Detailed concept design of Yamba-Iluka ebb tide release

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WRL Technical Report 2008/28
December 2014

By W C Glamore, D S Rayner and B M Miller

Water Research Laboratory
University of New South Wales
School of Civil and Environmental Engineering

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Executive Summary

Clarence Valley Council (CVC) is currently upgrading the sewage treatment systems for the townships of Iluka and Yamba. These towns are located at the mouth of the Clarence River with Iluka to the north and Yamba to the south of the river entrance. The proposed systems involve the intake of varying volumes of sewage, the treatment of the waste water to tertiary standards and the sustainable disposal of the recycled water. The proposed sewage treatment plants (STP) will be a significant improvement on current systems and are designed to provide recycled water at a water quality equivalent to the Accepted Modern Technology.

The recycled water will be reused in a sustainable manner. The volume of reuse, however, is limited and recycled water in excess of demand will need to be sustainably released to the environment. It is currently proposed that the excess recycled water for both townships be discharged via ebb tide river releases in the lower Clarence River. Due to a range of hydraulic and construction criteria, it was determined that the Yamba and Iluka releases would be independently designed and operated.

The New South Wales (NSW) state government has a range of criteria that must be adhered to when designing any river release. In addition to these criteria, local community stakeholders have requested further criteria on the design. In particular, the proposed releases must be designed so that in normal operation the released recycled waters clear the entrance of the Clarence River on each tide. These criteria have been adopted into the designs for both Yamba and Iluka releases.

The Water Research Laboratory (WRL) at the University of New South Wales has been commissioned by CVC, via the NSW Department of Public Works (previously Department of Commerce), to develop a detailed concept design of the ebb tide releases at Yamba and Iluka. The detailed concept designs presented within this report have been developed based on results gathered from a focused field program and a range of computer modelling simulations undertaken solely for this project.

The detailed concept design presented within this report has been developed to comply with the NSW standard criteria and exceed the community stakeholder's higher requirements. A brief outline of the design parameters and project findings is detailed below. Further detailed information is provided within this technical report. It is important to note that water levels throughout this report are referred to as either Iluka Port Datum (IPD) or Australian Height Datum (AHD). IPD is 0.92 m below AHD (i.e. 0 m IPD is equivalent to the lowest standing water level likely to be measured in the river entrance).

Following extensive stakeholder engagement, CVC adopted an area of the lower estuary for further investigation. Due to additional navigability constraints the Yamba and Iluka release structures are to be located within 60 m of one another located on the north side of the NSW Maritime dredge channel with the Iluka location (GDA94 MGA56 co-ordinates E:534292, N:6745050) located 60 m downstream from the Yamba release (E:534258, N:6745100) (Figure E.1). The Iluka ebb-tide release was constructed during 2012/2013, with Yamba yet to be constructed.

Figure E.1: Ebb-tide release locations

Located outside of the main navigation channel, the depth of water at the release locations is less than other locations in the river. An average bed elevation was assumed at approximately -4.0 m IPD with the discharge elevation located at -3.0 m IPD. This depth influences the near-field dilutions that can be achieved, thus increasing the distance until the required dilution is reached. This is particularly relevant for the Yamba ebb tide release, due to the larger volume of recycled water to be discharged.

The discharge release window and the ambient flow velocities are important factors in optimising water quality. Based on findings from the field investigation and flow path (i.e. hydrodynamic) modelling, it was determined that both Yamba and Iluka could operate during normal flow conditions over a 3 hour window commencing 30 minutes after the onset of the ebb tide flow. Modelling results indicated that recycled water released over this 3 hour window will clear the Clarence River entrance. Further, the released water is unlikely to impact upstream sensitive receivers during high flow events. Modelling of the lower Clarence River flow paths also assisted in calculating a design ebb tide velocity of 0.5 m/s (50th percentile) for the 3 hour operational window. A 90th percentile flow velocity of 0.24 m/s (i.e. the current velocity that would occur 10% of the time or less) was used to simulate a worst case scenario. Variations to the 3 hour release window will require reassessment of the potential impact.

The sediment composition in the main channel, near the proposed ebb tide releases, is dominated by fine to medium grained marine sands. Tidal currents in the lower estuary were shown to have the potential to mobilise these bed sediments. Conservative estimates suggest that floods of a magnitude of the 5 year Average Recurrence Interval or greater have the potential to scour sand at the proposed release locations to the coffee rock strata. Final design should ensure the delivery pipelines are installed below the coffee rock and that the diffuser sections of the ebb tide release are adequately anchored to the river bed. Additional studies undertaken after the completion of this report, to address sediment transport, are attached in the appendices. Further laboratory studies to investigate sedimentation and scour processes around the release structures area also recommended.

Water quality modelling was undertaken based on the proposed diffuser configurations, the design flow rates (Table E.1), the estimated depth of the diffusers, the outcomes of the field investigation and the flow path modelling. This modelling focused on ensuring that the water quality criteria were met or exceeded within the near-field zone. The near-field zone is the region where the released fresh water is rising through the water column under its own buoyancy and is typically in the order of 10 - 20 m from the release.

Table E.1: Discharge rates for Yamba and Iluka ebb tide release

Location	Discharge during release window (m^3/s)
Yamba	0.267
Iluka	0.091

A range of diffuser configurations (including port size, number and angle) were developed and tested for the Yamba and Iluka releases. Based on hydraulic considerations (i.e. head loss and discharge exit velocity), diffuser configuration was determined for both sites. For the Iluka release the optimal diffuser configuration was two 300 mm ports orientated 90 degrees to the ebb tide flow. For the Yamba release, a range of 200 mm and 300 mm duckbill port configurations were assessed with 6, 8, or 10 discharge ports in a rosette configuration. A final diffuser configuration for Yamba has not been recommended, as the final diffuser configuration should be determined during the detailed design and construction phase of the project to ensure construction feasibility. Note that there is potential for plume interaction between discharge ports between the Yamba and Iluka releases which may result in reduced dilution. Additional information on the structural design, including riser circumference, is required to finalise the design configuration. Further on-site confirmation of ambient tidal velocities and sediment dynamics is recommended prior to construction.

Water quality modelling results indicated that dilutions varied with background (or ambient) flow conditions. A minimum dilution of 65 times was required for the majority of analytes, although a dilution of approximately 200 times was required to adequately dilute ammonia. Dilutions are calculated using numerical models with a stated accuracy of ±30% and are based on discharge volume, discharge velocity, ambient velocity, density difference between discharge and ambient fluids, discharge depth, ambient current velocity and orientation to the ambient current. Modelling results indicated that average dilutions would exceed 65 times for Yamba and Iluka based on a 50th percentile ebb tide flow. These dilutions would occur at the end of the near-field zone which is approximately 10 m to 20 m. It is important to note that all of the water quality modelling was undertaken conservatively assuming the lowest astronomical tide. Dilutions during average tidal water levels are likely to be higher. The modelling undertaken for the revised Yamba location in April 2014 (Appendix D) and the "as constructed" Iluka release undertaken in May 2009 (Appendix C), should be referred to and supersedes all other modelling. A summary of near-field modelling results is detailed in Tables E.2 to E.5.

The detailed concept design described within the attached report provides information on the location, operation and impact of the proposed ebb tide releases. Based on available information, the investigation indicates that recycled water released from separate ebb-tide releases for Yamba and Iluka will clear the Clarence River entrance and meet water quality dilution requirements in normal operating conditions. Information on the pipeline hydraulics, including purging calculations and design forces are also provided.

Since completion of the original draft report (March 2009), further studies have been undertaken and are provided as appendices to this report:

- Appendix A details a field program undertaken immediately following a large rainfall event in May 2009 to examine discharge and sediment dynamics;
- Appendix B provides assessment of a revised Iluka release location (May 2009);
- Appendix C provides additional release design criteria for the Yamba ebb tide release (January 2010); and
- Appendix D details a revised Yamba release location and the implications of mixing plumes from Yamba and Iluka on dilutions (April 2014).

Table E.2: Yamba near-field model results (50th %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilution (m)#
			Corjet	Jetlag				
200	4	0.0668	39	71	55	19	47	137
200	6	0.0445	66	92	79	13	13	91
200	8	0.0334	70	110	90	13	13	75
300	4	0.0668	45	62	54	11	40	128
300	6	0.0445	56	82	69	12	12	99
300	8	0.0334	59	102	81	12	12	79
300	10	0.0267	65	121	93	12	12	66

#Calculated using Brooks (1960) and based on adopted near-field results.

* Calculated from Corjet.

Table E.3: Iluka near-field model results (50th %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilution (m)#
			Corjet	Jetlag				
300	2	0.0445	56	114	85	11	11	107

#Calculated using Brooks (1960) and based on adopted near-field results.

* Calculated from Corjet.

Table E.4: Yamba near-field model results (90th %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilution (m)#
			Corjet	Jetlag				
200	4	0.0668	27	42	35	9	31	79
200	6	0.0445	32	53	43	10	28	71
200	8	0.0334	30	57	44	6	19	50
300	4	0.0668	20	32	26	6	34	86
300	6	0.0445	25	47	36	7	25	64
300	8	0.0334	29	65	47	6	17	48
300	10	0.0267	41	63	52	7	20	59

#Calculated using Brooks (1960) and based on adopted near-field results.

* Calculated from Corjet.

Table E.5: Iluka near-field model results (90th %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilution (m)#
			Corjet	Jetlag				
300	2	0.0445	26	56	41	10	25	80

#Calculated using Brooks (1960) and based on adopted near-field results.

* Calculated from Corjet.

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1. Introduction

Clarence Valley Council (CVC) is currently upgrading the sewage treatment systems for the townships of Iluka and Yamba. These towns are located at the mouth of the Clarence River (Figure 1.1), with Iluka to the north and Yamba to the south of the river entrance. The proposed systems involve the collection of varying sewage volumes, the treatment of this waste water to tertiary standards and the sustainable disposal of the treated recycled water. The proposed sewage treatment plants (STP) will be a significant improvement on current systems and are designed to provide recycled water at a water quality equivalent to the Accepted Modern Technology. Due to a range of hydraulic and construction criteria, it was determined that the Yamba and Iluka releases would be independently designed and operated.

The recycled water will be reused in a sustainable manner. The volume of reuse, however, is limited and recycled water in excess of demand will need to be sustainably disposed. It is currently proposed that the excess recycled water for both townships be disposed of via ebb tide river releases in the lower Clarence River.

Detailed discussions have been undertaken to determine a socially acceptable location for the recycled water releases. These discussions have involved a range of stakeholders including (but not limited to) representatives from local recreational fishing groups, local commercial fishing cooperatives, the NSW Maritime Authority, the NSW Department of Lands, the NSW Department of Primary Industries (including NSW Fisheries), the NSW Department of the Environment and Climate Change, local Aboriginal Land Claimants and local community working groups. A range of constraints were identified which resulted in Yamba and Iluka being relocated several times with assessments being undertaken for various potential locations. Appendices B, C and D detail revised location assessments. The Iluka ebb-tide release was constructed during 2012/2013, with Yamba to be constructed approximately 60m upstream. The modelling detailed in the appendices should be referred to in preference to and supersedes all other modelling.

Community working groups for both Yamba and Iluka have determined that to encourage the efficient removal of the recycled water from the estuary, the releases should operate predominately during the ebb tide. An ebb tide release was defined by both the Yamba and Iluka working groups as "when there is an outgoing flow which clears the entrance" to the Clarence River. As such, all recycled water released must be transported beyond the end of the training walls of the Clarence River (a distance of approximately 1,800 m) even though complete mixing of the recycled water would be achieved within 150 – 300 m of the release structure.

Independent diffuser systems are required for Iluka and Yamba. The releases are proposed to be emergent structures located on the bed of the river. Both diffuser systems must be designed to achieve water quality concentrations that comply with the NSW Environmental Protection Authority's guidelines and the additional requirements of the local stakeholders.

Based on the above background information, the Water Research Laboratory (WRL) at the University of New South Wales was commissioned by Clarence Valley Council (via the NSW Department of Public Works (previously Department of Commerce)) to develop a Detailed Concept Design (DCD) for the Yamba-Iluka ebb tide release.

The primary tasks of the Detailed Concept Design study are to:

1. Increase the understanding of how water circulates and is transported in the lower Clarence River estuary via literature review, data gap analysis and computer modelling;
2. Undertake field studies to collect river flow data critical for the design of the ebb tide release;
3. Develop a calibrated and verified computer model of the Clarence River;
4. Use the computer model to simulate a range of environmental conditions and apply this information to optimise the ebb tide release designs;
5. Develop a conceptual design of the release that incorporates sedimentation, water quality, hydraulics and design forces concerns;
6. Conduct consultation workshops with construction and stakeholder groups to assess design feasibility and construction options; and
7. Report and present results of the study to Clarence Valley Council and relevant community groups.

This report details the outcomes from the tasks listed above. Specifically, this report covers the data available for assessment, the relevant flow and circulation processes of the Clarence River important to the design of the ebb tide release, the outcomes of the field studies and the development, calibration and scenario testing of a computer model that simulates the flow paths (i.e. hydrodynamics) in the lower Clarence River. Based on these computer simulations, hydraulic calculations and water quality modelling, a draft concept design is provided for Iluka and Yamba.

This Technical Report is divided into seven sections. Following this introduction:

- Section 2 outlines the rationale behind the site selection process;
- Section 3 provides an analysis of the available scientific studies and the implications of this data on the ebb tide releases;
- Section 4 discusses the fieldwork programme and outcomes;
- Section 5 outlines the computer modelling process and the range of scenario tests undertaken to finalise the design parameters.;
- Section 6 details the hydraulic calculations and water modelling simulations completed to design the diffuser sections including port size and angles; and
- Section 7 summarises the preliminary detailed concept designs and outlines specific recommendations.

Since completion of the original draft report (March 2009), further studies have been undertaken and are provided as appendices to this report:

- Appendix A details a field program undertaken immediately following a large rainfall event to examine discharge and sediment dynamics;
- Appendix B provides assessment of a revised Iluka release location;
- Appendix C provides additional release design criteria for the Yamba ebb tide release;
- Appendix D details a revised Yamba release location and the implications of mixing plumes from Yamba and Iluka on dilutions.

The modelling detailed in the appendices should be referred to and supersedes all other modelling.

2. Rationale for Ebb Tide Release Location

2.1 Background

The location proposed for the ebb tide release has been selected through an extensive consultation process. Stakeholder groups involved in the discussions included Clarence Valley Council, the Water Research Laboratory, NSW Department of Lands, NSW Department of Commerce, NSW Maritime Authority, NSW Department of Primary Industries (Fisheries), NSW Department of the Environment and Climate Change, Native Title Claimants, local Recreational Fishing Associations, Clarence Professional Fishing Association, the Yamba Water Recycling Management Committee, the Iluka Consultative Working Group, GHD Pty Ltd, Worley Parsons Pty Ltd and other local groups.

From a technical/engineering perspective the ideal location for an ebb tide release:

- Is sufficiently deep to promote buoyant mixing;
- Has sufficient ambient currents for plume mixing and transport;
- Is not subject to excessive movements in bed levels; and
- Is close enough to the river entrance to ensure an adequate operational schedule.

In addition to these technical concerns any proposed ebb tide release must also:

(i) Not interfere, limit or be a hazard to commercial or recreational waterway navigation;
(ii) Be constructed on land available to Council;
(iii) Not interfere with the proposed electricity undercrossing;
(iv) Be approved by representatives of the local Native Title Claimants; and
(v) Not impact on commercial and/or recreational fishing.

This section of the report outlines the rationale behind the selection of the proposed ebb tide release location based on feedback from the above stakeholders and the technical requirements discussed above. Figure 2.1 shows the lower Clarence River and outlines the range of competing interests in this section of the river. Starting from the ocean, the influence of these stakeholders on the decision making process is detailed below.

2.2 Rationale for Ebb Tide Release Location

In 1997, the NSW Coastal Policy stated that "new ocean outfalls will be embargoed until a full investigation of alternative wastewater strategies has been undertaken and considered by the Government". In that policy document goal 1.3.15 states "A public inquiry into ocean sewerage outfalls and effluent re-use opportunities will be undertaken and results used in formulating future Government policy on ocean disposal of effluent". WRL has consulted with staff from the NSW Department of Environment, Climate Change and Water and no related public inquiry has been conducted since the coastal policy was released. Therefore, based on the current State policy, proposed release locations situated in the ocean could not be considered until the estuarine locations were deemed unsatisfactory.

As noted in Figure 2.1, on the north and south side of the river entrance are large breakwaters. These breakwaters are administered by the NSW Department of Lands and fall within Crown Land jurisdiction. Clarence Valley Council received advice from the NSW Department of Lands that due to the dynamic nature of the breakwaters, construction of a release structure would be prohibited. In addition, the construction of an ebb tide release on the southern breakwater would likely involve drilling through the sub-soil to secure the infrastructure. Local Native Title Claimants have lodged a native title claim on the rock reef immediately upstream of the southern breakwater (as depicted in Figure 2.1) and discussions with this group have indicated that they would not be amenable to any engineering works that may impact the rock reef. Further, the Native Title Claimants have requested that the release structure is not constructed east of the proposed Country Energy river undercrossing.

On the northern side of the river, upstream from the main breakwater, there are a series of smaller breakwaters, relic training walls and a 'wave trap' beach. The wave trap beach is used by commercial fisherman to haul in large schools of mullet that annually migrate to the sea. Concern was raised by representatives of the Clarence River Professional Fishermen's Association that any release located in this area may have the potential of diverting the mullet run towards the middle of the channel and thus, away from the fishing haul nets. In combination with the NSW Department of Lands previous concerns, and the Native Title Claimants requests, the northern breakwaters area was deemed not suitable for construction of an ebb tide release.

As marked on Figure 1.2, a training wall exists down the middle of the Clarence River. This training wall was part of series of entrance works (known as the Sir John Coode's Scheme (Mashiah, 2008)) and was largely completed by 1914. This area is now a popular recreational fishing area and has been gazetted a 'recreational fishing haven' by NSW Department of Primary Industries (now NSW Department of Industry and Innovation). Due to concerns that the ebb tide release may interfere with recreational fishing access, the ebb tide release could not be situated within 100 m of the middle training wall. Further, due to concerns regarding the transport of recycled water through the gap in the middle wall, and potentially upstream towards the oyster leases (and eventually Wooloweyah Lagoon), all efforts have been made to locate the ebb tide release structure downstream of this gap.

In addition to the above concerns, the Clarence River is a highly trafficked waterway with several large vessels requiring navigation access. The Port of Yamba is Australia's easternmost port and handles a range of imports and exports including a shipping service to Lord Howe Island. The main port facilities are located at the Goodwood Island wharf approximately 10 kilometres upstream from the entrance to the Clarence River. Several plans have been previously proposed to expand commercial shipping traffic from the Port of Yamba (Manly Hydraulics Laboratory (MHL), 2000), although no formal process is currently underway. A formal navigation channel exists along the waterway and advice received from NSW Maritime Authority stated that a release location at least 50 m from either side of the centreline of the channel would be considered appropriate to avoid any risk of damage that may occur during maintenance dredging.

Based on the navigation issues outlined above, all attempts were made to move the release location away from the main channel. However, the further the release is located upstream of the river mouth the less amount of time is available for releasing the recycled water. This is due to the imposed constraint agreed to by the relevant local working groups which states that the outgoing flow must clear the entrance. To satisfy this requirement, and still provide sufficient time for the release to operate, the system should be located as close to the river mouth as possible.

Due to the above constraints the proposed location, as shown on Figure 2.1, was selected. The proposed location is outside of the recreational fishing zone, does not interfere with current commercial fishing operations, is beyond the distances required by NSW Maritime and Native Title Claimants and would not be adjoining any breakwaters administered by the NSW Department of Lands. The proposed site is also within sufficient distance from the river mouth to effectively operate as an ebb tide release and information recently obtained for the proposed electricity cable undercrossing could be used to assist the geotechnical tasks. Technical issues associated with bed movements, ambient currents, release depths and general constructability of the proposed site are discussed in subsequent sections of this report.

3. Clarence River Estuary Characteristics

A limited number of recent references are available to characterise the lower Clarence River estuary. This section outlines and briefly discusses the available data and, where appropriate, highlights key data gaps. Particular attention is given to the processes that are fundamental to the operation of an ebb tide release namely, geology/fluvial geomorphology, currents/tide and wave climate. A full analysis of all the data available for the entire Clarence River estuary can be found in MHL (2000).

3.1 Geology and Fluvial Geomorphology

Detailed conceptual models of sediment dynamics in the Clarence River are presented in MHL (2000) and Hashimoto and Hudson (1999). Site specific sediment transport investigations are discussed in WRL Technical Report 2007/29 and Appendix A. Parsons Brinckerhoff (PB) (2008) also provides onsite geotechnical data.

Sediments in the main channel are dominated by clean marine sands with an upstream transition from marine to mixed to fluvial sands. MHL (1996a) states that these fine to medium grained sands extend from the ocean entrance to more than 10 km upstream and are moderately-well to well sorted and contain no fine (i.e. clay) sediments. PB (2008) confirmed this hypothesis through geotechnical investigations in the vicinity of the proposed location. As shown in borehole logs BH6 and BH8 in PB (2007) (which are located along the proposed Country Energy line crossing shown in Figure 2.1), the region of the proposed site is underlain with a fine to medium-grained grey sands strata approximately 2 – 7 m in thickness that contains traces of shell fragments. Underlying the grey sands is an indurated sand (i.e. coffee rock) of varying thickness ranging from approximately 15 m at BH6 (south of the middle wall) to approximately 9 m thickness at BH8 (489 m north of BH6 and approximately 300 m south of where the Country Energy line reaches the Iluka foreshore). Underlying the coffee rock is an interbedded layer of sand, clay and silt, which is approximately 40 m in thickness. The proposed location of the release, as marked on Figure 1.1, is due west of the proposed Country Energy line.

Longitudinal sections (BH3-BH9) prepared by PB (2007) suggest that in the region immediately north of the middle wall, and thus in a location similar to the one proposed for the release, the sand layer overlying the coffee rock is potentially 2 – 5 m thick. Analysis of the bathymetric surveys given below, however, suggests that sand accumulates with distance heading upstream (at an approximate rate of 1 m vertical per 100 m horizontal) and it is reasonable to assume that more sand would overlay the coffee rock strata in the northwest corner of the proposed release location than in the southeast corner. The actual volume of sand immediately overlying the proposed location, the depth to coffee rock and the extent of the coffee rock layer is a key data gap in the proposed site knowledge. Further site investigations have recently been undertaken (Douglas Partners, 2010) and should be assessed in relation to this study to assess the geotechnical conditions in the vicinity of the proposed release.

The transport of sediment within the channel is dominated by tidal and flood currents. In low-flow periods there is a bias of net transport of marine sand into the estuary under the influence of wave action and a flood tide bias in the tidal flows. Indeed, MHL (2000) estimated a gross annual net sediment transport rate in the upstream direction due to tidal currents of 200,000 m3/year at the entrance. During high-flow flooding periods, sand can be scoured from the estuary and deposited either in the entrance or further offshore. Sediments may be completely scoured away during these events, resulting in an exposed layer of indurated sand or rock reef. Depending on the magnitude of the flooding event, some of the scoured sand may be completely removed from the estuarine system. In this case the sand is likely to become part of the northward littoral drift that supplies sand to Iluka Beach. Conversely, if the sand is not completely removed from the entrance it may be reworked back into the various shoals that form in the lower estuary.

Based on available data, the proposed site appears to be presently located downstream of the confluence of two sand shoals. These shoals are located on the northern side of the middle wall and on the southern side of the main channel. When these shoals converge sand accumulates in the middle of the channel and eventually this accretion zone moves downstream. The channel bed likely fluctuates between a moderate scour zone and an accretion zone depending on river discharge levels.

The location of the sand shoals and their likely impact on the proposed release site can be assessed by analysing previous bathymetric surveys. A range of bathymetric surveys were obtained and analysed for this study dating back to 1979. Of these surveys, only a limited number covered the vicinity of the proposed release location. The relevant surveys, including two surveys undertaken by WRL in 2007 and 2008, were assessed for this study. The analysis, shown in Figures 3.1 and 3.2, indicated different results for the proposed release area depending on the western versus eastern extent of the proposed area.

In general, the available water depth increased with increasing distance downstream. As shown in Figure 1.2, the proposed release location is orientated parallel to the middle training wall in a predominately NW-SE direction. The NW corner of the proposed area is located on the downstream lobe of the southern shoal and during periods of strong accretion (i.e. as shown in the 1979 hydrographic survey in Figure 3.1) the water depth can be less than 2 m. Conversely, the SE corner of the proposed release location has been consistently in deeper water (7 -10 m) since 1979 and less fluctuations in depth are apparent with time. Table 3.1 further emphasises this point by providing the recorded depths on the western versus eastern extent of the proposed release location.

Table 3.1: Recorded depths at the proposed release location

Survey	**Western extent depth (m IPD)#**	**Eastern extent depth (m IPD)#**
1986 - Maritime Services Board of NSW (April)	3.15	7.5
1988 - Maritime Services Board of NSW (21-23 June)	2.2 to 2.6	7.1 to 7.8
1993 - Australian Army (15 September)	3.2 to 3.6	5.9 to 7.6
1999 - Sydney Ports (digital data, month unknown)	3.2	7.5 to 7.7
2002 - Department of Land and Water Conservation (May)	3.2 to 3.8	5.8 to 7.8
2004 - NSW Waterways Authority (March)	not surveyed	not surveyed
2006 -NSW Maritime (November)	not surveyed	not surveyed
2007 - DECC Coastal Unit (May)	not surveyed	not surveyed
2007 - Water Research Laboratory (July)	4.5 to 5.2*	7.4 to 7.8
2008 - Water Research Laboratory (October)	4.5	7.5

Note Iluka Port Datum (IPD) is 0.92 m below local Australian Height Datum (AHD)
* Note entire western extent not covered in survey

It is important to note that the recorded depths given in Table 3.1 are in Iluka Port Datum (IPD), which is 0.92 m below Australian Height Datum (AHD). As such, 0 m IPD is approximately equivalent to the lowest astronomical tide (the lowest water level likely to occur in the river) or -0.92 m AHD. It is also important to note that on the far eastern extent of the proposed release location, the seven applicable surveys (as shown in Table 3.1) indicated a minimum value of 7.5 m IPD. Therefore, based on the available data and channel sedimentation processes outlined above, a maximum depth of 6.0 m IPD was estimated as a reasonable depth for the releases (i.e. mid-line depth for ports). Based on the available information, this depth provides approximately 1.5 m of clearance (or freeboard) from the previous minimum measured depths. Note that the seven (7) surveys over 22 years only provide a snapshot of conditions onsite and this recommended depth does not ensure that the releases will always be free from sediment build-up. Additional sedimentation studies were undertaken to provide further information on localised sedimentation patterns and these results are provided in Appendix A.

3.2 Currents and Tides

The Clarence River tidal limit is approximately 106 km in length. The average river depth of the main channel is 6 m (MHL, 2000), with large shallow off-channel storages including the Broadwater and Lake Wooloweyah. MHL (2000) state that the tidal prism of the river is 40×10^6 m^3, while the river surface area is 62×10^6 m^2. Tidal velocities in the lower estuary typically exceed 1 m/s and peak flood flows at the entrance have been estimated to exceed 6 m/s (PWD, 1988).

The development of the natural and artificial channel network within the lower section of the Clarence River estuary has had an significant impact on the tidal and flood current regime. Soros-Longworth and McKenzie (1978) detailed the evolution of the lower estuary from the mid-19th century to its current form. As shown in Figure 3.3, this evolution process has primarily involved the installation of training walls and breakwaters. The installation of training walls focused the flow into the middle of the channel, thus increasing discharge velocities. As shown in Figure 3.4, the increased discharge rates in the main channel appear to have virtually eliminated the sand shoals that previously existed in the main channel. Importantly, due to the lack of development in the lower estuary since the mid-1970s, the currents in the channel are likely to be in dynamic equilibrium; oscillating with the tides and floods.

Since 1963 there have been a series of tidal surveys undertaken, often with limited success, at a range of locations in the lower Clarence River estuary. MHL (2004) states that measurements were undertaken in March 1963, October 1964, August 1977, September 1978, May 1979, March 1984 and October-November 1996. The most comprehensive source of information is from MHL Report 798 (MHL, 1998). This report outlines a data collection exercise undertaken in October-November 1996 at a number of locations along the Clarence River. During this investigation water level data was obtained from seven (7) permanent stations and 16 temporary stations and basic water quality parameters were measured at nine (9) sites. On 24th October 1996 current velocity and discharge measurements were gathered over a spring ebb-flood semi-diurnal tidal cycle. On this day, tidal discharge was monitored at nine (9) sites and water levels were monitored at an additional two (2) sites. A summary of the water level and discharge data is given in Figure 3.5.

Analysis of the data within MHL (1998) provides some background information on the lower river estuary. Overall, MHL (1998) state that "the estuary acts like a typical river system, with maximum tidal flows usually recorded during the two hours following mid-tide and minimum tidal flows (or slack water) usually recorded within one hour after high and low tide." The report showed that the tidal range decreased from a mean range of 1.07 m in the ocean to 0.95 m at the entrance and 0.40 m at Maclean, and then slightly increasing to 0.51 m at Grafton and 0.57 m at Rogan Bridge. The tidal range then decreased again to 0.42 m at Tindal Bridge on the Orara River. A 13 minute tidal phase lag was evident at the entrance, while at Maclean and Grafton the lag was 137 and 279 minutes, respectively. A full summary of tidal ranges and tidal phase lags is given in the MHL report.

Over the one-day sampling period, MHL (1998) provided useful information on current velocities and discharge. Throughout the entire river, peak current velocities were measured within the vicinity of the proposed ebb tide release (1.51 m/s on the ebb tide and 1.46 m/s on the flood tide at ~700 m inland from the entrance). Tidal prism calculations at the river entrance suggest that the tidal volume is orders of magnitude greater than typical upland inflows with the ebb tide calculated as 39.72 $m^3 \times 10^6$ versus 41.34 $m^3 \times 10^6$ for the flood tide. The Acoustic Doppler Current Profiler (ADCP) measurements also confirmed suggestions that the main channel of the lower river has a largely vertically uniform (i.e. depth averaged) current velocity distribution.

WRL was able to obtain the raw data records of the entire 1996 field investigation undertaken by MHL (1998). This information was analysed and subsequently employed to calibrate the hydrodynamic computer model discussed in Section 5. In addition to this information, data from all of the permanent water level stations currently run by MHL was obtained for the 2008 calendar year. The available water level data and the date since the station commenced are provided in Table 3.2. Historical and flood level data available from other locations was not used in this study.

Table 3.2: Water level data

Location	Date commenced sampling
Entrance Breakwater	July 1986
Maclean	February 1990
Brushgrove	September 1989
Grafton	July 1987
Rogans Bridge	July 1993
Palmers Island	April 1990
Empire Vale Creek	May 1999
Sportsman Creek	April 2000

Though the available references provide useful information on the entire river, there is only limited data regarding recent current velocity and discharge measurements in the lower estuary, particularly in the vicinity of the proposed outfall. Therefore, due to the evolving nature of the channel (as discussed previously), the limited time span of the available current data (1 day) and the lack of specific data in the area of interest, further onsite data was required. The primary data gaps relate to updated current velocity measurements undertaken concurrently with bathymetric surveys (i.e. to calculate discharge) and further information on the flow patterns downstream of the proposed release structure (i.e. to determine the circulation patterns of the released recycled water). These data gaps were addressed during the field investigations discussed in Section 4. Once obtained, the data was also used to verify the computer model (Section 5).

3.3 Wave Climate

A preliminary assessment of the wave climate was undertaken to determine if the wave forces were significant in comparison to the current velocities. An assessment of the wave climate at the site includes an understanding of the wind, boat and ocean waves to determine a design wave.

3.3.1 Wind Wave Climate

Wind wave analysis was previously undertaken in MHL (2005) for a location very close to the proposed site and is applicable to this site due to the standard methods used to calculate the wind wave climate (AS/NZS1170.2:2002). The primary components of concern when determining the wind wave climate are the adjusted 10-minute average wind speeds (Table 3.3) and the estimated fetch data.

Table 3.3: Design regional wind velocities – Region B (terrain category 2)

Return Period (Years)	3-Second Gust (m/s)	Adjusted 10-minute Average (m/s)
5	28	20
25	39	27
50	44	31
100	48	33

Taking into account the large number of shoals within the river, the primary fetch of interest for the site is an easterly fetch of approximately 2000 m. Therefore, by using the shallow water forecasting curves presented in the Shore Protection Manual (CERC, 1984), the maximum hindcast wind wave heights at the proposed site are given in Table 3.4 (as per MHL, 2005).

Table 3.4: Hindcast maximum wind wave heights in vicinity of release location

Return Period (Years)	H_s ($H_{1\%}$) (m)	T_p (s)
5	0.6 (0.9)	2.3
25	0.83 (1.26)	2.6
50	0.97 (1.47)	2.7
100	1.04 (1.57)	2.8

3.3.2 Boat Wave Climate

Boat waves also have the potential to impact a marine structure. Currently commercial vessels that operate in the lower Clarence River are restricted by both water depth (with approval given to deepen the navigation channel to 4 m below Iluka Port Datum) and beam (with a typical guide of 3 - 4.5 times the beam being the limiting channel dimension). Discussion with NSW Maritime Authority suggest that the Port of Yamba may be expanded in the moderate future and that larger ships may have access to the lower Clarence River. Therefore, to provide a conservative estimate of the boat wave climate, it is assumed that a vessel as large as a Sydney Ferry First

Fleet Vessel may be encountered on the river. As per Edwards and Lord (1998), a vessel of this size would generate a wave with a maximum wave height of 0.54 m and a maximum wave period of 4.3 seconds.

3.4 Ocean Wave Climate

A design wave height of 3 m (T_p = 12 s) was estimated by MHL (1996b) for the wave trap beach. As the channel depth is likely to be maintained at or around 4.0 m below Iluka Port Datum it is reasonable to suggest that a wave of this magnitude would reach the proposed site as an unbroken wave.

Based on the above assessment of all wave types, the maximum wave that would impact the structure is likely to be the ocean wave, with a 3.0 m wave height and 12 second wave period. Random effects of wave grouping may lead to larger waves of limited duration.

4. Field Investigations

A series of field experiments were undertaken on October 13 - 16 2008 to better characterise the circulation patterns and to fill in key data gaps in the vicinity of the proposed ebb tide release. Information from the 2008 experiment is provided below.

An additional field investigation was undertaken over five (5) days from 22 – 27 June 2009. The field campaign followed significant rainfall resulting in widespread flooding across the northern rivers area, including the Clarence River catchment, during May 2009. In conjunction with a river hydrosurvey, additional measurements were obtained during the field study to provide information on the flow path and bed sediment dynamics, particularly after large flood events. The results of the study were considered in finalising the detailed concept design specifications of the Yamba-Iluka ebb tide release (Appendix B). A comprehensive summary of the June 2009 Lower Clarence River Hydrosurvey is provided in the WRL letter report (dated 19/08/09) included in Appendix A.

The field experiments were undertaken to measure:

- **Water Velocity and Direction:** An RDI 1200 kHz ADCP was used to measure water velocity and associated direction at various locations within the lower section of the Clarence River. The ADCP was attached to the vessel (downward looking) and had bottom tracking enabled. Measurements were taken predominantly during the ebb tide, however, some flood tide measurements were obtained. Field calibration checks were undertaken prior to deploying the instrument.
- **River Discharge:** At various times during the ebb tide, river discharge measurements were undertaken at predetermined transects using the ADCP. Three transect locations were repeated at locations (i) upstream, (ii) in the vicinity and (iii) downstream of the proposed ebb tide release (Figure 4.1).
- **Flow paths:** GPS drifter drogues were deployed during various stages of the ebb tide to measure flow paths in the vicinity of the proposed ebb tide release. The GPS drifter drogues consisted of a mesh 'sail' set 2 m below the surface connected to a steel line and small surface float. Delorme Earthmate Blue Logger GPS units were attached to the surface float and internally recorded their location at preset intervals. The drogues were released slightly upstream of the proposed release site and retrieved after being transported approximately 1200 m (inside the entrance breakwater walls).
- **Bathymetric information:** Subsurface bathymetry data was acquired for the lower Clarence River estuary in the vicinity of the proposed ebb tide release. This data was collected using a Ceestar Echo sounding unit coupled with a Trimble RTK-GPS. Collected data was quality controlled and adjusted to meters Australian Height Datum.
- **Salinity:** Salinity measurements were taken using the salinity probe attached to the Seabird 19 plus.
- **Diffusion:** Diffusion was measured using standard tracer techniques. Rhodamine WT was released from a stationary vessel at a known rate. The dye plume was measured using a calibrated Chelsea Scientific fluorimeter attached to the Seabird 19 plus.

4.1 Environmental Conditions During 2008 Sampling

The field work was undertaken in conditions typical of low river flows (i.e. low base flow). In the 10 days preceding the field work there was no significant rainfall in the catchment and inflows were all below minor flood levels. These inflow conditions suggest that the measurements collected are representative of dry periods when the tidal prism dominates the discharge volume exiting the river mouth. In relation to the ebb tide release, this provides conservative velocity and discharge estimates (i.e. the discharge is not affected by flood waters) and provides a good representation of how the release would operate under average (or low flow) conditions.

Sampling was conducted to coincide with moderate spring tide conditions. Figure 4.2 depicts the recorded water level at the Yamba entrance (as provided by the MHL water level recorder) and the time of representative ADCP transects during the field study. A peak high tide of 0.745 m AHD was obtained on 16 October at 10:45 and the minimum ebb tide of -0.965 m AHD was reached at 03:30 on the 15th October. The tidal range at the Yamba entrance on 14th October, when the majority of ADCP transects were undertaken, was 1.37 m. In contrast, long term analysis of water level data at the MHL sensor located at the entrance from 1990 to 2005 indicated that the average mean tidal range is 0.95 m (MHL, 2005).

A field program was developed to maximise the amount of data collected during the three (3) days of testing. On the first day, October 14th, the field program focused on obtaining bathymetric data and conducting ADCP transects. The second day of testing, October 15th, completed the bathymetric and ADCP data collection and included drogue releases and CTD profiles. The final day, October 16th, focused on dye testing and further CTD profiles. While the first two (2) days were undertaken during daylight hours, the final day of testing was conducted between 0200 am and 0900 am to maximise the ebb tide prism, minimise wind mixing of the surface plume and ensure that the dye tracing was not interrupted by other passing boats.

A variety of wind conditions were experienced during the three (3) days of testing. As shown in Table 4.1, strong north-easterly winds were prevalent on October 14th. During the late afternoon of October 14th a southerly system came through and on October 15th strong south to south-easterly conditions prevailed. These conditions persisted throughout the testing on October 16th. Despite the windy conditions, only a minor amount of rain was recorded during the entire field investigation.

Table 4.1: Weather conditions at Yamba pilot station during 2008 field study

Date/Time EDT	Temp	Wind					Press	Rain since 9 am
		Dir	Speed	Gust	Speed	Gust	MSL	
	°C		km/h		knots		hPa	mm
14 Oct /03:00pm	21.7	NNE	30	43	16	23	1017.1	0
15 Oct/09:00am	20	S	17	32	9	17	1018.3	5.2
15 Oct/03:00pm	21.9	SSE	32	43	17	23	1016.6	0
16 Oct/03:00am	18.7	SSE	24	35	13	19	1020.2	0
16 Oct/09:00am	17.5	S	19	30	10	16	1022.7	0.2

4.2 2008 Field Study Observations

A large number of ADCP transects were undertaken throughout the three (3) days of field testing. Three (3) transects were established to represent the upstream boundary, the conditions at the proposed site and the conditions at the entrance. These three transects are labelled on Figures 4.1 and 4.2 as the west, middle and east transects. Data recovery was near

100% and due to the large data set recovered, representative samples from each series of data sets were selected and are depicted (as red dots on the tidal water level graph) on Figure 4.2.

Representative ADCP transects from each of the three (3) sampling locations (west, middle and east) are depicted in Figures 4.3, 4.4 and 4.5. Each of these figures detail the velocity magnitude (in m/s), the velocity direction (degrees), the depth averaged velocity transect and the water level at which the sample was taken. Importantly, all three of these transects were taken within 40 minutes of each other and at the commencement of the ebb tide. Gaps in the eastern transect dataset (as shown in Figure 4.5) were associated with large waves penetrating into the entrance, physically lifting the ADCP from the water.

The ebb discharge in the lower portion of the estuary significantly lagged behind the changing water levels. For example, though water levels indicated a falling (or ebb) tide commenced at the Yamba entrance at approximately 08:45 on the October 14th, ebb flows were not recorded in the main channel until approximately 11:00; nearly 135 minutes after the tide changed. This lag in discharge is not a fixed rate but varies depending on upstream inflows, previous tidal levels (i.e. tidal inequities) and a range of other factors. Further analysis of the ebb flows and tidal levels was undertaken with the calibrated numerical model and is discussed in Section 5.4.3.

Interestingly, ebb flows were noted discharging from south of the main training walls at approximately 10:00 and finished discharging approximately an hour before the main channel. This is likely due to the draining/filling of Lake Wooloweyah and its relative isolation from the main channel system. Further analysis of the discharge versus water level timings is provided in Section 5.4.5.

As discussed above, the ADCP transects shown in Figures 4.3, 4.4 and 4.5 were taken at the commencement of the ebb tide. These figures show weak tidal currents and slight inconsistencies in the velocity direction. However, in the time taken to sample between the western and eastern transects (Figure 4.3 versus Figure 4.5) an increase in velocity magnitude is apparent. As the currents increase, the water column became completely depth averaged with very little difference in velocity magnitude or direction with depth. Indeed, within 1 hour of the ebb discharge commencing, the flow was completely depth averaged and remained this way until within 30 minutes of the end of the ebb discharge. These findings are in line with previous field observations at the river mouth (MHL, 1998).

Measured current velocities in the channel were similar to previously measured values. Drogue tracking undertaken by SLM (1978) and ADCP measurements shown in MHL (1998) and MHL (2005) suggested an average tidal current velocity of 0.3 m/s for the neap tide and 0.4 m/s for the mean tide at a location in close proximity to the proposed release. These estimates were based on the ADCP measurements undertaken in October 1996 when the tidal range was 1.28 m. In contrast, the tidal range on October 14th 2008 when the majority of ADCP transects were undertaken was 1.37 m. As such, the average velocity measured for this study of 0.6 m/s is slightly higher due to the larger tidal range. Table 4.2 provides the ebb tide current velocity statistics for all the measurements taken at the middle transect. As this data only represents the ebb tide currents measured onsite over three days of testing, additional current velocity statistics were generated from the calibrated computer model. This information is discussed further in Section 5.4.2.

Table 4.2: Measured ebb tide current velocity statistics

Percentile	Velocity (m/s)
Average	0.59
Minimum	0.25
Maximum	1.05
99th %ile	0.30
90th %ile	0.37
50th %ile	0.60
10th %ile	0.81
1st %ile	0.93

The release of the GPS drifter drogues provided useful information regarding the flow paths in the lower estuary. As shown in Figure 4.6, on the 15th October 2008, four (4) GPS drifter drogues were released at various locations across the river. This release was undertaken approximately 30 minutes after the ebb tide release commenced in the main channel. As depicted in Figure 4.6, the four drogues converged in the middle of the channel and were transported to the north of the entrance channel. This is likely due to water discharging from Yamba Channel, which commenced flowing approximately 40 minutes before the main channel. In the beginning of the ebb tide it was evident that the flows discharging from Yamba Channel had a greater velocity than the main channel and thereby, forced flows in the main channel towards the north.

Conversely, during the same ebb tide once the discharge velocities in the main channel increased, the main channel flow paths were not affected by water discharging from Yamba Channel. As shown in Figure 4.7, a drogue release undertaken at 16:00 on October 15th did not depict strong discharges from the south. This drogue release was undertaken from the approximate location of the proposed release and indicated that no major eddy circulations exist downstream of the release. This information is also useful in calibrating the numerical model.

The additional information obtained from the field study primarily relates to variables that are required for the numerical modelling. In particular, the Rhodamine WT tracer findings are discussed in the numerical modelling Section 5.3. This data was used to verify the diffusivity parameters.

Overall, the field study provided a large amount of useful data to better characterise the lower estuary. The intensive bathymetry survey covered the entire vicinity of the proposed release and was subsequently used as the base layer in the numerical model. The current profiling and drogue releases indicated that:

- There is a significant lag (in the order of 30 – 120 minutes) between tidal water levels and the onset of discharge from the main channel;
- Yamba channel commences to discharge earlier, and finishes earlier, than the main channel;
- Flows within the main channel were largely depth-averaged within 1 hour of the ebb tide discharge commencing;
- The flows from Yamba channel impact the main channel in the beginning of the ebb tide by directing the flow northwards;
- The impact of Yamba channel on the main channel is not evident during subsequent periods of the ebb tide;

- The flow path from the release to the entrance is nearly due easterly with no apparent large eddies;
- Upstream of the proposed release structure, at the west transect, ebb tide flow moves in a southerly direction which is then redirected into an easterly direction around the middle transect; and
- Velocities in the study are generally in line with previous estimates (0.5 m/s average velocity).

While the above information was useful to characterise the region of interest, it only provides information on the days that the study was undertaken. To further understand the estuarine hydrodynamics, a computer or numerical model was developed, calibrated, verified and subsequently tested to simulate a range environmental conditions. The numerical model is based on the real world data from previous studies and detailed above. Further information on the numerical model is provided in Section 5.

5. Numerical Model of the Estuarine Hydrodynamics

Numerical models simulate the hydrodynamic processes in an estuary by using local data and relevant equations that represent physical processes. Once constructed, the model is calibrated to the available real-world data. This model is then verified against additional field data to prove that it can adequately simulate a range of environmental conditions. In addition to the hydrodynamic outputs, water quality modules can be used to simulate changes in water quality.

A range of commercial programs are available for simulating complex hydrodynamic processes in estuarine environments. For this study, the RMA suite of models was employed. WRL has successfully used the RMA models, including RMA-2 and RMA-11, to recently simulate estuarine flows in several other locations including (but not limited to) the Richmond River, the Hawkesbury-Nepean River, the Shoalhaven River, Darwin Harbour and the Manning River.

RMA-2 is a two-dimensional (2-D) hydrodynamic finite element model for depth averaged flow (King, 2002). The model solves the Navier-Stokes equations in two dimensions, together with the continuity equation, to obtain velocities and water surface elevations at each node on the finite element mesh. The model is used throughout the world and is the primary hydrodynamic model employed by the US Army Corps of Engineers. RMA-11 is a finite element model that uses RMA-2 hydrodynamic outputs to simulate water quality processes in estuaries, bays, lakes and rivers.

