revegetation and buoys are not sufficient to reduce the riverbank vulnerability rating to 'Monitor'.

Justification: Managed retreat permits bank erosion to continue, while managing any safety or environmental concerns. It can reduce down-drift erosion and allow the river to migrate. This is often the least expensive approach, with the least adverse environmental impacts.

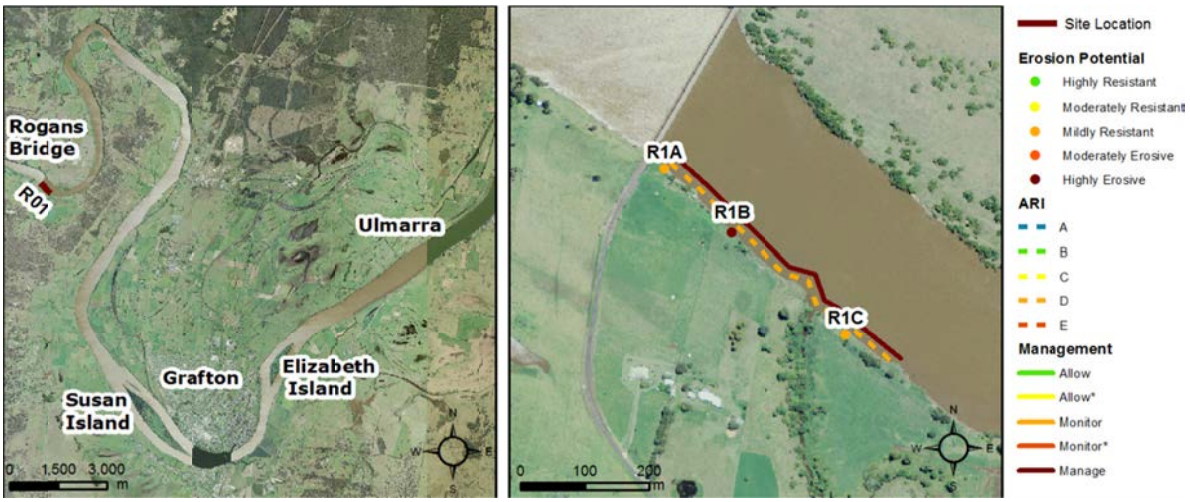


Site Description: The site is located on the left bank of Susan Island on the Clarence River. The site is exposed to moderate fetch lengths from west/south-east directions. The site was well vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained abundant native understorey regeneration and relatively good verge cover. The bank height was greater than three (3) metres with a 1H:5V bank slope. Significant vegetation undercutting at transect 'A' and transect 'B' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation, native revegetation and renourishment. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Planting of native trees, in combination with renourishment is recommended across the entire stretch. It is also encouraged that buoys are placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Renourishment will improve the sediment deficit and reduce the erosion risk at the site while also allowing revegetation to establish behind the nourishment zone. Note that buoys are satisfactory as a stand-alone management option for this stretch.

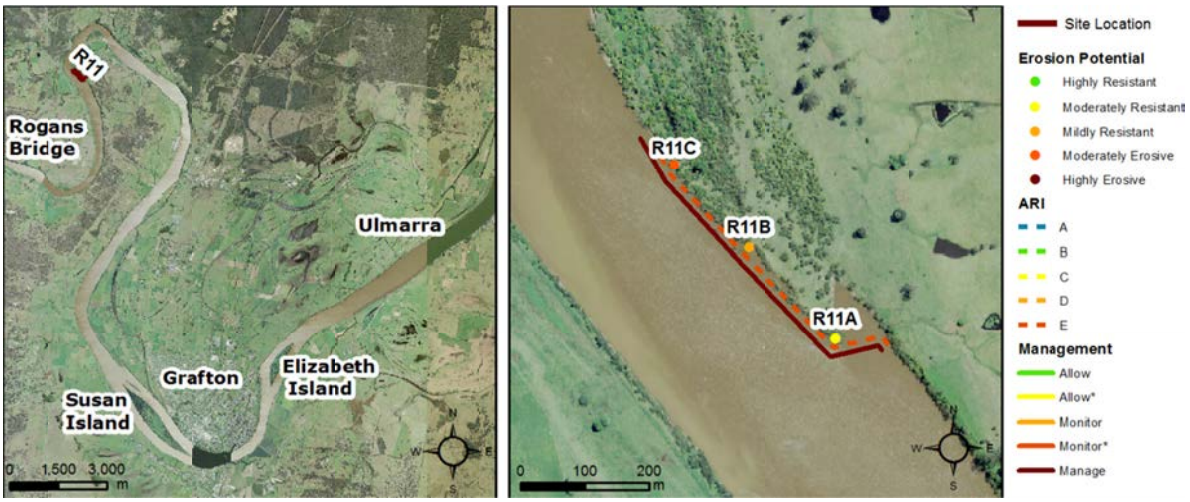


Site Description: The site is located on the right bank of the Clarence River downstream of Rogans Bridge. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north/north-east directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion at transect 'A' and transect 'B' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), reshaping and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with reshaping and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works where possible. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing bank destabilisation and damage caused by stock access. Buoys, revegetation with renourishment will establish local native vegetation to stabilise bank sediments by generating a network of roots and partially absorbing wave attack. Reshaping can be used to remove near-vertical erosion scarps. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

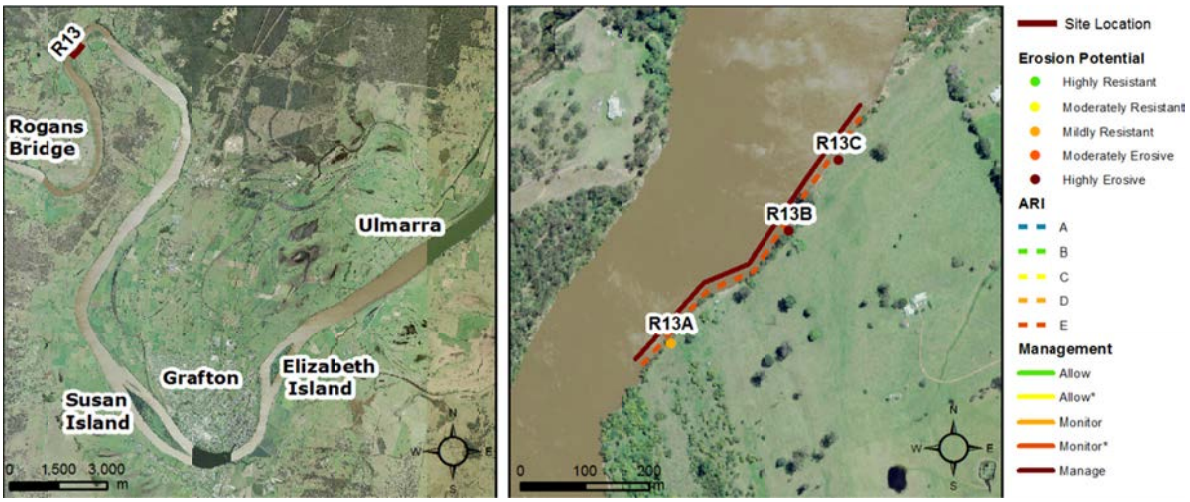


Site Description: The site is located on the right bank of the Clarence River opposite to the entrance of Whiteman Creek. The site is located on a straight section of the river and is exposed to moderate fetch lengths from west/south directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and good verge cover at transect 'C'. The bank height for this stretch was generally greater than three (3) metres with an upper bank slope ranging between 1H:7V at transect 'A' to near-vertical at transect 'C'. Significant erosion at transect 'A' and transect 'C' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), renourishment and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Renourishment is encouraged. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are satisfactory as a stand-alone management option for this stretch.

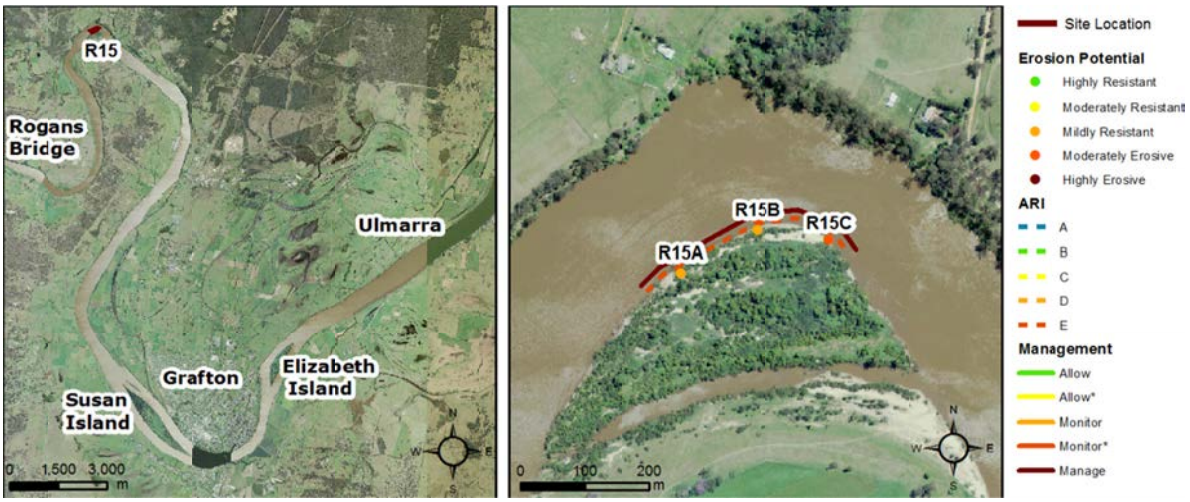


Site Description: The site is located on the right bank of the Clarence River. The site is located on a straight section of the river and is exposed to moderate fetch lengths from west/south directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover at each transect. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion across the entire stretch was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering of the upper bank to create terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

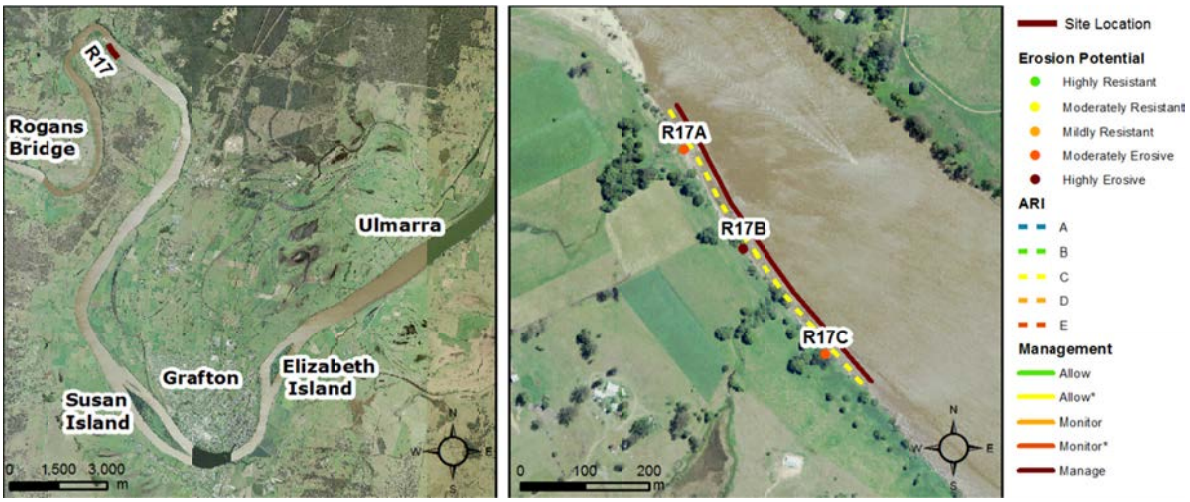


Site Description: The site is located on the right bank of the Clarence River in an area known as 'Seelands'. The site is located on an inside-bank and is exposed to moderate fetch lengths from north/north-west directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation or verge cover across all sites. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion across the entire stretch was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), renourishment and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Renourishment is encouraged. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