For this study a numerical model of the Clarence River was established using RMA-2 from upstream of Grafton to the ocean boundary. Extensive bathymetric data was used to simulate the river channel. Water level data from multiple sites throughout the river were used in conjunction with discharge and current velocity data (from the 1996 and 2008 field studies) to calibrate and verify the hydrodynamics. Once it was shown that the model could effectively simulate the circulation patterns in the vicinity of the lower estuary, a range of scenarios were tested. These scenarios primarily used the water quality model RMA-11 to optimise the operation of the proposed ebb tide release.

The remainder of this section details the modelling process including initial set-up, calibration, verification and scenario testing. Although a pilot model was initially set-up to provide preliminary information prior to the field investigation, the results presented in this section are focused on the final outcomes. Data from the hydrodynamic model was also used within the near-field water quality modelling discussed in Section 6.

5.1 Model Set-Up

The finite element mesh was constructed with the best available data to characterise presently existing real world conditions in the Clarence River estuary. Cross sections from the 1978-1979 PWD river hydro-survey data (in AHD as supplied by Greg Rogencamp of BMT-WBM) were used to define the river bed dimensions in the main channel from upstream of Grafton (near the junction with Whiteman Creek) to the lower parts of the estuary (Figure 5.1). In the vicinity of the proposed release, the 2008 WRL bathymetric survey data of the lower Clarence estuary was employed.

The finite element mesh for the entire model is shown in Figure 5.2. As depicted, the model consists of 1-D elements that represent the hydraulic radius of the main river channel from the junction with Whiteman Creek to upstream of Goodwood Island in the lower estuary. 1-D elements were also included for the tidal sections of Coldstream River, Sportsman Creek, the

South Arm, the Broadwater, the Back Channel and the Esk River. Detailed 2-D elements exist further downstream, throughout the vicinity of the proposed release and within Wooloweyah Lake and the entrance to the Oyster Channel. The 2-D elements also extend approximately 2 km offshore (i.e. beyond the extent of the breakwaters). Element resolution varies throughout the 2-D sections with the mesh refined in the lower regions of the estuary to better simulate flow paths and water quality processes.

The model was run with 1996 and 2008 data. The 1996 data was used to calibrate the model as it had a better spatial extent of real data. The 2008 data was used to verify the model, particularly in relation to flow paths and velocity in the vicinity of the proposed releases. In both simulations a time transient tidal condition was applied to the offshore mesh boundary. For the 1996 model runs, measured water level (i.e. tidal) data from offshore of Yamba was obtained from MHL. This data was subsequently applied to the ocean boundary (in m AHD) without manipulation. For the 2008 model runs, predicted offshore water level data was provided by MHL. Measured data for 2008 was not available as the Yamba offshore monitoring site was moved to a location near the Tweed River between 1998 and 2008. To ensure the predicted data accurately represented the real conditions, MHL also provided actual data measured offshore of the Tweed River until July 2008. As shown in Figure 5.3, the 2008 predicted data at Yamba was largely in close agreement with the measured Tweed River data. Discrepancies were associated with high and low pressure systems acting on the measured data and were not included in the tidal predictions. The predicted Yamba data for 2008 was subsequently applied as an oceanic boundary condition.

In addition to the tidal boundary, an upland inflow boundary was applied to the main channel at the junction near Whiteman Creek. As no discharge data is available for this location, and only limited discharge data is available for adjacent waterways, an assumed volume of 50 m^3/s of freshwater base flow was applied at this boundary. Sensitivity testing of this inflow value (± 100%) did not have an appreciable impact on the model calibration within the lower sections of the estuary as the tidal prism is orders of magnitude greater than upland inflows during non-flooding periods. No further boundary conditions were applied within the model.

Channel roughness (or Manning's 'n') values were set within the model to simulate different environmental conditions. Throughout the majority of the model including the main channel, Lake Wooloweyah, and the large left/right bank creeks Manning's 'n' was set to 0.02. In Palmers Channel Manning's 'n' was set to 0.045. In the area within and around the entrance to the Oyster Channel Manning's 'n' was set to 0.045 and in the South Arm and in the upper reaches of the main channel (upstream of Brushgrove) Manning's 'n' was set to 0.025. Eddy viscosity was set at 0.50 Pascal-sec throughout the modelling domain. Diffusion was set at 0.5 m^2/sec for all water quality simulations.

5.2 Calibration

The numerical model was calibrated to water level and discharge measurements undertaken during 1996. The location of the sites where data was available for calibration is given in Figure 5.4. As depicted, the water level sites cover the length of the river from Grafton to Yamba and include two (2) sites in the entrance to the Oyster Channel and one site (1) in Palmers Channel. Discharge measurements are also available at a range of upstream and downstream locations (as noted in red on Figure 5.4).

Figures 5.5, 5.6, 5.7 and 5.8 provide a snapshot of water level data for the calibration period with numerical modelling results overlying measured field results. This data indicates that the modelled water level data is in phase with the measured tide throughout the estuary and that the model reasonably produced the tidal levels. The accuracy of the model varied depending on the location and the age of the bathymetric data.

The model also calibrated to discharge and current velocity measurements, which are the most relevant data for an ebb tide release. Figures 5.9, 5.10 and 5.11 depict the modelled and measured discharge curves at Yamba and Maclean, Brushgrove and Grafton, and at the entrance to the Oyster Channel, respectively. Positive discharge values in these figures are representative of the flood tide, whereas negative discharge numbers represent the ebb tide. As shown, modelled discharge at Yamba is in good agreement with measured discharge. This implies that the velocity of water, the tidal volume exchange and the cross-sectional area of the model are well calibrated. Discrepancies in discharge between modelled and measured values in the upper estuary such as shown in Figure 5.10 are likely due to variations in the cross-sectional area, noting that the majority of the upper estuary is characterised by bathymetric data from 1978-79.

To ensure that the model adequately represents the flow paths in the lower section of the estuary, in vicinity of the proposed release, the 1996 modelled flow paths were plotted against the ADCP transect data. As shown in Figures 5.12a, 5.12b and 5.12c, the model predicts both the measured velocity and direction of the depth averaged currents across the entrance at Yamba. The calibration data shown above suggests that the model is fit for the purpose of designing an ebb tide release as it can adequately predict flow paths, flow speeds and tidal volume in the lower sections of Clarence River.

5.3 Verification

The data obtained in the 2008 field investigation was used to verify the calibrated model. As shown in Figure 5.13, the 2008 verification data sites cover the extent of the estuary. Due to the large number of ADCP profiles undertaken in the 2008 field study, and the importance of accurately simulating flow paths in the lower estuary, the verification procedure focused primarily on the circulation patterns in the lower estuary.

The 2008 model runs were simulated by applying the 2008 boundary condition to the calibrated model with the adopted 1996 calibration parameters. Model accuracy for the 2008 period was similar to the calibration data, with tidal phasing at Yamba (Figure 5.14) well simulated. Tidal phasing was also well simulated at Grafton (Figure 5.15), Maclean and Brushgrove. Water levels at all locations are over predicted by up to 0.2 m during spring tides. The over/under prediction of tidal levels is likely due to discrepancies within the predicted tidal values applied at the ocean boundary versus the measured data used verify the model, and exacerbated by the dated bathymetry used in the upper estuary. In contrast, the 1996 calibration process had measured data for both the tidal boundary condition and at the measured sites and the bathymetric data, while still dated, was of a more comparable era.

Discharge and current velocity measurements undertaken in 2008 were also verified with the calibrated model. Calculated discharge was in-line with modelled discharge during the flood and ebb tides at the western, middle and eastern transects (Figure 5.16 and 5.17). Further, comparison of measured versus modelled velocity vectors (Figures 5.18a and 5.18b) indicates that the model effectively reproduces channel hydrodynamics, including velocity and flow direction in the immediate vicinity of the proposed release (Figure 5.18b).

As an additional verification procedure, the drogue tracking and dye tracing experiments undertaken during the 2008 field investigation were compared against water quality model outputs from RMA-11. In these tests, RMA-11 was run using the hydrodynamic outputs from RMA-2 to depict how a plume discharged from the proposed release site would be transported within the lower estuary on an ebb tide. As shown in Figure 5.19, the drogues tracked largely in line with the released plume. This further verified the hydrodynamic predictions and confirmed that the model was fit for the purpose intended.

To confirm the diffusivity coefficients applied in the model, the dye tracing experiment results were compared against a simulated release. As depicted in Figure 5.20, the Rhodamine WT dye diffused in a pattern similar to that of the model. Upon release, the dye was highly concentrated and located in a small area but with further distance downstream the dye diffused over a wider area. Based on this assessment, the diffusivity coefficient in the model was set at 0.5 m^2/s.

5.4 Model Outputs

The calibrated and verified numerical model was subsequently used to resolve a number of technical concerns relating to the proposed release. These concerns include:

- Where is the optimal location for the ebb tide release?
- What is the design ebb tide velocity?
- Is there a relationship between the ebb tide water level and the time when discharge commences in the lower estuary?
- What is the maximum amount of time that the ebb tide discharge could operate without impacting upstream sites?
- What is the risk of released recycled water being transported into the entrance of the Oyster Channel and/or Lake Wooloweyah during tidal or flood flows?
- Based on the flow patterns under spring tides and high flows, what are the conceptual sand transport dynamics?
- When is the maximum scour likely to occur onsite and what is the resultant minimum depth of the pipeline?

These concerns are addressed below.

5.4.1 Optimal Location of the Ebb Tide Release

With regards to hydrodynamics, the optimal location for the ebb tide release (within the constraints of the proposed area for consideration, Figure 1.2) is a location furthest to the east. In an easterly location the proposed release would be:

- Closer to the river mouth, thereby allowing for an extended discharge window;
- In a region with predominately easterly currents, versus further upstream where the currents have a northerly component; and
- Downstream of the gap in the middle training wall, which would reduce the likelihood of recycled water being funnelled into the entrance of the Oyster Channel.

Based on these criteria the approximate mid-line location is Easting 534310 and Northing 6744822 in MGA coordinates (Zone 56). This location would be the centreline point with the Iluka diffuser located to the north and the Yamba diffusers located to the south. The above location also complies with the range of constraints identified in Section 3. Further information on the conceptual design of the ebb tide release is given below and summarised in Section 7.

5.4.2 *Design Ebb Tide Current Velocity*

Previous ebb tide current velocity estimates have been based on field investigations. Though this information is useful it only provides a snapshot of the conditions that occurred on the day of testing. As such, the numerical model was used to provide a better understanding of the ebb tide velocities over the full spring/neap tidal cycle. In these simulations 15 minute time variant velocities were extracted from the model at the proposed ebb tide release location over a 29 day period. Results were selected for both the entire ebb tide (i.e. 6 hours) and a 3 hour ebb tide discharge window. The 3 hour window commenced 30 minutes after the ebb tide began. The results from this simulation are given in Table 5.1.

Table 5.1: Ebb-tide current velocity

Percentile	Velocity for entire ebb tide at X^{th} percentile (in m/s)	Velocity for 3 hour ebb tide at X^{th} percentile (in m/s)
50^{th}	0.40	0.50
90^{th}	0.09	0.24
99^{th}	0.02	0.13

As shown in Table 5.1, the velocities for the entire ebb tide current are less than the 3 hour ebb tide window. The increase in velocity for the 3 hour ebb tide window is largely associated with precluding the first 30 minutes of the ebb tide when the velocities are the lowest. Since the lowest velocities are generated during this period, the 90^{th} and 99^{th} percentiles are particularly affected, with very low velocities evident over the entire ebb tide. Reducing the operating window to the middle of the ebb tide (i.e. 1 hour after the ebb tide commences) would further increase the ebb tide current velocities.

The values listed in Table 5.1 are also slightly below previous field measurements. This difference is due to previous measurements being undertaken during spring tides, which may overestimate the average velocity. It is important to note, however, that the velocities provided in Table 5.1 were generated at the proposed location for the ebb tide release and that further downstream the velocities are likely to be slightly higher due to the constrained channel. Therefore the velocities noted above are deemed conservative estimates.

Based on these results, and length of time required for the release (discussed in Section 5.4.4), the 3 hour ebb discharge velocity was selected as the design velocity. Any subsequent change to this release window would require additional modelling scenarios.

5.4.3 *Ebb Tide Water Level versus Ebb Tide Discharge*

As noted in the field investigation, there is a varying lag between the time when the tidal water level begins to decrease and the time when the ebb tide currents in the main channel start flowing. This lag is related to a range of factors including the physical dimensions of the estuary, the tidal prism, the tidal wave shape/celerity, upland inflows and channel roughness. As discussed in the calibration and verification process, the numerical model accurately predicts this lag in the vicinity of the proposed ebb tide release.

An example of the tidal water level versus ebb tide discharge plot is given in Figure 5.21. When reading this chart it is important to note that while the tide changes when the water level begins to fall, the ebb tide does not commence to flow until the discharge becomes negative. With this information, the numerical model can adequately simulate the lag and provide forecasts for when the ebb tide release should operate. However, due to varying upstream inflows, actual flow data from the river may be the preferred option for triggering the operation of the ebb tide release. Long-term analysis of tidal flows could then be used to confirm the model's ability to accurately predict ebb tide flows.

5.4.4 Ebb Tide Release Operational Window

An ebb tide release was defined by both the Yamba and Iluka working groups "as when there is an outgoing flow which clears the entrance". As such, all recycled water released must be transported beyond the end of the training walls of the Clarence River (regardless of water quality or mixing efficiencies). Therefore, to determine the duration of time that the release could operate, without compromising the agreed operating criteria, a range of scenario tests were devised and undertaken.

The modelling scenarios involved discharging a diffusive plume solely during ebb tides from the proposed release location over a full spring/neap tidal cycle (29 days). The different scenarios tested are provided in Table 5.2. Once the plume was released a range of sites (as shown in Figure 5.22) were monitored to determine if the plume ever reached these locations. For the scenarios listed in Table 5.2, failure to conform with the operational criteria would occur when any site upstream of the release, including those in the entrance of the Oyster Channel, had a measurable plume concentration. It is important to note that once the plume cleared ~150 m seaward of the entrance, it was removed from the model (i.e. not allowed to return on the flood tide). This is in line with MHL (2000), which stated that, 'only a small fraction of the water ejected from the estuary during the ebb is returned on the subsequent flood'.

Table 5.2: Ebb-tide release: Operational window scenario testing

Scenario	Length of discharge (in hours)	Time when discharged commenced
1	3	30 mins after change in flow
2	4	30 mins after change in flow
3	5	At the change in flow
4	4	1 hour prior to flow change

Results from the above scenarios indicated that the 3 hour ebb tide release (commencing 30 minutes after change in flow) was the only operational scenario that satisfied all criteria. Though measurable concentrations were noted at the sites immediately south of the middle training wall, no measurable concentrations were noted at the site near the gap in the middle wall, in the entrance to the Oyster Channel or upstream in the main channel.

The other scenario worth noting is #4 (4 hour release commencing 1 hour prior to change in flow). During this scenario the plume was not measured at any site south of the middle training wall or in the entrance to the Oyster Channel but was measured at the sites immediately upstream of the release. However, as this scenario permits discharge during the flood tide, the reduced current velocities prevalent during the slack tide would result in reduced mixing efficiencies.

The modelling results indicated that releases over 4 or 5 hours (i.e. Scenarios 2 and 3) did not comply with the testing criteria. In these scenarios the plume was transported through the gap in the middle wall and into the entrance of the Oyster Channel. This predominantly occurred during periods when a small amplitude tide was followed by a large amplitude tide (i.e. large tidal inequity). In these situations the lag in the ebb tide discharge, combined with the quickly rising large amplitude tide, results in a short release window. In theory this could be effectively managed by reducing the release window during these periods and increasing it during other periods when the tidal inequity is reduced.

The outcome of this scenario testing is that the 3 hour release (commencing discharge 30 minutes after the change in flow) satisfies the operational criteria established by the working groups and would not impact upstream sites. Attention to this window timing (as proposed in Appendix B) will require additional modelling to confirm any potential impacts.

5.4.5 Transport of Recycled Water during Flood Periods

WBM (2004) conducted a flood study of the lower Clarence River examining a range of flood scenarios including overbank flows. This study included 6 flooding events as noted in Table 5.3. WBM (2004) stated within their report that the flooding behaviour of the Lower Clarence River floodplain is dominated by the flow from the catchment upstream of Grafton and that the smaller tributaries in the lower floodplain only play a minor role in the flood behaviour.

Table 5.3: Flood modelling scenarios undertaken by WBM (2004)

ARI	Inflows (m3/s)
5	9,360
20	16,280
100	19,060
500	20,000
Extreme flood 1	29,160
Extreme flood 2	57,180

The numerical model presented in this study is solely designed for the purpose of developing a detailed conceptual model of the ebb tide release. One of the major concerns related to the release was that during significant flooding events Lake Wooloweyah and the main channel would be out of phase (i.e. the water level of one will lag behind the other). If this was to occur there could be the potential for released recycled water to be transported upstream and eventually into the Lake. While the modelling discussed in Section 5.4.4 indicated that this would not happen under normal tidal flows, additional modelling was undertaken to evaluate conditions during a flood event.

Based on the flooding scenarios undertaken by WBM (2004), a five year flood hydrograph was developed (using the shape of 100 year hydrograph to simulate the rate of rise) and simulated within the model. Since the lower Clarence River floodplain is dominated by flow from the upstream catchment, the five year hydrograph was applied on the upstream boundary. The model was then run over the 2008 field investigation period and the flow paths were analysed.

Results from the flood scenarios indicated that although Lake Wooloweyah and the main channel go out of phase, no water from the proposed ebb tide release would be transported into the entrance of the Oyster Channel. Figure 5.23 shows the indicative flow paths generated by the computer model when Lake Wooloweyah is out of phase with the main channel during a flood. The modelling snapshot provided in Figure 5.23 shows that the lower section of the estuary is dominated by high velocity flows in a seaward direction. During the peak of the flood, current velocities in the vicinity of the proposed release remain seaward regardless of the tidal level. As floodwaters recede, Lake Wooloweyah tides become out of phase with the main channel tides. Modelling results indicate that water from upstream of Freeburn Island (i.e. the island in the middle of the channel to which the middle training walls is connected), versus water from the lower sections of the main channel, is directed into the entrance of the Oyster Channel during these periods. This circulation pattern continues until the flood passes and the normal ebb/tide cycle resumes. Importantly, the model results show that at no time during the flood hydrograph is water in the vicinity of the proposed ebb tide release transported upstream. (Animations of the flooding process are also available to provide additional information on the flow paths.)

5.4.6 Sediment Scour and Minimum Pipeline Depths

Figure 5.24 provides bed velocities at hourly intervals over an entire spring ebb tide. As evident in Figure 5.24 (hour 0) at the slack tide, velocities across the lower section of the estuary are low. At hour 1 the tidal velocity increases and continues to increase until hour 5 when the ebb flows start to reduce. The highest velocities experienced during the middle of the ebb flow (> 1.0 m/s) are most prevalent in the lower or eastern section of the estuary where the flow is confined between the middle training wall and the northern breakwater. As the proposed release would be located upstream of Moriarty's Wall, the bed velocities experienced at this site are slightly less than the downstream velocities.

The velocities experienced during a spring ebb tide are sufficient to generate sediment transport. Using standard practices (i.e. Shield's diagram for particle motion), and an average particle diameter (i.e. d_{50}) of 0.26 mm (based on bore logs from PB, 2007), it can be determined that velocities greater than 0.6 m/s are sufficient to generate particle transport. As such, sand particles are likely to be in suspension throughout the ebb tide cycle for much of the lower estuary. These particles are likely to be transported downstream with the ebb tide and upstream with the flood tide. Since the estuary has a slight flood tide dominance, the net particle movement would be in the flood tide direction, however large floods have the potential to reset the system.

To determine the minimum depth that the delivery pipeline could be positioned, an assessment was made of the potential scouring that could occur onsite during a flood. A range of assumptions were made for these calculations. First, the width of the site was assumed to be a fixed distance between Moriarty's Wall and the middle training wall. Second, due to the very shallow nature of the channel south of the training wall, it was assumed that the majority of the floodwater would be conveyed via the main channel. Third, the depth of the coffee rock was set at 15 m below the water level (and approximately 6.5 m below the sand bed). Finally, it was assumed that once sand was removed from the site no sand was available for infill.

Based on the above assumptions, and using the 5-year average recurrence interval (ARI) flooding event, it was determined that the site has the potential to scour down to the coffee rock strata. Indeed, even with the increased cross-sectional area provided by the scoured section, discharge velocities would be greater than 1.5 m/s during the 5 year ARI flooding event. These calculations are based on current velocities much less than the reported flood velocities which can increase to upwards of 6 m/s. It is therefore recommended that the minimum pipe depth for the delivery pipeline be set below the coffee rock strata.

It is worth noting that additional wet weather flow field investigations were undertaken to examine sediment dynamics and those results are provided in Appendix A.

5.5 Summary

A hydrodynamic model was developed, calibrated and verified for the lower Clarence River. The model was shown to adequately describe the hydrodynamics in the vicinity of the proposed ebb tide release and is fit for the intended purpose of providing base data and analysis for the release designs. A range of model simulations were tested to optimise the design of the ebb tide release.

The main findings of the modelling include:

- Based on flow paths and circulation patterns (and the area available for consideration), the optimal location for the ebb tide release is furthest to the east, downstream of the gap in the middle training wall.
- The design velocity over a 3 hour ebb tide release (commencing 30 minutes after the ebb tide flow commences) was determined to be 0.50 m/s and 0.24 m/s for the 50th and 90th percentile, respectively. Further precluding the operating window to avoid more of the slack tide would likely increase the design velocities.
- The hydrodynamic model could be used as a forecasting tool to predict the time lag between the falling water levels and the ebb tide flows during dry periods but additional field data is necessary to predict the lag during wet periods.
- Regardless of near-field dilutions, a plume discharged during base flow conditions from the proposed release site could operate over a 3 hour window, commencing 30 minutes after the ebb tide flow starts, without impacting upstream locations.
- In flooding periods a plume from the proposed ebb tide release site would not be directed towards the entrance of the Oyster Channel or Lake Wooloweyah despite Lake Wooloweyah water levels being out of phase with the main channel.
- Ebb tide velocities are sufficient to scour sediment from the bed during spring tide conditions.
- Conservative estimates suggest that floods of a magnitude of the 5 year ARI or greater have the potential to scour sand at the proposed release site to the coffee rock. All attempts should therefore be made to ensure the delivery pipelines are installed below the coffee rock.

It is important to note that all discussions of plume transport provided above do not take into account the dilutions that would be achieved during the buoyant rise of the plume and hence, are only provided for design and illustrative purposes. Further information on these processes and predicted dilutions are provided in Section 6.

6. Near-field Modelling and Diffuser Design

This section describes the near-field modelling undertaken to design the release diffuser and comply with the water quality criteria. Information provided throughout this report and by the Department of Commerce have been used in the design process.

Throughout this section the term near-field zone is commonly used. The near-field zone is defined as the region centred around the outfall, extending out to the point at which the mixture of river water and recycled water reaches its level of neutral buoyancy or the water surface. At the end of the near-field boundary, the plume is travelling with the speed of the surrounding waters and is of a similar density. The near-field zone is important as the dilutions are achieved predominately during the buoyant rise of the plume. In many locations in NSW, water quality concentrations are regulated at the end of the near-field zone.

Near-field modelling was undertaken using a commercially available model, JETLAG. JETLAG is a near-field model developed for the prediction of three dimensional trajectories of buoyant jets in a stratified ambient current. The model treats the unknown jet trajectory as a series of 'plume elements' that rise due to buoyancy, while gaining mass through entrainment of the ambient fluid. The performance of JETLAG has been verified for multiport releases similar to those proposed for Yamba/Iluka (Horton *et al.* 1996).

In addition to JETLAG, additional near-field modelling was undertaken with CORJET and VISJET to further substantiate the near-field modelling and provide additional visualisation of the near-field plumes. It is worth noting that the absolute accuracy of the concentrations (or dilutions) predicted by any near-field model is within ± 30 % when compared to controlled laboratory experiments (Jirka *et al.* 1996). This value may be greater when comparing with field data due to the inherent complexities of the ambient site conditions. This absolute accuracy should be acknowledged when interpreting the model results.

During the detailed concept design process it was determined that the Yamba and Iluka systems would operate independently. As such, the hydraulics of each system can be designed as standalone units. Further, the Department of Commerce advised that each system would discharge under pressure at a single pumping rate. Based on previously mentioned findings, the pumping rate is based on releasing recycled water over a 3 hour ebb tide window (twice per day). The advised rates for each system are provided in Table 6.1. Alterations to this rate and relevant impacts are discussed in Appendix B.

Table 6.1: Ebb tide release design flow rates

Design Flow	Iluka	Yamba
ML/day	1.95	7.92
L/sec over 3 hour release window	91	367

6.1 Diffuser Requirements

Based on the design flow rates provided in Table 6.1, a range of diffuser designs were developed and tested. Standard and duckbill valves were tested for each design to calculate exit velocities and head loss. The results for the Yamba simulations with standard ports is given in Table 6.2, whereas the results for duckbill valves are given in Table 6.3. The results for the Iluka simulations with standards ports is given in Table 6.4 and with duckbill valves are given in Table 6.5.

Table 6.2: Yamba ebb tide release design standard ports

Number of Ports	Nozzle Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	100	0.3670	0.1835	23.36	27.82
4	100	0.3670	0.0918	11.68	6.96
6	100	0.3670	0.0612	7.79	3.09
8	100	0.3670	0.0459	5.84	1.74
10	100	1.3670	0.1367	17.41	15.44
2	150	0.3670	0.1835	10.38	5.50
4	150	0.3670	0.0918	5.19	1.37
6	150	0.3670	0.0612	3.46	0.61
8	150	0.3670	0.0459	2.60	0.34
10	150	0.3670	0.0367	2.08	0.22
2	200	0.3670	0.1835	5.84	1.74
4	200	0.3670	0.0918	2.92	0.43
6	200	0.3670	0.0612	1.95	0.19
8	200	0.3670	0.0459	1.46	0.11
10	200	0.3670	0.0367	1.17	0.07
2	300	0.3670	0.1835	2.60	0.34
4	300	0.3670	0.0918	1.30	0.09
6	300	0.3670	0.0612	0.87	0.04
8	300	0.3670	0.0459	0.65	0.02
10	300	0.3670	0.0367	0.52	0.01

Table 6.3 Yamba ebb tide release design: Duckbill ports

Number of Ports	Duckbill Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	100	0.3670	0.1835	n/a	n/a
4	100	0.3670	0.0918	n/a	n/a
6	100	0.3670	0.0612	n/a	n/a
8	100	0.3670	0.0459	n/a	n/a
10	100	0.3670	0.0367	n/a	n/a
2	150	0.3670	0.1835	n/a	n/a
4	150	0.3670	0.0918	n/a	n/a
6	150	0.3670	0.0612	n/a	n/a
8	150	0.3670	0.0459	5.4	1.5
10	150	0.3670	0.0367	4.8	1.2
2	200	0.3670	0.1835	n/a	n/a
4	200	0.3670	0.0918	6.0	1.8
6	200	0.3670	0.0612	4.8	1.15
8	200	0.3670	0.0459	4.0	0.75
10	200	0.3670	0.0367	3.6	0.65
2	300	0.3670	0.1835	5.4	1.51
4	300	0.3670	0.0918	3.8	0.74
6	300	0.3670	0.0612	3.1	0.49
8	300	0.3670	0.0459	2.7	0.36
10	300	0.3670	0.0367	2.4	0.29

Table 6.4: **Iluka ebb tide release design: Standard ports**

Number of Ports	Nozzle Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	100	0.0910	0.0455	5.79	1.71
4	100	0.0910	0.0228	2.90	0.43
6	100	0.0910	0.0152	1.93	0.19
8	100	0.0910	0.0114	1.45	0.11
10	100	0.0910	0.0091	1.16	0.07
2	150	0.0910	0.0455	2.57	0.34
4	150	0.0910	0.0228	1.29	0.08
6	150	0.0910	0.0152	0.86	0.04
8	150	0.0910	0.0114	0.64	0.02
10	150	0.0910	0.0091	0.51	0.01
2	200	0.0910	0.0455	1.45	0.11
4	200	0.0910	0.0228	0.72	0.03
6	200	0.0910	0.0152	0.48	0.01
8	200	0.0910	0.0114	0.36	0.01
10	200	0.0910	0.0091	0.29	0.00
2	300	0.0910	0.0455	0.64	0.02
4	300	0.0910	0.0228	0.32	0.01
6	300	0.0910	0.0152	0.21	0.00
8	300	0.0910	0.0114	0.16	0.00
10	300	0.0910	0.0091	0.13	0.00

Table 6.5: **Iluka ebb tide release design: Duckbill ports**

Number of Ports	Duckbill Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	100	0.0910	0.0455		
4	100	0.0910	0.0228		
6	100	0.0910	0.0152	4.60	1.10
8	100	0.0910	0.0114	3.90	0.75
10	100	0.0910	0.0091	3.20	0.60
2	150	0.0910	0.0455	5.40	1.50
4	150	0.0910	0.0228	4.20	0.90
6	150	0.0910	0.0152	2.90	0.45
8	150	0.0910	0.0114	2.4	0.3
10	150	0.0910	0.0091	2.2	0.25
2	200	0.0910	0.0455	4.00	0.85
4	200	0.0910	0.0228	3.20	0.50
6	200	0.0910	0.0152	2.20	0.25
8	200	0.0910	0.0114	1.80	0.15
10	200	0.0910	0.0091	1.70	0.12
2	300	0.0910	0.0455	2.65	0.36
4	300	0.0910	0.0228	1.85	0.17
6	300	0.0910	0.0152	1.50	0.12
8	300	0.0910	0.0114	1.30	0.09
10	300	0.0910	0.0091	1.15	0.07

As both system are designed to operate for a total of 6 hours each day it was determined that duckbill valves would be better suited. Based on WRL's experience elsewhere and factory recommendations, exit velocities below 3.0 m/s were deemed ideal for the long term operation of the release and to minimise head loss. Minimising the numbers of ports was also a key criteria in the release design.

Based on the above calculations and design criteria, optimal designs were selected for both locations. These designs are highlighted in Tables 6.3 and 6.5 and are provided for clarity in Table 6.6. Each design ensures exit velocities are below 2.7 m/s (thus minimising head loss). For Yamba the optimal configuration is an 8 × 300 mm port configuration. For Iluka a 2 × 300 mm port configuration is optimal. For the Yamba design the 8 port configuration could either be a single 8 port release or dual 4 port releases, depending on onsite design constraints. Appendix B should be referred to for alternative release designs based on varied discharge timings.

Table 6.6: **Final release configuration**

Location	Number of Ports	Duckbill Port Diameter (mm)	Total Flow Rate (m^3/s)	Flow Rate per Port (m^3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
Yamba	8*	300	0.3670	0.0459	2.7	0.36
Iluka	2	300	0.0910	0.0455	2.65	0.36

*Note this design could be either a single 8 port release or dual 4 port releases

6.2 Water Quality

6.2.1 Water Quality Criteria

The water discharged from the proposed ebb tide releases will be at a water quality equivalent to the Accepted Modern Technology (AMT). The water quality concentrations achieved for this high standard of treatment are provided in Table 6.7.

Table 6.7: **Discharged water quality concentrations for Accepted Modern Technology***

Analyte	Units	Recycled Water Quality
Faecal Coliform	cfu/100mL	<200#
DO	mg/L	2
BOD	mg/L	10
TSS	mg/L	10
Oil and grease	mg/L	10
pH	Standard units	6.5 - 8.5
Ammonia	mg/L	2
Total N	mg/L	10
Total P	mg/L	0.3

*Note values are 90th percentile values; mean values would be lower
#Flows for reuse will be treated to <10 cfu/100 mL

Water quality objectives for the Clarence River are based on public health, aquatic ecosystem and aquaculture criteria. The adopted water quality criteria are set out in Table 6.8.

Table 6.8: **Water quality criteria**

Analyte	Units	Criteria	Trigger Value
Faecal Coliform	cfu/100mL	ANZECC - Primary contact ANZECC - Human consumer of seafood Safe Foods - Oyster Ecology	150 14 70
DO	mg/L	ANZECC - Aquatic Ecology (Estuarine Waters)	5
BOD	mg/L	ANZECC - Aquatic Ecology (Estuarine Waters)*	15
TSS	mg/L	ANZECC - Aquaculture (Estuarine Waters)	10
Oil and grease	mg/L	ANZECC - Aquaculture (Estuarine Waters)	0.3
Ammonia	mg/L	ANZECC - Aquatic Ecology (Estuarine Waters) ANZECC - Aquaculture (Estuarine Waters) 1.5 x background	0.015 0.1 0.03
Total N	mg/L	ANZECC - Aquatic Ecology (Estuarine Waters) 1.5 x background	0.3 0.45
Total P	mg/L	ANZECC - Aquatic Ecology (Estuarine Waters) 1.5 x background	0.03 0.045

*primarily freshwater criteria

The ambient water quality concentrations in the lower Clarence River have been derived from a number of references. A list of analytes relevant to the release is provided in Table 6.9.

Table 6.9: **Ambient water quality concentrations**

Analyte	Unit	Source						Adopted Background Value*
		SPCC 1987		EPA 1996 Low Flow	MHL 2004	SKM 2003 (EIS)	HRC 1999	
		Low Flow	Med Flow					
Faecal Coliform	cfu/ 100mL	-	-	5	-	5	-	5
DO	mg/L	-	-	7-9	-	6-9	-	9
TSS	mg/L	10	8	3-9	5.7	9	-	9
Ammonia	mg/L	0.21	0.81	0.01-0.02	-	0.02	-	0.02
Total N	mg/L	0.3	0.3	0.2-0.4	0.17	0.4	0.14 - 1.3	0.3
Total P	mg/L	0.03	0.03	0.01-0.03	0.019	0.03	0.01 - 0.17	0.03

*Due to the adopted background values above being greater than or equal to the criteria level for protection of aquatic ecology for ammonia, total nitrogen and total phosphorus, a local criteria of 1.5 times background was adopted for dilution modelling as per MHL (2005).

6.2.2 Dilutions Required

The required dilutions to satisfy water quality criteria are computed by the formula:

$$D = \frac{C_o - C_b}{C_c - C_b}$$

Where:

D = Dilution

C_o = concentration of recycled water

C_b = background concentration of ambient water

C_c = water quality criteria concentration

On this basis, the dilutions required to satisfy the criteria are provided in Table 6.10.

Table 6.10: Required dilutions to satisfy water quality criteria

Analyte	Units	Recycled Water Quality	Dilutions Required
Faecal Coliform	cfu/100mL	200	22
DO	mg/L	2	2
BOD	mg/L	10	N/A
TSS	mg/L	10	N/A
Oil and grease	mg/L	10	33
pH	Standard units	6.5 - 8.5	N/A
Ammonia	mg/L	2	198
Total N	mg/L	10	65
Total P	mg/L	0.3	18

Based on the dilution calculated above, all analytes except for ammonia would be satisfied with a dilution of 65. To satisfy the criteria for ammonia, a dilution of ~200 is required. It is worth noting that the dilution required for ammonia is highly conservative as it assumes that no chemical transformations would occur.

6.2.3 Dilution Modelling

Based on the release configurations and required dilutions outlined above, near-field modelling was undertaken to determine the resultant dilutions that could be achieved for each design. Note that a mid-line port depth of 6 m was assumed for the diffusers based on the sedimentation analysis discussed in Section 3.1. This is a conservative value as the releases will operate during the ebb tide and not the low tide (i.e. a depth of 6 m is based on an average water level of 0 m IPD or -0.92 m AHD).

The results from the Yamba modelling are provided in Table 6.11 (for a single 8 port design) and Table 6.12 (for dual 4 port designs). The results from the Iluka modelling are provided in Table 6.13. Modelling results are presented for the 50th and 90th percentile flows (0.50 and 0.24 m/s, respectively) and for each port angle with respect to the ebb current. Note that a 300 mm duckbill has an effective diameter of 148 mm and that the average dilution is the sum of the dilutions from each port angle divided by the total number of ports.

Table 6.11: **Yamba release dilutions: Single eight port diffuser**

Port Angle	Dilution for 3 hour ebb discharge (50th %ile velocity)	Dilution for 3 hour ebb discharge (90th %ile velocity)
0	179	68
45/315	232	132
90/270	304	145
135/225	188	84
180	391	154
Average	252	118

Table 6.12: **Yamba: Dual four port diffusers**

Port Angle	Dilution for 3 hour ebb discharge (50th %ile velocity)	Dilution for 3 hour ebb discharge (90th %ile velocity)
0	179	68
90/270	304	145
180	391	154
Average	295	128

Table 6.13: **Iluka: Two port diffuser**

Port Angle	Dilution for 3 hour ebb discharge (50th %ile velocity)	Dilution for 3 hour ebb discharge (90th %ile velocity)
90/270	306	146

In summary, for the 50^{th} %ile ebb tide flow, the average dilution at Yamba is 252 and 295 times for the single (8 ports) and dual (2 × 4 ports) diffuser configurations, respectively. However, a single eight port diffuser is likely to have some plume interactions at the end of the near-field zone which are not included in these dilutions. These interactions would reduce plume dilution and therefore, the average dilution for the 8 port diffuser would likely be lower than calculated in Table 6.11. For the two port diffuser at Iluka the calculated dilution is 306 and 146 for the 50^{th} and 90^{th} percentile flow, respectively. Alternative dilutions for a 6 port design at Yamba are provided in Appendix B.

6.2.4 Plume Visualisation

Figures 6.1 – 6.5 assist in visualising the buoyant plumes in the near-field for the Yamba diffuser options. A visualisation of one of the dual 4 port diffuser is provided in Figure 6.1. In this figure the ports are at 0, 90, 180 and 270 degrees to the ebb tide flow and no plume interactions are evident. An alternative design with ports at 45, 135, 225 and 315 degrees is provided in

Figure 6.2. In this design some plume interaction is evident at the top of the near-field zone. 3-D visualisation of these two designs is provided in Figure 6.3.

The single eight port diffuser is a combination of the two above 4 port diffusers with ports located at angles of 0, 45, 90, 135, 180, 225, 270 and 315 degrees. As depicted in Figure 6.4, the single 8 port diffuser design has the potential for plume interactions, although the degree of interaction is dependent on the circumference of the diffuser head, with a larger diffuser spreading the plume over a wider area and minimising plume interaction. Further visualisation of the single 8 port diffuser and the dual 4 port diffuser designs is provided in Figure 6.5. The final design of the diffuser would largely depend on the construction methods developed for securing the diffuser to the river bed.

Figure 6.6 depicts 2-D and 3-D visualisations of the 2 port diffuser proposed for Iluka. As each port would be at 90 degrees to the flow (and 180 degrees from each other) no plume interactions is anticipated. Similar to the Yamba diffuser, the final detailed concept design, including riser dimensions, would be developed in conjunction with the construction methods determined for securing the diffuser to the river bed (AECOM, 2010).

The plume visualisations depicted in Figures 6.1 – 6.6 also provide an indication of the distance from the release structures to the end of the near-field zone. For the Yamba diffuser this distance is approximately 50 m, whereas for Iluka this distance is approximately 40 m. Both distances are based on the 50th percentile ambient flow rates and will vary under alternative ambient flow velocities.

6.2.5 Recycled Water Plume Performance

As stated in Section 6.2.2, a dilution of 65 times would satisfy the water quality criteria for all analytes except ammonia, which requires a dilution of approximately 200 times. Based on a 50th percentile current velocity (0.5 m/s), a dilution level of 200 times is exceeded at the end of the near-field zone for all concept designs tested (for both Yamba and Iluka).

In the 90th percentile flow velocity scenarios (0.24 m/s), the dilution level is exceeded for all analytes except ammonia. Further modelling was therefore undertaken to calculate the additional far-field mixing required to obtain the sufficient dilutions. These modelling results indicated that >200 times dilution would be achieved within 150 m of the release at both locations.

The dilution results presented in Tables 6.11 – 6.13 are based on a water elevation of 0 m IPD, the 50th and 90th percentile flow velocities and the 90th percentile recycled water quality concentrations. Ambient flows below the 90th percentile (i.e. flows that will occur ~10 % of the time) will result in reduced dilutions. Further, water quality concentrations worse than predicted could occur 10 % of the time. However, based on conjunctive probability, the chances of these two independent events occurring at the same time is 1 %. It is worth noting that all recycled water, regardless of background currents and quality, would be released at a water level greater than 0 m IPD (i.e. allowing for a greater mixing zone).

Within the above discussion it is important to note that the lowest ambient current velocities occur during the beginning of the discharge window when the water levels are the highest. Additional analysis may be required to determine if the higher water levels that occur during this period are sufficient to offset the lower ambient current velocities. Alternatively, if the 3 hour operating window could be shortened, then the time until when the release commences could be increased from 30 minutes to say 60 or 90 minutes. This would ensure that the recycled water is released during the highest ambient current velocities.

6.3 Hydraulic Assessment

The head loss calculations for each of the conceptual designs are provided in Tables 6.2 - 6.4. Trenchless Advisors Pty Ltd have been commissioned to calculate the length and orientation of the pipeline. Preliminary estimates for the delivery pipelines suggest a 315 mm Outside Diameter (OD) HDPE pipe for Iluka and a 560 mm OD HDPE pipe for Yamba. Values for the mean inside diameter (ID) of the delivery pipelines (see Table 6.14) were sourced from Iplex Pipelines NZ Limited (Iplex Civil Product Brochure, 2008) and were used in the completing the following hydraulic assessment.

Table 6.14: **Polythene pipe dimensions certified to AS 4130 Series 1 (mm)**

(Iplex Civil Product Brochure, 2008)

	Mean Wall Thickness	**Mean ID**
PE100 PN20 DN315	37.1	242.3
PE100 PN20 DN560	66.1	430.3

To prevent intrusion of ambient saline water (including sediments) into the outfall, especially during low flow, the port densimetric Froude number should be above unity (Wood *et al.* 1993):

$$F_P = \frac{V_P}{\left(\Delta\rho / \rho_w g D_P\right)^{0.5}} > 1.0$$

Where:

- F_P = densimetric Froud number
- V_P = port exit velocity (m/s)
- D_P = port diameter (m)
- g = gravitational acceleration (9.81 m/s^2)
- ρ_w = density of water (1000 kg/m^3)
- ρ_S = density of seawater (1030 kg/m^3)
- $\Delta\rho$ = $\rho_S - \rho_w$

The above formulation gives a critical port velocity of 0.30 m/s for the Yamba and Iluka diffusers using 300 mm duckbill ports. For the scenarios considered, port exit velocities are considerably higher at the applied design flow rates and the port densimetric Froude number is greater than 2 (two), therefore saltwater intrusion is not likely to be significant. In addition, duckbill valves will help to prevent saltwater intrusion and growth in the diffuser.

As there are no risers for the Yamba and Iluka diffusers, sedimentation can be managed with a flow-purging regime. Estimates of the average dimensions for the Iluka and Yamba delivery pipelines likely to be used to transport effluent to the diffusers are shown in Table 6.14. To achieve scouring of cohesive sediments once a day, shear stress should exceed 4 N/m^2 or minimum daily average flows should result in pipe velocities greater than 0.5 m/s (Wood *et al.* 1993). Based upon the updated design flow rates for Yamba and Iluka (see Appendix B: Table 2), the abovementioned conditions are satisfied for pipeline with pipe velocities greater 2.0 m/s. A friction factor of 0.020 was assumed for smooth HDPE pipes.

As mentioned previously, tidal velocities in the lower estuary typically exceed 1 m/s and peak flood flows at the entrance have been estimated to exceed 6 m/s (PWD, 1988). Recent field observations by WRL (see Section 4.2 and Appendix A) confirm plausible velocity ranges in the vicinity of the ebb tide release locations between 0.52 m/s – 2.5 m/s. WRL considered the above data to be the best approximations available to calculate forces on the Yamba and Iluka ebb tide releases.

Preliminary concept designs (AECOM, 2010) for Yamba and Iluka suggest a maximum 3 m of pipe presenting to the flow (from the point where the pipe emerges from the bedrock to the port). For all considered velocities, the drag force on the pipe is less than 10 kN when the pipe is new. However, marine growth encrusting on the duckbills over time is considered to have negligible effect on the above force calculations. It is important to note that during flood conditions, debris may build up against the pipeline causing even greater drag force on the pipe. Standards Australia (2005) recommend that structures in river estuarine conditions should be designed to withstand a minimum load of 10 kN per metre of structure as they are likely to be subject to flood debris forces.

6.4 Summary

This section provides detailed conceptual designs for the diffuser configurations. Exit velocity and head loss calculations were used to develop optimal configurations for Yamba and Iluka (Table 6.6). Water quality modelling in the near-field zone was then employed to calculate the dilutions that would be achieved with these diffuser configurations under different ambient flow regimes. Both configurations were shown to provide the dilutions required in the near-field zone (approximately 50 m from the release) under 50th percentile flows. Under 90th percentile flows (i.e. the tidal velocities that would occur 10% of the time), the dilution requirements would be achieved within 150 m of the releases.

7. Conclusion

Clarence Valley Council is currently upgrading the sewage treatment systems for the towns of Yamba and Iluka, located at the mouth of the Clarence River. As part of this upgrade, excess recycled water will be discharged to the lower Clarence River via independently operating ebb tide releases. Local stakeholder groups have established a range of operating criteria and a proposed area for consideration (Figure 1.2). WRL at the University of New South Wales were commissioned by Clarence Valley Council (via the Department of Commerce) to develop a detailed concept design for both releases.

This report outlines the draft findings of the detailed concept design. The specifications of the designs and the relevant report sections are provided in Table 7.1. These specifications were determined via a targeted fieldwork investigation, computer modelling and analytical calculations in the lower estuary and particularly in the immediate vicinity of the proposed ebb tide releases.