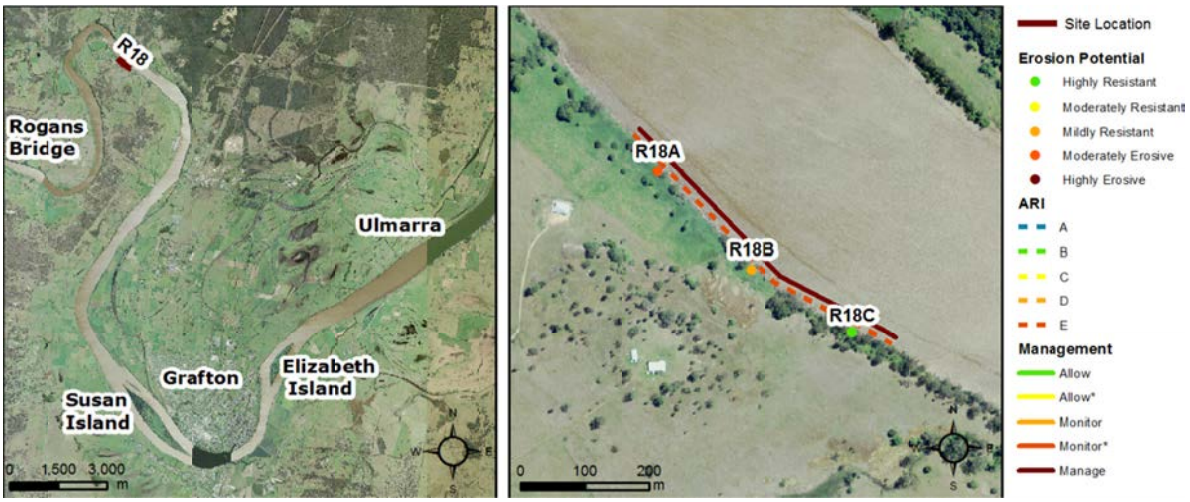


Site Description: The site is located on the right bank of the Clarence River upstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north/east directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. With the exception of transect 'A', the site contained limited native vegetation or verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion across the entire stretch was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), renourishment and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Renourishment is encouraged. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are satisfactory as a stand-alone management option for this stretch.

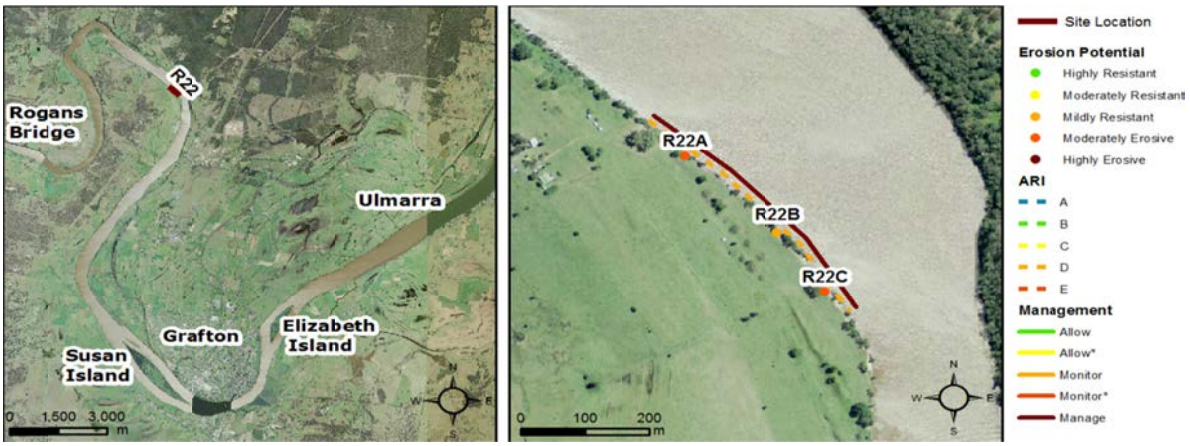


Site Description: The site is located on the right bank of the Clarence River upstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north/east directions. The site was poorly vegetated in the wave zone, with the exception of transect 'C' which contains bedrock, and was relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation or verge cover. The bank height was greater than three (3) metres with an upper bank slope of 1H:3V. No erosion, slumping or vegetation undercutting was observed at the time of the inspection. Stock access is permitted at the site.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible) and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Reshaping is not recommended at locations where the upper bank is well vegetated. Note that buoys are satisfactory as a stand-alone management option for this stretch.

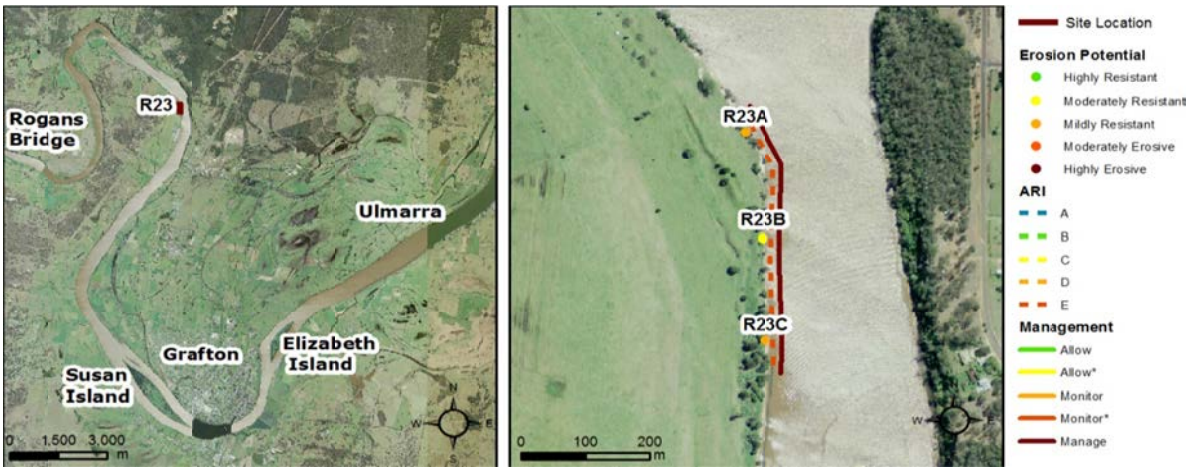


Site Description: The site is located on the right bank of the Clarence River upstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on an inside-bank and is exposed to moderate fetch lengths from north/north-east directions. The site was poorly vegetated in the wave zone and on the upper bank, with the exception of transect 'B' which contained fallen trees and tree roots, at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion across the entire stretch, with moderate slumping at transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, stock management and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering to create terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Investigate the potential for rock fillets in conjunction with toe armouring to encourage phragmites growth. In addition, buoys should be placed at the mid-river width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Rock fillets are recommended as this stretch is upstream of a constriction in the river which provides favourable flow conditions for their use in protecting vegetation. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

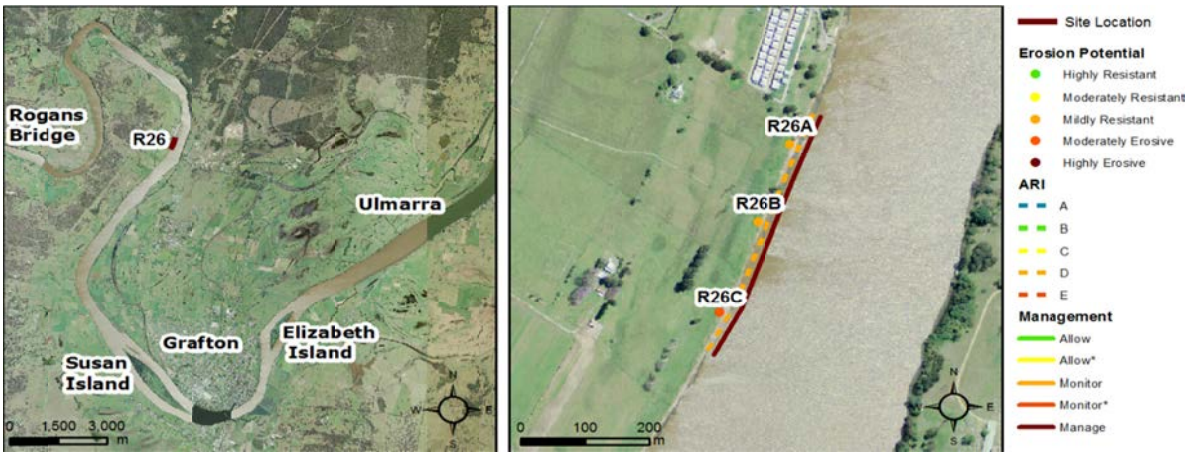


Site Description: The site is located on the right bank of the Clarence River upstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-west directions. The site was poorly vegetated in the wave zone and on the upper bank, with the exception of transect 'A' which contained fallen trees and tree roots, at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion at transect 'A' and transect 'C' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), reshaping, stock management and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Investigate the potential for rock fillets in conjunction with toe armouring to encourage phragmites growth. In addition, buoys should be placed at a width from the shore in this stretch.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Rock fillets are recommended as this site is at a constriction in the river which provides favourable flow conditions for their use in protecting vegetation. Reshaping is permitted to remover near-vertical erosion scarps. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

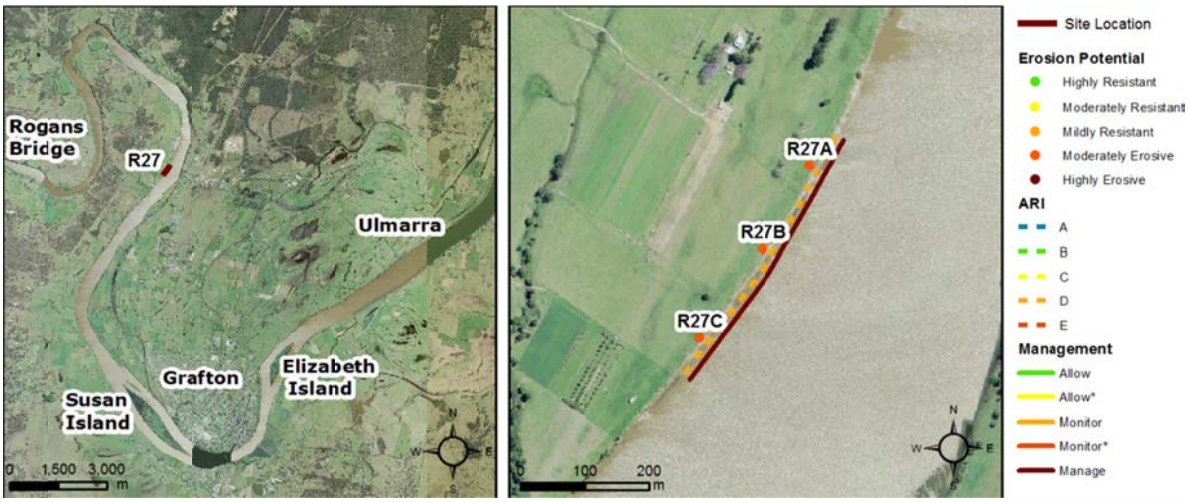


Site Description: The site is located on the right bank of the Clarence River downstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-west directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion across the entire stretch, with slumping and undercutting at transect 'C', was observed at the time of the inspection.

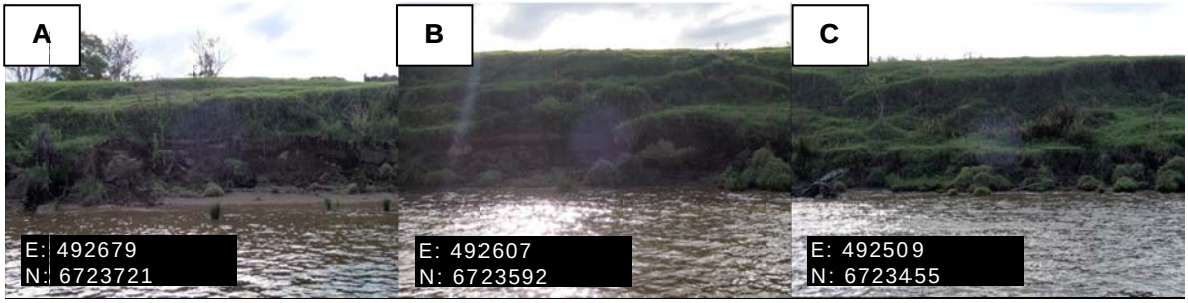
Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, stock management and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering to create multi-level terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Investigate the potential for rock fillets in conjunction with toe armouring to encourage phragmites growth. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Rock fillets are recommended to provide riverbank stabilisation and to protect native regeneration. Note that buoys are not satisfactory as a stand-alone management option for this stretch.