Table 7.1: **Detailed concept design specifications**

General Circulation and Operational Issues		
Section	**Design Specification**	**Outcome**
5.4.1	Location*	The releases should be located approximately 50 m upstream of the easterly extent of the proposed area (Figure 1.2). The releases should be spaced at a minimum of 15 m apart (in a N-S configuration). The final location is dependent on agreement from various parties. The current approximate location is Easting 534310 and Northing 6744822 in MGA coordinates.
3.1	Depth*	Using limited sedimentation data, it is proposed that the mid-line depth of the diffuser ports be set at 6 m below Iluka Port Datum; approximately 1.5 m above the bed level.
5.4.4	Operational Timeframe*	During average (or base) flows the releases can effectively operate for 3 hours, commencing 30 minutes from the start of the ebb tide flow.
5.4.2	Design Velocity (for Water Quality)	Based on the operational timeframe: A 50^{th} percentile ebb tide velocity of 0.50 m/s A 90^{th} percentile ebb tide velocity of 0.24 m/s Design forces will be determined based on the final structure.
3.1	Sedimentation Analysis*	Sediments are actively being mobilised in the lower estuary. The sediment dynamics are highly complex and scouring / burying of the release structure is a significant risk.
5.4.6	Scouring Dynamics*	Spring ebb and flood tides mobilise sediment. During flood flows there is the potential for scouring to the coffee rock strata. Delivery pipelines and related infrastructure will be secured within the coffee rock strata.
5.4.5	Circulation Processes during High Flows	Modelling simulations indicate that recycled water released during high flows will not be transported upstream or in the vicinity of the Oyster Channel
Diffuser Design and Near-Field Modelling		
6.1	Exit Velocity	The exit velocity of the preferred diffuser configuration is < 3.0 m/s (Table 6.6)
6.1	Headloss	Headloss per riser is <0.4 m (Table 6.6)
6.1	Number of Ports*	Iluka: 2 ports Yamba: 8 ports
6.1	Port Size	Port sizes are 300 mm duckbill valves
6.2.4	Port Angle	Iluka: 90 and 180 degrees

	(relative to flow)	Yamba: 0, 45, 90, 135, 180, 225, 270 and 315
6.2.2	Required Dilutions	Required Dilutions: 65 for most parameters; ~200 for Ammonia
6.2.3	Achieved Dilutions* (50th percentile flow)	Iluka: Average near-field dilution > 300 Yamba: Average near-field dilution is 295 for dual design and 252 for single design (does not include plume interaction).
6.2.5	Achieved Dilutions* (90th percentile flow)	Both configurations achieve required dilutions within 150 m of release location for 90th percentile flows. Flows >90th percentile require further analysis.
6.2.4	Near-field Plume Dynamics*	Near-field zone ends at 40 m for Iluka and 50 m for Iluka based on 50th percentile ambient flows.
6.3	Hydraulic Assessment	Once purged, saltwater intrusion is not likely to be significant and scouring should be achieved regularly. A minimum load design of 10 kN per metre of structure is recommended.

* See attached appendices for additional specifications.

Additional information is required concerning the sedimentation dynamics and the construction of the delivery pipeline and diffuser support structure. Preliminary consultation with relevant engineering groups has been undertaken and the relevant investigations are either underway or in the process of being commissioned. Once this data is available, further specifications regarding the hydraulics and the diffuser configurations will be developed, including detailed conceptual drawings. The final configuration would be presented and discussed with the various stakeholder groups.

Additional investigations undertaken subsequent to the submission of this report are provided as appendices. These WRL reports pertain to sediment and flow dynamics in the vicinity of the release (Appendix A) and updated hydraulic analyses of the release structure based on varied discharge regimes (Appendix B). Information related to the bed and superstructure can be found in AECOM (2010) and Douglas Partners (2010).

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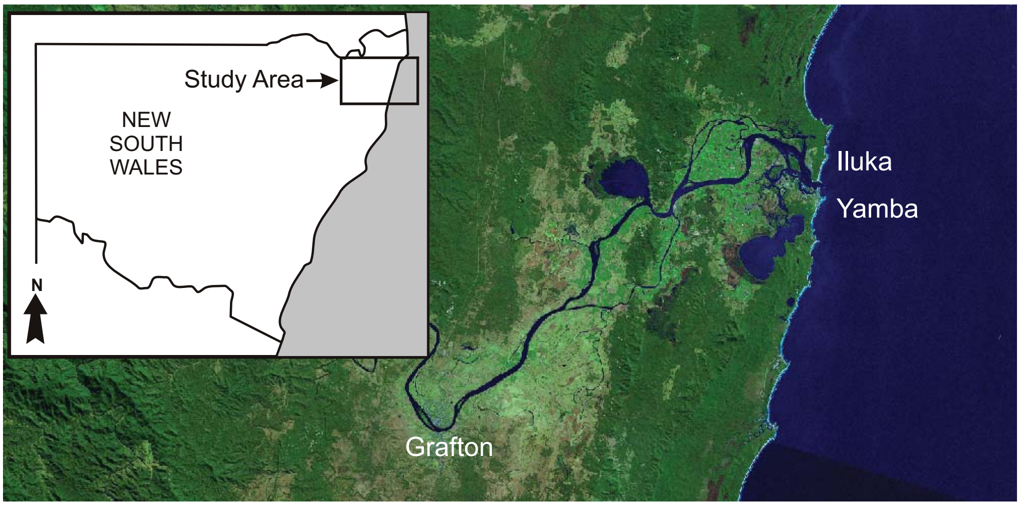

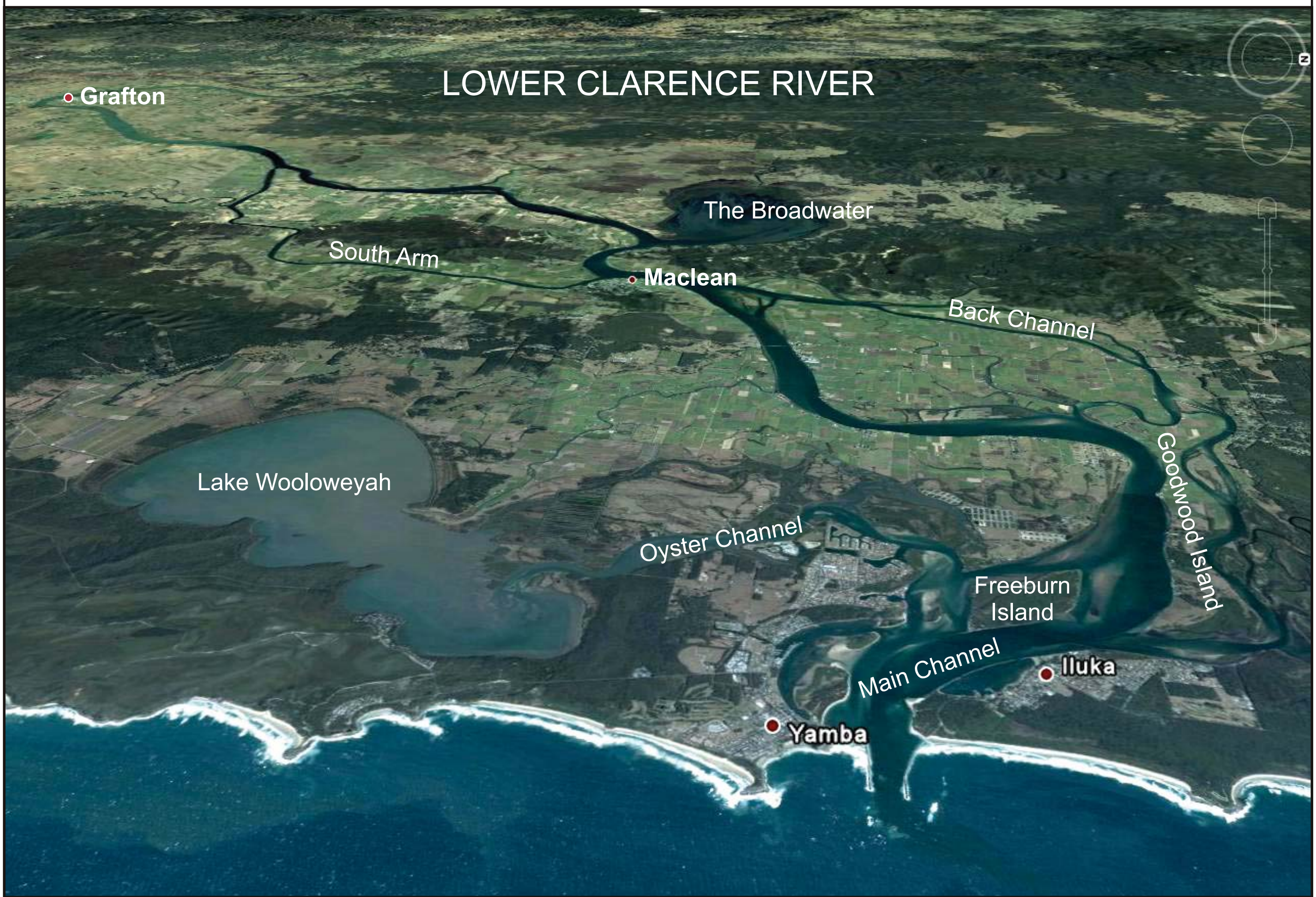

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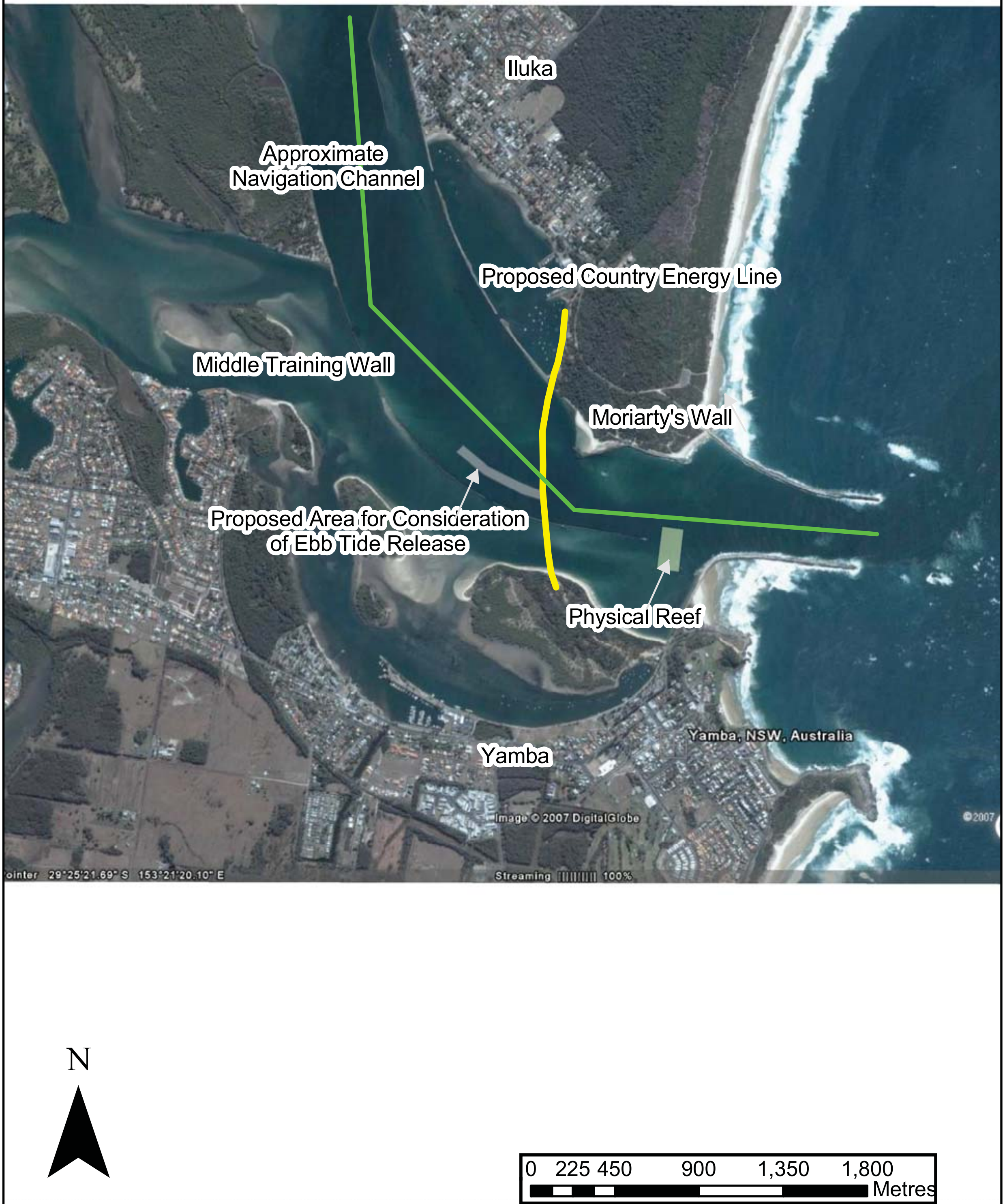

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PROPOSED RELEASE LOCATION

Figure 1.2

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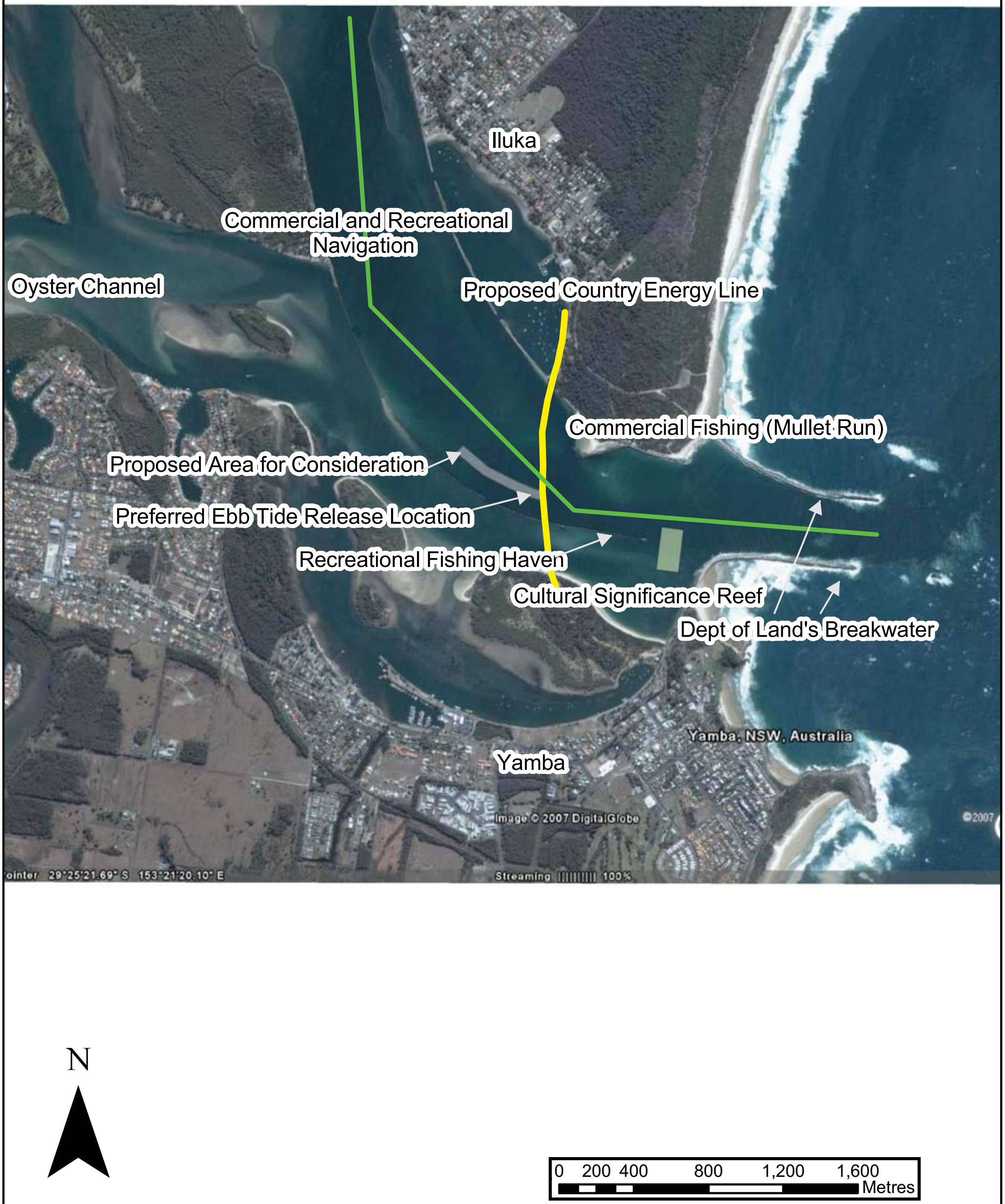

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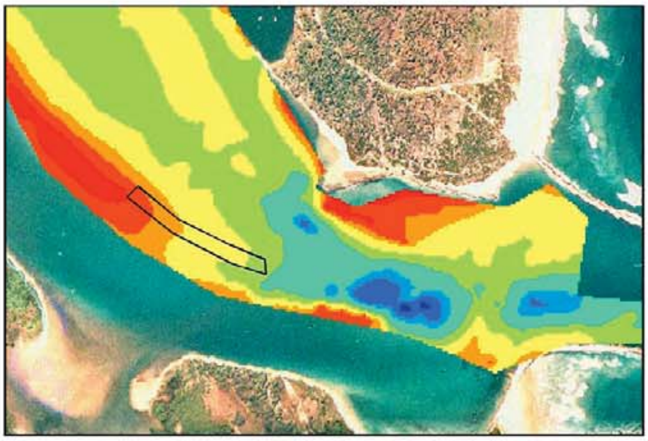
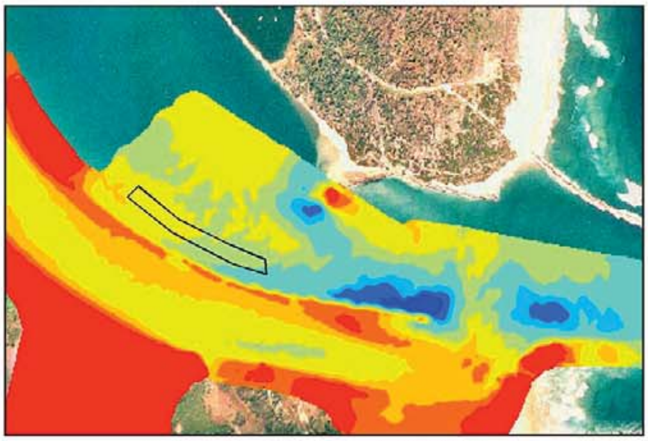
SITE CONSTRAINTS AND PREFERRED RELEASE LOCATION

Figure 2.1

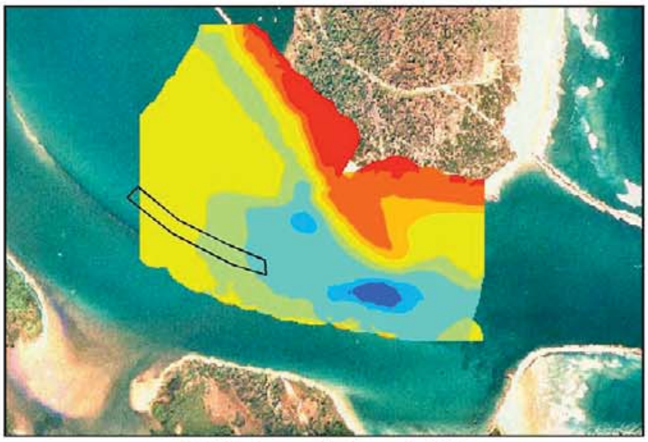
L080620_Fig8.mxd



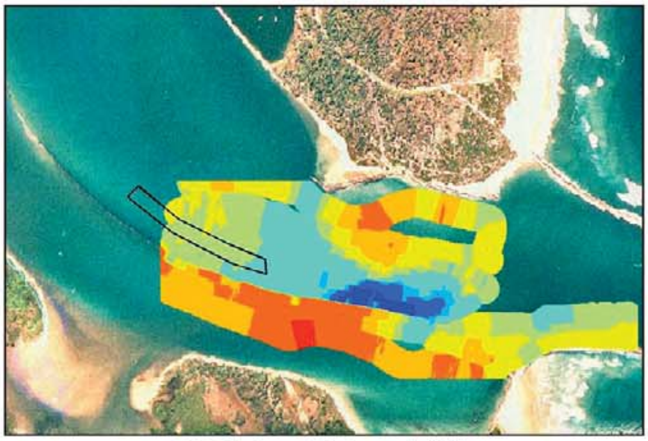
1979 Hydrographic Survey by PWD



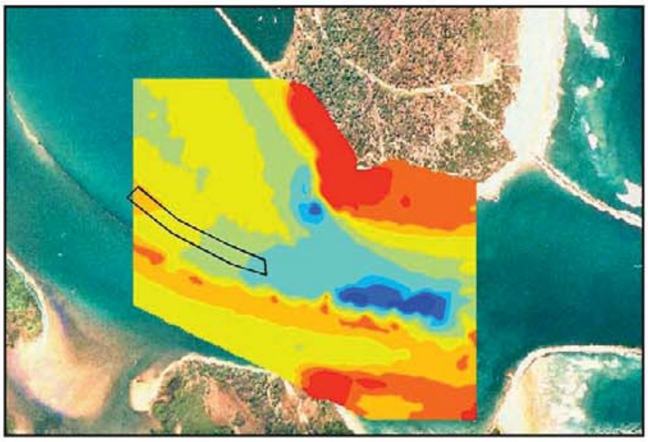
2002 Hydrographic Survey by NSW DLWC



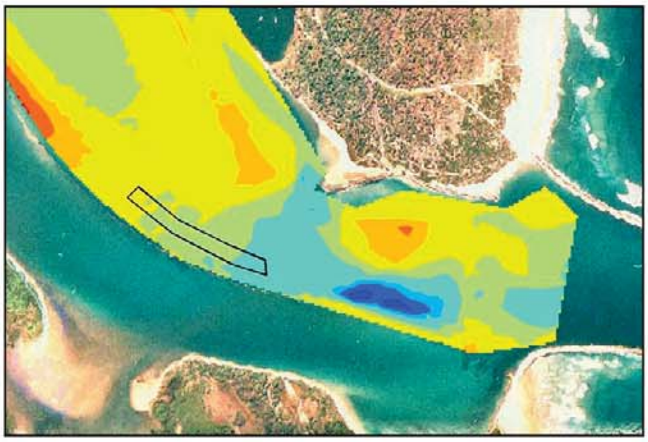
1986 Hydrographic Survey by MSB



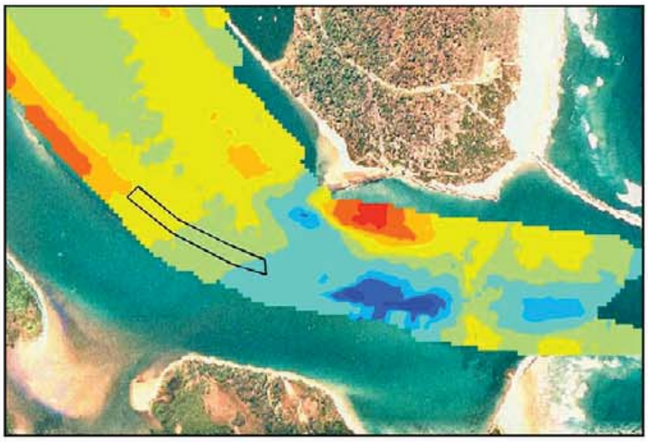
2007 Hydrographic Survey by WRL



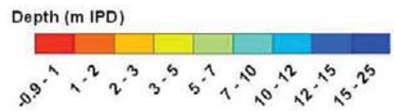
1988 Hydrographic Survey by MSB



2008 Hydrographic Survey by WRL

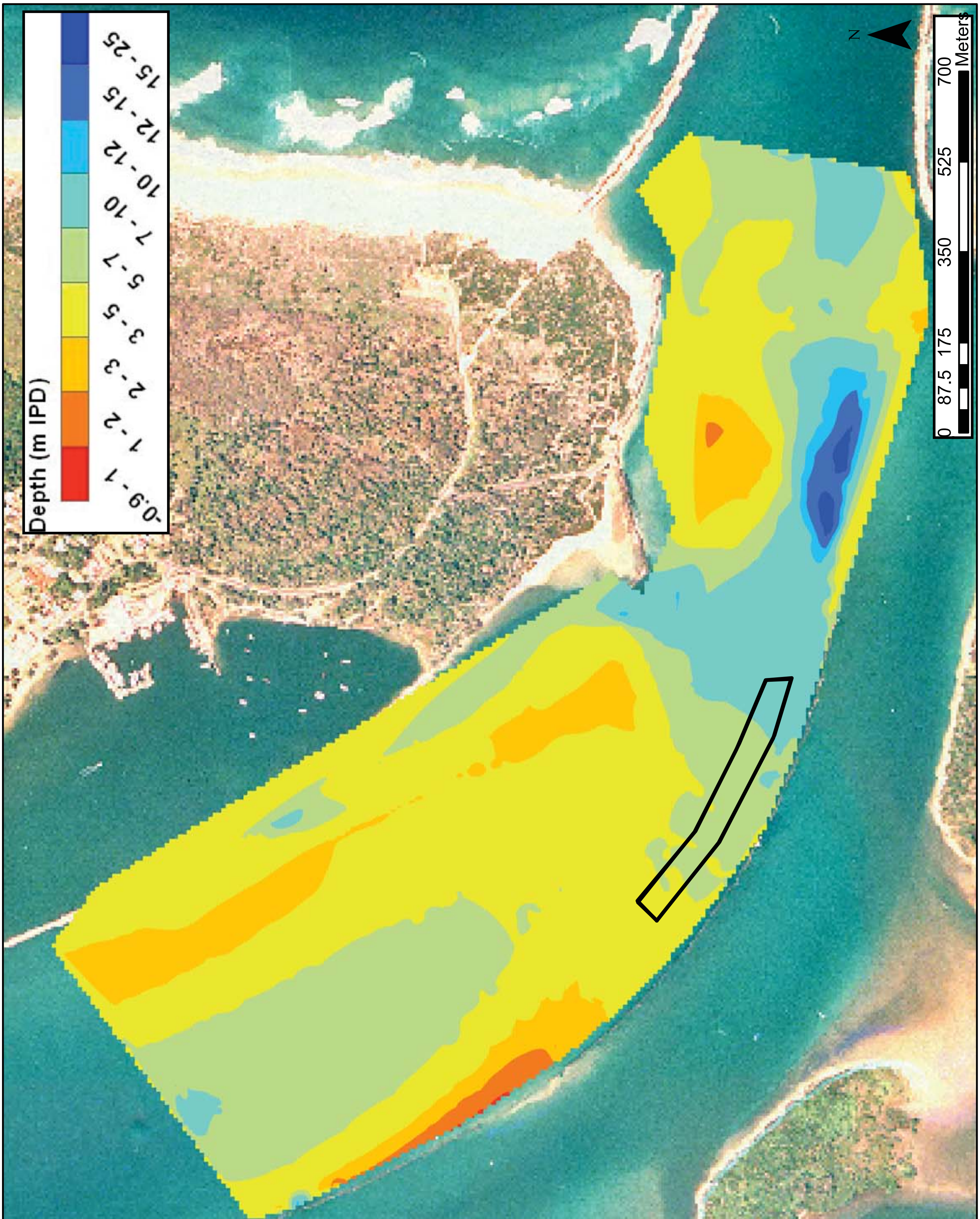


1999 Hydrographic Survey by Sydney Ports

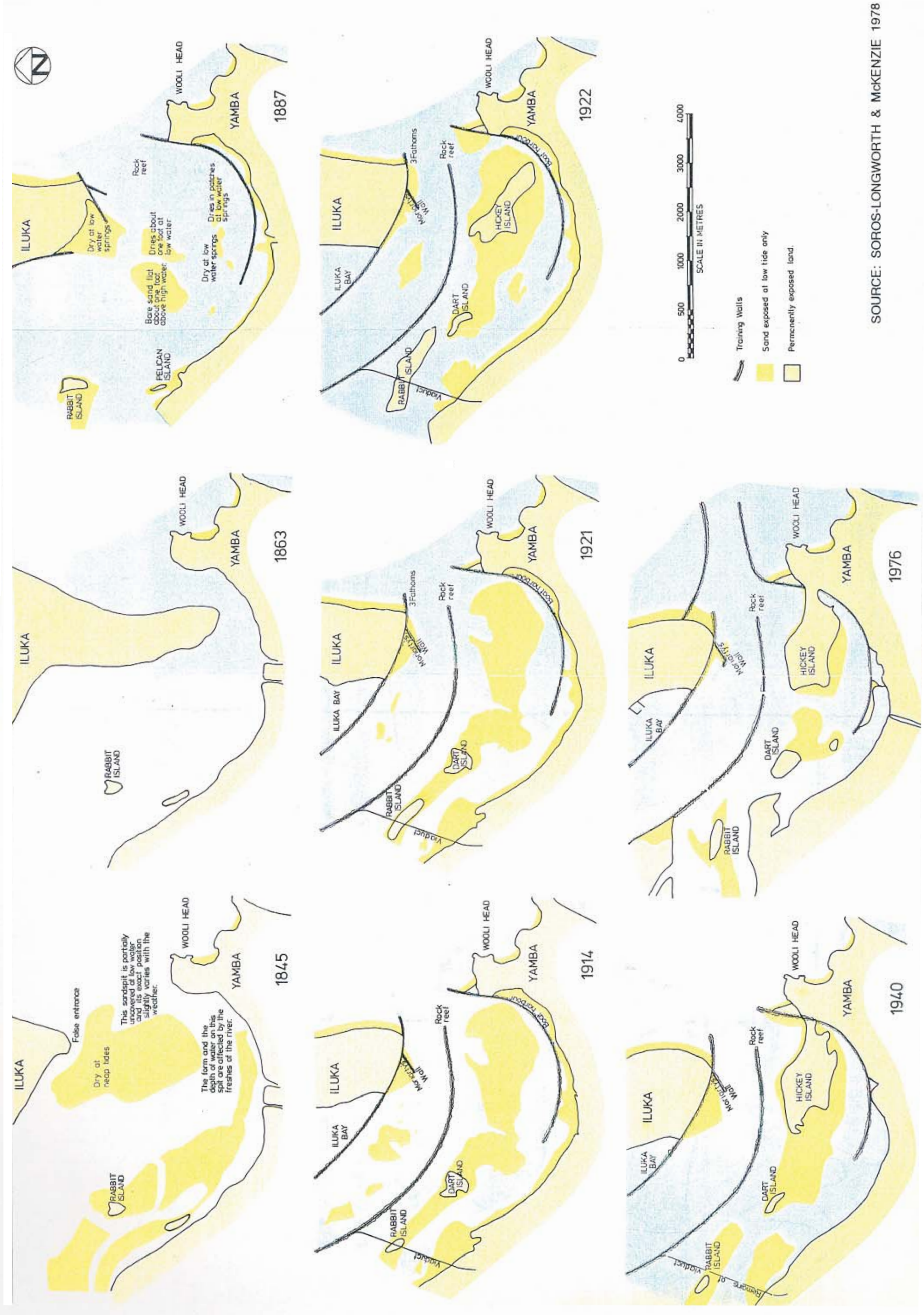


SUMMARY OF ENTRANCE HYDROGRAPHIC SURVEYS
(PROPOSED AREA OF INTEREST INDICATED BY RECTANGLE)

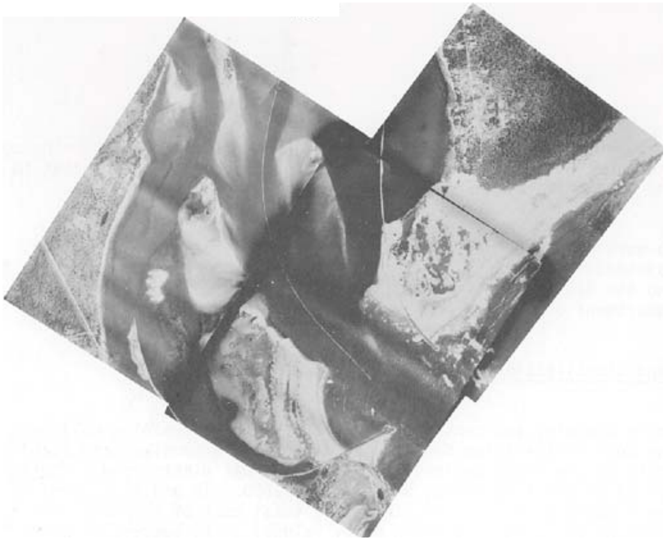
Figure
3.1



WRL Report No. 2008/28	2008 WRL BATHYMETRIC SURVEY RESULTS (in m IPD)	Figure 3.2 insert filename



WRL Report No. 2008/28	NATURAL AND INDUCED SITE GEOMORPHOLOGY	Figure 3.3 08069-3.3.cdr



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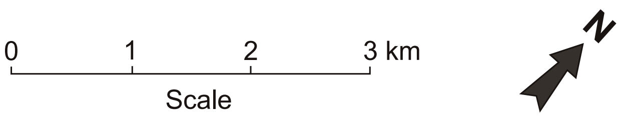

Source of photos: Soros-Longworth & McKenzie

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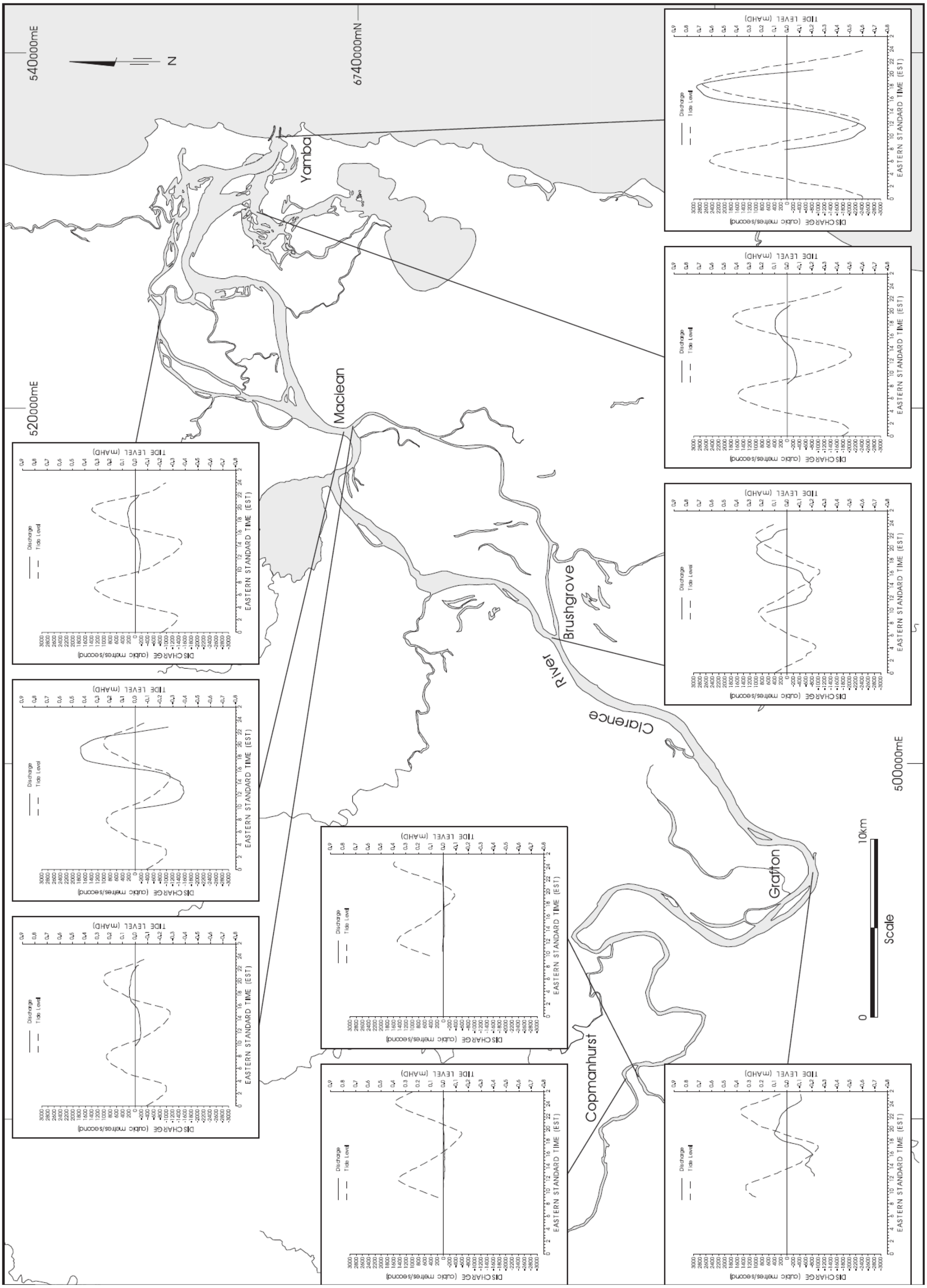
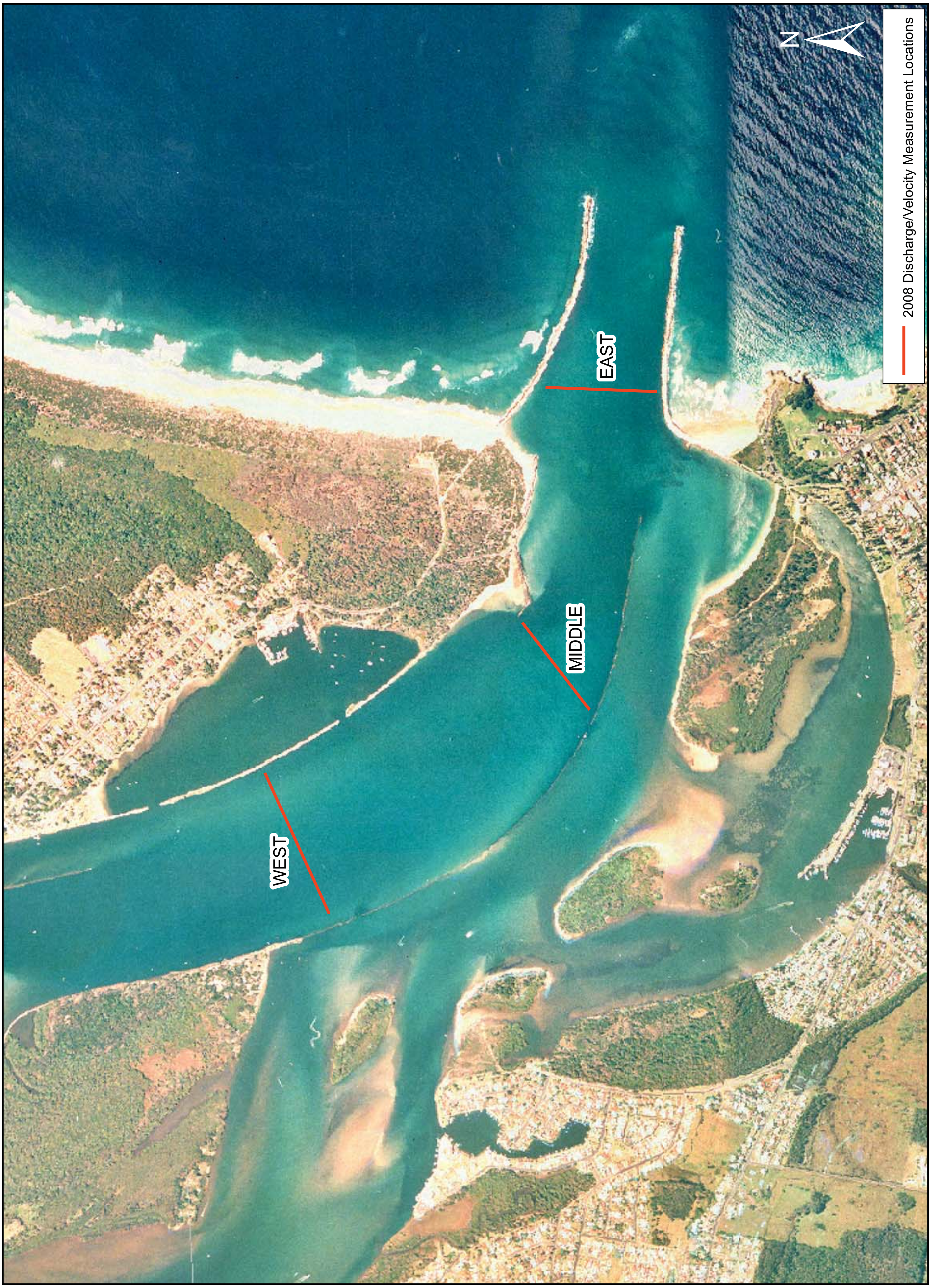


WRL Report No. 2008/28	MHL TIDAL DATA COLLECTION OCTOBER – NOVEMBER 1996 (SOURCE: MHL 1998)	Figure 3.5



WRL Report No. 2008/28	2008 ADCP TRANSECT LOCATIONS	Figure 4.1

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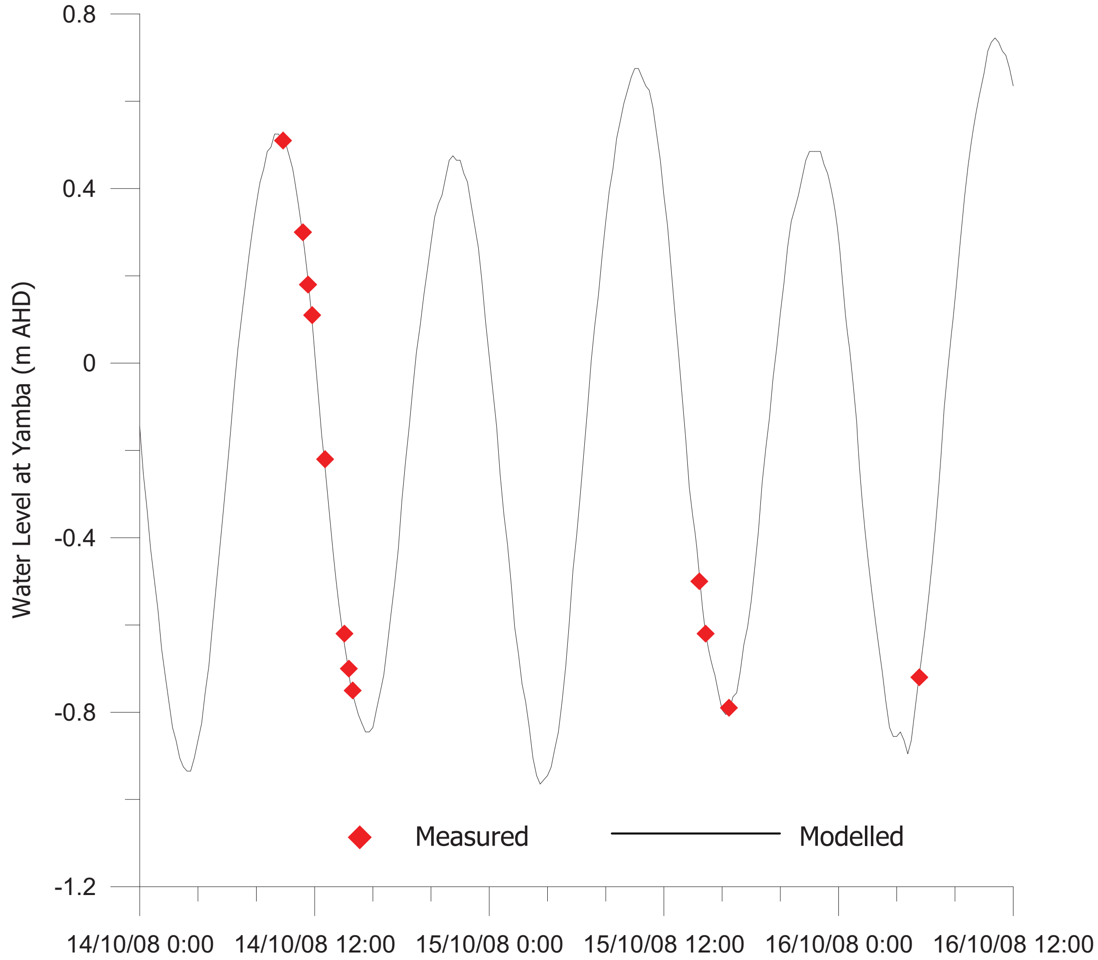
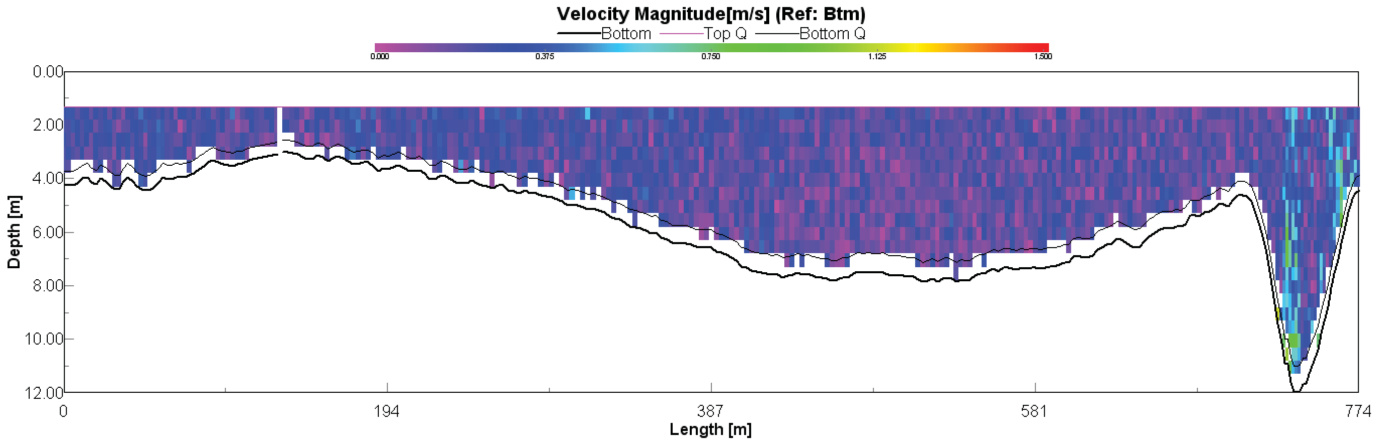
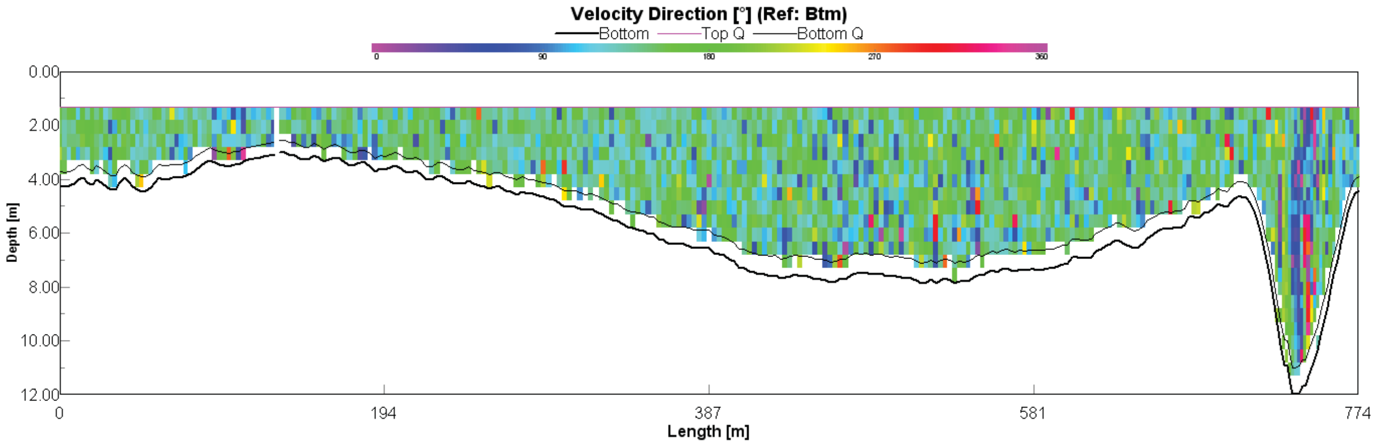
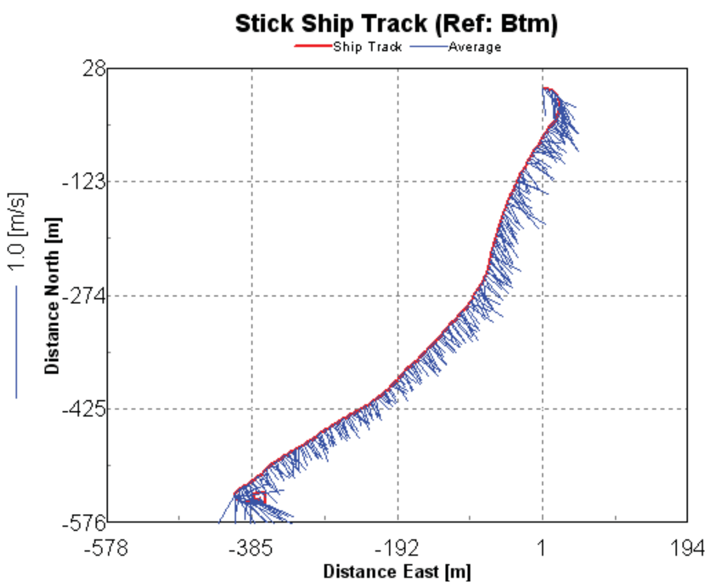
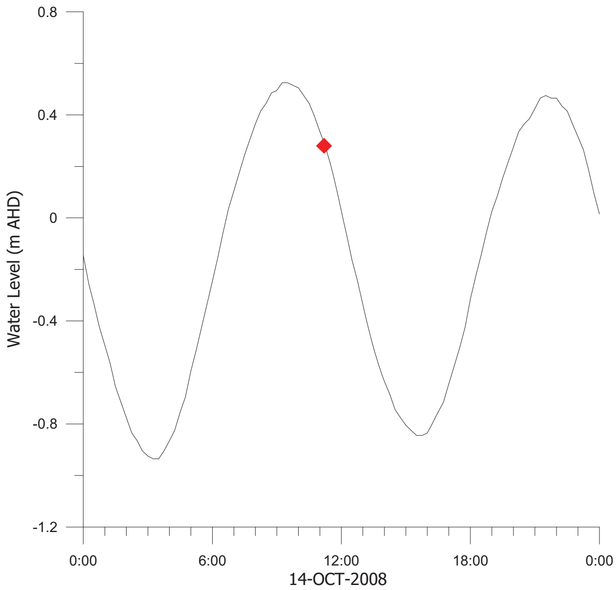