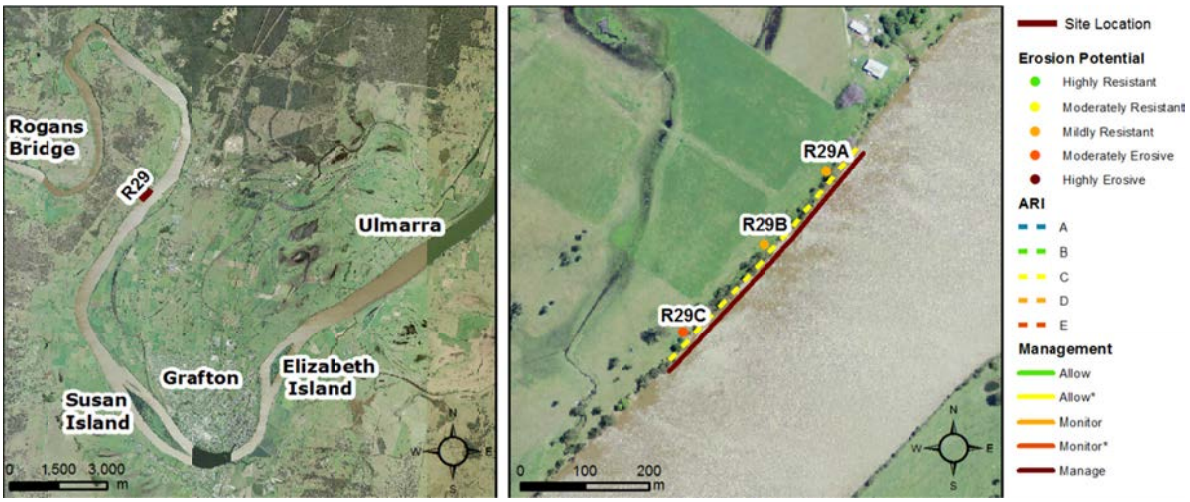
Site Description: The site is located on the right bank of the Clarence River downstream of the Big River Holiday Park and Ski Lodge in Grafton. The site is located on an inside-bank and is exposed to moderate fetch lengths from north-east/south-west directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion, slumping and undercutting across the entire stretch was observed at the time of the inspection.



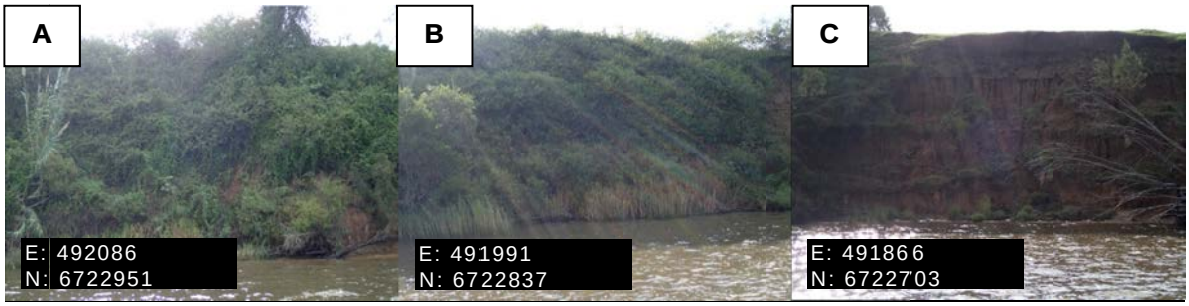
Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, stock management and rock fillets. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering to create terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Investigate the potential for rock fillets in conjunction with toe armouring to encourage Phragmites growth. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Rock fillets are recommended as this stretch is on an inside-bank providing favourable flow and sedimentation conditions and the wave zone slope is 1H:7V. Note that buoys are not satisfactory as a stand-alone management option for this stretch.



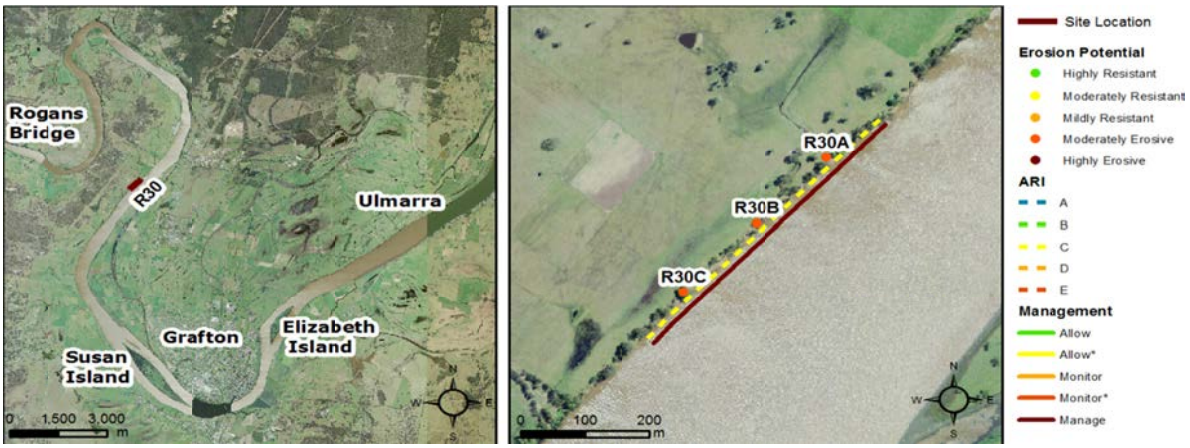
Site Description: The site is located on the right bank of the Clarence River opposite to the Junction Hill boat ramp. The site is on a straight stretch of the river and is exposed to moderate fetch lengths from north-east/south directions. The site was well vegetated in the wave zone but poorly vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion at transect 'A' and transect 'C', and slumping at transect 'C', was observed at the time of the inspection.



Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, renourishment and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering to create terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

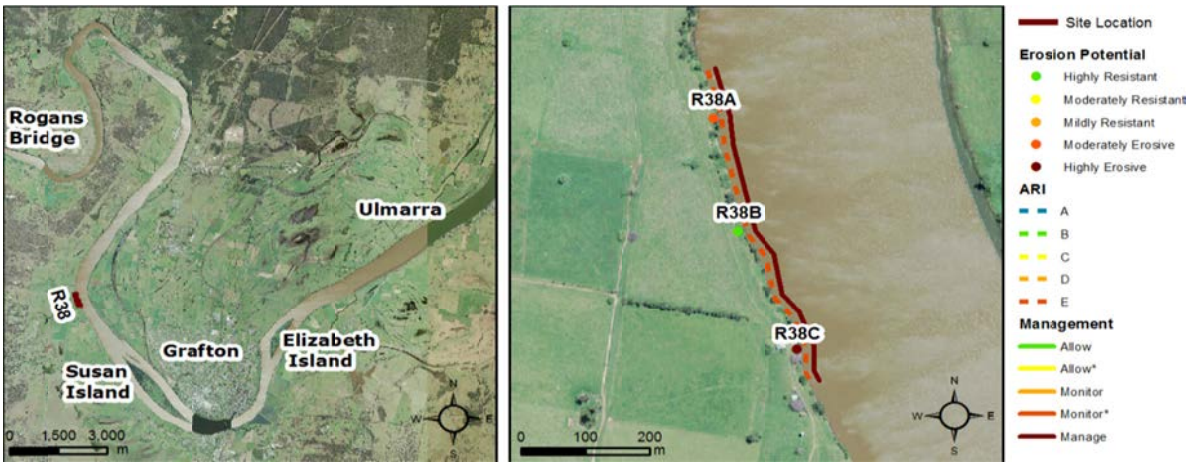


Site Description: The site is located on the right bank of a straight section of the Clarence River opposite from Crowther Island. The site is located on a straight section of the river and is exposed to moderate fetch lengths from south/south-east directions. The site was poorly vegetated in the wave zone and on the upper bank, with the exception of transect 'B' which contained trees and tree roots, at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion and slumping across all three transects, and vegetation undercutting at transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), battering, renourishment and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, battering to create terraces with a back-slope of 1H:3V and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Buoys, revegetation and renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

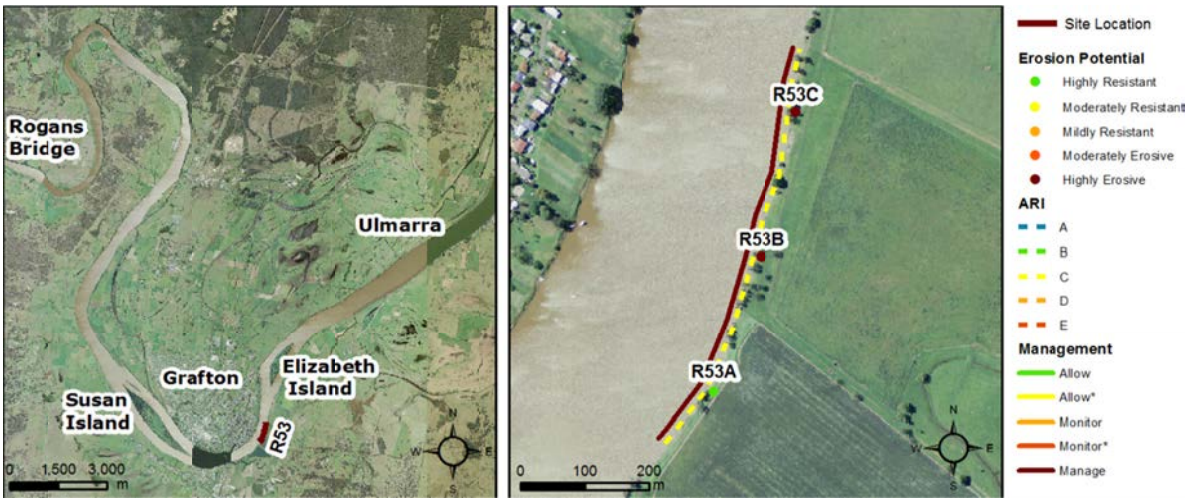


Site Description: The site is located on the right bank of the Clarence River opposite from Carrs Peninsula. The site is located on an outside-bank and is exposed to moderate fetch lengths from north/south-west directions. The site was protected by a rock revetment in the wave zone and well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and no verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Catastrophic erosion due at transect 'C' was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), renourishment, armouring and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Cut riverbank material should be used for toe renourishment to protect revegetation works. Repair rock revetment across entire stretch. Investigate potential for battering to create terraces with a back-slope of 1H:3V at transect 'C'. Full engineering design of rehabilitation works is required. In addition, buoys should be placed at mid-river in this stretch.

Justification: Stock management is required for safety concerns and to prevent ongoing riverbank destabilisation. Revegetation with renourishment will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