WRL Report No. 2008/28	ADCP TRANSECTS AND WATER LEVEL AT YAMBA	Figure 4.2









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REPRESENTATIVE WESTERN ADCP TRANSECT

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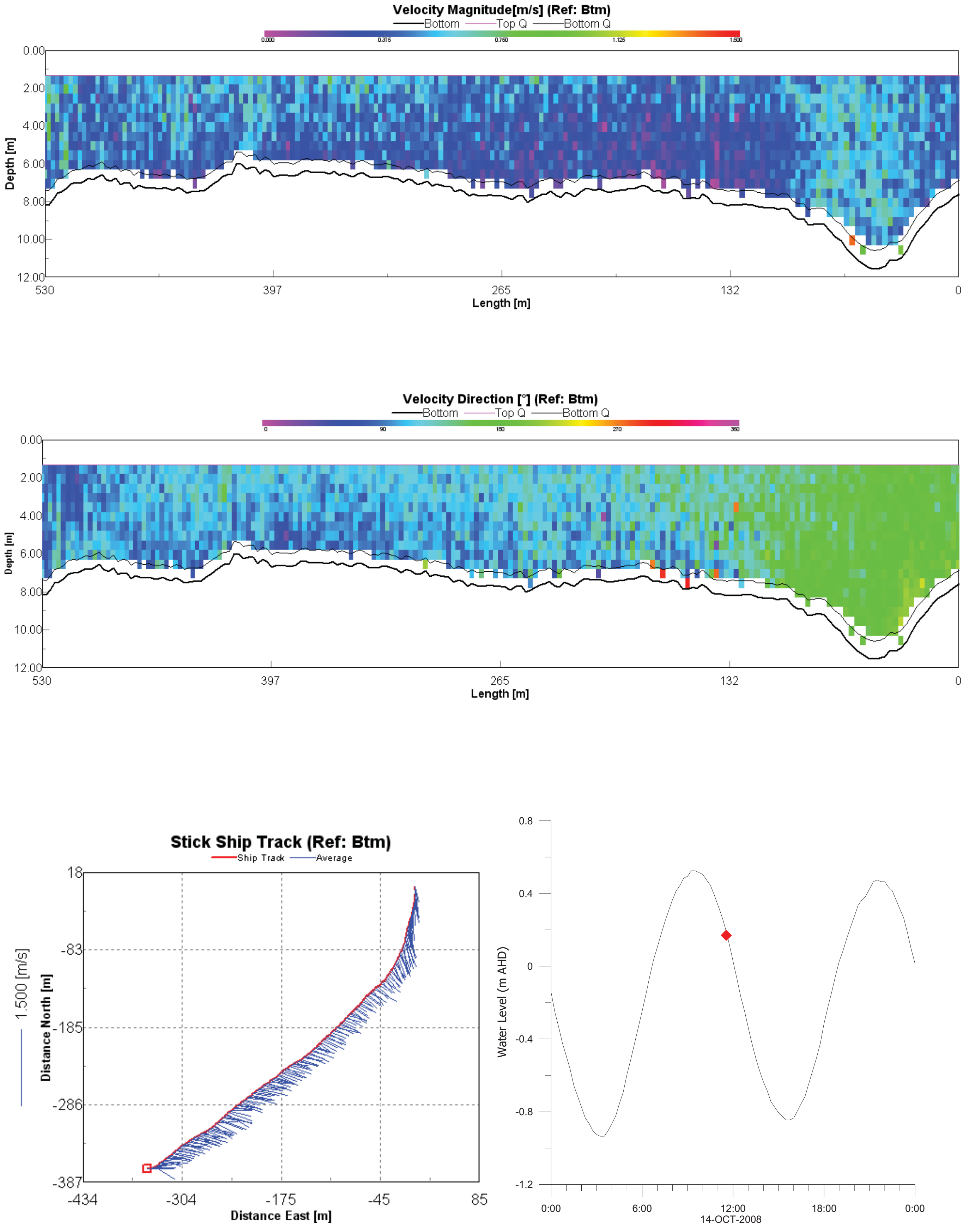
Figure 4.3



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REPRESENTATIVE MIDDLE ADCP TRANSECT

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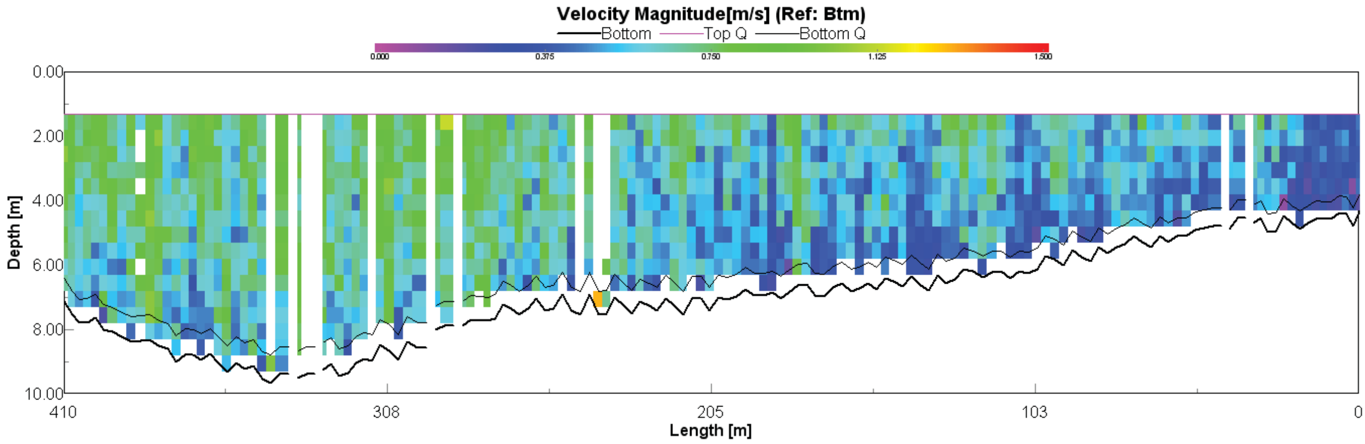
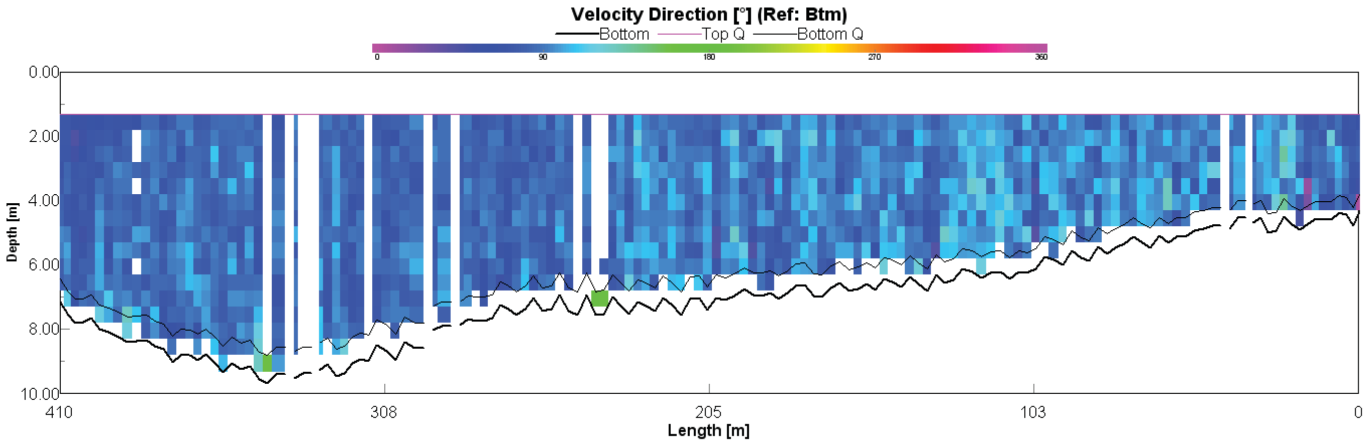
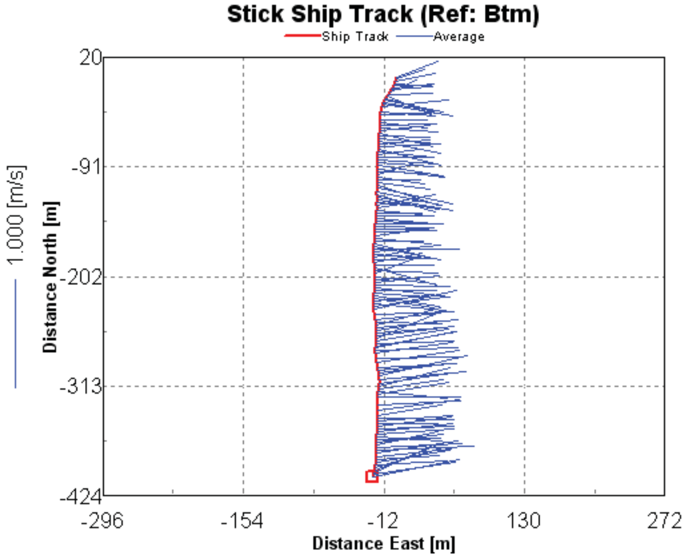
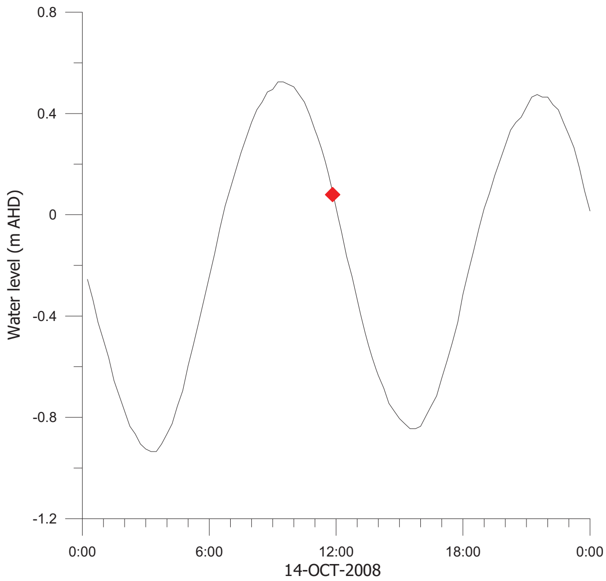
Figure 4.4

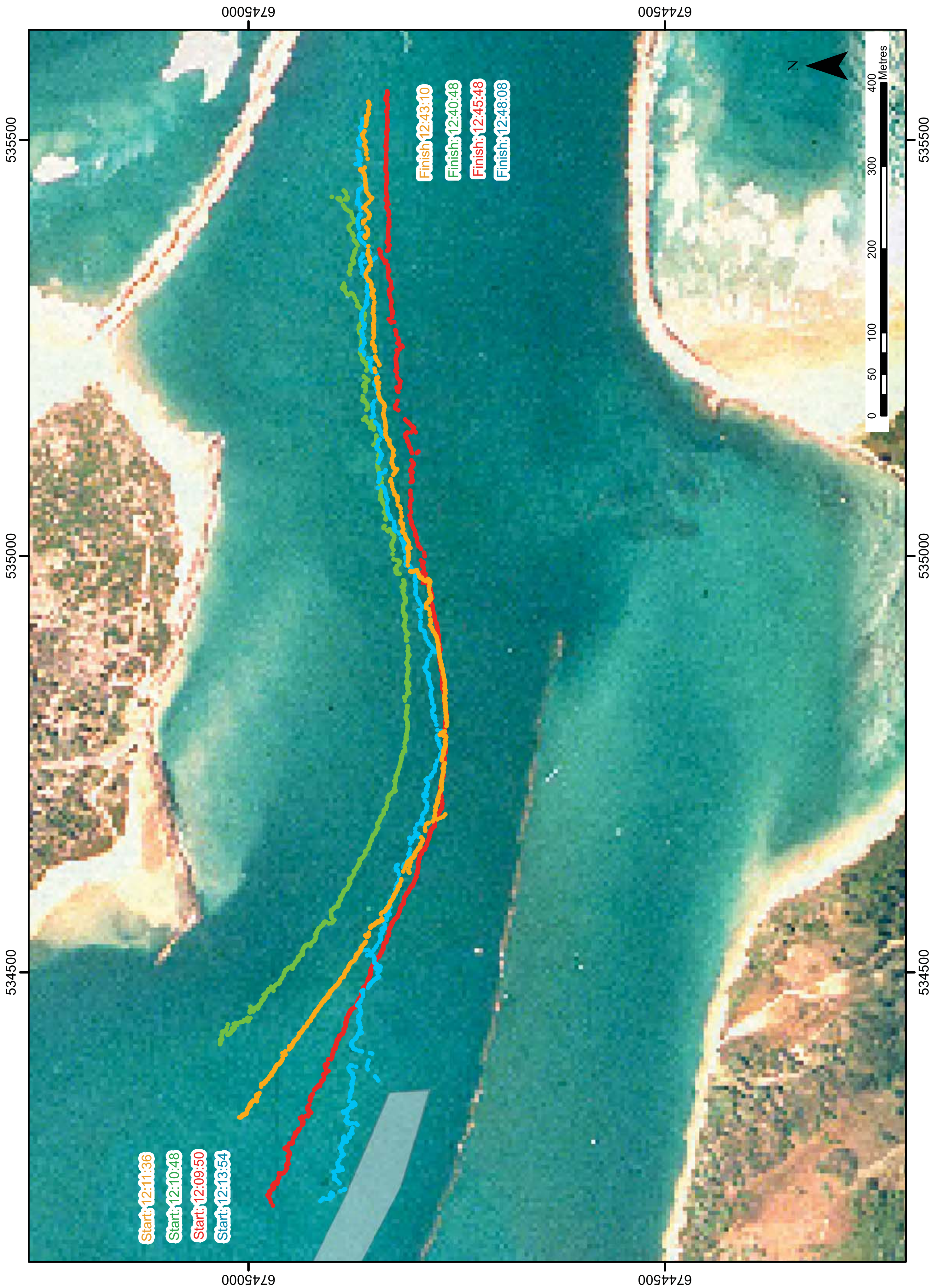








WRL Report No. 2008/28	REPRESENTATIVE EASTERN ADCP TRANSECT (Transect: East 03 14/10/2008 11:50:07)	Figure 4.5

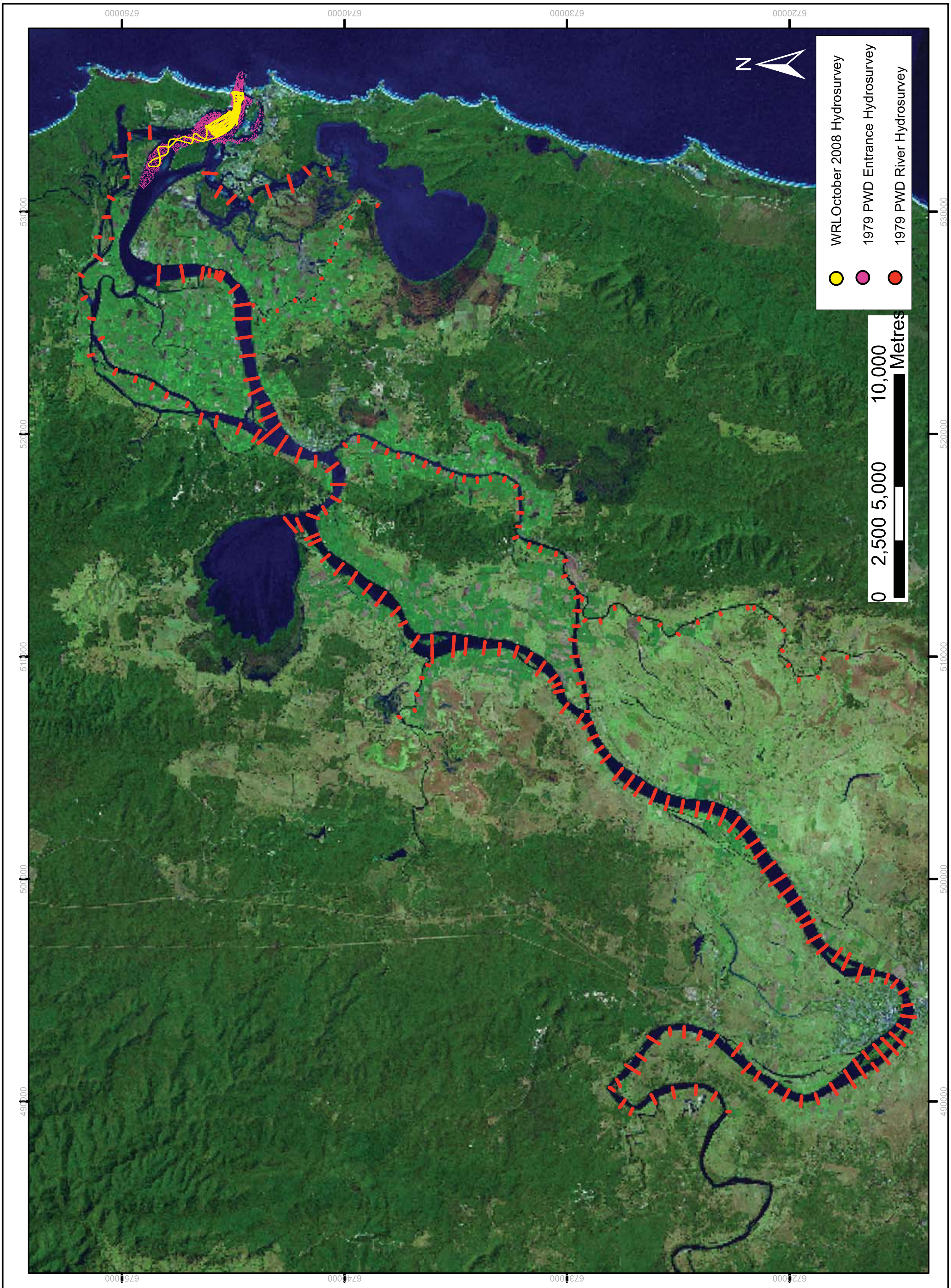


WRL Report No. 2008/28	GPS DROGUE TRACKING RELEASE # 1 (15/10/2008)	Figure 4.6

insert filename

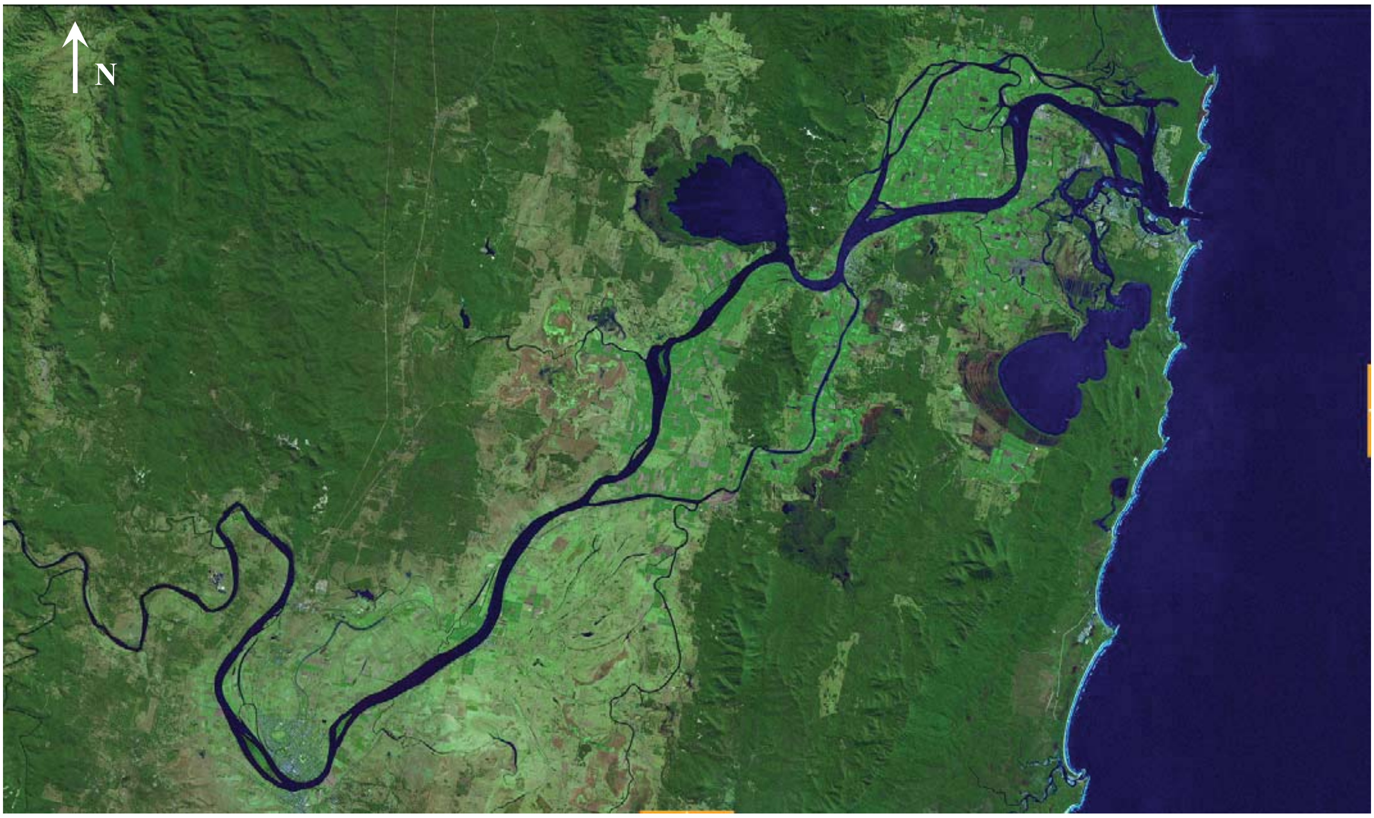
WRL Report No. 2008/28	GPS DROGUE TRACKING RELEASE # 2	Figure 4.7

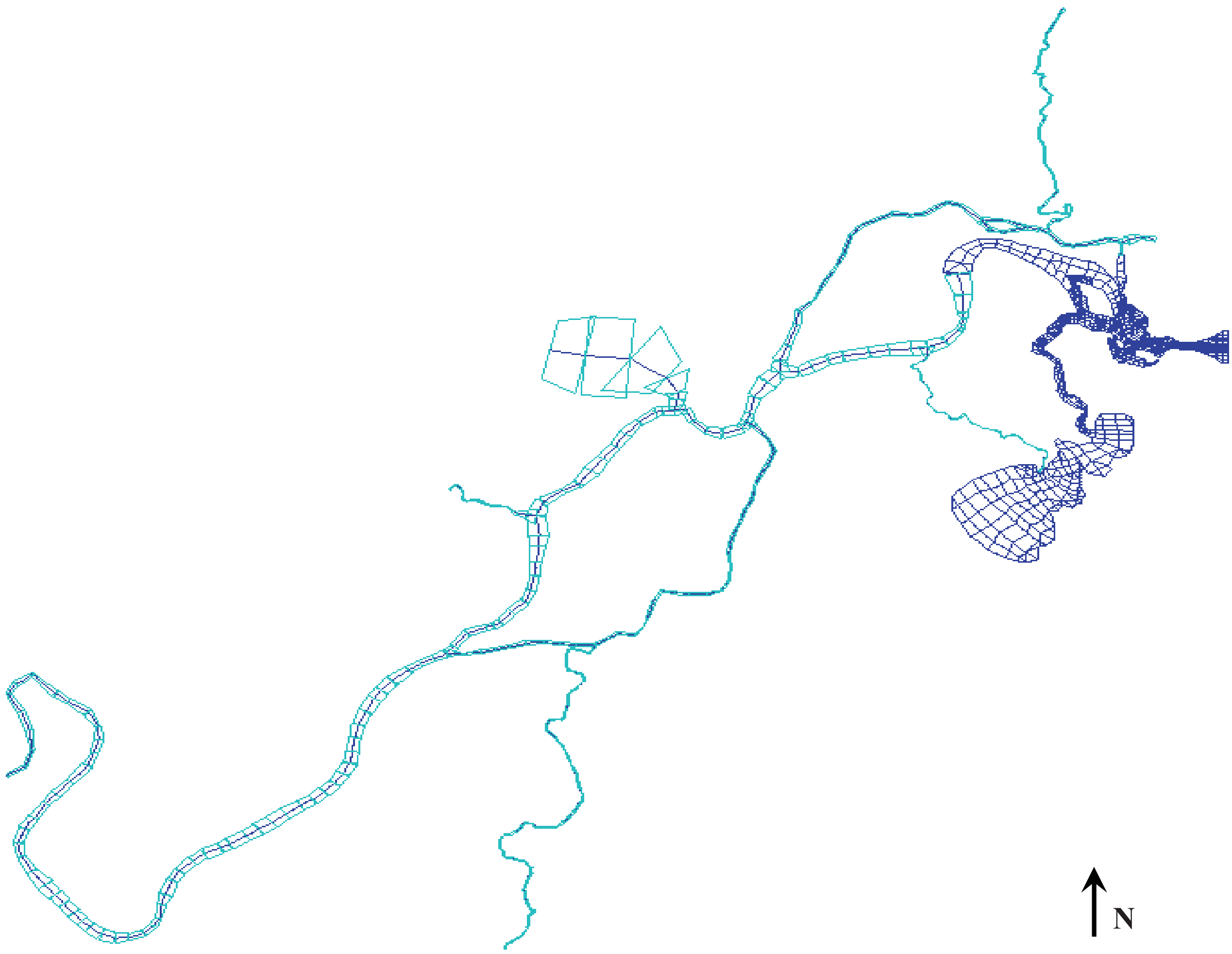
insert filename



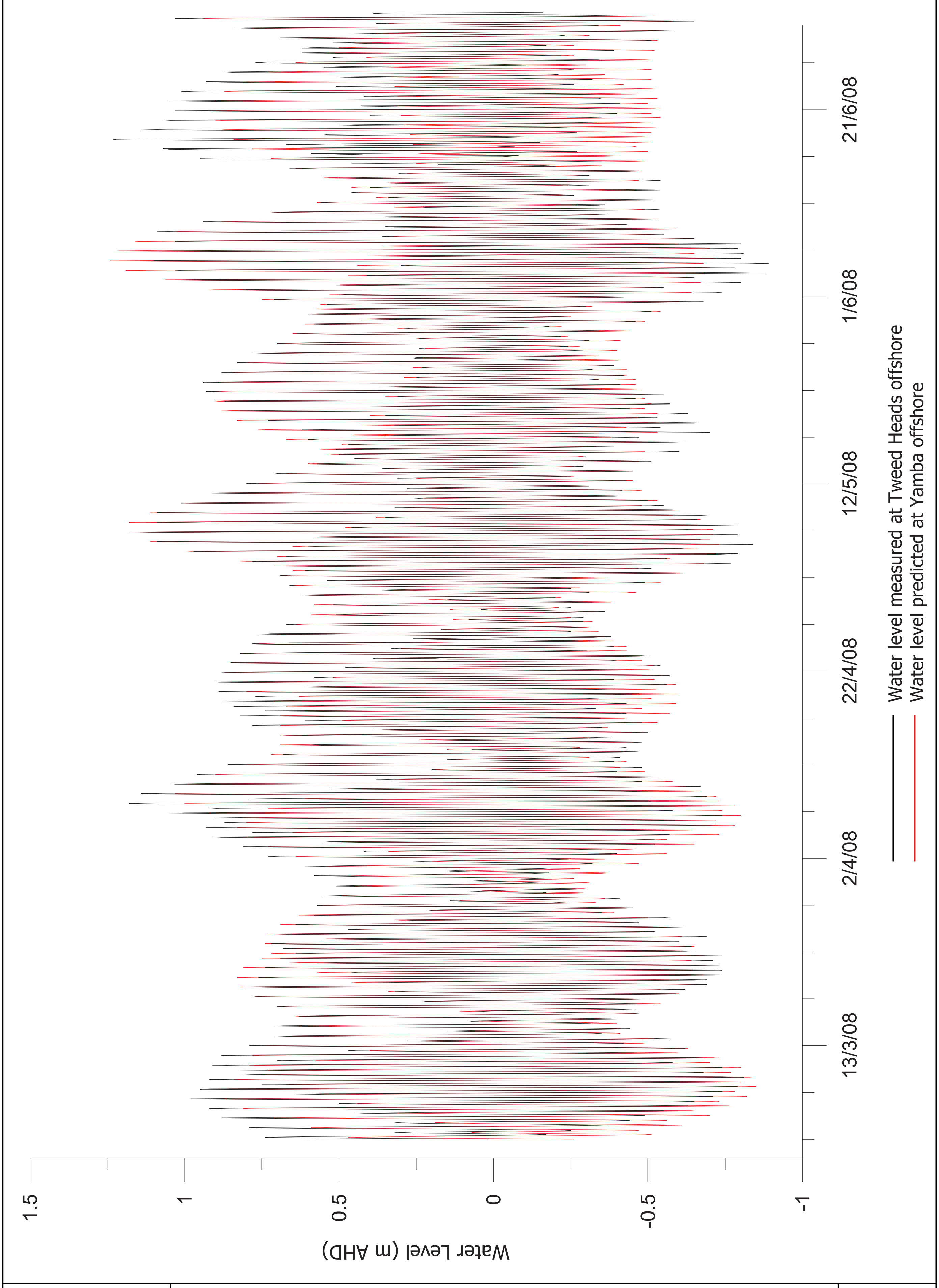
WRL Report No. 2008/28	SURVEY DATA USED TO CONSTRUCT NUMERICAL MODEL	Figure 5.1

TR2008-28-5-1.mxd

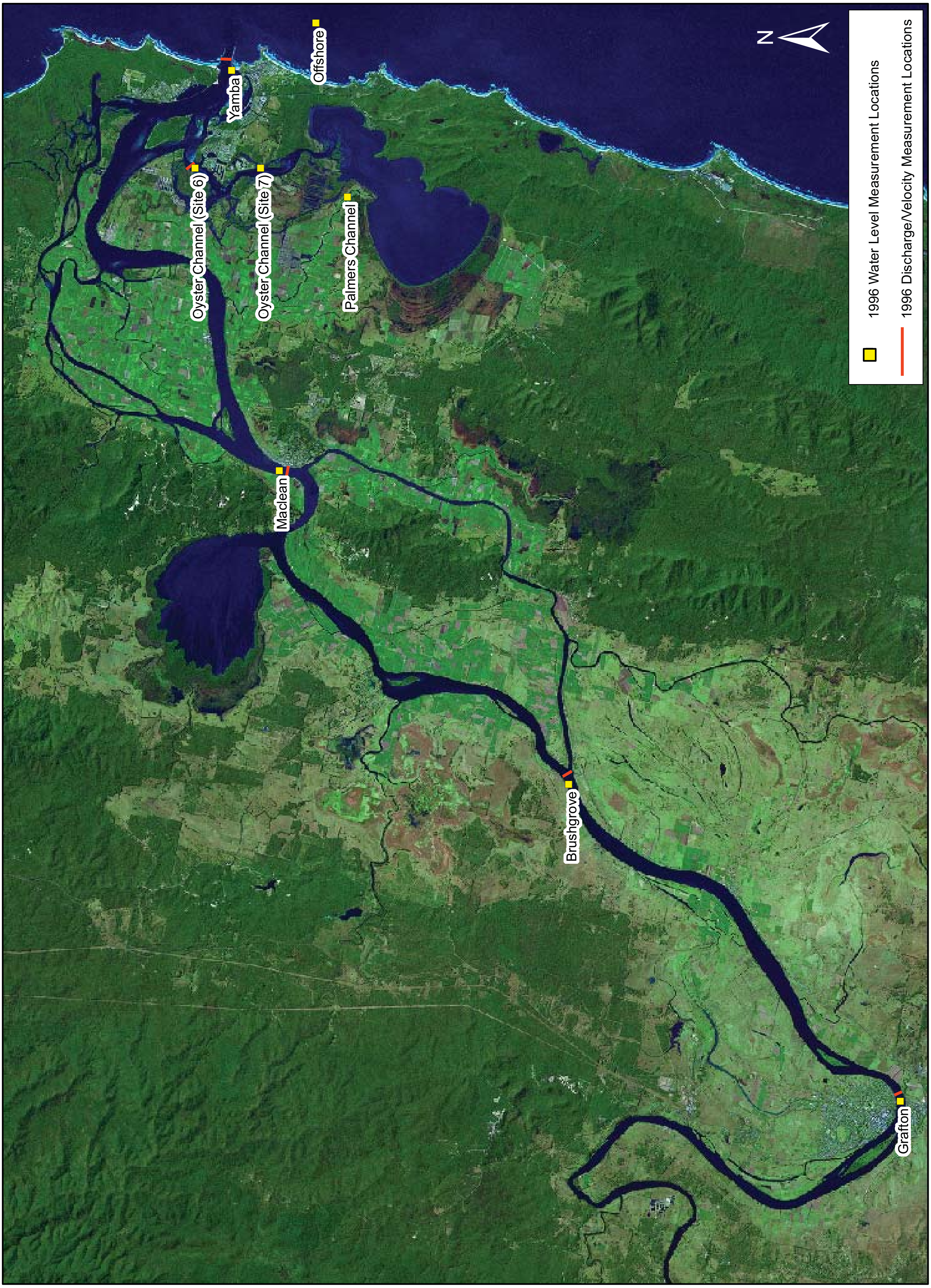




WRL Report No. 2008/28	NUMERICAL MODEL MESH EXTENT	Figure 5.2

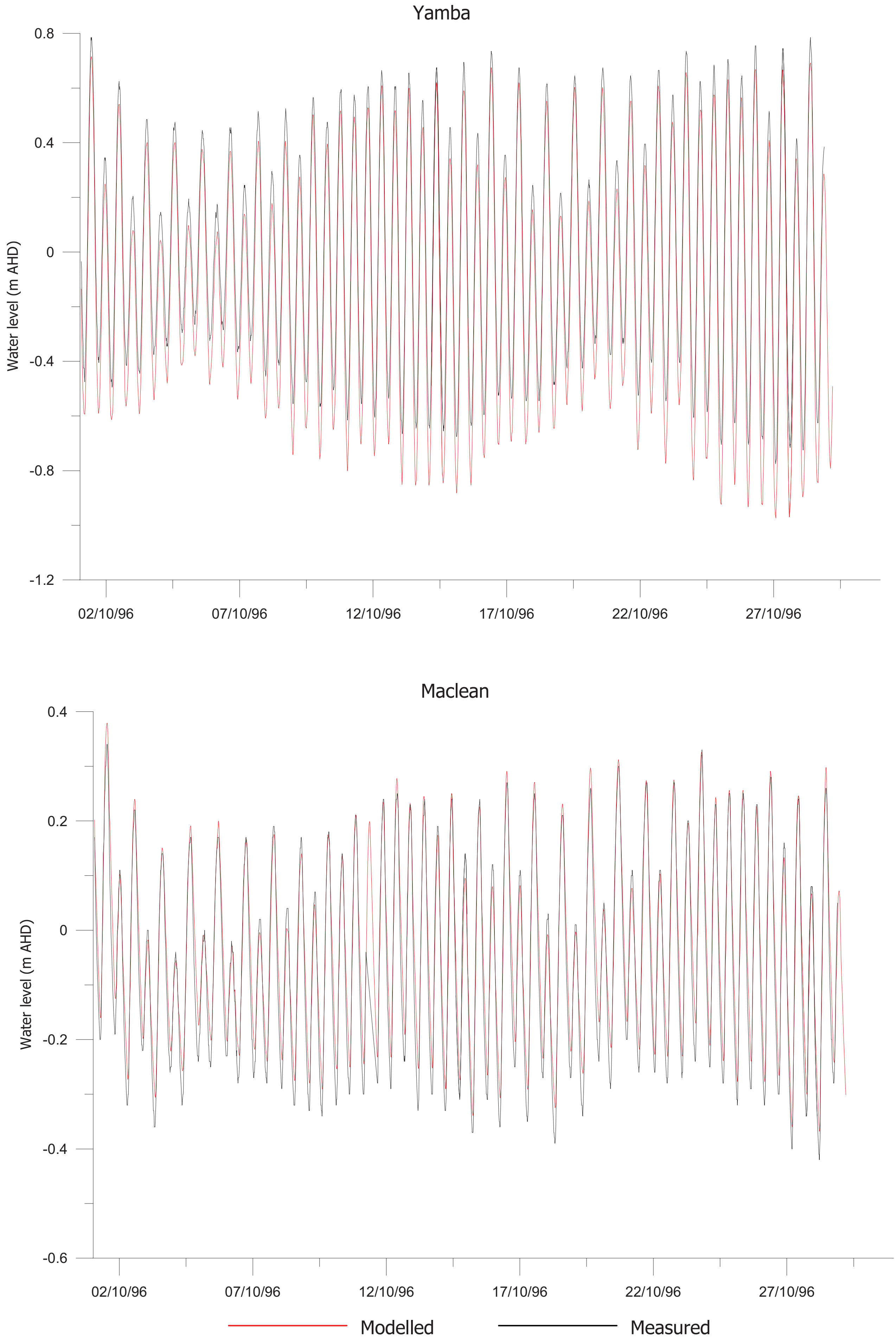


WRL Report No. 2008/28	COMPARISON OF MEASURED AND PREDICTED 2008 OFFSHORE WATER LEVELS	Figure 5.3

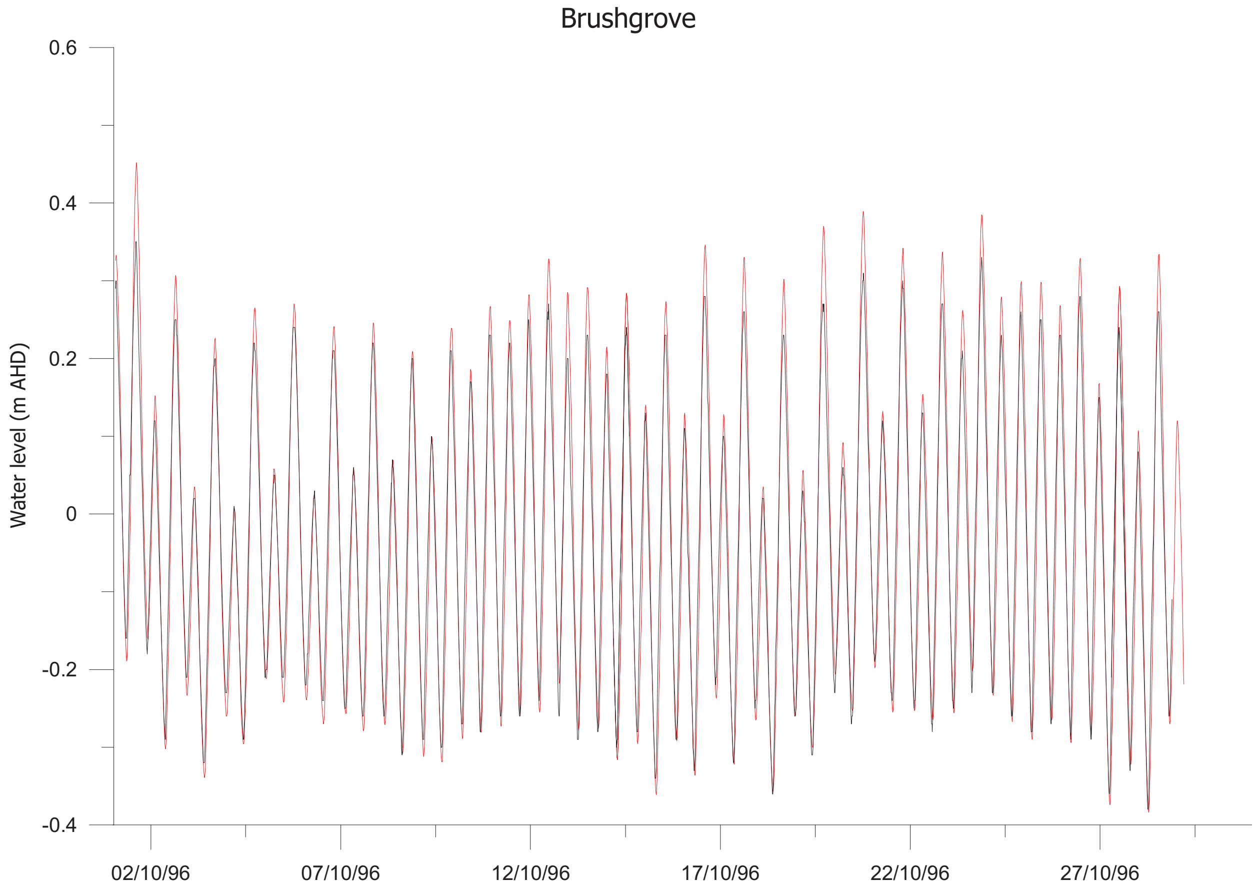


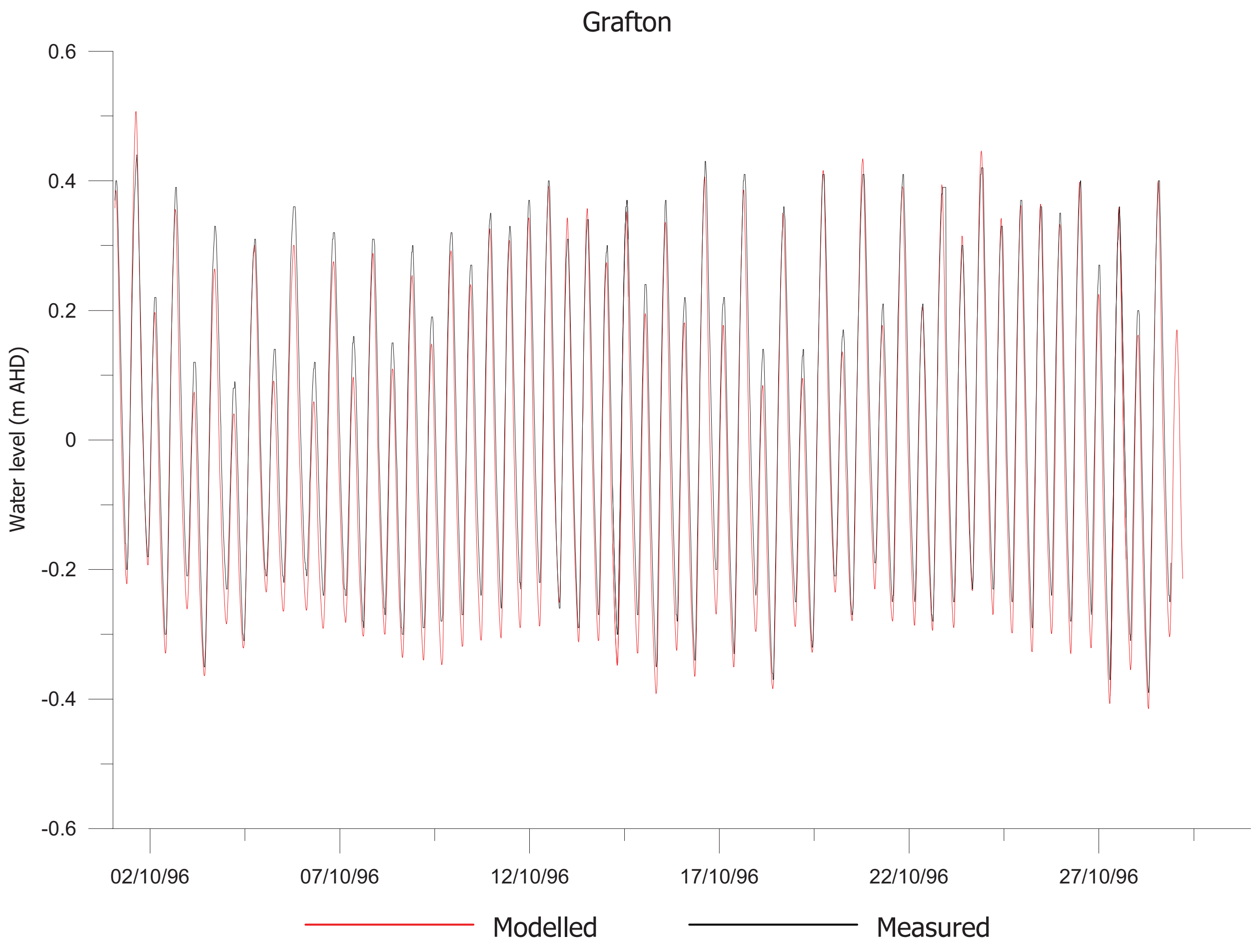
WRL Report No. 2008/28	MEASUREMENT LOCATIONS USED FOR CALIBRATION OF NUMERICAL MODEL	Figure 5.4

TR2008-28_5.4.mxd

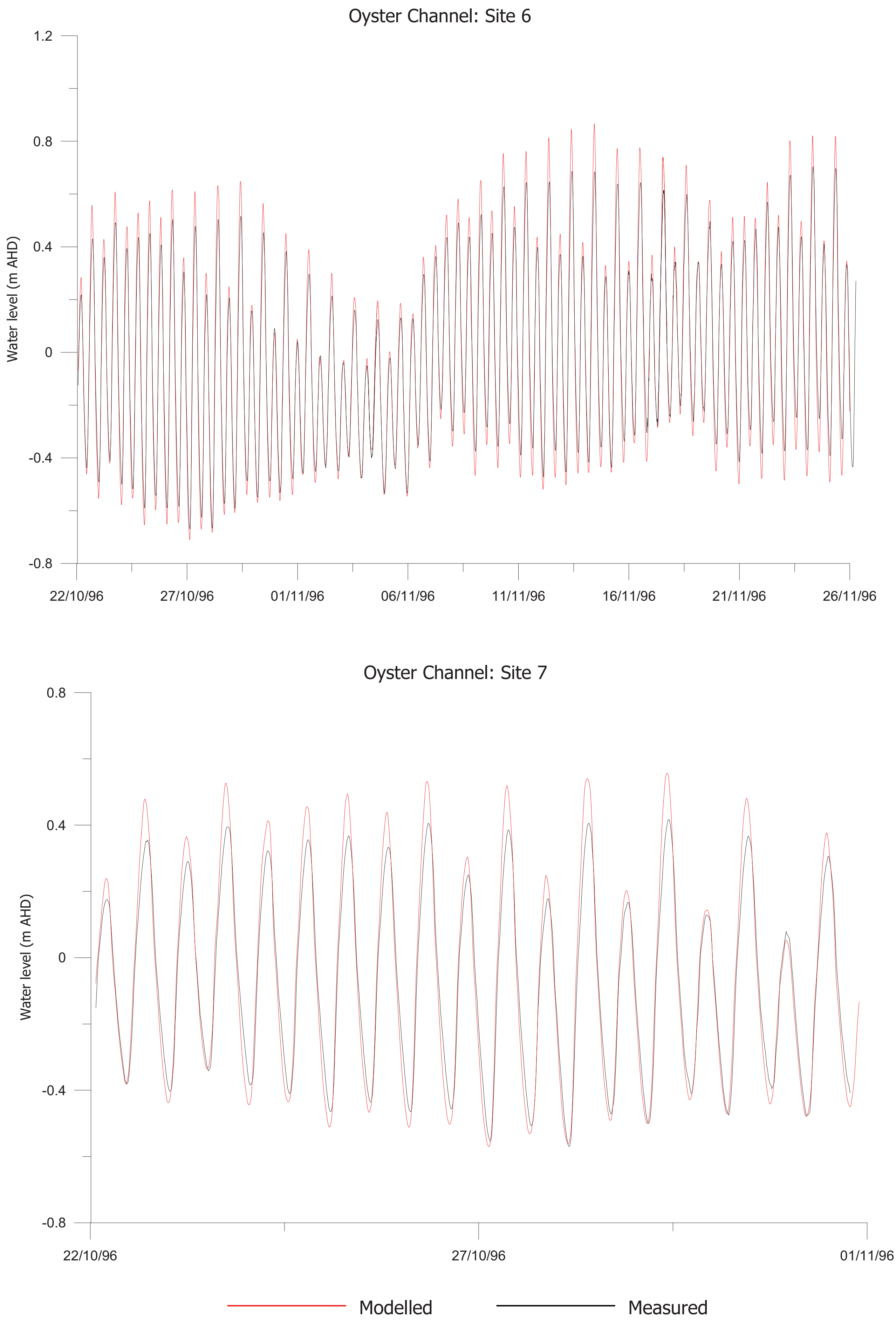


WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 1996 WATER LEVELS AT YAMBA AND MACLEAN	Figure 5.5

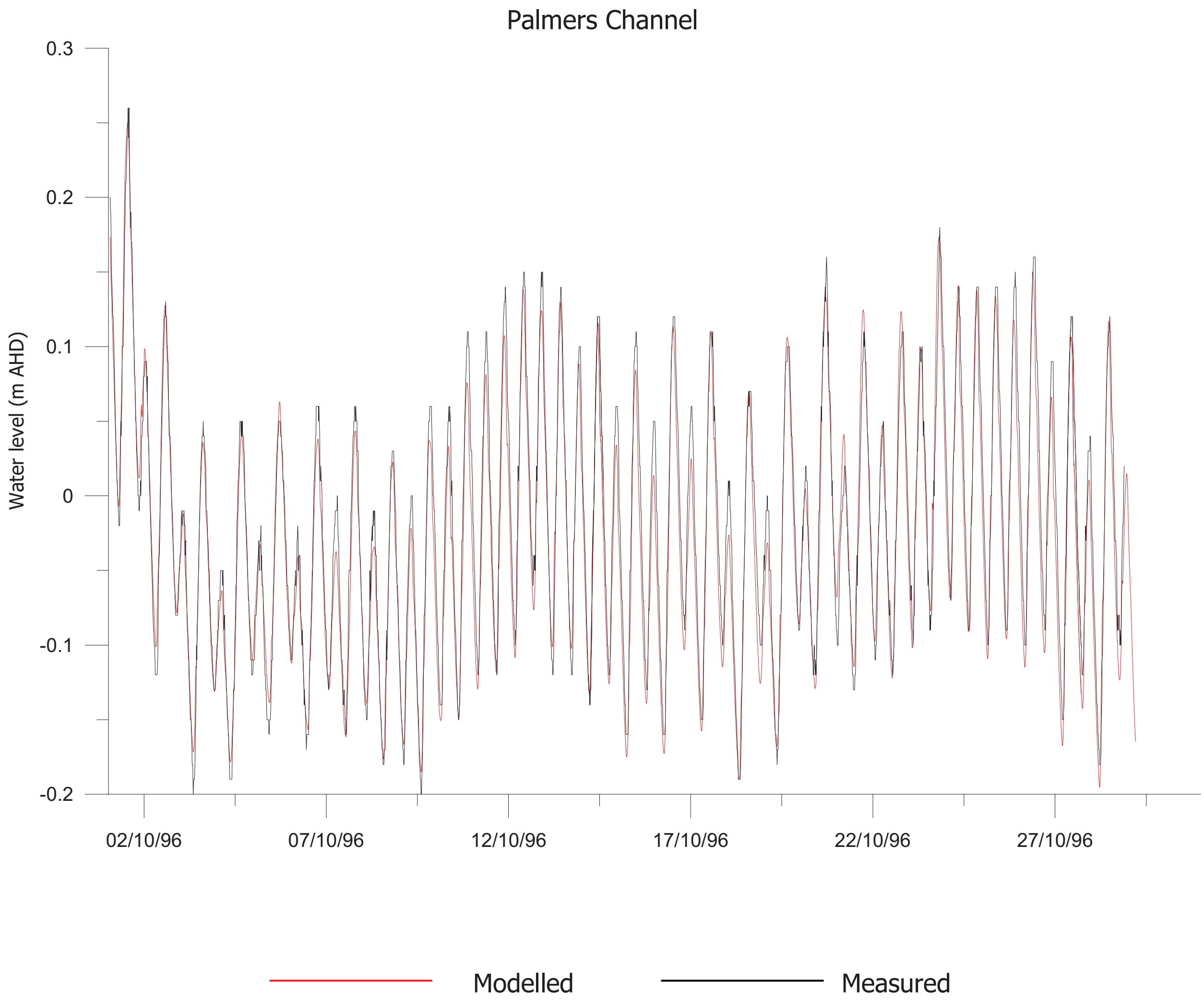




WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 1996 WATER LEVELS AT BRUSHGROVE AND GRAFTON	Figure 5.6



WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 1996 WATER LEVELS ALONG THE OYSTER CHANNEL	Figure 5.7

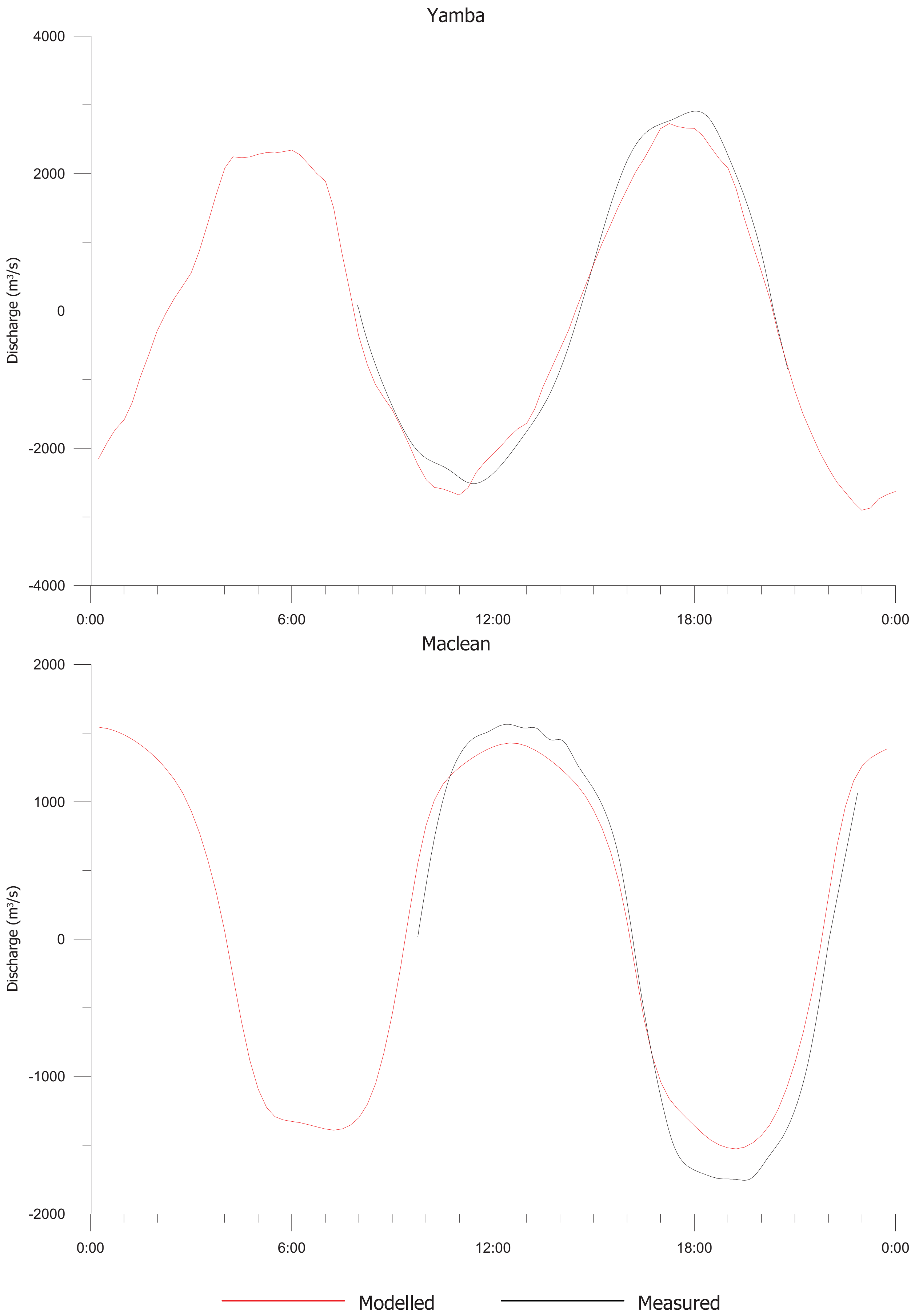


WRL

Report No. 2008/28

COMPARISON OF MODELLED AND MEASURED
1996 WATER LEVELS IN PALMERS CHANNEL

Figure
5.8

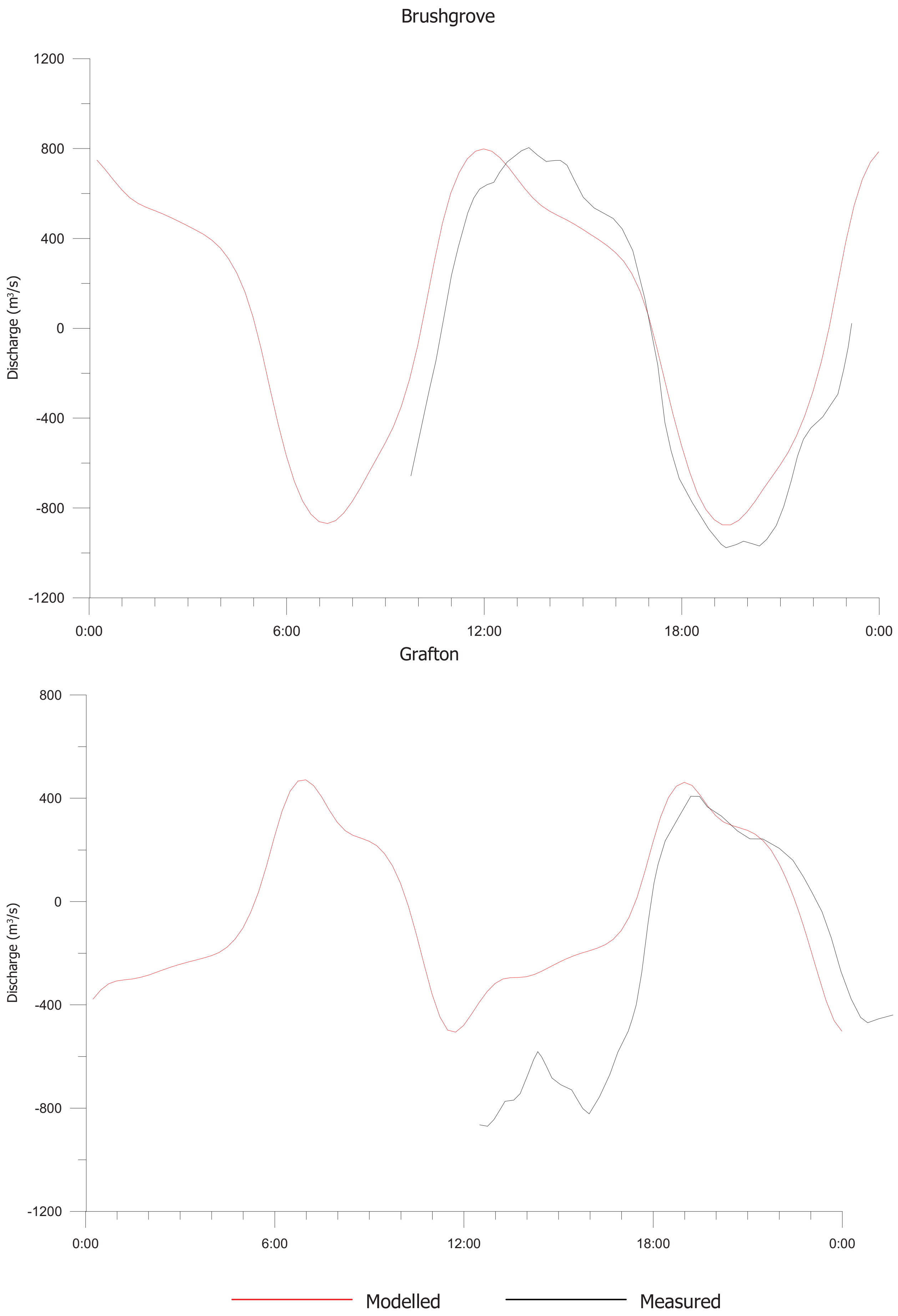


WRL

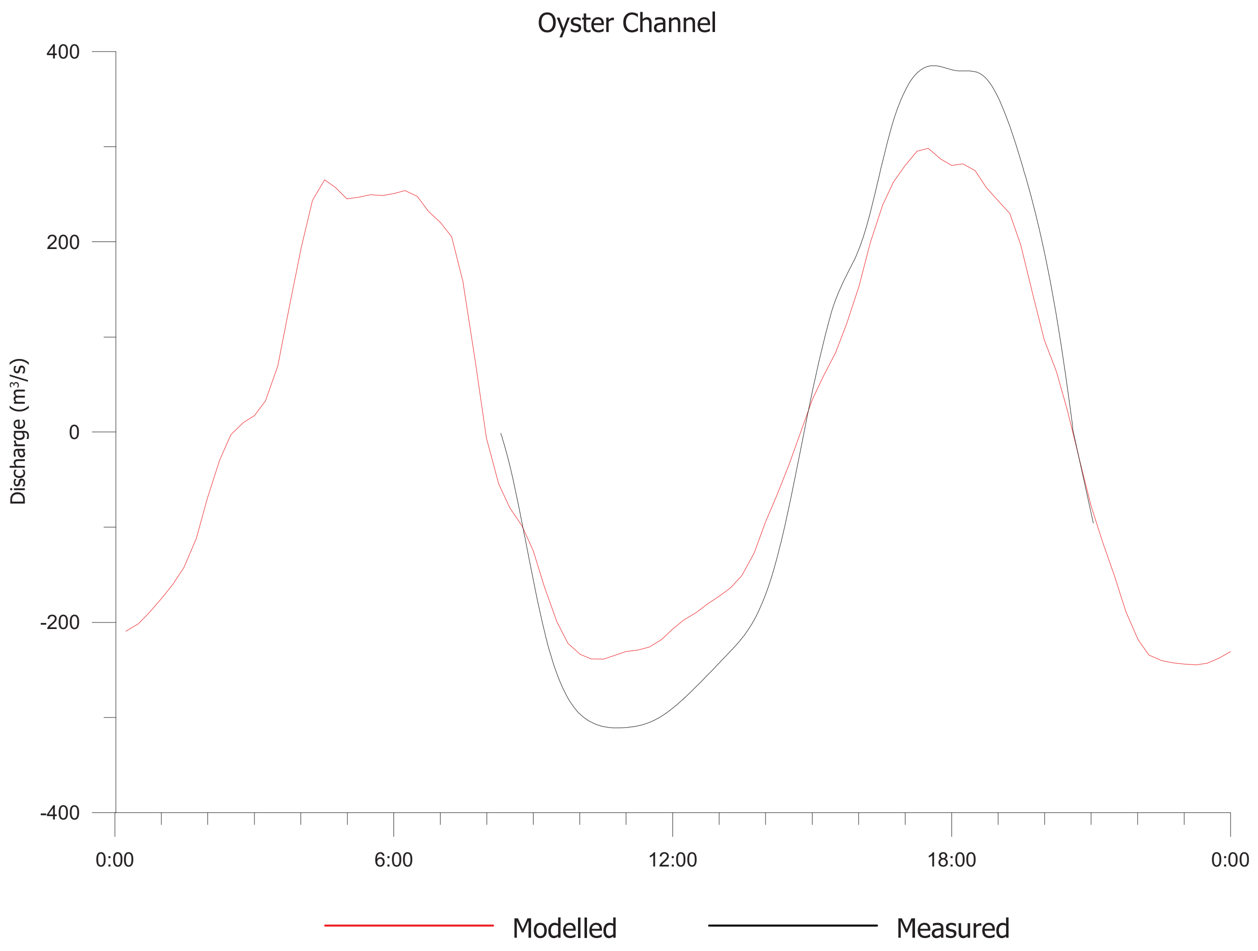
Report No. 2008/28

COMPARISON OF MODELLED AND MEASURED 24TH OCT1996 DISCHARGE AT YAMBA AND MACLEAN

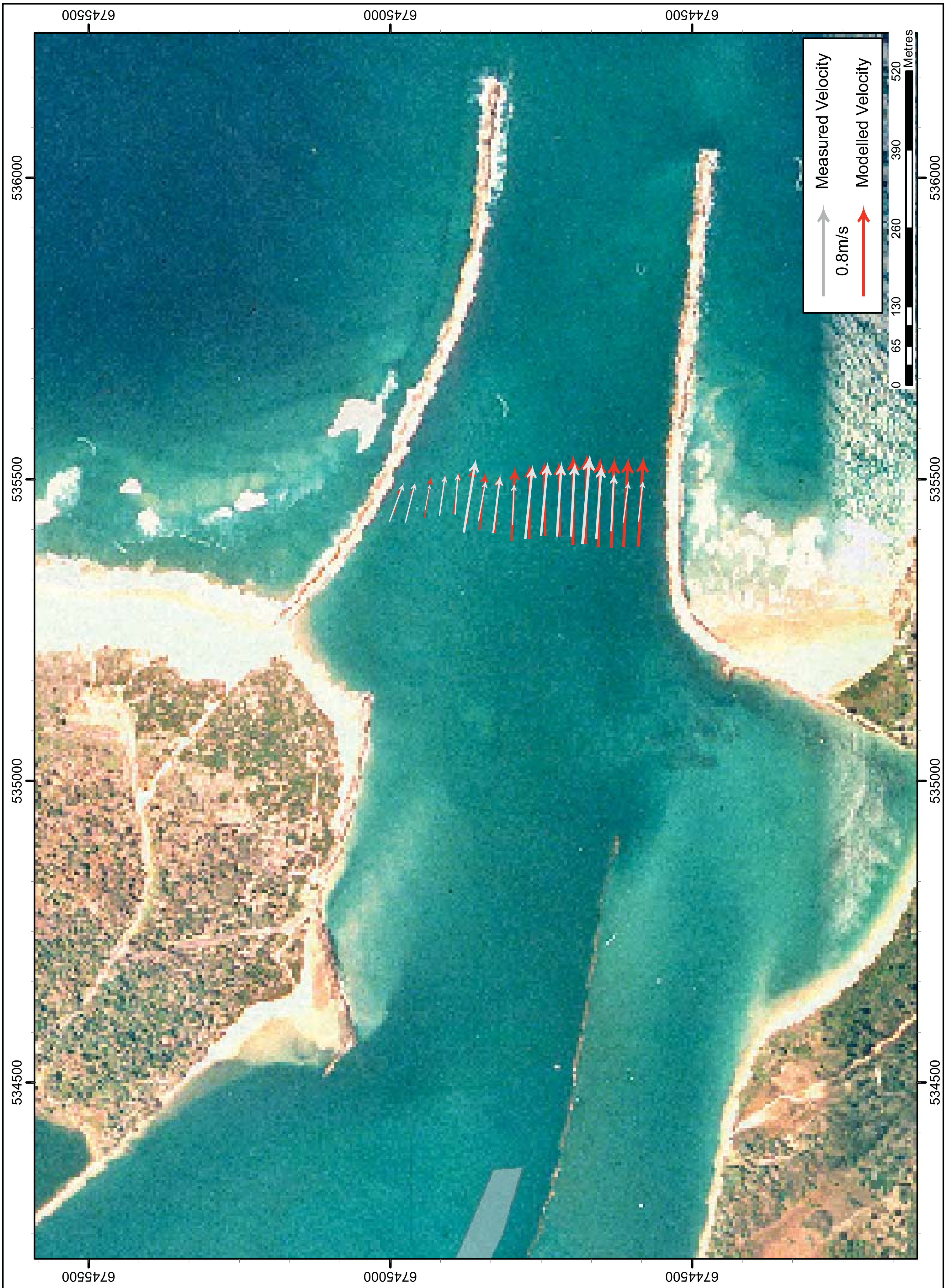
Figure 5.9



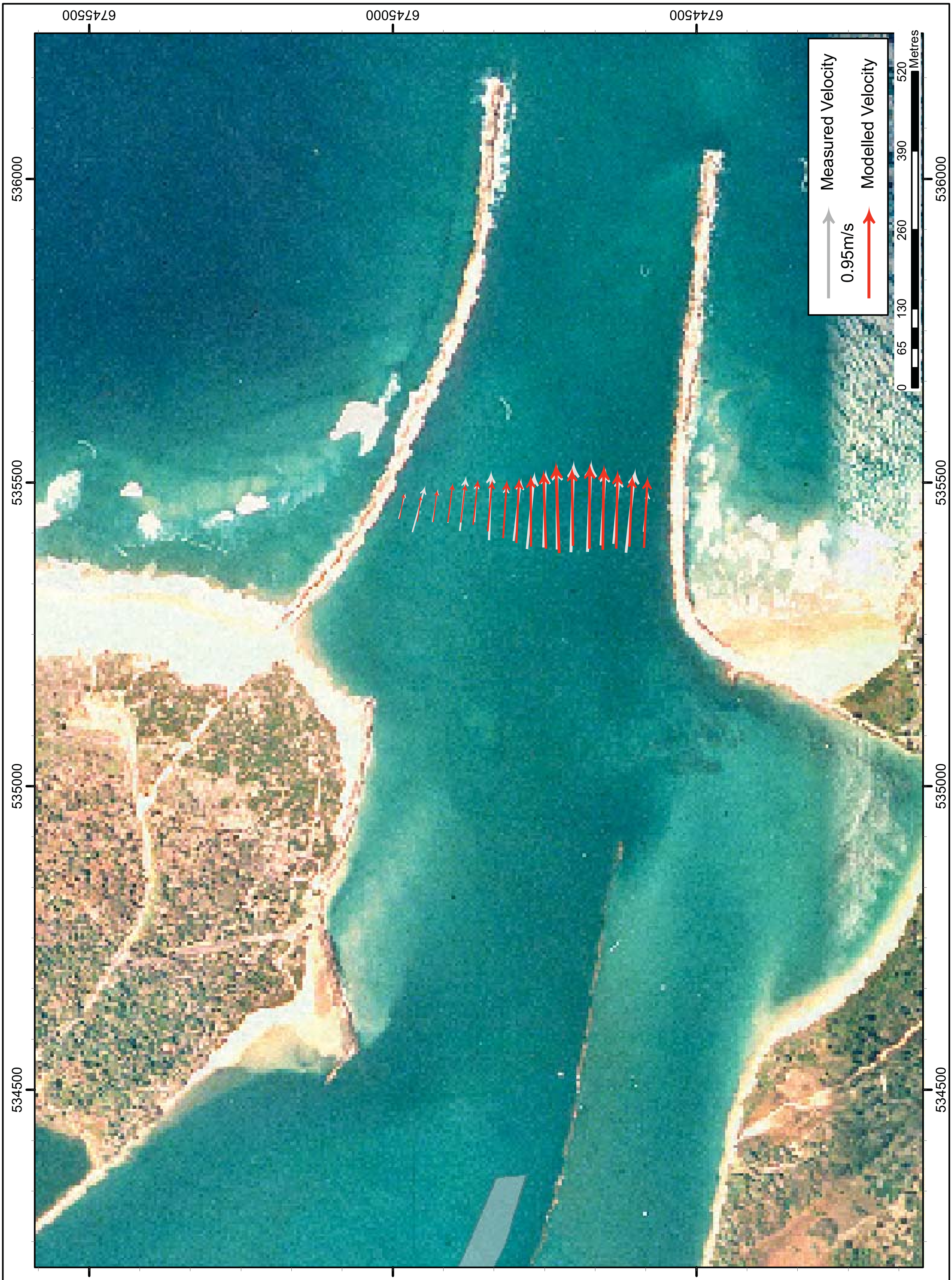
WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 24TH OCT1996 DISCHARGE AT BRUSHGROVE AND GRAFTON	Figure 5.10



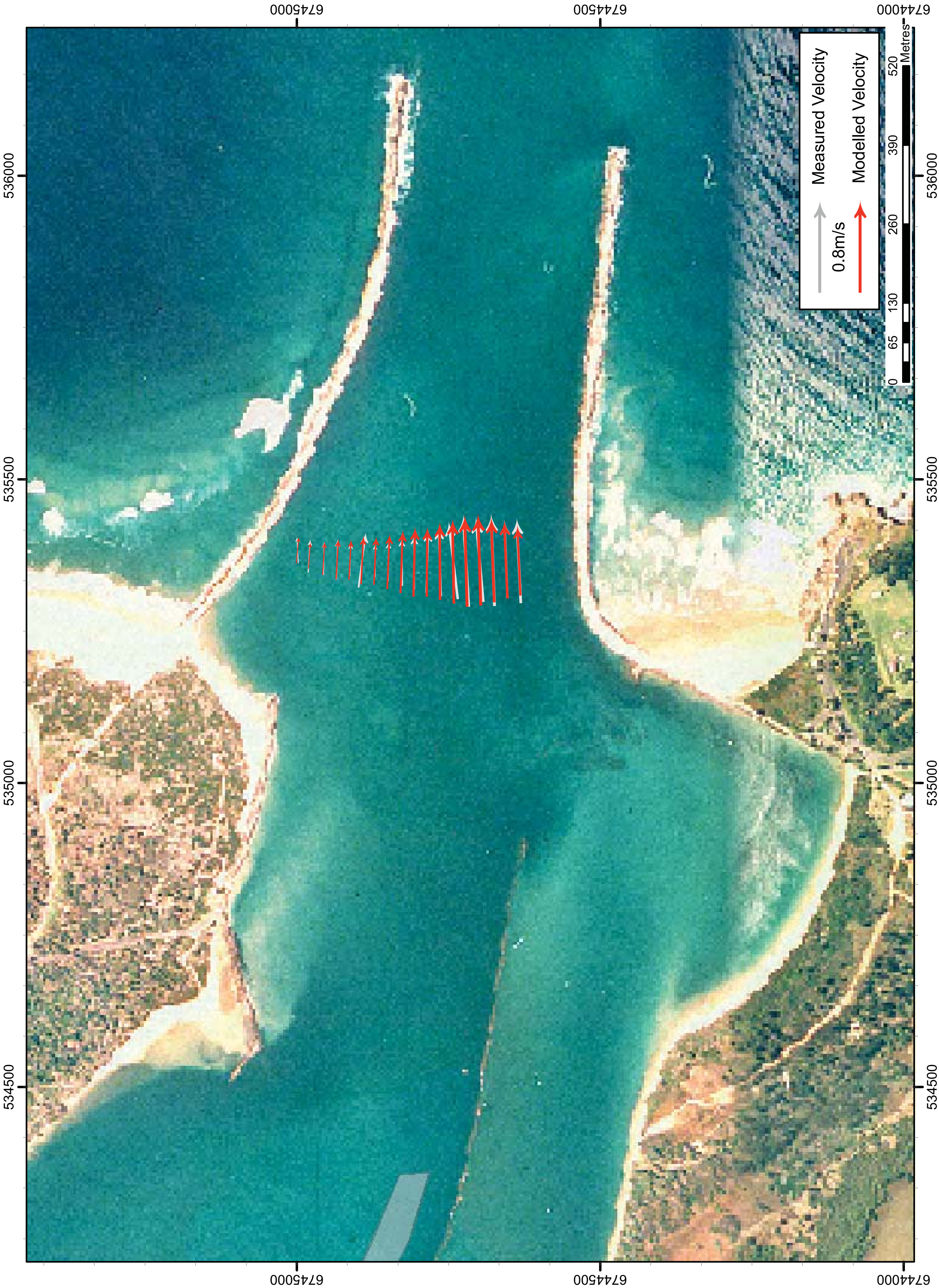
WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 24TH OCT1996 DISCHARGE AT OYSTER CHANNEL	Figure 5.11



WRL Report No. 2008/28	COMPARISON OF MEASURED AND MODELLED 24-OCT-1996 VELOCITIES AT YAMBA (MHL TRANSECT 3 SITE 2)	Figure 5.12a TR2008-28-5-12.mxd



WRL Report No. 2008/28	COMPARISON OF MEASURED AND MODELLED 24-OCT-1996 VELOCITIES AT YAMBA (MHL TRANSECT 5 SITE 2)	Figure 5.12b TR2008-28-5-12.mxd



WRL

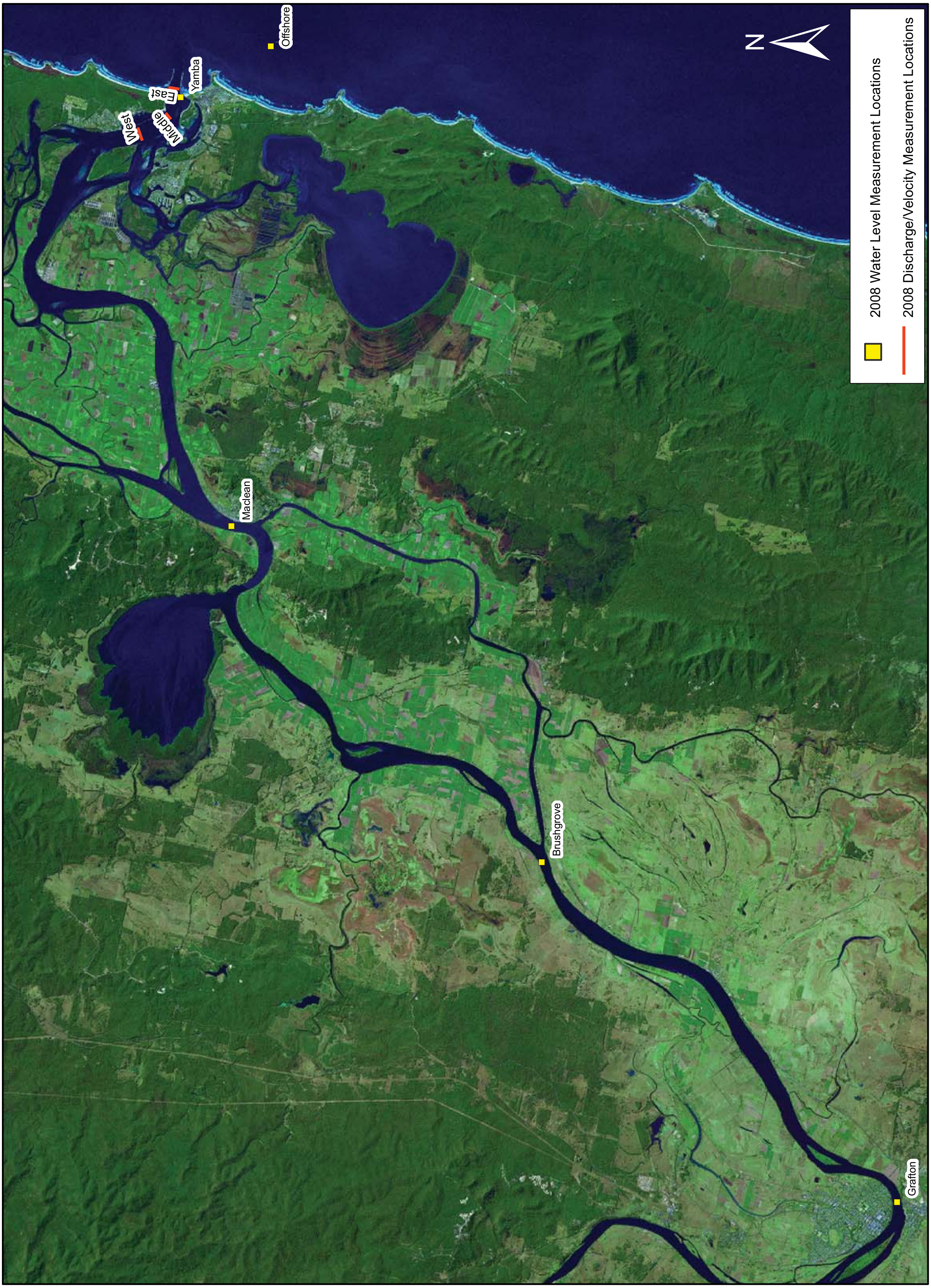
Report No. 2008/28

COMPARISON OF MEASURED AND MODELLED
2008 VELOCITIES AT YAMBA

(ADCP Transect: East 03 14/10/2008 11:50:07)

Figure
5.12c

TR2008-28-5-12.mxd



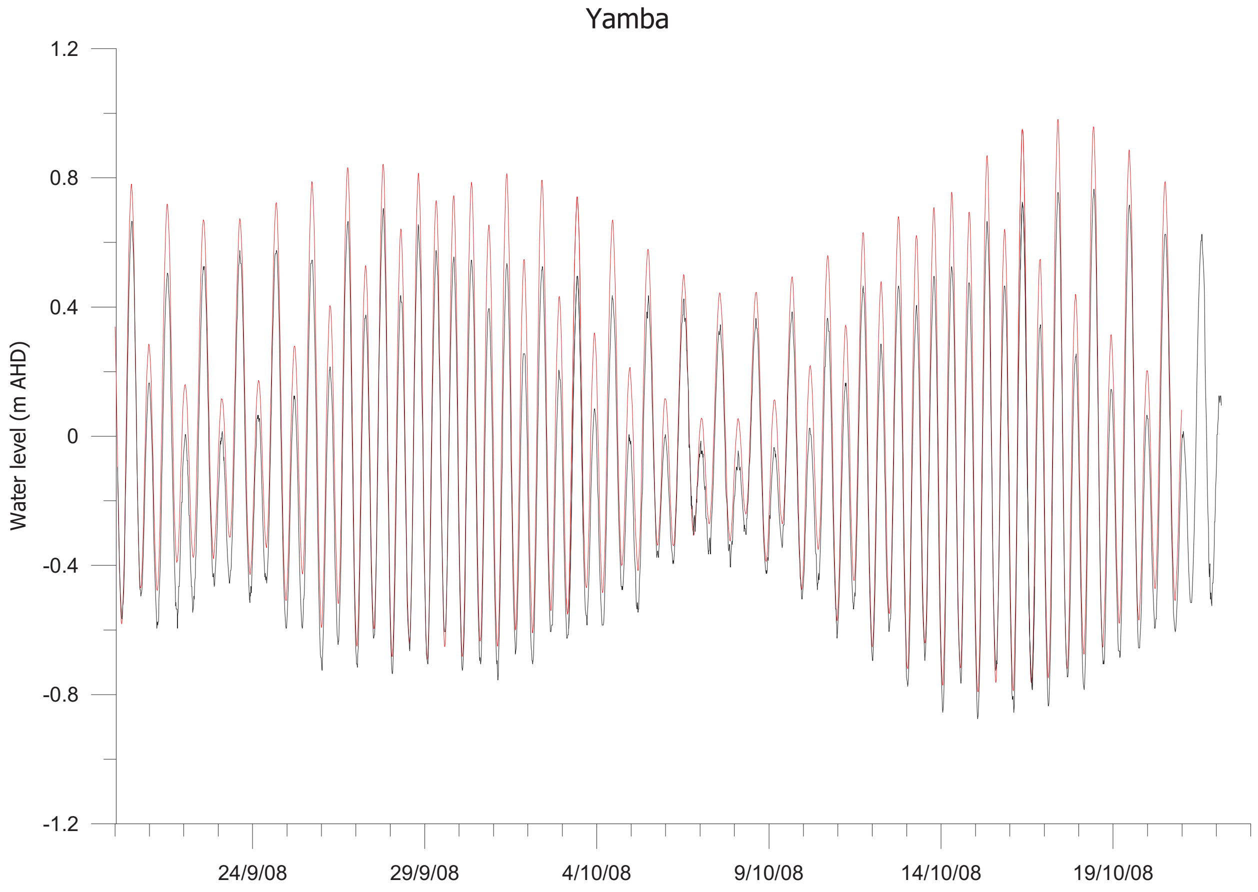
WRL

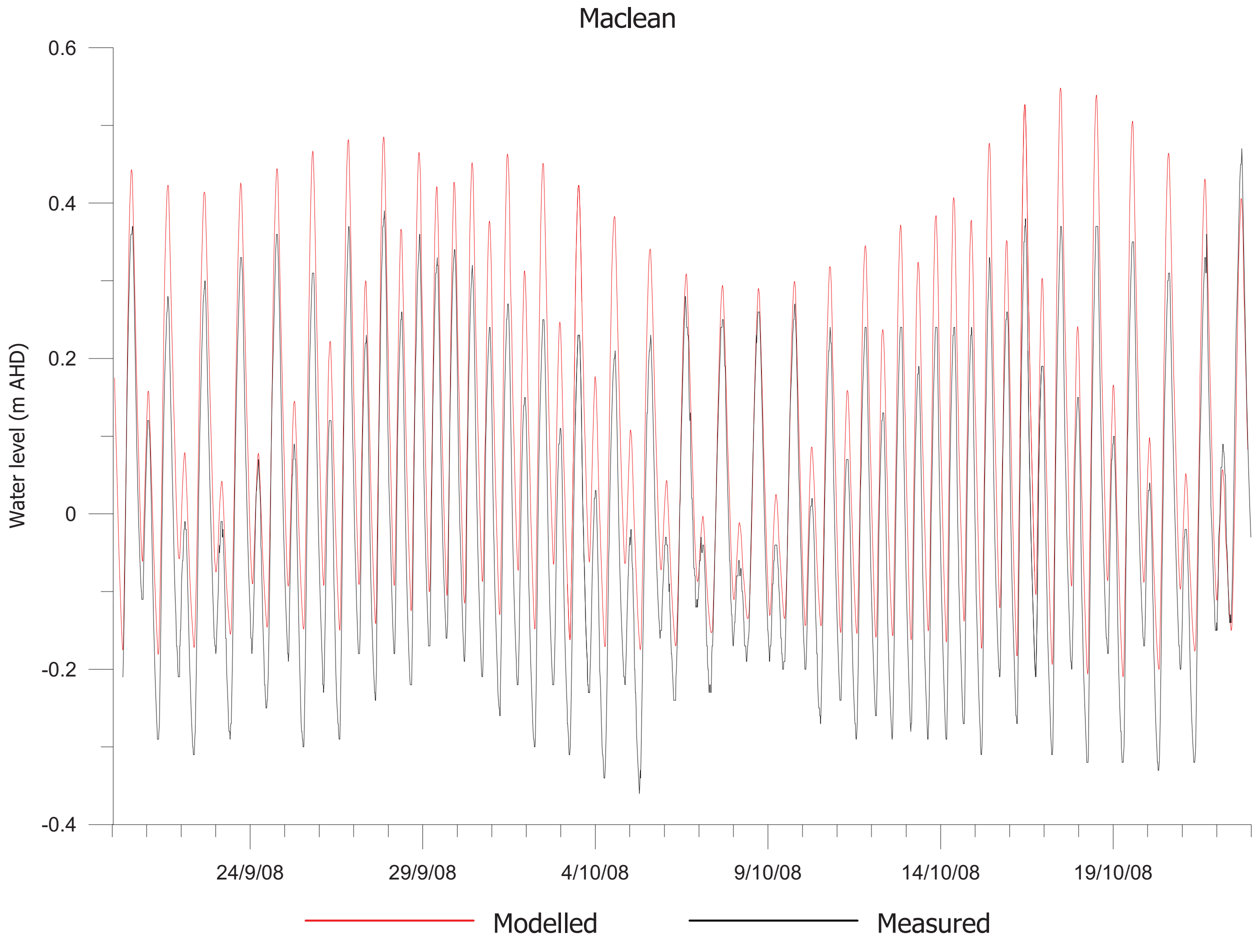
Report No. 2008/28

2008 MEASUREMENT LOCATIONS USED FOR VERIFICATION OF NUMERICAL MODEL

Figure 5.13

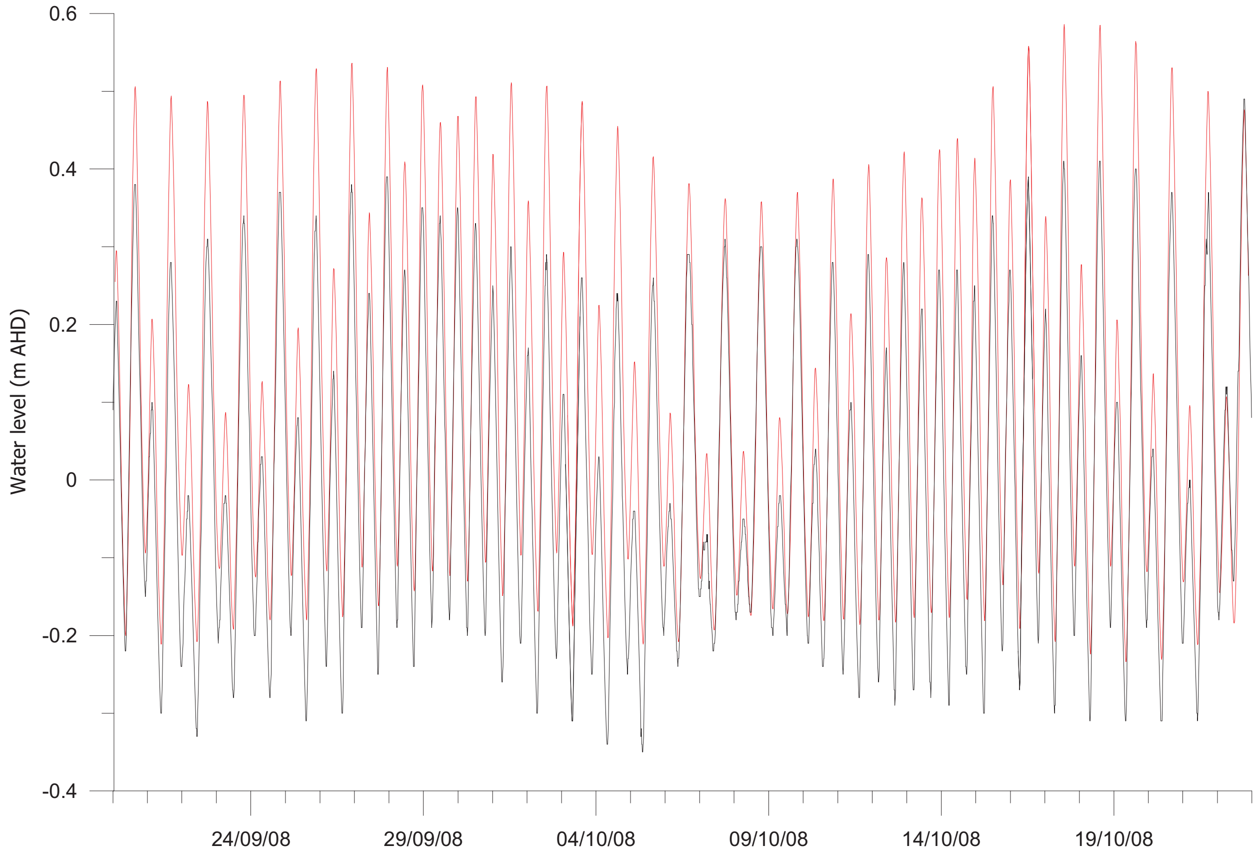
TR2008-28_5-13.mxd



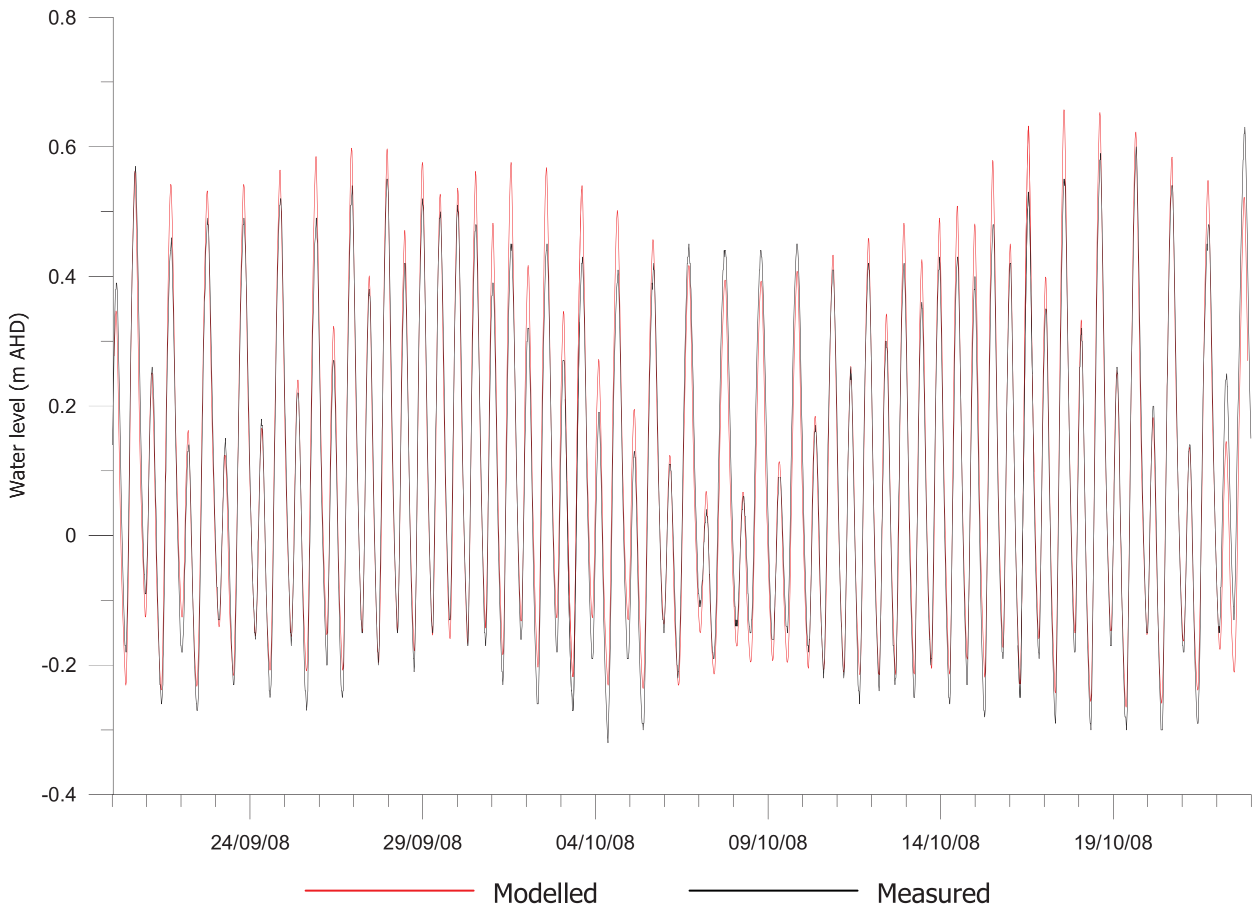


WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 2008 WATER LEVELS AT YAMBA AND MACLEAN	Figure 5.14