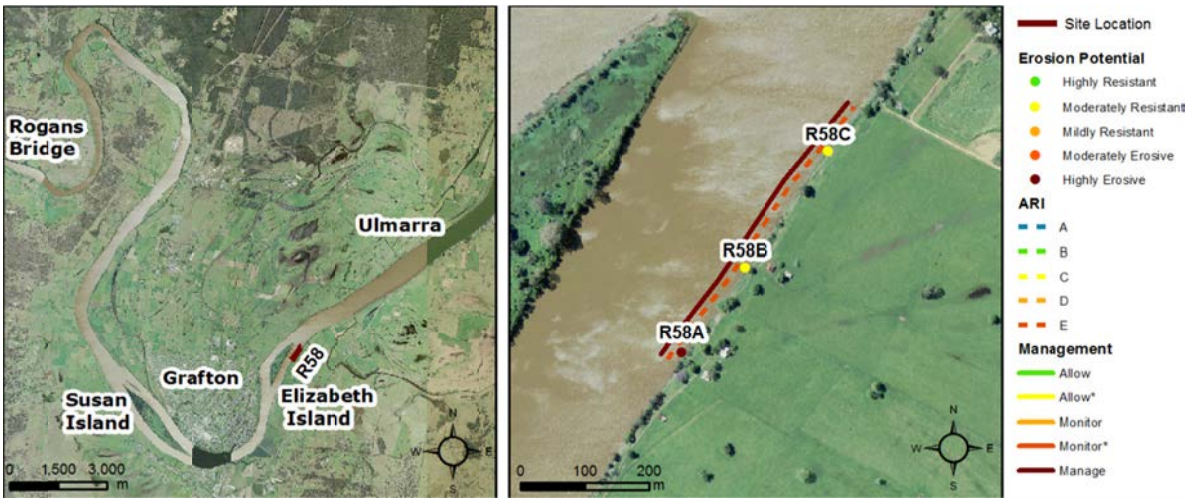


Site Description: The site is located on the right bank of the Clarence River downstream of the Grafton bridge. The site is located on an outside-bank and is exposed to moderate fetch lengths from north-west/south-west directions. The site is protected by a rock revetment in the wave zone and was relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native understorey regeneration and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion at transect 'A' and transect 'C', and vegetation undercutting at transect 'B' and transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), armouring and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Repair existing rock revetment. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments while the rock revetment will provide toe protection from wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.

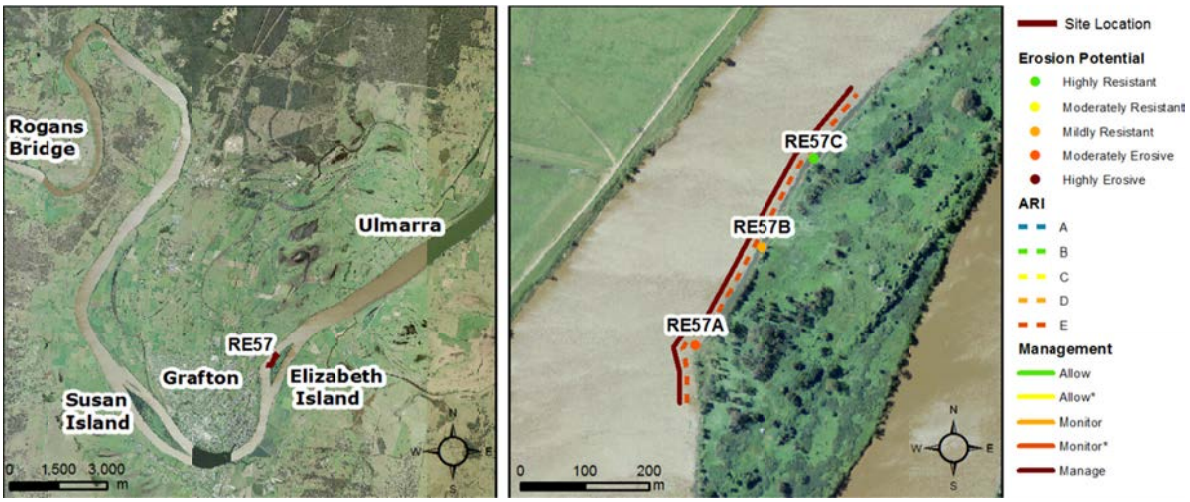


Site Description: The site is located on the right bank of the Clarence River downstream of the Grafton bridge, opposite from the northern end of Elizabeth Island. The site is located on an inside-bank and is exposed to moderate fetch lengths from north/south-west directions. The site was well vegetated in the wave zone and on the upper bank at the time of the inspection. Note that adjacent sites are protected in the wave zone by a rock revetment. The site contained limited native understorey regeneration and no verge cover. The bank height was greater than three (3) metres with a near-vertical upper bank slope. Significant erosion and undercutting at transect 'A' was observed at the time of the inspection.

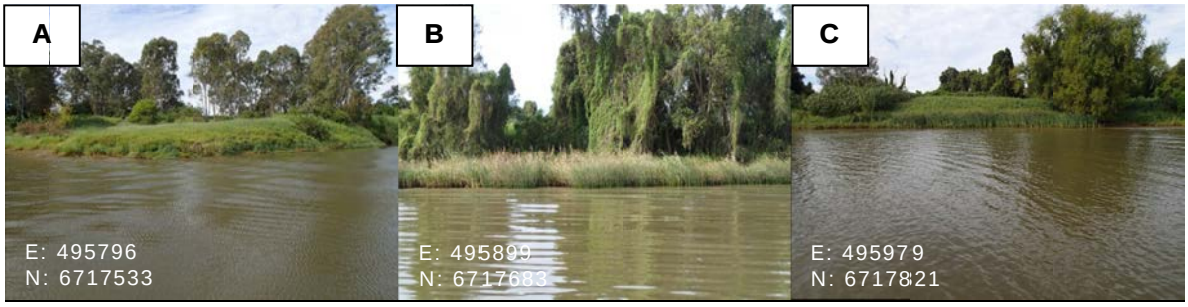
Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), armouring and stock management. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Stock management, in combination with the removal of exotic vegetation, and native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge should be used to stabilise the riverbank in the riparian zone across the entire stretch. Repair existing rock revetment. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Stock management is required to prevent ongoing riverbank destabilisation and damage caused by stock access. Revegetation will establish local native vegetation to stabilise riverbank sediments while the rock revetment will provide toe protection from wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.