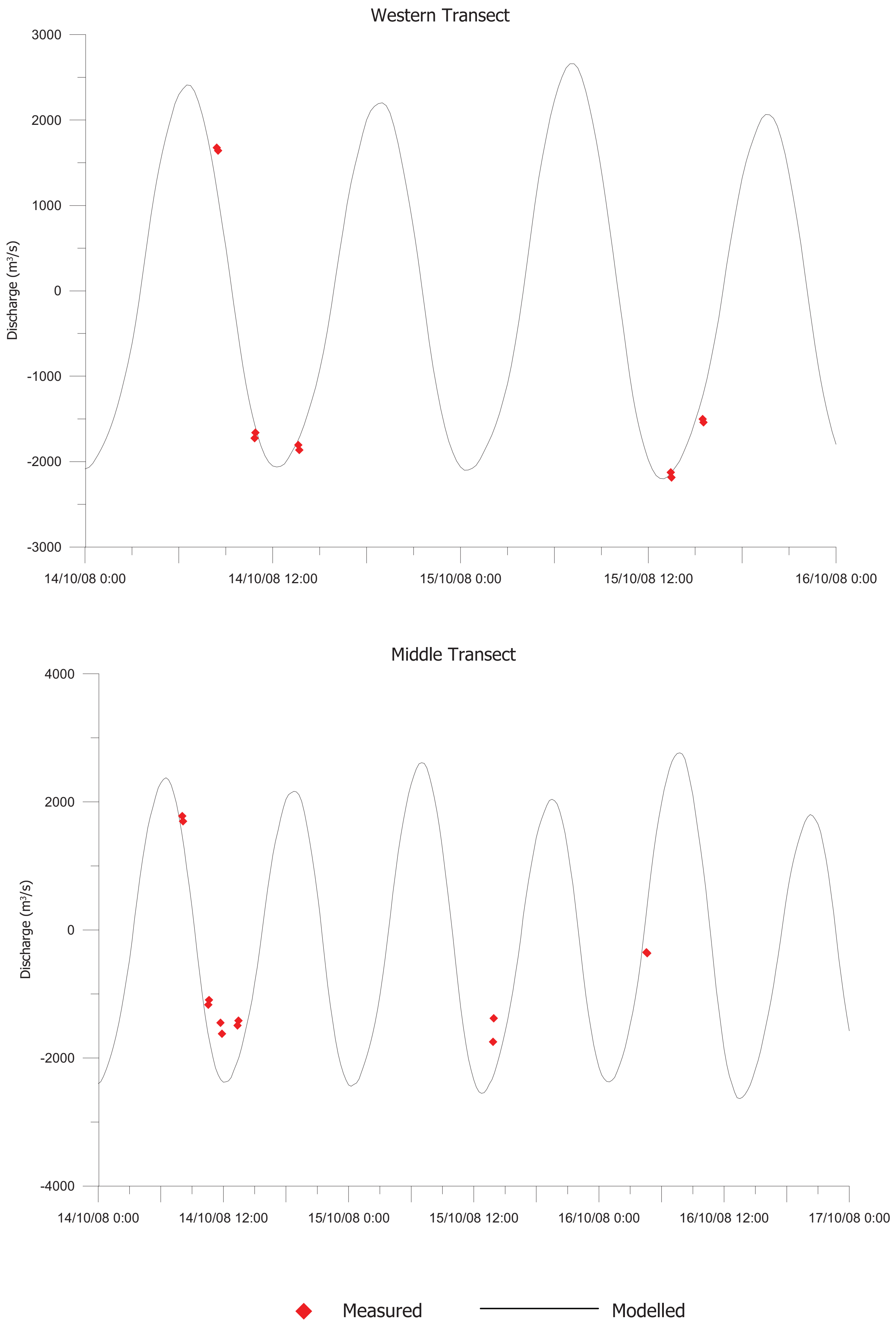
Brushgrove



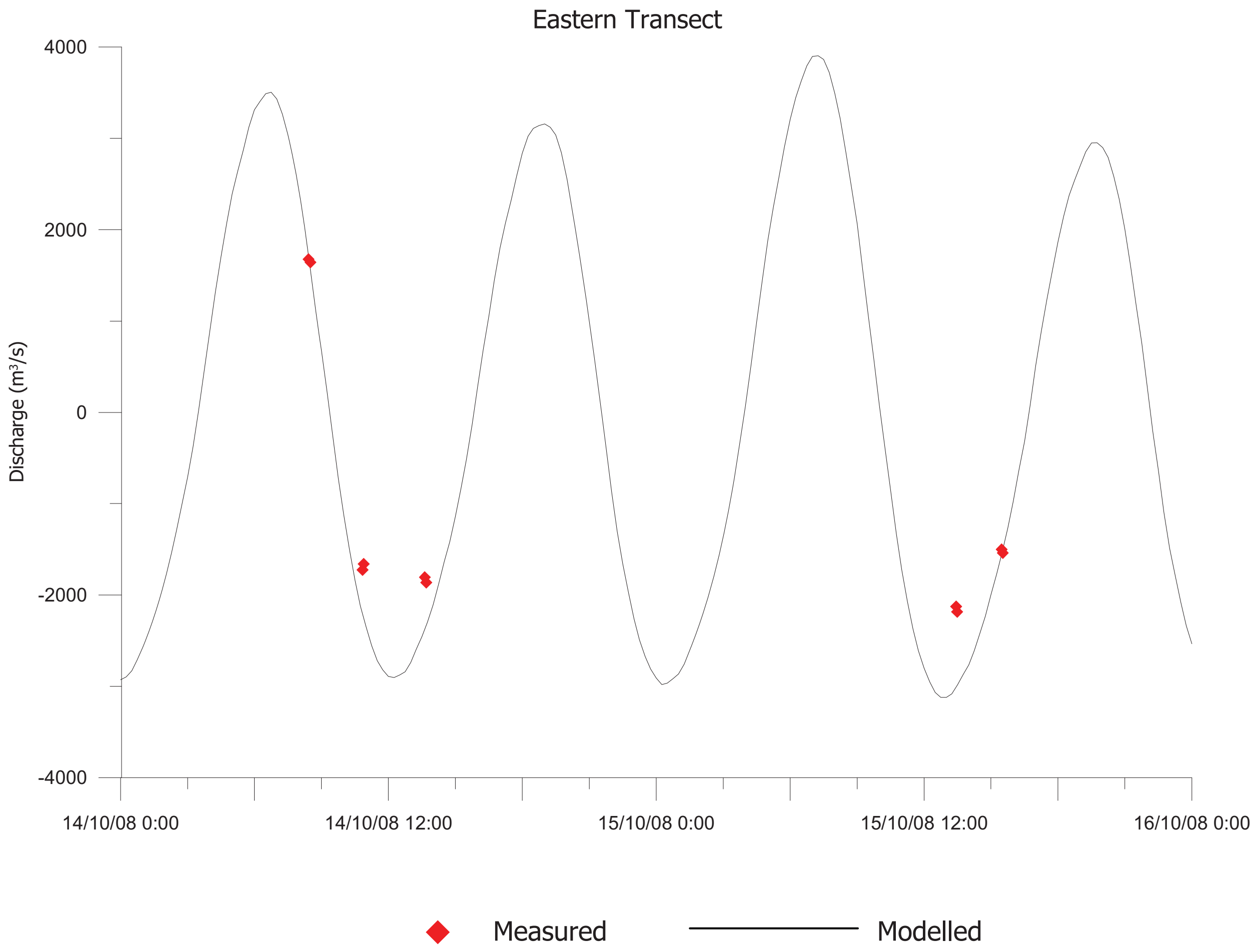
Grafton



WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 2008 WATER LEVELS AT BRUSHGROVE AND GRAFTON	Figure 5.15

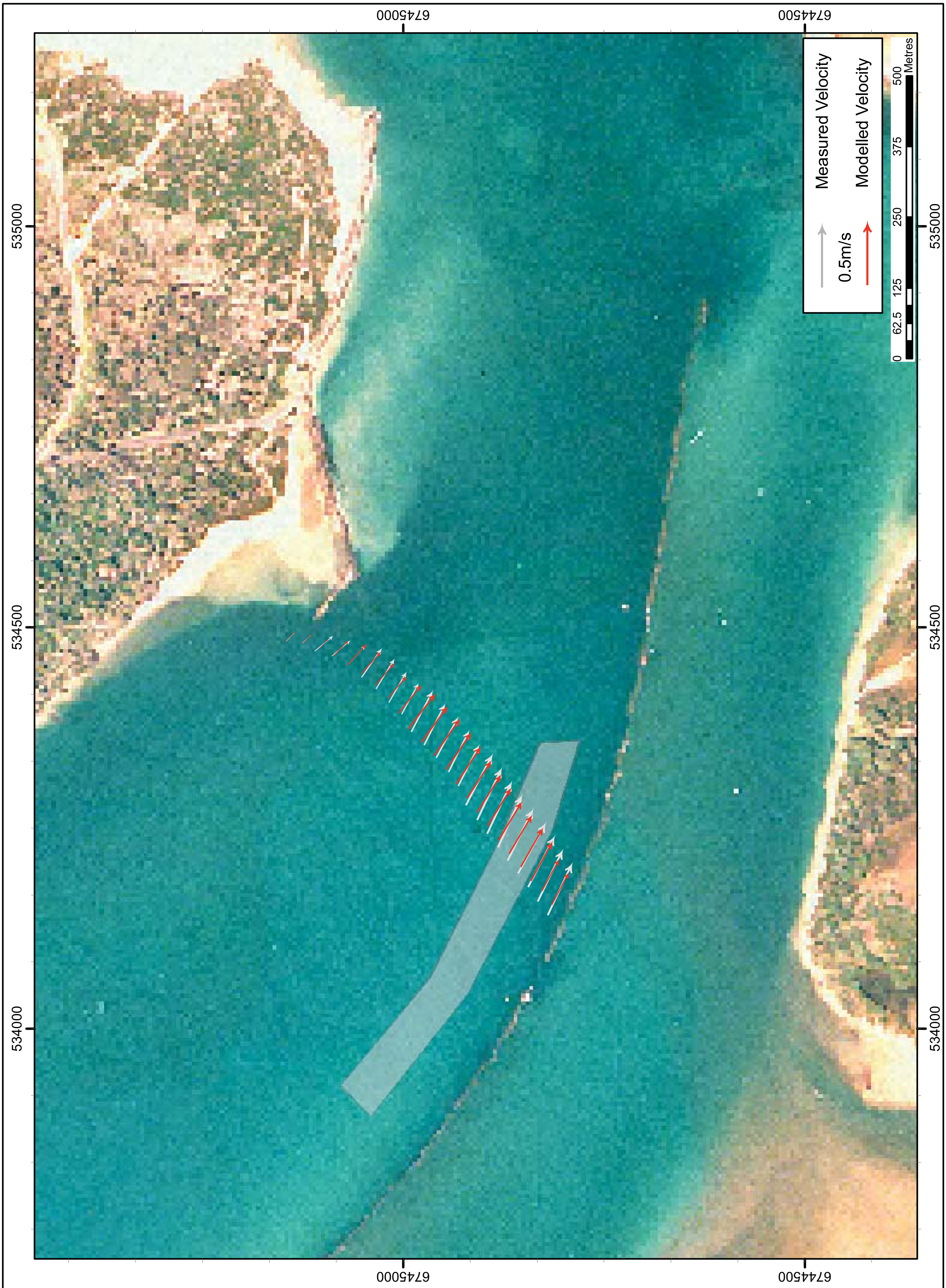


WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 2008 DISCHARGE AT THE WESTERN AND MIDDLE TRANSECT SITES	Figure 5.16



WRL Report No. 2008/28	COMPARISON OF MODELLED AND MEASURED 2008 DISCHARGE AT THE EASTERN TRANSECT SITE	Figure 5.17

WRL	COMPARISON OF MEASURED AND MODELLED 2008 VELOCITIES AT YAMBA	Figure
Report No. 2008/28	(ADCP Transect: West 03 14/10/2008 11:11:50)	5.18a
		TR2008-28-5-18a.mxd



WRL Report No. 2008/28	COMPARISON OF MEASURED AND MODELLED 2008 VELOCITIES AT YAMBA (ADCP Transect: Middle 03 14/10/2008 11:32:59	Figure 5.18b TR2008-28-5-18b.mxd

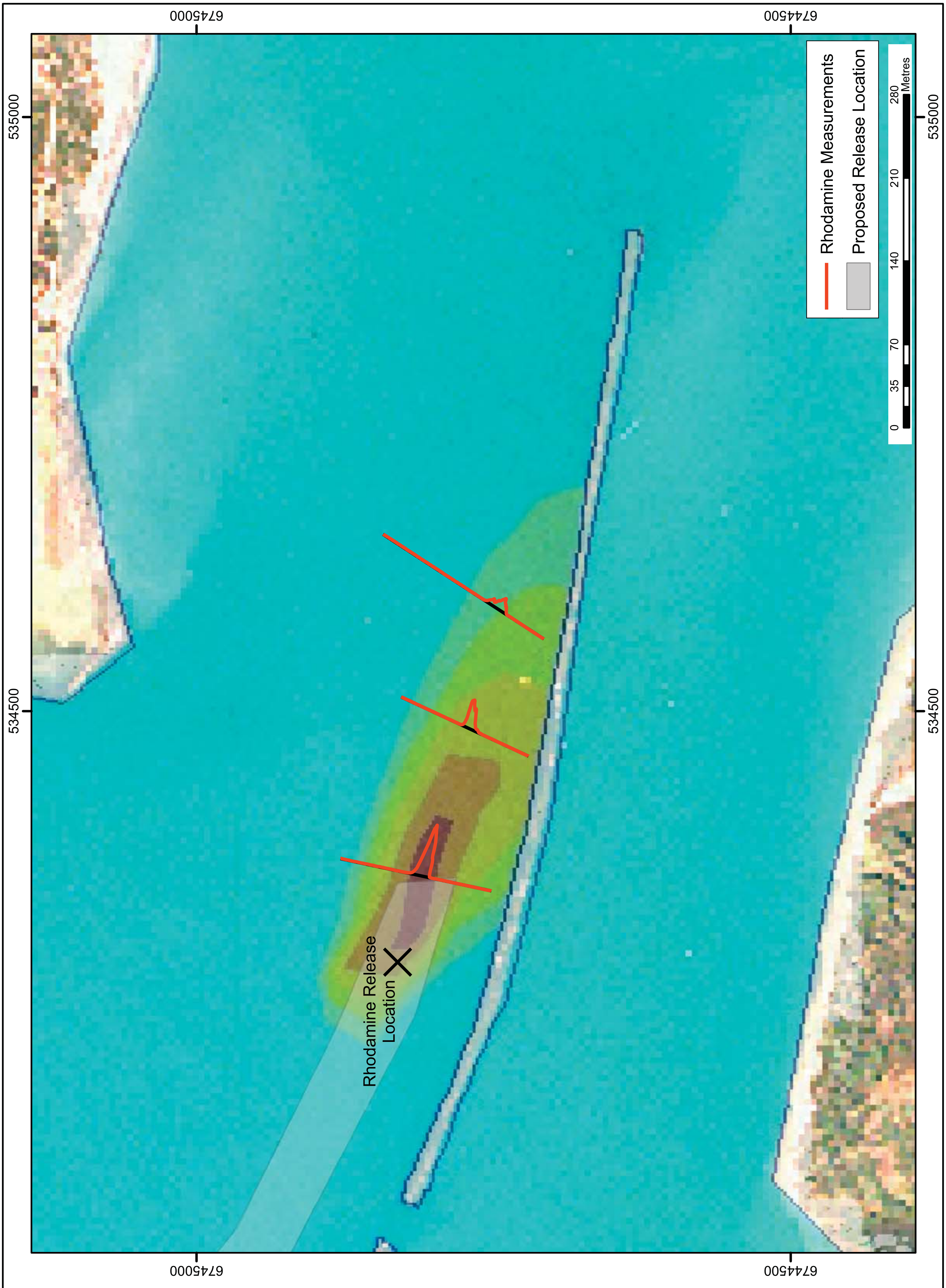
WRL

Report No. 2008/28

GPS DROGUE TRACKING RELEASE # 2
COMPARED TO NUMERICAL MODELLING OF RELEASE
(15/10/2008)

Figure 5.19

insert filename



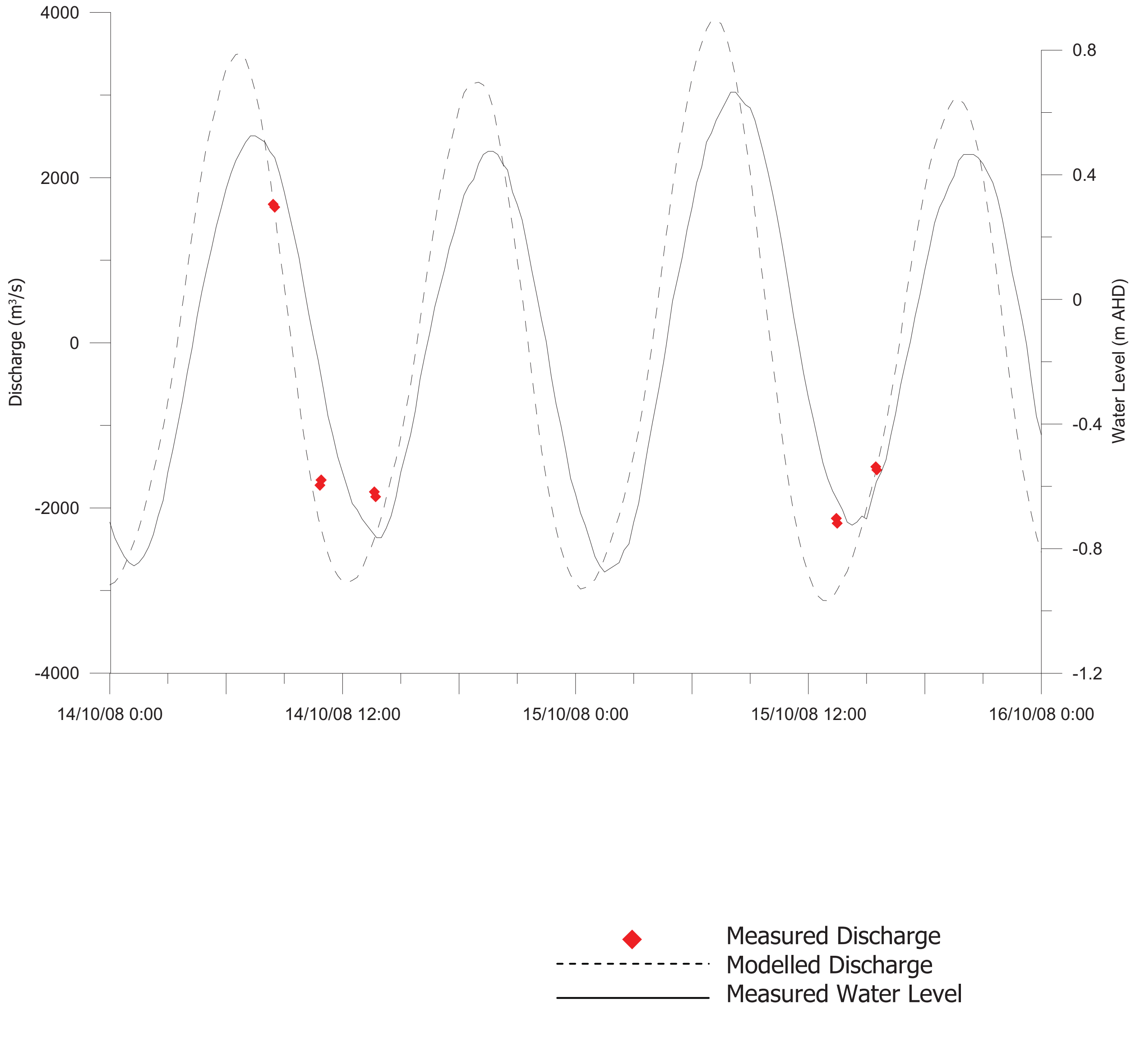
WRL

Report No. 2008/28

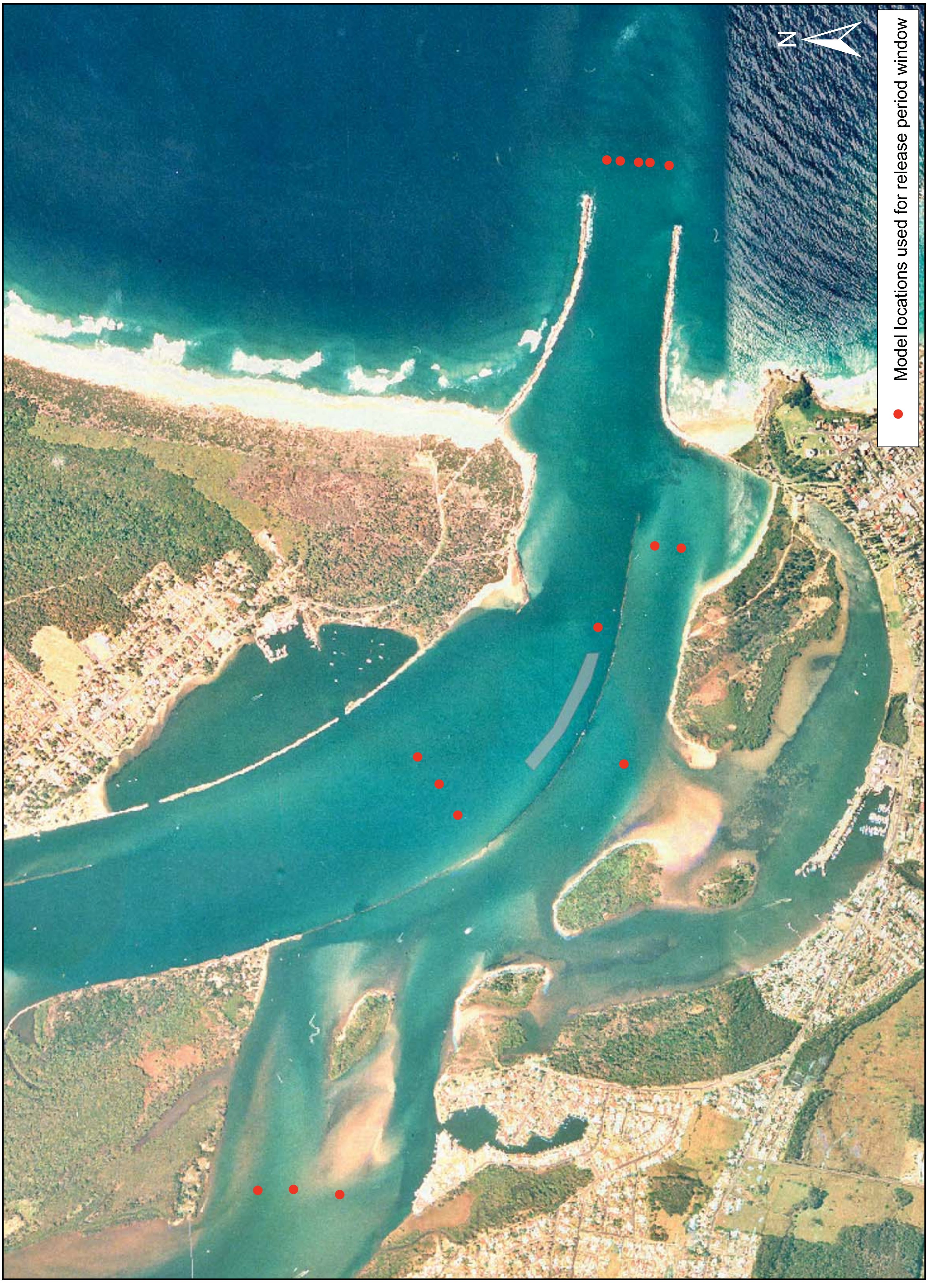
RHODAMINE DYE TRACING (3:30AM 16/10/2008)
COMPARISON TO NUMERICAL MODEL RESULTS

Figure 5.20

insert filename



WRL Report No. 2008/28	WATER LEVEL VS DISCHARGE AT YAMBA	Figure 5.21



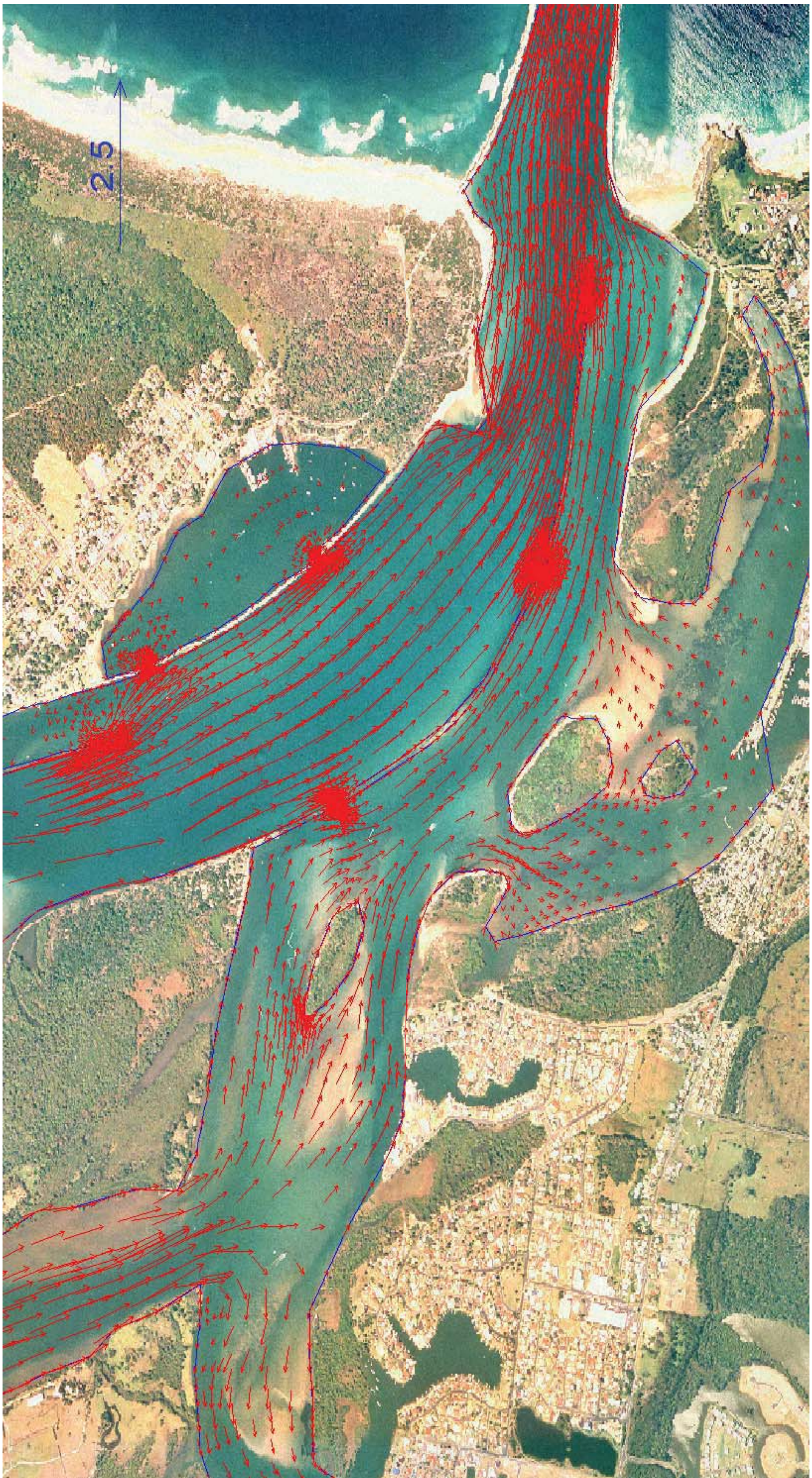
WRL

Report No. 2008/28

MODEL LOCATIONS USED FOR RELEASE PERIOD WINDOW

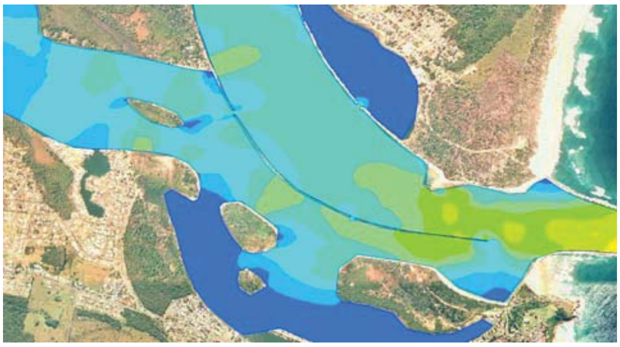
Figure 5.22

TR2008-28_5-13.mxd

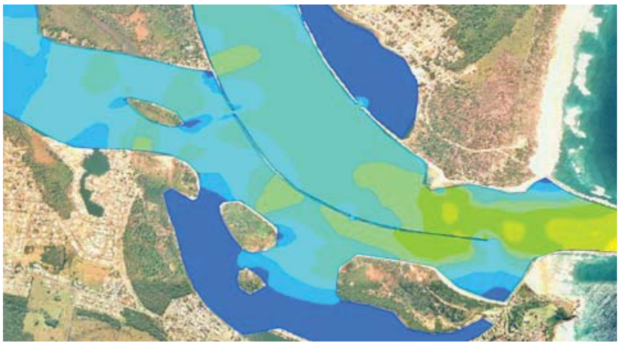


WRL Report No. 2008/28	FLOW PATHS IN LOWER CLARENCE ESTUARY DURING FLOOD EVENT (day 245 19.75hrs)	Figure 5.23

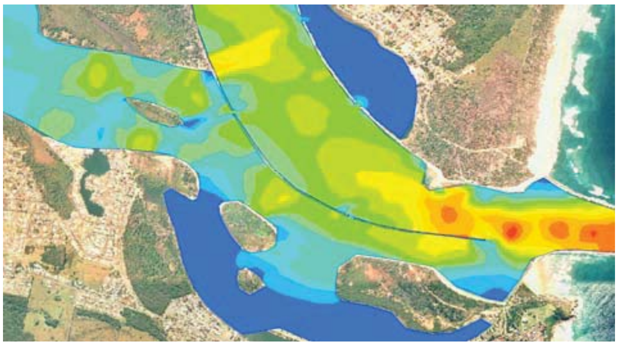
SPRING EBB TIDE HOUR 0



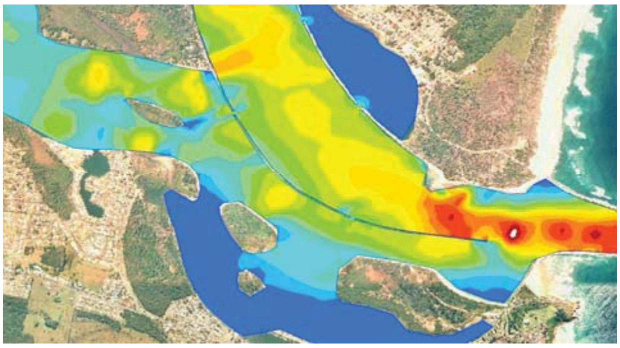
SPRING EBB TIDE HOUR 1



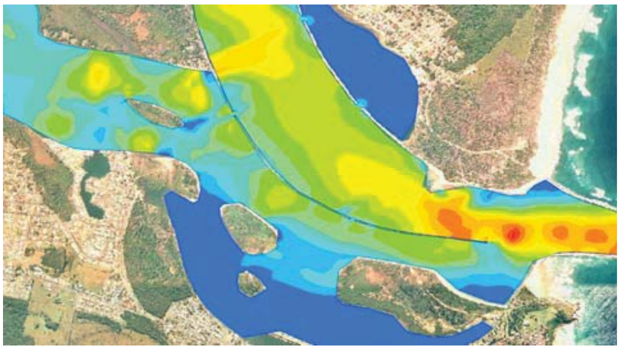
SPRING EBB TIDE HOUR 2



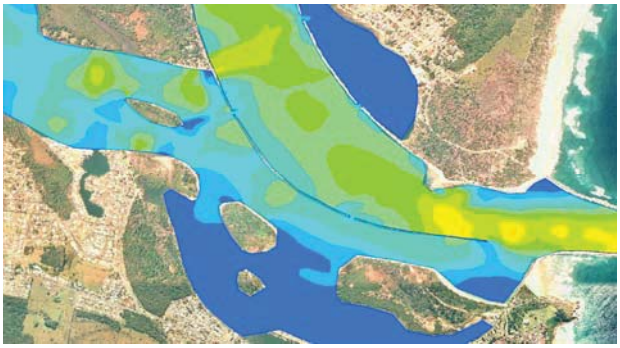
SPRING EBB TIDE HOUR 3



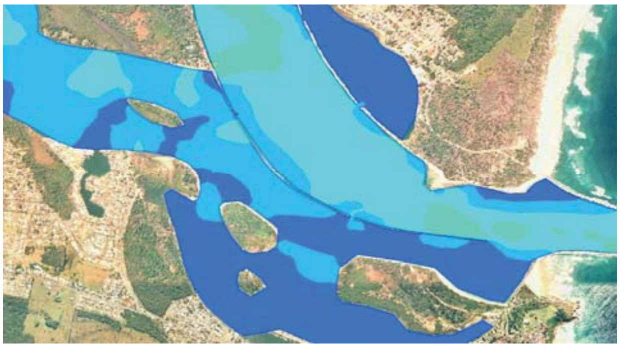
SPRING EBB TIDE HOUR 5



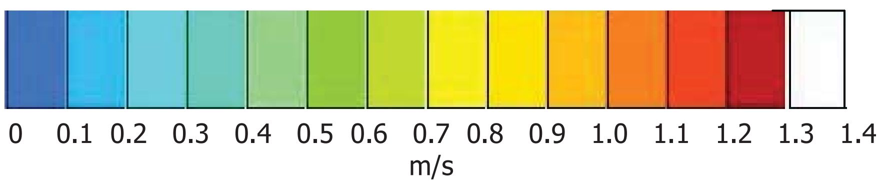
SPRING EBB TIDE HOUR 5



SPRING EBB TIDE HOUR 6

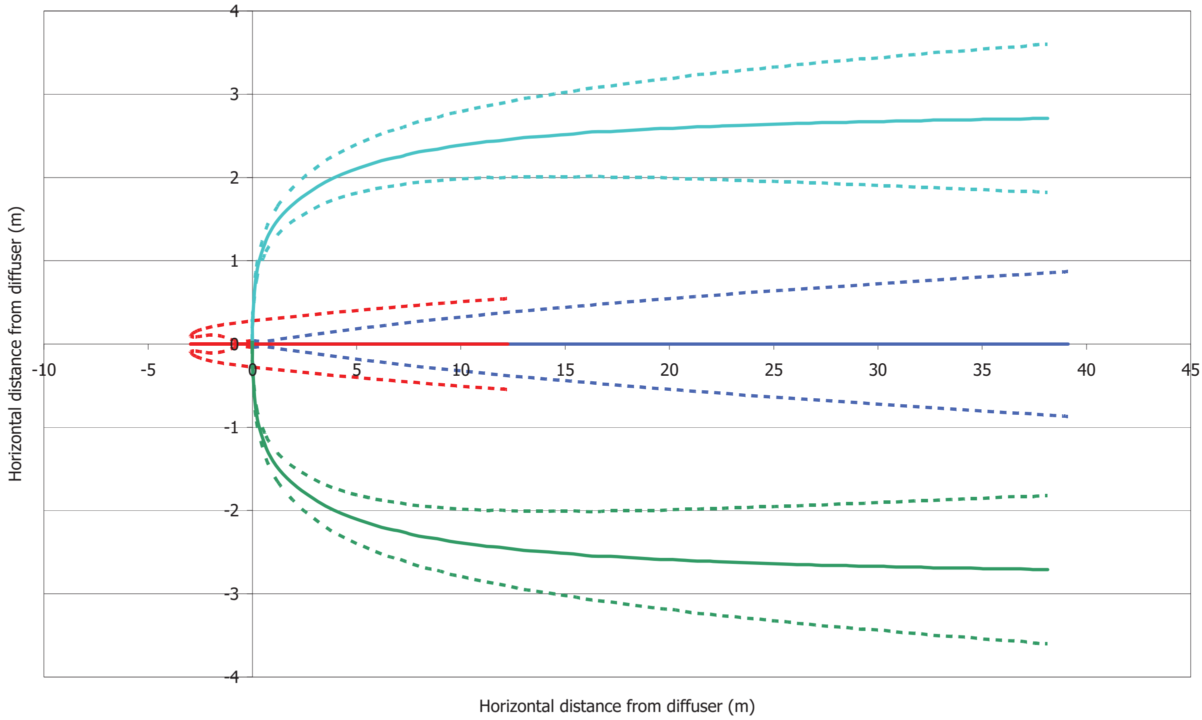


SPRING EBB TIDE HOUR 7

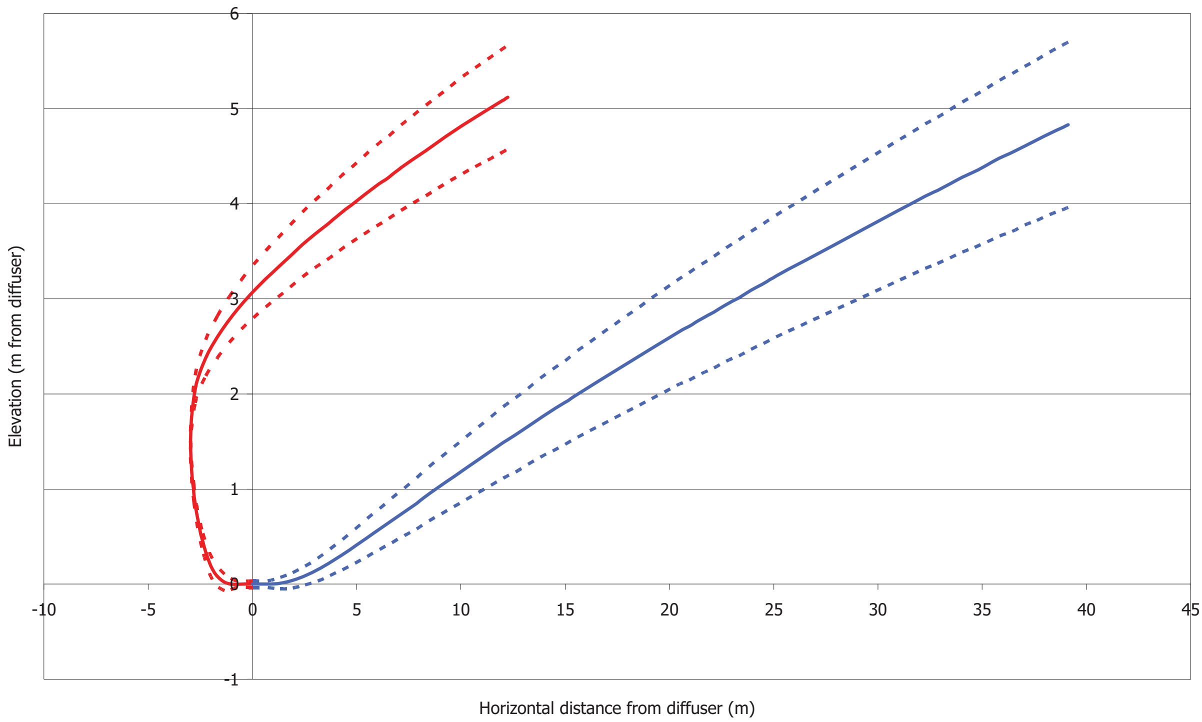


WRL Report No. 2008/28	VELOCITIES AROUND PROPOSED RELEASE LOCATION OVER A SPRING EBB TIDE	Figure 5.24

PLAN VIEW



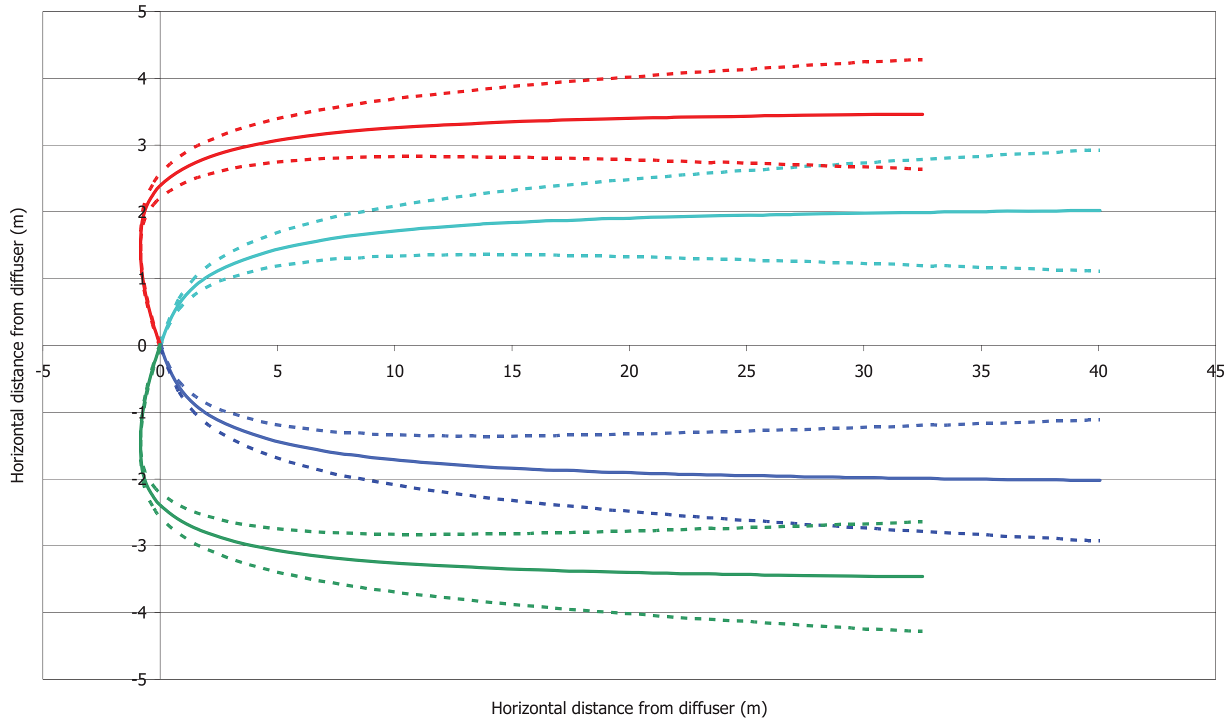
CROSS SECTION



Note: Flow is from left (upstream) to right (ocean)

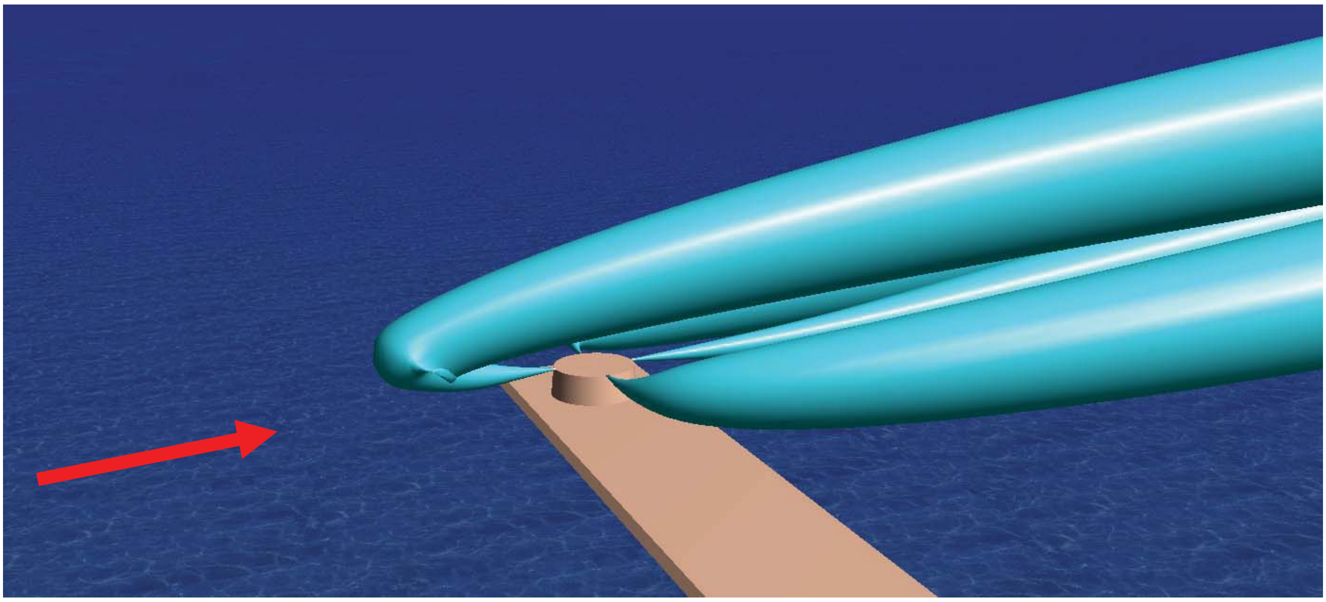
WRL Report No. 2008/28	PLUME PROFILES: YAMBA DIFFUSER CONFIGURATION 1, 4 PORTS	Figure 6.1

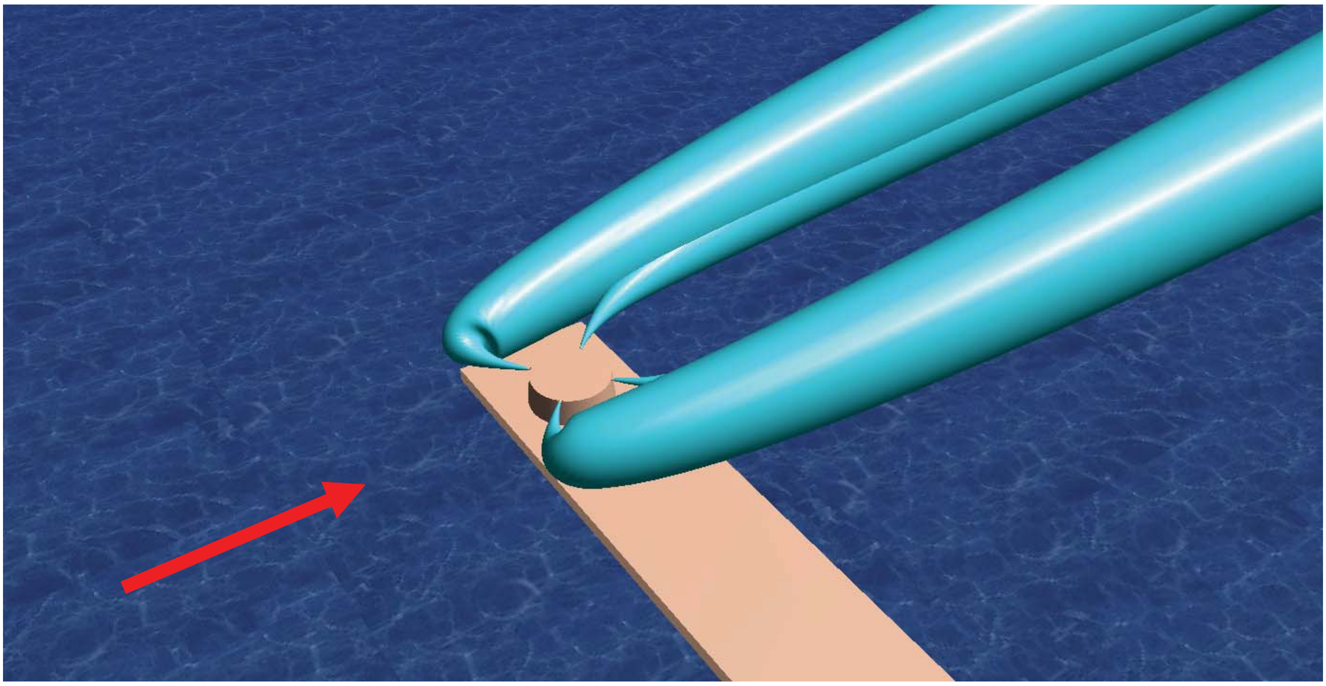
PLAN VIEW



Note: Flow is from left (upstream) to right (ocean)

WRL Report No. 2008/28	PLUME PROFILE: YAMBA DIFFUSER CONFIGURATION 2, 4 PORTS	Figure 6.2

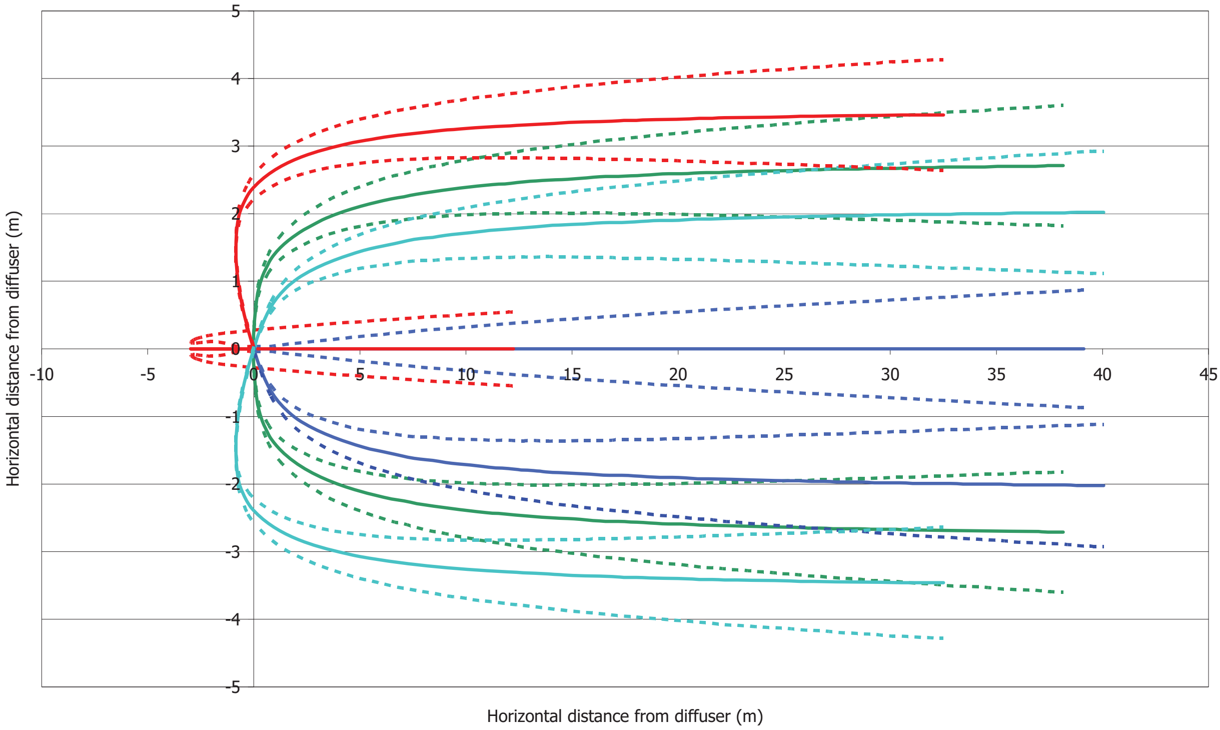




Note: Flow is from left (upstream) to right (ocean)

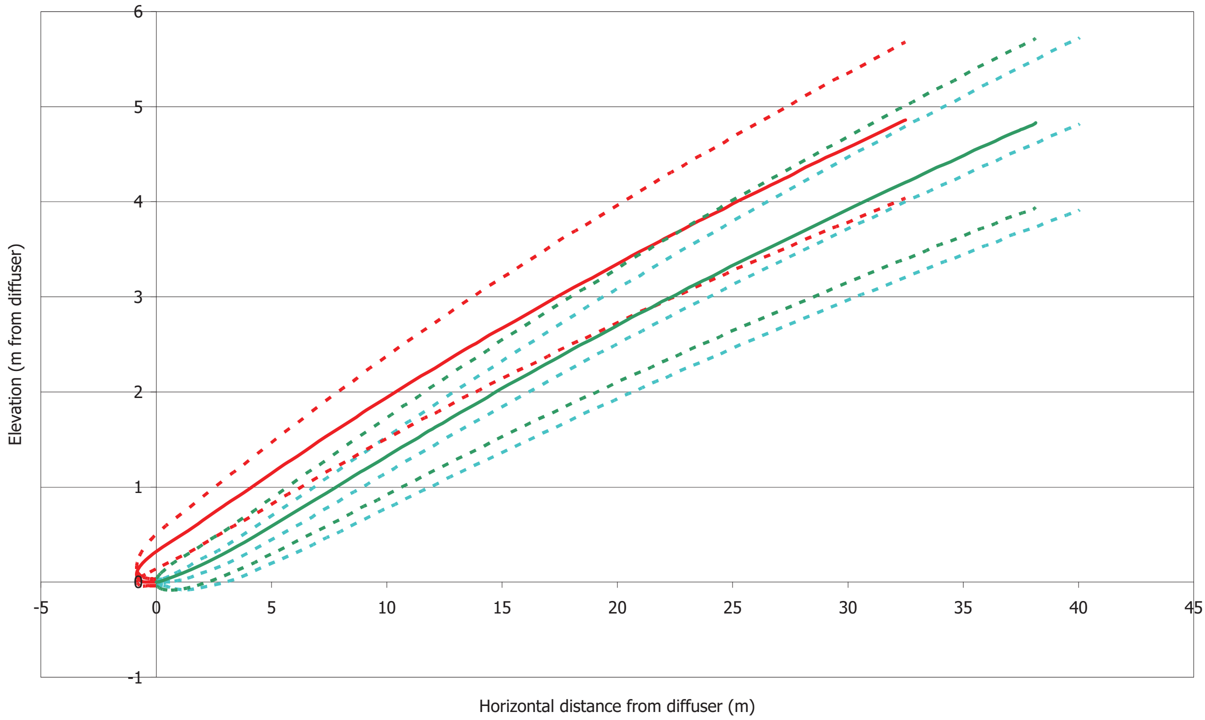
WRL Report No. 2008/28	PLUME PROFILES: YAMBA 4 PORT DIFFUSER CONFIGURATIONS	Figure 6.3

PLAN VIEW



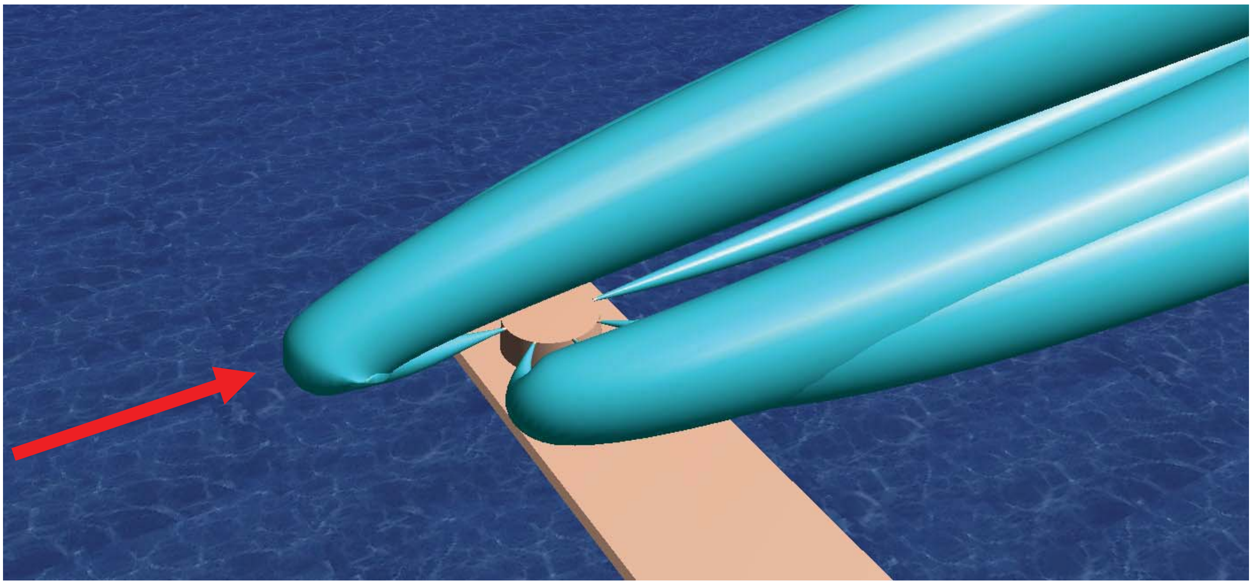
CROSS SECTION

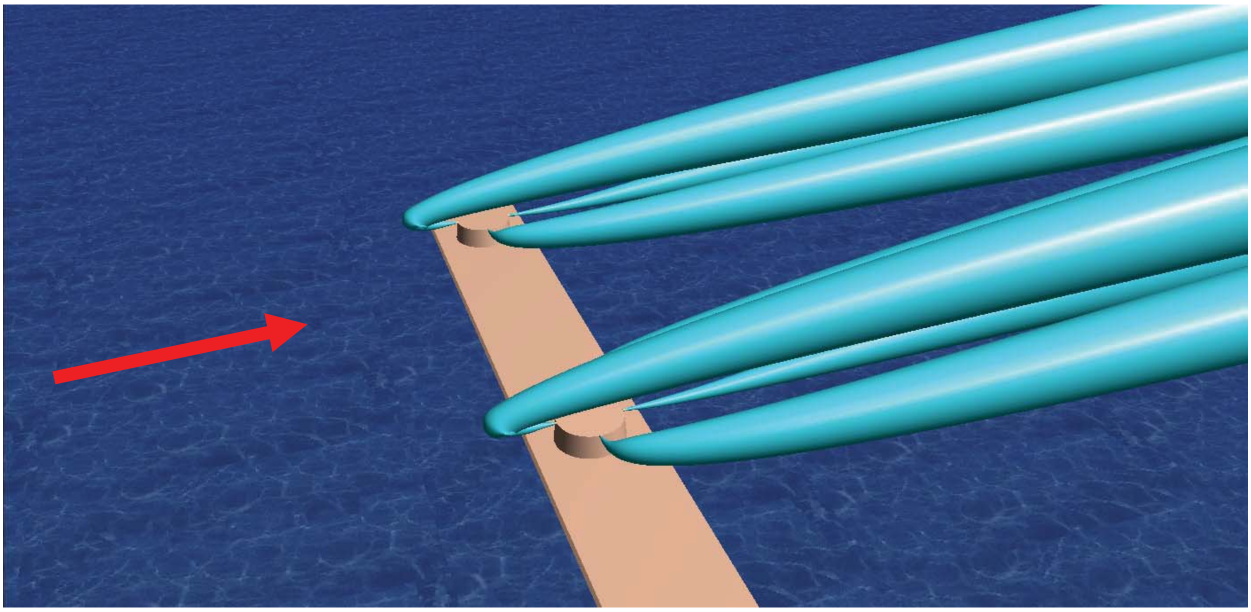
(ONLY INTERACTING ON ONE SIDE PLUMES SHOWN)



Note: Flow is from left (upstream) to right (ocean)

WRL Report No. 2008/28	PLUME PROFILES: YAMBA DIFFUSER CONFIGURATION, 8 PORTS	Figure 6.4

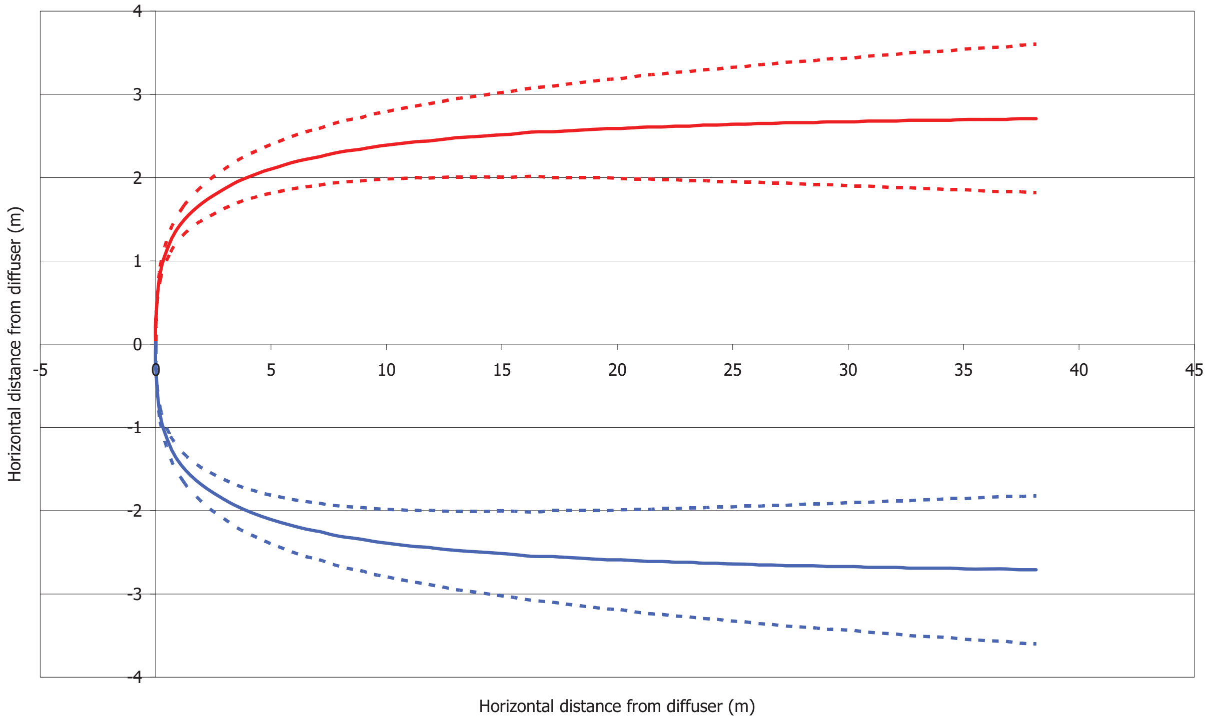




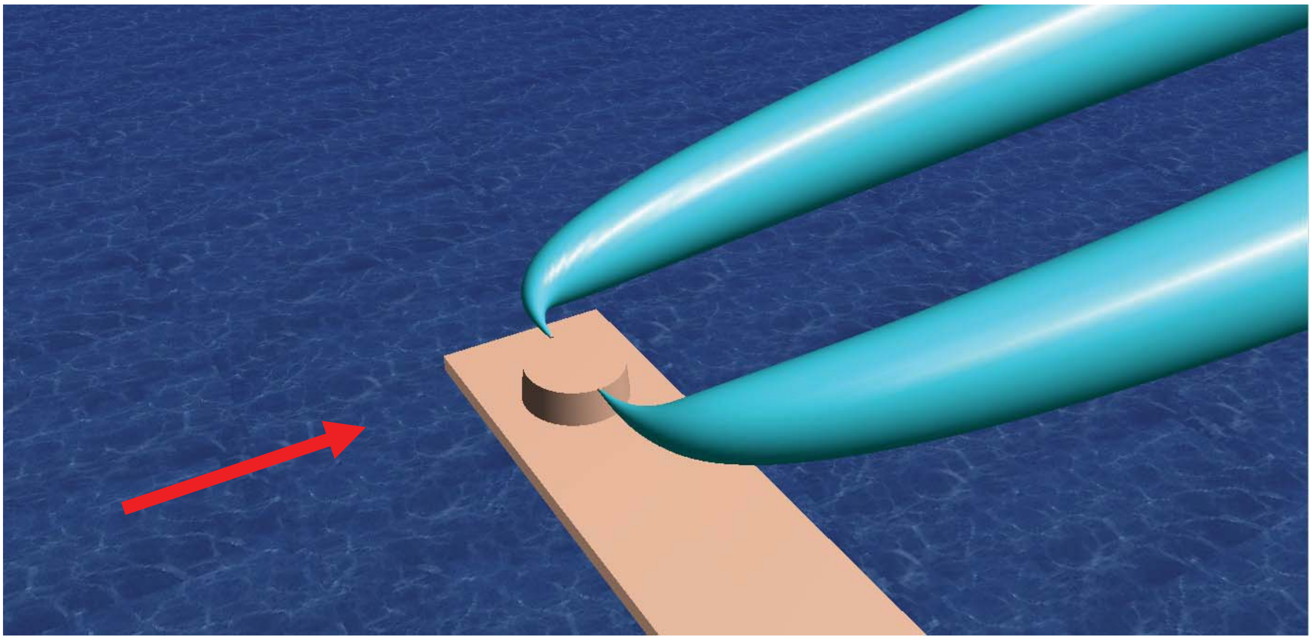
Note: Flow is from left (upstream) to right (ocean)

WRL Report No. 2008/28	PLUME PROFILES: YAMBA 8 PORT DIFFUSER CONFIGURATIONS	Figure 6.5

PLAN VIEW



3-D VIEW



Note: Flow is from left (upstream) to right (ocean)

WRL Report No. 2008/28	PLUME PROFILES: ILUKA DIFFUSER CONFIGURATION, 2 PORTS	Figure 6.6

Appendix A

Sediment and discharge dynamics following a large rainfall event in May 2009 (August 2009)

THE UNIVERSITY OF NEW SOUTH WALES

Water Research Laboratory

School of Civil and Environmental Engineering

19th August 2009

Our Ref: WRL 08069 WCG:DSR L090819

Department of Commerce
359 Harbour Drive (PO Box 63J)
COFFS HARBOUR JETTY NSW 2450

Attention: Tom Blow and Greg Mashiah

Dear Tom and Greg,

JUNE 2009 LOWER CLARENCE RIVER HYDROSURVEY

The Water Research Laboratory (WRL) has been undertaking the Detailed Concept Design (DCD) for the Yamba-Iluka Ebb Tide Release (WRL Technical Report 2008/28). During the DCD investigation, sedimentation and scouring around the proposed release site(s) (Figure 1) was identified as a significant unknown in the design process, potentially threatening the design's longevity and performance. Sedimentation dynamics, particularly after large flood events, was highlighted as a particular concern.

1. BACKGROUND INFORMATION

During May 2009, northern NSW received significant rainfall resulting in widespread flooding across the northern rivers area, including the Clarence River catchment. Following this flooding event, WRL was commissioned to undertake a post-flood hydrosurvey of the Lower Clarence estuary. In conjunction with the hydrosurvey, additional measurements were obtained during the field study to provide information on the flow path and bed dynamics.

The entire field investigation was undertaken over five (5) days from 22 – 27 June 2009. Three of the five days were spent on the river conducting specific investigations, namely:

- Day 1 (23/6/09): Bathymetric surveying
- Day 2 (24/6/09): Bathymetric surveying and drifter drogue releases;
- Day 3 (25/6/09): Bathymetric surveying, ADCP transects and turbidity measurements.

While the majority of the flooding occurred in May, in the days immediately prior to the field investigation approximately 100 mm of rain was received across the lower catchment. This rainfall, coupled with a significant post-flood base flow, resulted in high river turbidity (i.e. increased suspended solids), elevated water levels and high velocities on the ebb tide.

Despite the previous inclement weather, site conditions on all three field days were favourable, with very light winds providing clean surface water conditions (Figure 2c). However, a 2 to 3 metre NE groundswell penetrated the river entrance, restricting data collection in some areas. This included the region east of Moriarty's Wall (on the northern river bank) where ~1 m waves were breaking over a shallow sand shoal and downstream of the training walls.

This letter report outlines the methods and results from the above field investigation. The bathymetric hydrosurvey results are detailed, examining both the specific sites of interest and the lower Clarence River estuary. Drifter drogues data is then discussed to highlight flow patterns in the lower estuary. Bed sediment dynamics are also detailed with emphasis on the bed transport rates. Finally, the implications of the field results on the design and construction of the ebb tide release(s) are provided.

2. BATHYMETRIC HYDROSURVEY POST-FLOOD

The main objective of this investigation was to conduct an extensive bathymetric hydrosurvey of the lower estuary in the vicinity of the proposed ebb tide release(s) after the May 2009 flood event. The collected data could then be compared against previous hydrosurveys to assess sediment dynamics following a significant flooding event. Particular attention was given to the potential release locations for Iluka (Location C) and Yamba (Location A) (Figure 1).

The hydrosurvey was undertaken with a RTK-GPS (Trimble 5700 base and 5800 rover) and Ceestar Dual Frequency Echo Sounder system referenced to a State Survey Mark (SSM) in Iluka Port Datum (IPD) (-0.895m below Australian Height Datum) (Figure 2a). The extent of the survey is shown in Figure 3. Once obtained, the raw survey data was subject to QA/QC procedures and was imported into ArcGIS. The data points were then interpolated using nearest neighbour techniques. Interpolated survey results, shown in metres below IPD, are presented in Figure 4. Bed level elevations at Locations A and C were extracted by querying the interpolated survey results taken at the respective locations using ArcGIS (version 9.3).

The flooding event appears to have had a minimal impact on bed levels in the immediate vicinity of the proposed ebb tide release(s). As shown in Table 1, in comparison to previous recorded bed levels, the Yamba site (Location A) is currently at a historically moderate depth, with both shallower and deeper readings previously recorded. The Iluka site, Location C, is at the shallower end of its historical range but was slightly accreted from the 2008 hydrosurvey.

The impact of the May 2009 flood event on the main channel of the lower estuary was analysed by comparing the June 2009 WRL survey (Figure 4) to the October 2008 WRL survey (Figure 5). This comparison (Figure 6) indicated that the two sand shoals on the western extent of the site adjacent to Iluka port (as discussed previously in WRL Technical Report 2007/28 and letter report dated 20/06/2008 (L080620) were eroded to produce a general flattening or smoothing of the bed profile. The sand from these shoals appears to have moved downstream to fill in a depression off Moriarty's Wall (dark blue area of accretion in Figure 6). Similarly, in the 2008 survey, water depths to the east of Moriarty's wall were generally shallow (~3 m IPD), having been eroded during the flood event to a depth of approximately 5 m below IPD.

Table 1
Historical water depths below Iluka Port Datum (IPD) (-0.895m AHD)

Survey	Yamba (m IPD)	Iluka (m IPD)
	E:534320,N:6744840	E:534290,N:6745050
	Location A	**Location C**
1979 - PWD	5.4	6.2
1986 - Maritime Services Board of NSW (April)	7.40	5.20
1988 - Maritime Services Board of NSW (21-23 June)	7.03	4.07
1993 - Australian Army (15 September)	7.6 (approx)	5.2 (approx)
1999 - Sydney Ports (digital data, month unknown)	6.46	4.10
2002 - Department of Land and Water Conservation (May)	5.8	5.20
2004 - NSW Waterways Authority (March)	not covered	not covered
2006 - NSW Maritime (November)	not covered	not covered
2007 - DECC Coastal Unit (May)	not covered	not covered
2007 - Water Research Laboratory (July)	7.73	5.70
2008 - Water Research Laboratory (October)	7.10	4.00
2009 - Water Research Laboratory (June)	6.46	4.20

Overall, the flood event has resulted in a general smoothing of the estuary bed with shallow areas eroded and deeper zones filled with deposited material. Two areas that do not follow this trend are the area directly west of Moriarty's Wall and an eroded area along the northern side of the Middle Wall. The accretion west of Moriarty's Wall is likely due to flood velocities on the ebb tide forming a strong eddy on the downstream side of Moriaty's Wall and resulting in significant deposition. This process was observed during the field study. Further, the scour hole at the downstream end of the Middle Wall remains due to the prevailing hydrodynamic conditions.

In addition to the measurements obtained during the field investigation, several trends/processes were observed during the course of the 2008 and 2009 studies. These include:

- During the peak ebb tidal flows a standing wave formed approximately 100 m downstream of the confluence of the Main and Southern Channels (at the upstream extent of the main breakwater). This may be due to upwelling that occurs due to the presence of the sub-surface reef or it may be due to super-critical flow conditions forming due to the combined discharge of the Main and Southern Channel being confined between the training walls.
- During both the 2008 and 2009 survey it appears that the area east of Moriarty's Wall on the northern riverbank is infilling. During the 2009 survey waves were breaking on the shoals throughout the entire field study.
- A scour hole occurs near the spur wall associated with Moriarty's Wall during periods of high flows. This scour hole was previously noted, however, the 2009

field investigation observed upwelling and downwelling currents associated with the scour hole that may be of interest to the proposed ebb tide release(s).

3. DRIFTER DROUGES

GPS drifter drogues were deployed over the ebb tide to assess potential flow paths following the flood event. As per the 2008 investigation, GPS trackers were attached to a float with a sail suspended approximately 2 m below the surface (Figure 2b). The drogues were deployed upstream of the proposed locations, west of Moriarty's wall, and removed from the river when wave action threatened retrieval.

The drogue releases were undertaken to assess flow paths in the immediate vicinity of the proposed release(s) and to assess any changes to the flow paths since previous test were undertaken in 2008. Three separate releases were undertaken:

- the first release focused on flow paths from the proposed Iluka release; and,
- the second and third releases covered the full width of the main channel.

As depicted in Figures 7, 8 and 9, repeated deployments at the proposed Iluka release (Location C, Figure 1) did not indicate any interactions with Moriarty's Wall or towards the northern riverbank. Coupled with the increased dilutions likely to occur during flood events, these results indicated that it was unlikely for recycled water to be deposited on or in the vicinity of the wave catch (or Mullet) beach.

As anticipated, the deployed drifter drogues were transported downstream at higher ambient velocities than during the 2008 study. Deployments 2 and 3 (Figures 8 and 9) assessed flow paths across the full width of the main channel. In the 2008 study, drogue velocities ranged from 0.65 m/s to 0.9 m/s across the main channel, whereas during this study drogue tracks indicated a higher velocity range from 0.9 m/s to 1.45 m/s. Interestingly, drogue tracks for the 2009 deployments indicated higher velocities through the southern half of the channel likely due to the angle of the channel in this area which encourages the majority of flow towards the scour hole at the Middle Wall.

Higher ambient velocities were also confirmed with the ADCP data. Transects of the main channel in 2008, indicated a late ebb tide discharge of approximately 1300 m^3/s, whilst similar transects undertaken in 2009 showed a discharge of approximately 1650 m^3/s. This is likely due to the freshwater discharge from the river, with consistent rainfall in the catchment in the days preceding the study (Figure 10). In addition, velocities recorded in the 2008 study were lower than those measured during this investigation. In 2008, a maximum velocity of 1.05 m/s was recorded, while in 2009 velocities were consistently recorded above 1.5 m/s.

Drogue flow paths near the proposed Yamba ebb tide release site reiterated observations from the October 2008 field study. These measurements indicated that effluent released at this location would travel eastward, parallel to the Middle Wall, at high velocities minimising residence time in the estuary. Sufficient dilutions within the near-field zone are required to ensure that the released water does not impact the middle wall recreational fishing haven.

4. BED SEDIMENT DYNAMICS

Bed sediment dynamics were investigated using an Acoustic Doppler Velocity Profiler (ADCP) (RDI 1200 kHz) and a Hydrolab Minisonde (Series 4) probe. The primary objective was to assess the bed transport rates and to provide a preliminary assessment of the suspended sediment profile.

4.1 Background Information

ADCP's determine current velocity by measuring the shift in the acoustic Doppler signal and subtracting the boat movements. The boat movements are determined by 'tracking the bed' (using bottom tracking software) and assumes that the bed is stationary. However, when the bed is moving, RTK-GPS techniques can be used in conjunction with the ADCP to determine bed transport loads. In these circumstances, the boat follows a track across the river, returning to the original point using the RTK-GPS for guidance. The distance between the beginning and the end of the track (as indicated by the ADCP) is known as the 'distance made good'. Dividing this distance by the time to complete the transect provides a gross bed transport rate.

Backscatter measured by the ADCP also provides an indication of suspended sediment load. The higher the ADCP backscatter measurement, the greater the absorption and deflection of the acoustic signal, thus indicating a higher suspended sediment concentration. Backscatter plots, in conjunction with turbidity readings provide a useful indication of suspended sediment dynamics.

4.2 Field Measurements

A range of ADCP measurements were undertaken throughout the field investigation. Two transects are highlighted here for reference. Both reported transects were undertaken on June 25th (Day 3) during peak ebb flows (Figure 10).

Figure 11 details the actual boat track and the ADCP measured transect for the first run. This transect recorded a distance made good of 205 m, indicating a mobile bed sediment velocity of 0.23 m/s. The presence of a mobile bed was confirmed by high backscatter measurements near the bed (Figure 12). It is worth noting that the highest backscatter measurements were recorded at the bed in the main channel but that the suspended sediment load extended throughout the water column (Figure 12).

Figure 13 depicts the actual boat track and ADCP measurements for the second reported transect. This transect recorded a distance made good of 200 m, indicating a mobile bed velocity of 0.27 m/s (Figure 13). This was again confirmed by the backscatter ADCP readings (Figure 14) and was most prevalent immediately south of the scour hole at Moriarty's Wall.

ADCP backscatter observations were also compared against turbidity readings to confirm the backscatter readings were related to high turbidity zones. For these measurements, the boat was anchored at the proposed Iluka release location (Location C) and the ADCP was run to measure velocities and backscatter throughout the water column. As expected, backscatter was highest at the bed, indicating a mobile sediment load (Figure 15). The backscatter readings were verified against the calibrated Hydrolab turbidity probe, which measured increasing turbidity with depth recording the highest NTU at the bed.

Assuming a course relationship of 1 NTU ≈ 1 mg/L, a background suspended sediment concentration can be calculated throughout the water column of approximately 150 mg/L. Further, the suspended sediment concentration at the bed can be estimated at approximately 200 to 300 mg/L. This level of suspended sediment is likely due to the high velocities associated with the catchment runoff from the preceding days of rain and/or the relatively steep hydrograph of the flooding event in May. While outside the scope of works for this study, detailed analysis of suspended sediment loads versus turbidity readings could be undertaken to better characterise the suspended sediment load and dynamics.

4.3 Discussion

The backscatter and turbidity readings suggests that a large volume of sediment is suspended and transported during and following flooding events. Measurements taken during the field investigation indicate that the bed is highly dynamic and that sediments are suspended throughout the entire water column. It is worth noting that experienced fishermen on the river were calling this event a ‘dirty’ flood due to what they perceived was a large amount of debris/sediment in the water. As such, it is difficult to determine if this is a typical flooding event or a worse than usual event. It is also worth noting that due to the large volume of suspended sediment in the water column during field testing, the bathymetry measurements outlined in Section 2 may be affected as the high base flow recedes and regular tidal flows return.

5. SUMMARY AND IMPLICATIONS

WRL was commissioned to undertake a bathymetric hydrosurvey of the lower Clarence River in the vicinity of the proposed ebb tide release(s) following recent floods. The field campaign was undertaken between June 22 – 25 2009. During and following the hydrosurvey a range of additional measurements were undertaken to assess flow paths (using GPS drifter drogues) and bed sediment dynamics (using an ADCP and Hydrolab turbidity probe).

The field results indicated that the river bathymetry was affected by the flood event. In comparison to the 2008 hydrosurvey, an overall flattening of the bed profile was observed with sediment being largely transported downstream to infill previous depressions. Scour holes at the end of Moriarty’s Wall and the Middle Wall were also evident. The scour hole and associated currents at Moriarty’s Wall may influence future velocity measurements used to operate the ebb tide release and further consideration of the velocity measurement location may be required. Importantly, changes in bed elevations at the proposed ebb tide release locations were within the previously recorded range of measurements, although immediately downstream of both locations was subject to significant deposition.

Drifter drogue releases suggested that within 200 m of the proposed ebb tide release(s) the main flow path is in an easterly direction. Further the flow paths appear to be unobstructed by the training walls and/or large circulating eddies. This suggests that any water released during high (or regular) flow periods would be transported directly towards the river entrance and away from sensitive receivers.

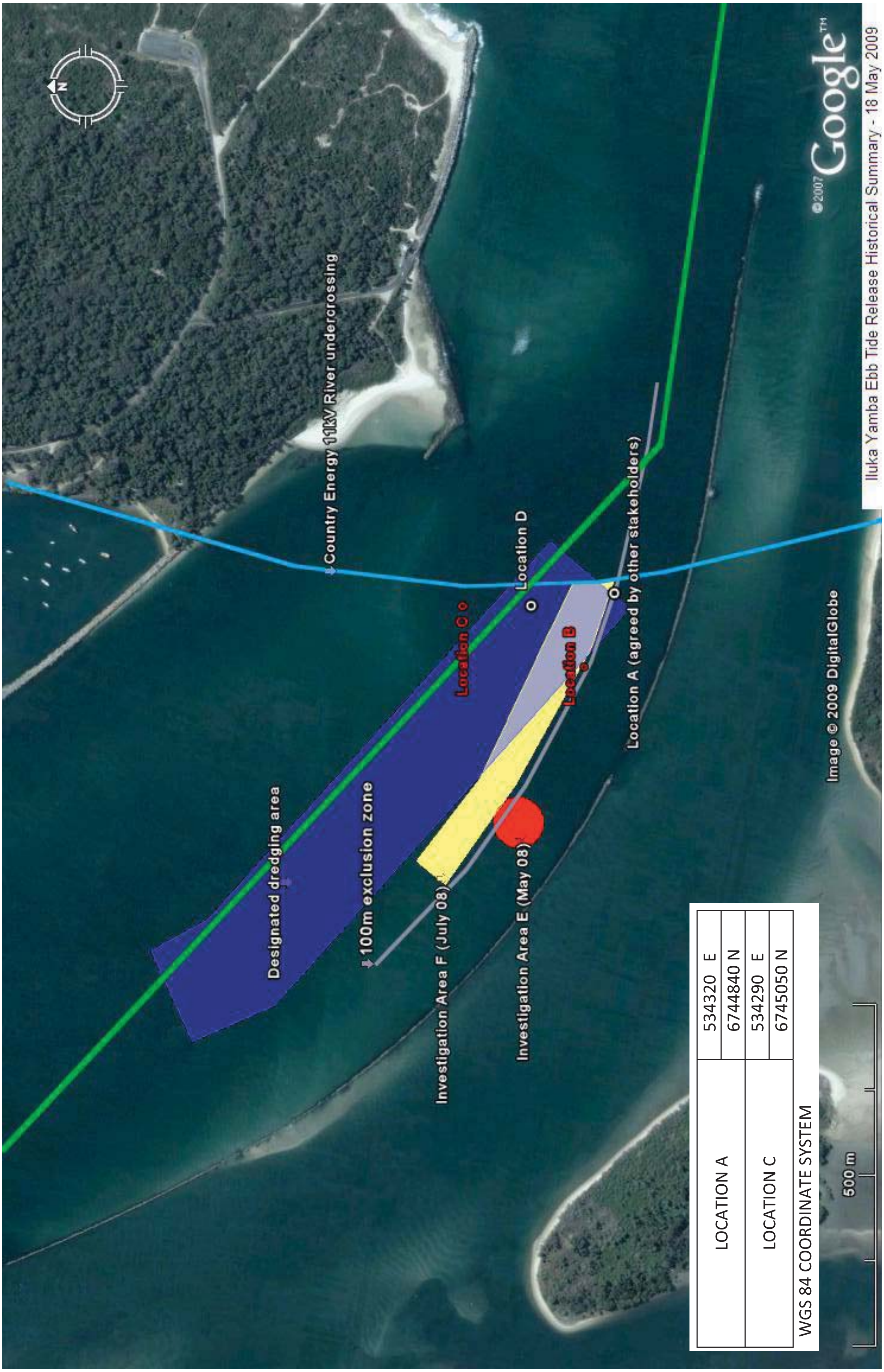
Bed and suspended sediment analysis was undertaken using backscatter and turbidity readings. These investigations were designed to assess the suspended sediment dynamics and the thickness of the bed transport load. Results from the field investigation suggest that during and/or proceeding flooding events a large volume of suspended sediment is transported through the lower estuary. Bed transport rates exceeding 0.2 m/s were measured at the two proposed ebb tide releases. In addition to the high transport rates, suspended sediment was measured throughout the lower half of the water column. In combination, the large volume of sediment transported (either as bed load or suspended sediment) through the water column presents a risk to the ebb tide release structure(s). Particular attention may be required during the construction of the ebb tide release(s) to ensure that sediment does not accrete around the structure. Further suspended sediment and bed dynamic analysis including on-going monitoring at the proposed release sites may be required.

A final point worth noting is related to the accumulation of sediment on the northern riverbank downstream of Moriarty's Wall. The large build-up of sediment in this area has the potential to influence fish migration patterns and hence, impact the mullet run. If sediment continues to accumulate in this region, and the ebb tide releases are constructed, it may be difficult to determine the cause of any changes in the mullet migration patterns (i.e. has the mullet migration pattern changed due to the accumulation of sediment or the construction of the ebb tide releases). Further investigations may be required to ensure that the ebb tide releases are not unduly blamed for any future impacts associated with natural estuarine processes.

If you have any questions regarding the findings of this investigation, please do not hesitate to call Will Glamore or myself on (02) 9949 4488 for further discussion.

Yours sincerely,

Brett Miller
Manager.



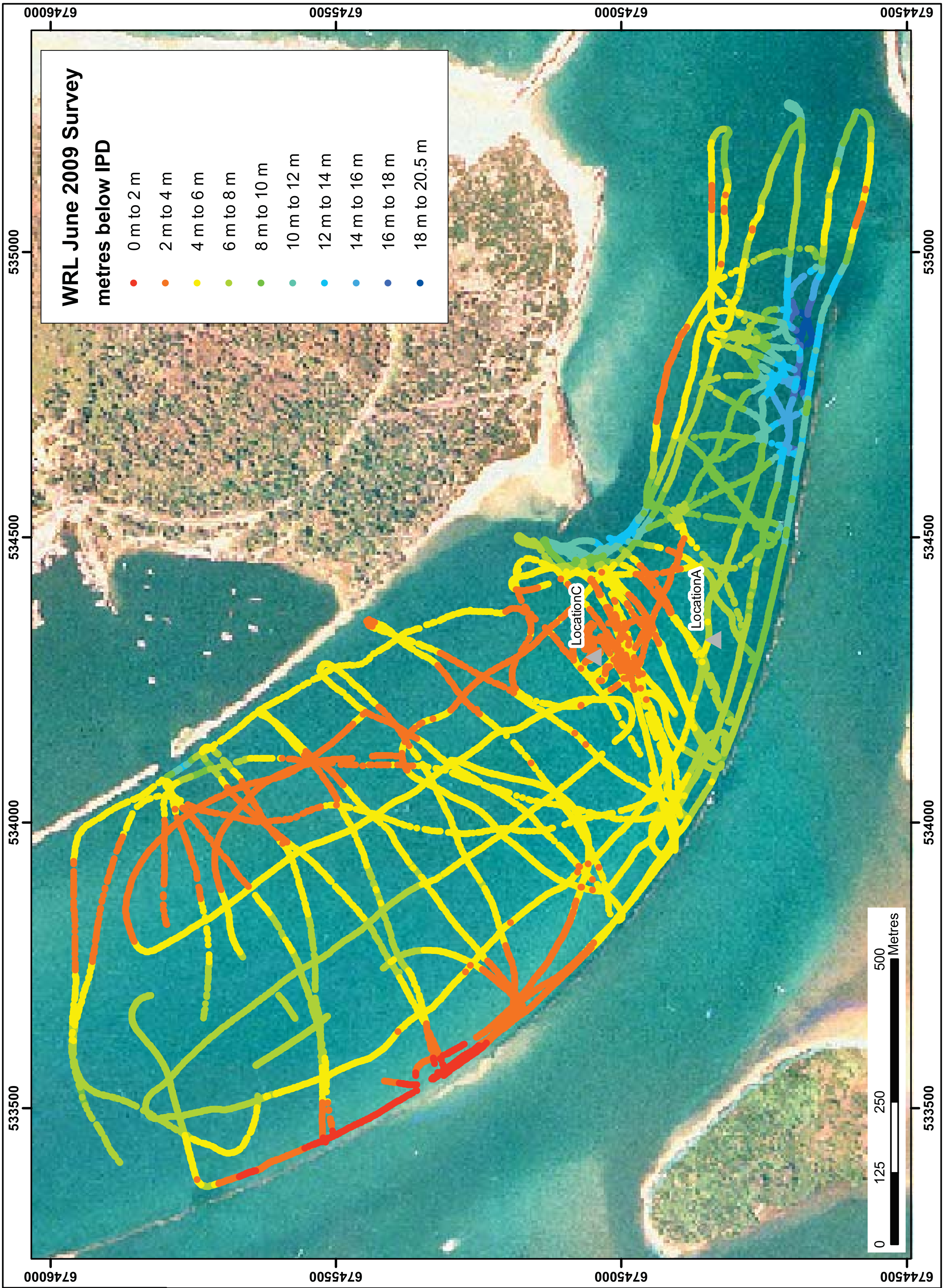
WRL Letter No. L090819	EBB TIDE RELEASE LOCATIONS (SOURCE: DoC)	Figure 1

a) RTK GPS station.