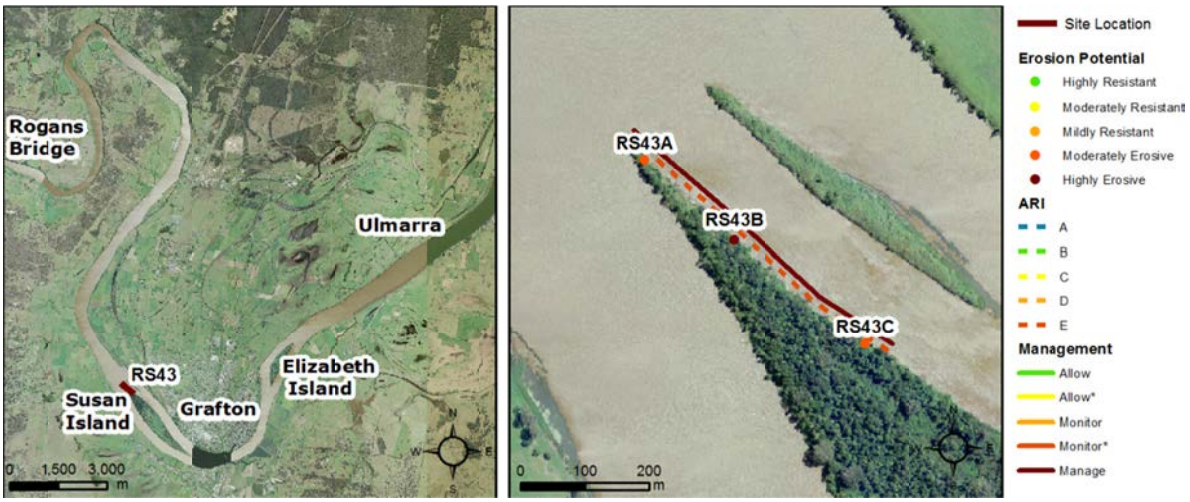
Site Description: The site is located on the right bank of Elizabeth Island on the Clarence River. The site is exposed to moderate fetch lengths from west/south-west directions. The site was poorly vegetated in the wave zone but relatively well vegetated on the upper bank at the time of the inspection. The site contained limited native vegetation and limited to no verge cover. The bank height was greater than three (3) metres with an upper bank slope of 1H:3V. Erosion and vegetation undercutting at transect 'A' was observed at the time of the inspection.



Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and native revegetation. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. Planting of native trees in combination with the removal of exotic vegetation should be used to stabilise the riverbank on the island across the entire stretch. In addition, buoys should be placed at the mid-river width from the shore in this stretch while revegetation is established.

Justification: Revegetation will establish local native vegetation to stabilise riverbank sediments by generating a network of roots and partially absorbing wave attack. Note that buoys are satisfactory as a stand-alone management option for this stretch.

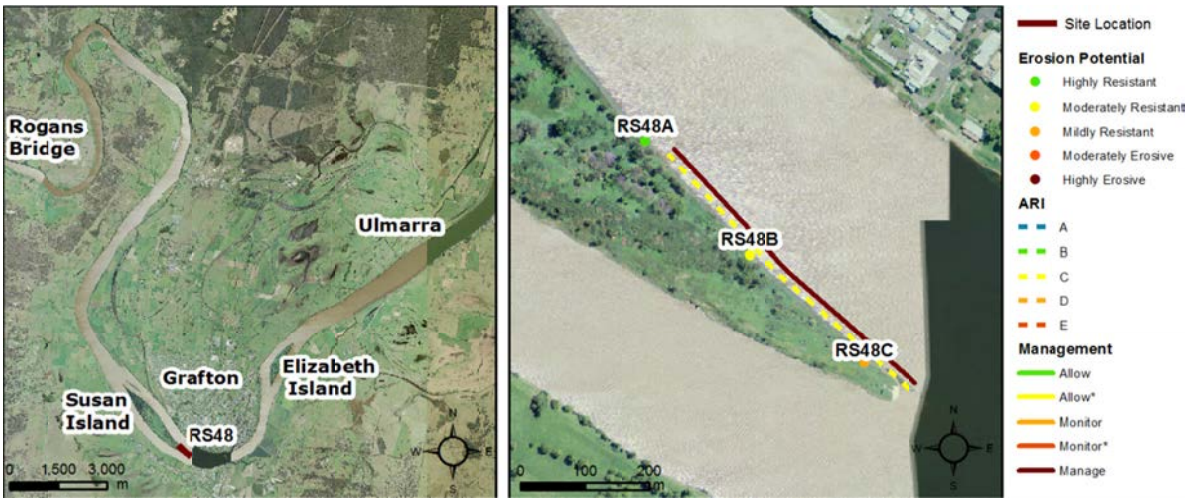


Site Description: The site is located on the right bank of Susan Island on the Clarence River. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north/north-east directions. The site was poorly vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and sufficient verge cover. The bank height was greater than three (3) metres with a near vertical upper bank slope. Significant erosion at transect 'A' and transect 'B', with slumping at transect 'B' and vegetation undercutting at transect 'C', was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation and weeds, native revegetation (with bioengineering where possible), renourishment and armouring. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a combination of land and water based management interventions for this stretch. The removal of exotic vegetation, in combination with native revegetation (planting of sedges, shrubs and trees) of the upper bank and verge and renourishment should be used to stabilise the riverbank in the riparian zone at each transect. Investigate the potential to extend existing armouring upstream of transect 'B' to provide rock protection at transect 'A'. In addition, buoys should be placed at mid-river in this stretch while revegetation is established.

Justification: Extensive erosion had claimed the northern point of Susan Island prior to the inspection. Armouring is required to protect power lines upstream of transect 'B'. Revegetation will establish local native vegetation to stabilise riverbank sediments while the rock revetment will provide toe protection from wave attack. Note that buoys are not satisfactory as a stand-alone management option for this stretch.



Site Description: The site is located on the right bank at the southern point of Susan Island on the Clarence River. The site is located on a straight section of the river and is exposed to moderate fetch lengths from north-east/south-east directions. The site was generally well vegetated in the wave zone and on the upper bank at the time of the inspection. The site contained limited native vegetation and sufficient verge cover. The bank height ranged between 1 – 3 metres with a 1H:3V bank slope. No erosion, slumping or undercutting was observed at the time of the inspection.

Management Assessment: Site-specific land and water based management options were assessed to reduce riverbank erosion. Land based interventions include removal of exotic vegetation, native revegetation and managed retreat. Water based interventions considered the placement of buoys to reduce nearshore boat traffic.

Recommendation: WRL recommend a managed retreat (or 'do-nothing' option) for this stretch. Note that the site was shown to be prograding at the time of the inspection.

Justification: Managed retreat permits bank erosion to continue, while managing any safety or environmental concerns. It can reduce down-drift erosion and allow the river to migrate. This is often the least expensive approach, with the least adverse environmental impacts.