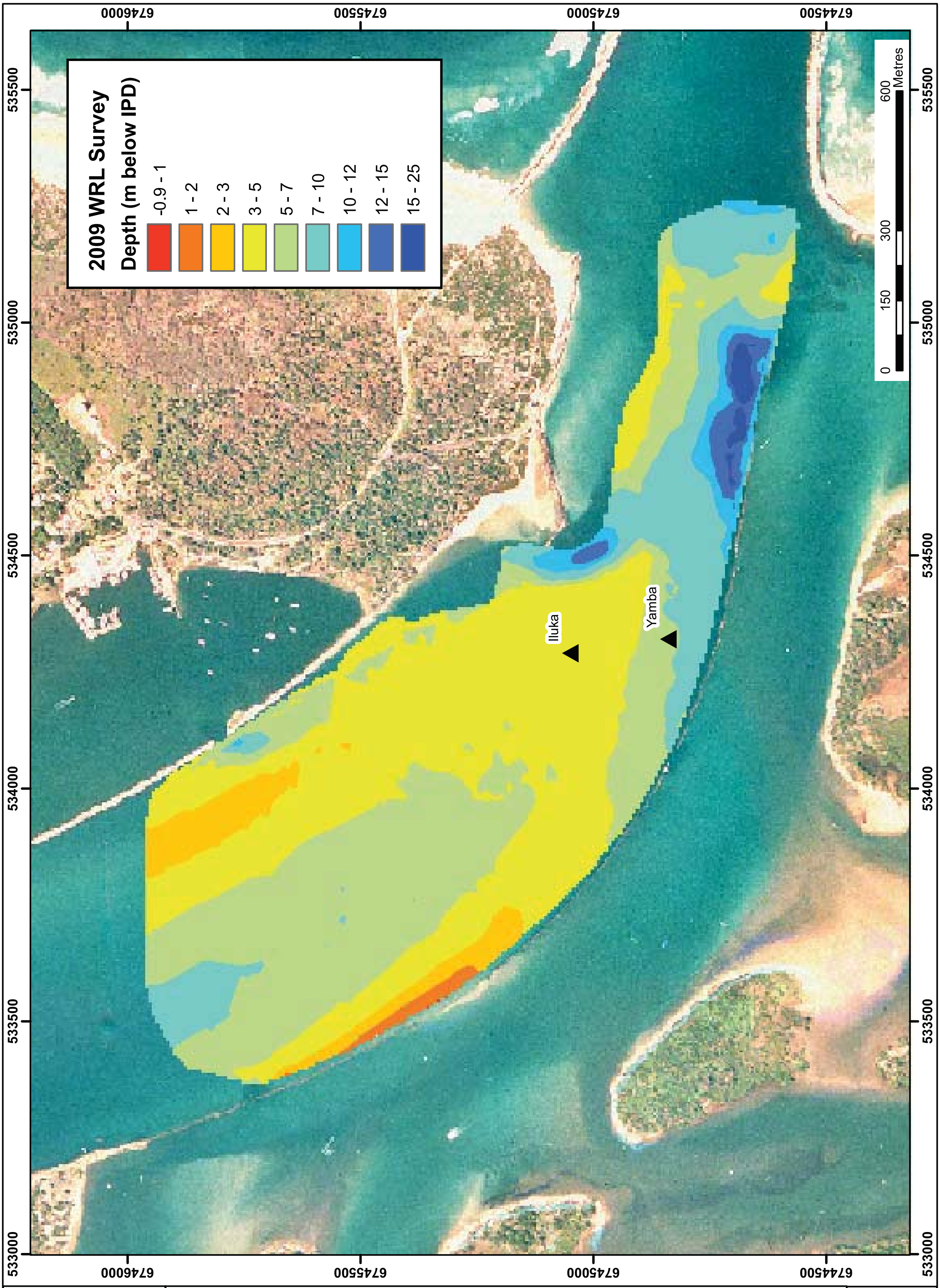
b) GPS drifter drogue.

c) Boat set up with GPS echo-sounder (port side) and ADCP. Calm conditions.

WRL Letter No. L090819	SITE CONDITIONS AND EQUIPMENT SETUP	Figure 2



WRL Letter No. L090819	WRL JUNE 2009 BATHYMETRY SURVEY EXTENT	Figure 3

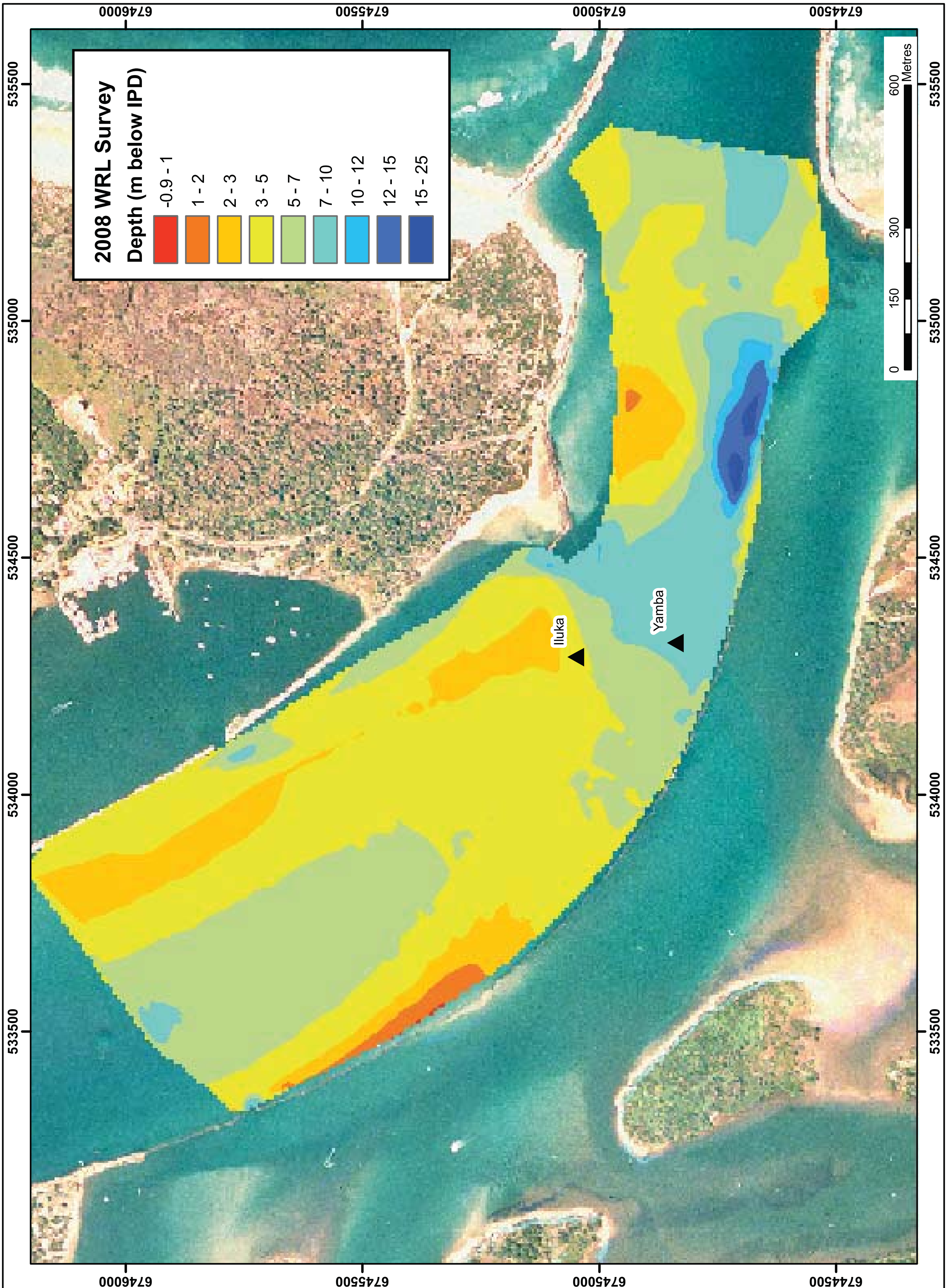


WRL

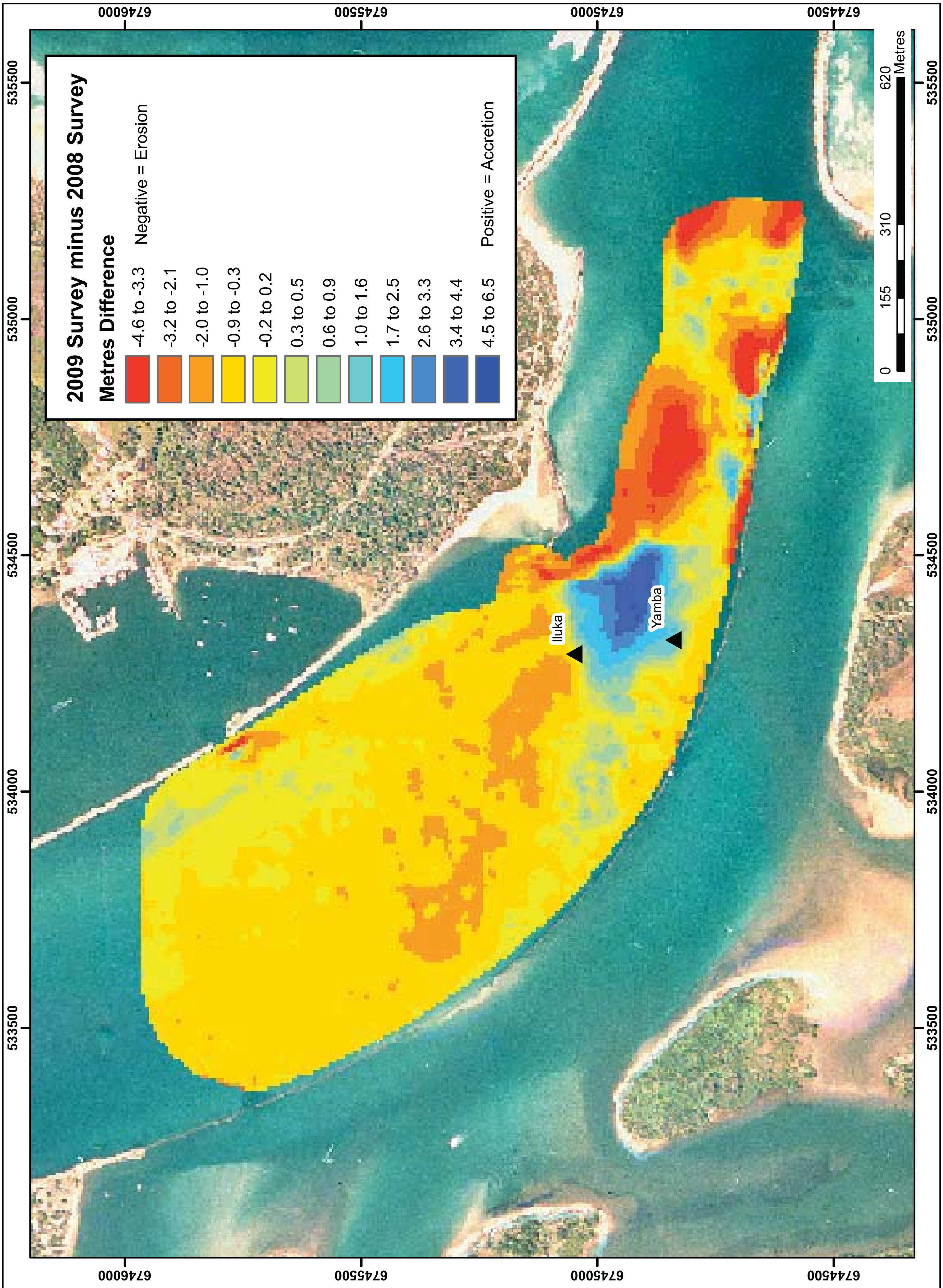
Letter No. L090819

WRL 2009 (JUNE) HYDROSURVEY (in m below IPD)

Figure
4

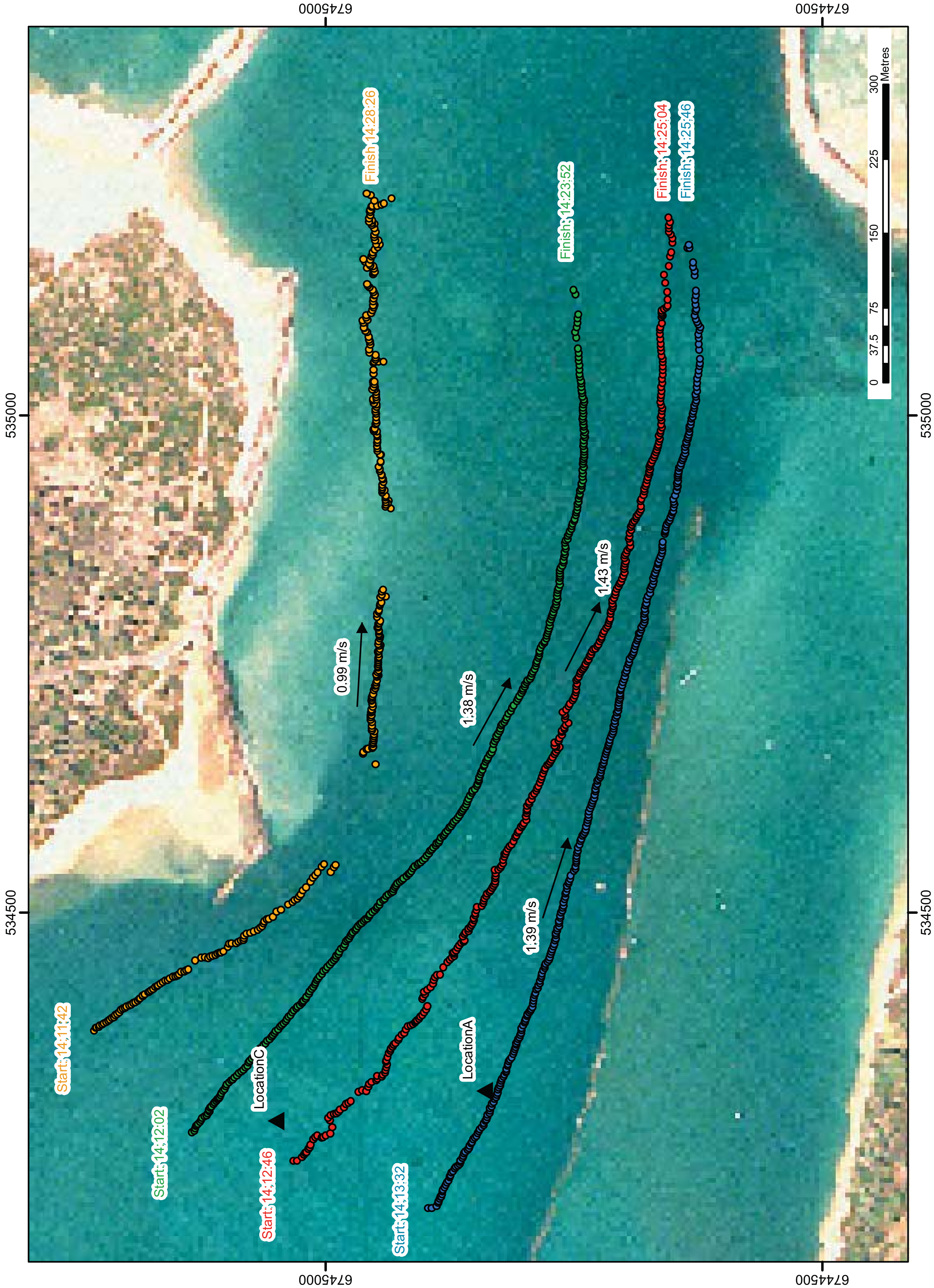


WRL Letter No. L090819	WRL 2008 (OCTOBER) HYDROSURVEY (in m below IPD)	Figure 5

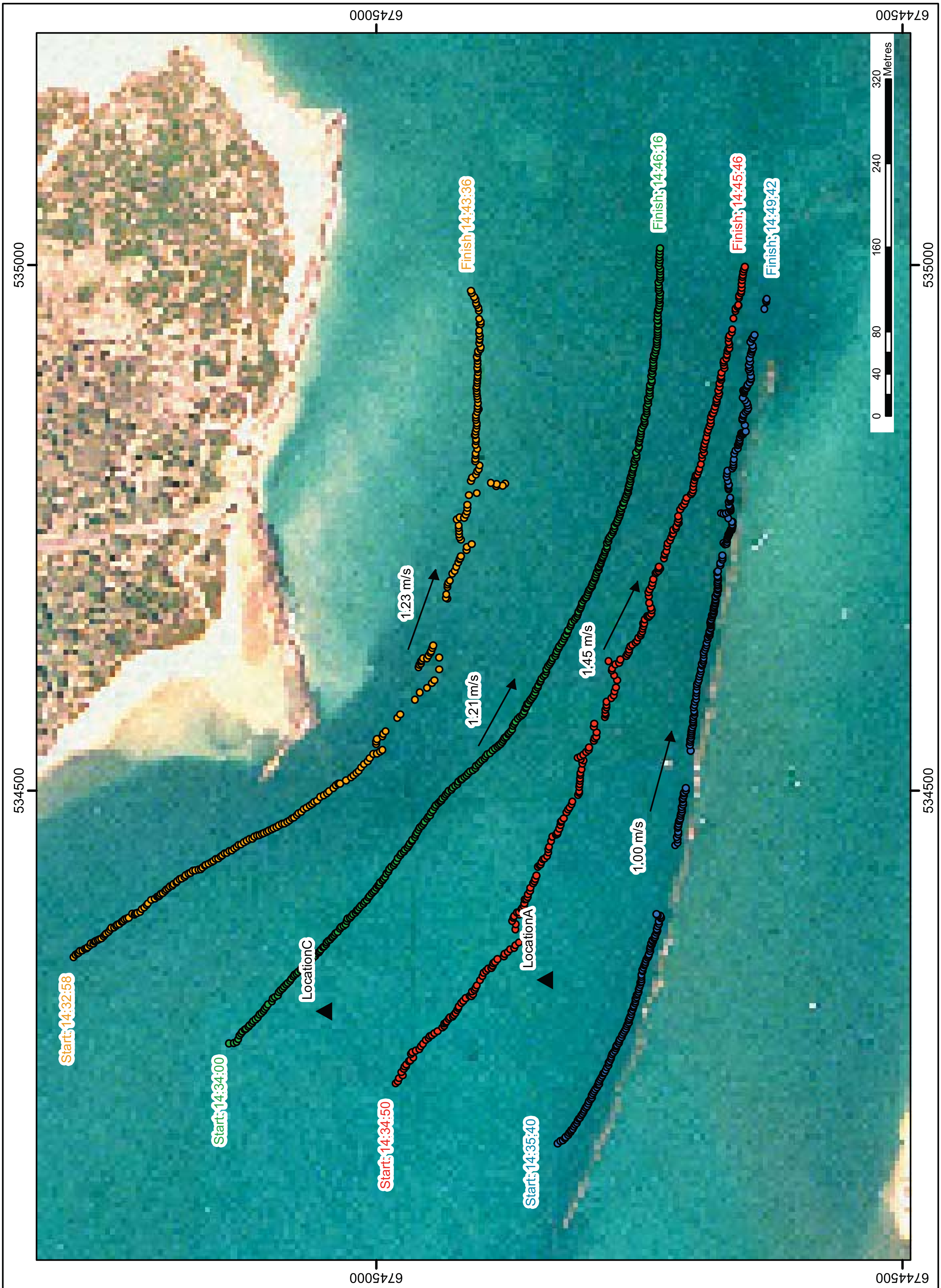


WRL Letter No. L090819	DIFFERENCE BETWEEN 2009 (JUNE) VERSUS 2008 (OCTOBER) SURVEY	Figure 6

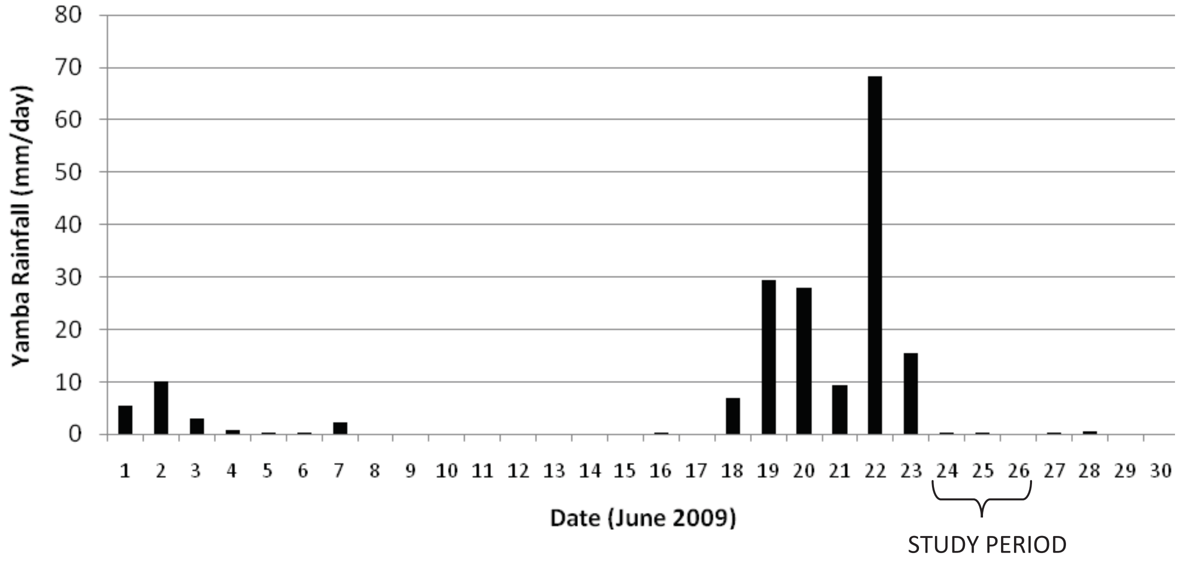
WRL Letter No. L090819	GPS DROGUE TRACKING RELEASE # 1 (24/06/2009)	Figure 7

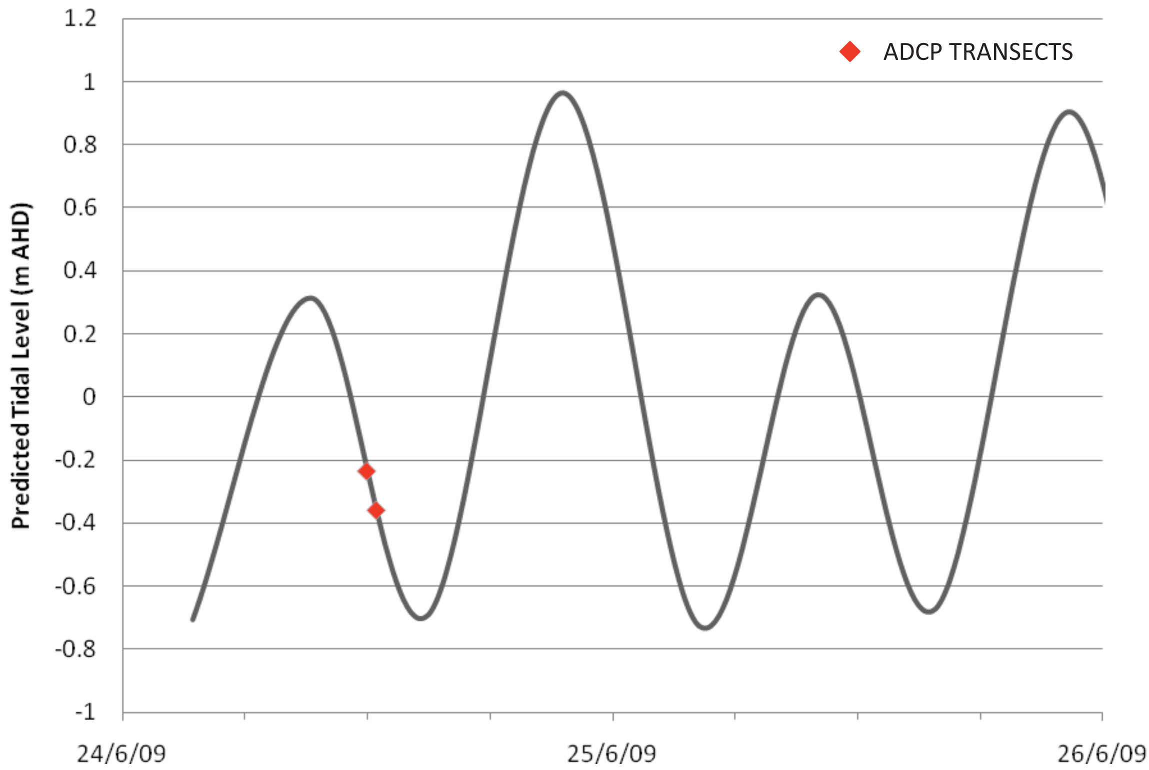


WRL Letter No. L090819	GPS DROGUE TRACKING RELEASE # 2 (24/06/2009)	Figure 8

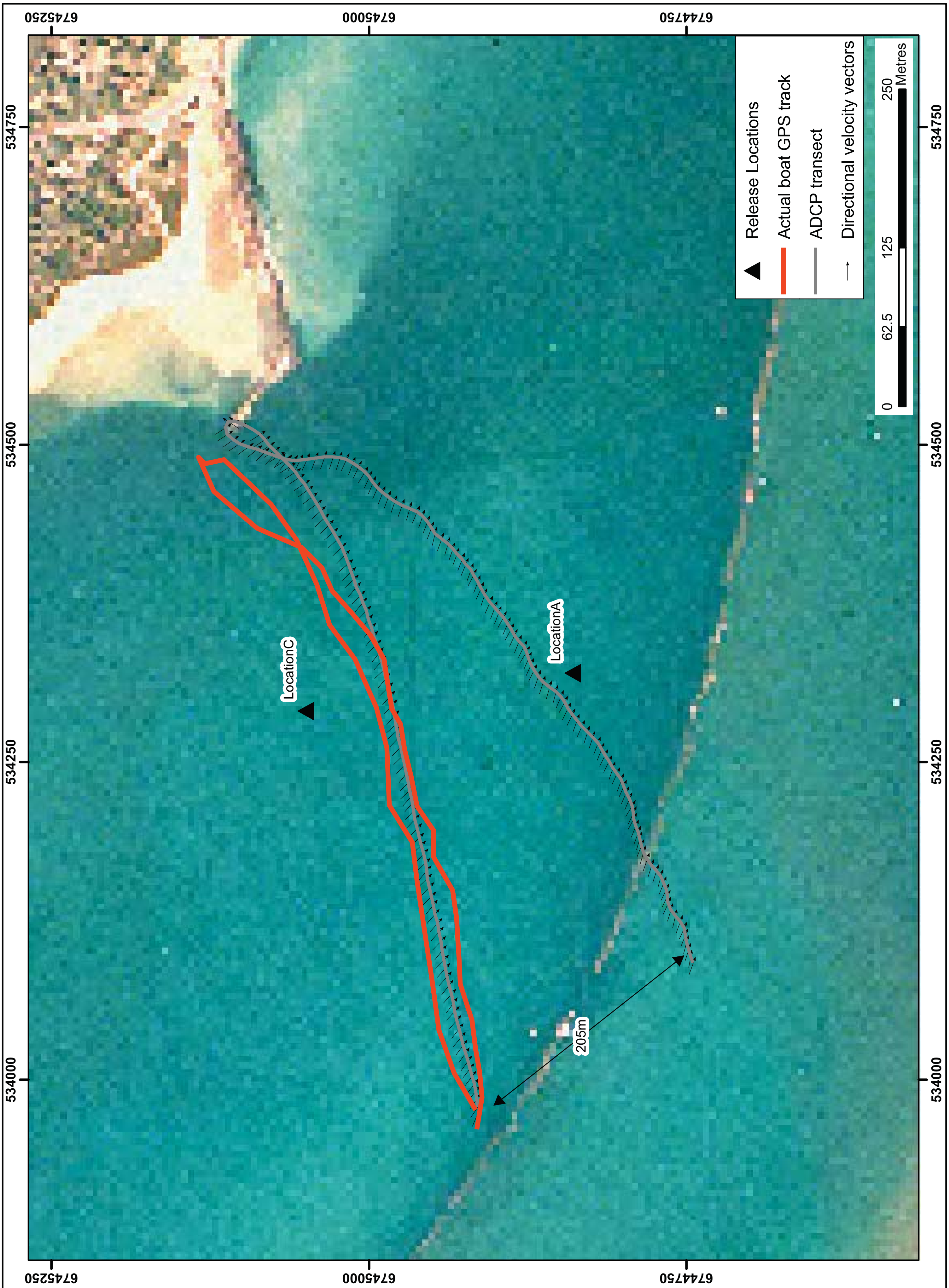


WRL Letter No. L090819	GPS DROGUE TRACKING RELEASE # 3 (24/06/2009)	Figure 9

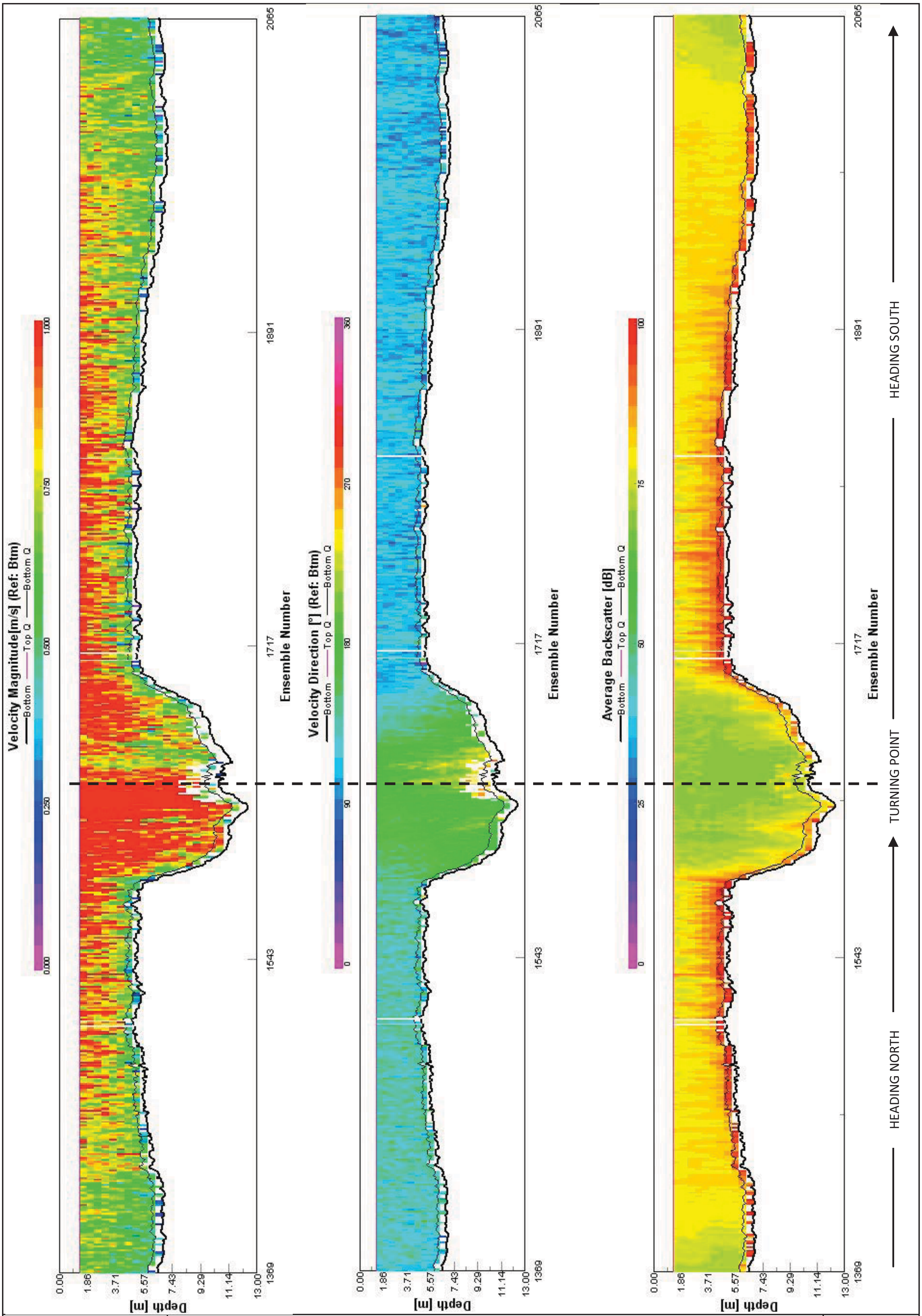




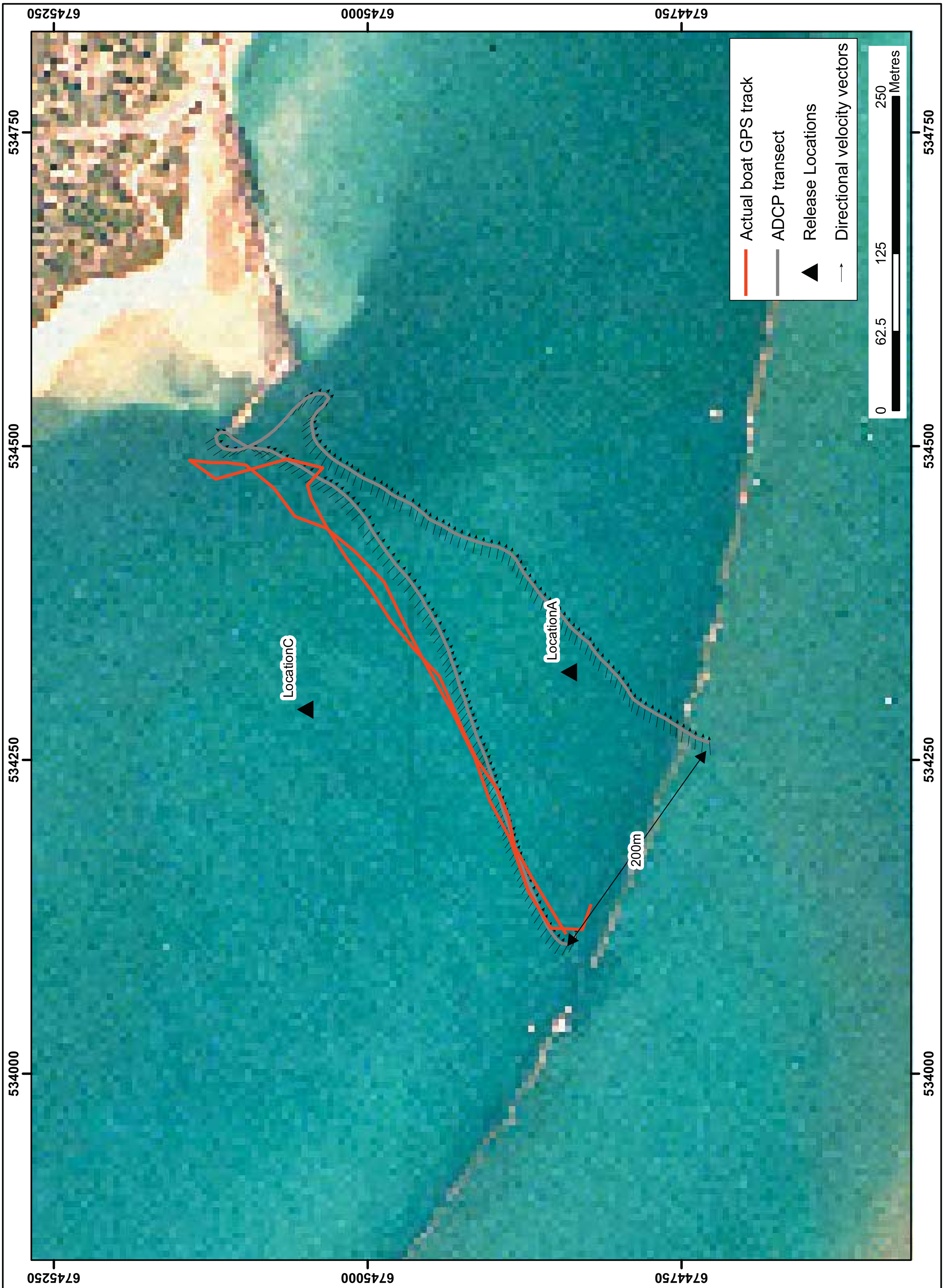
WRL Letter No. L090819	RAINFALL AND TIDES FOR STUDY PERIOD	Figure 10



WRL Letter No. L090819	ADCP BED SEDIMENT ANALYSIS # 1	Figure 11



WRL Letter No. L0900819	ADCP TRANSECT #1 OUTPUTS	Figure 12

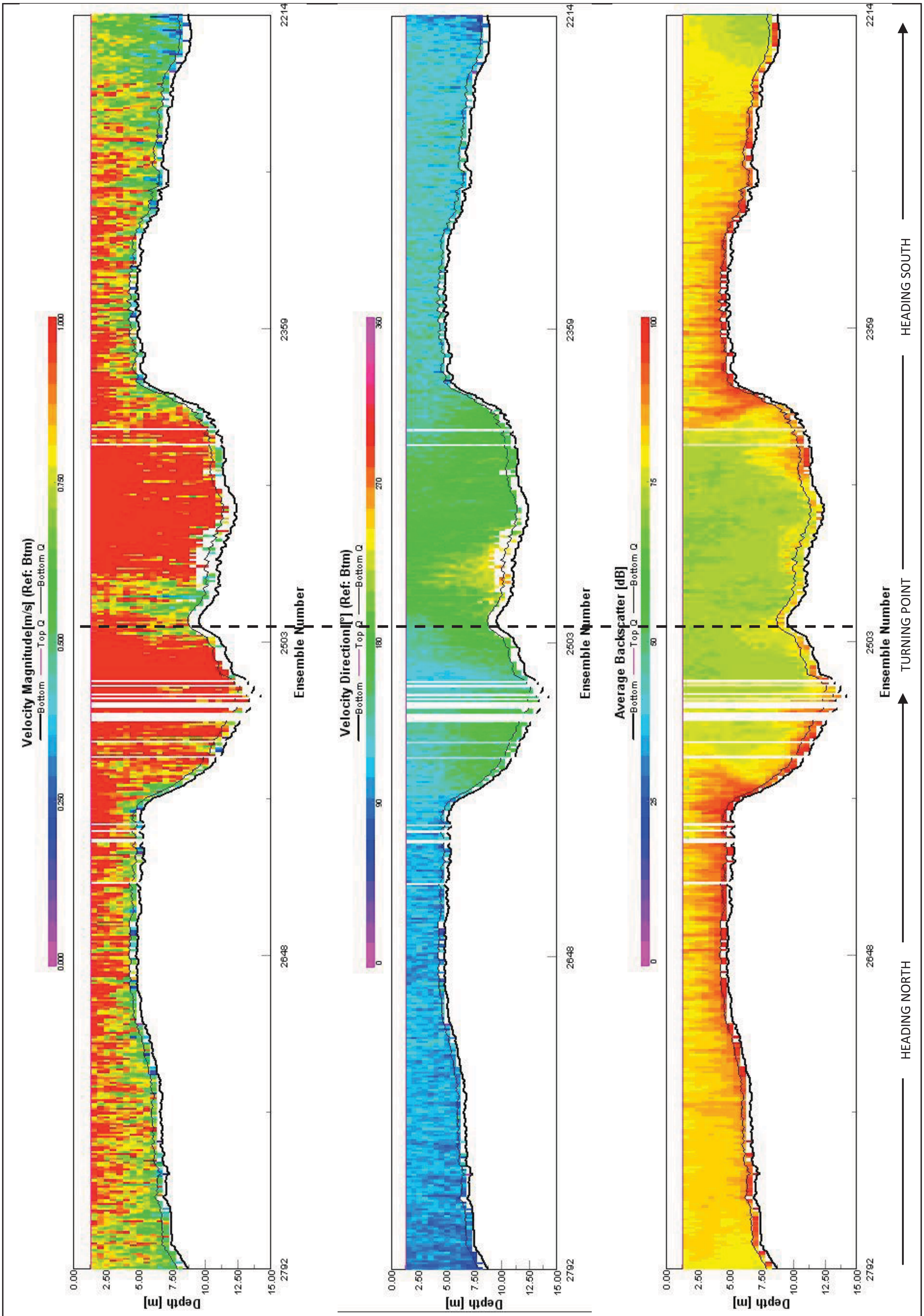


WRL

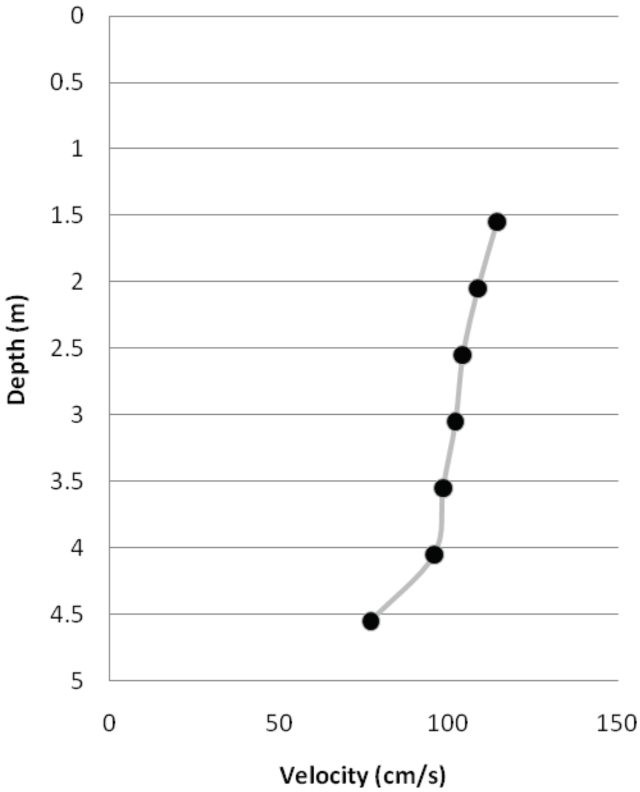
Letter No. L090819

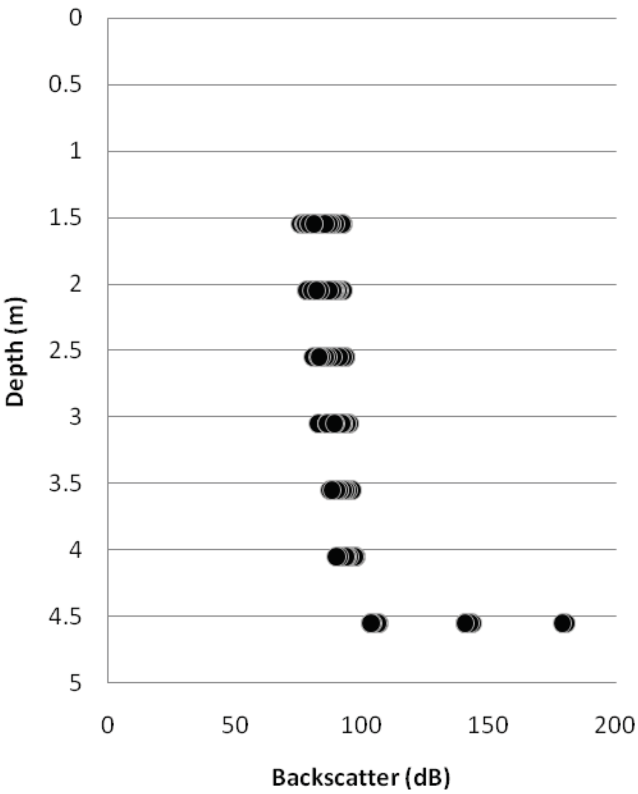
ADCP BED SEDIMENT ANALYSIS # 2

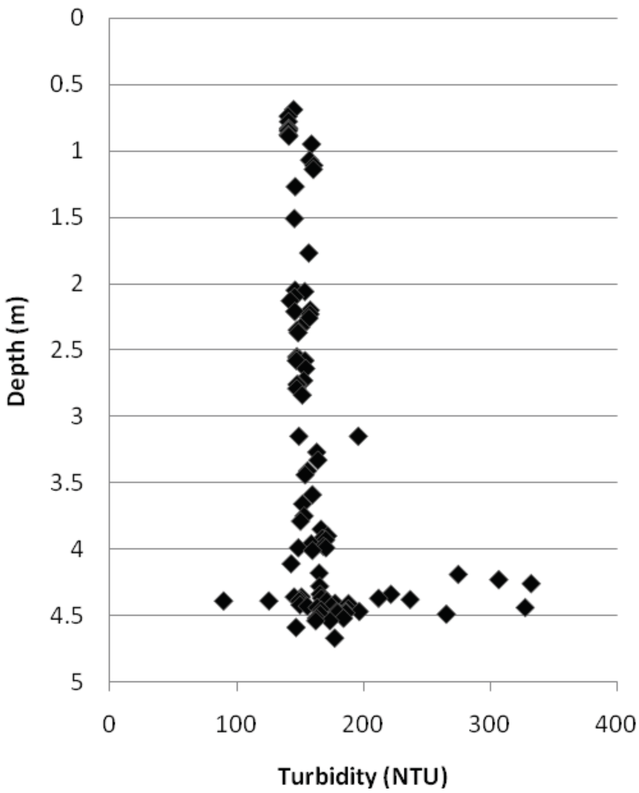
Figure 13



WRL Letter No. L090819	ADCP TRANSECT #2 OUTPUTS	Figure 14







WRL Letter No. L090819	BED LOAD ANALYSIS	Figure 15

Appendix B

Feasibility assessment of revised Iluka ebb tide release location (May 2009)

M E M O R A N D U M

WATER RESEARCH LABORATORY

School of Civil and Environmental Engineering

TO: Tom Blow and Greg Mashiah **DATE:** 29th May 2009

FROM: William Glamore **REF:** 08069 WCG:DSR M090529

SUBJECT: FEASIBILITY ASSESSMENT OF REVISED ILUKA EBB TIDE RELEASE LOCATION

This letter contains preliminary findings regarding the feasibility assessment of a revised Iluka ebb tide release location. The proposed site (E534292 N6745050) is located on the northern side of the NSW Maritime dredge channel (Figure 1).

The depth at the previous location was approximately -7.5 m IPD (Iluka Port Datum), with the Iluka diffuser positioned at -6 m IPD. Based on the results of this investigation, the depths at the revised Iluka location are approximately -4 m IPD and -3 m IPD respectively, with depths varying over time from -5.7 m IPD to -4.0 m IPD (Table 1)

Table 1

Recorded Depths at the Proposed Release Location

Survey	Iluka E:534292 N:6745050 (m IPD)#
1986 - Maritime Services Board of NSW (April)	5.1
1988 - Maritime Services Board of NSW (21-23 June)	4.1
1993 - Australian Army (15 September)	4.2
1999 - Sydney Ports (digital data, month unknown)	4.1
2002 - Department of Land and Water Conservation (May)	5.2
2004 - NSW Waterways Authority (March)	not surveyed
2006 -NSW Maritime (November)	not surveyed
2007 - DECC Coastal Unit (May)	5.2
2007 - Water Research Laboratory (July)	5.7
2008 - Water Research Laboratory (October)	4.0

Note Iluka Port Datum (IPD) is 0.92 m below local Australian Height Datum (AHD)

Design conditions for the ebb tide release are unchanged from WRL Technical Report 08/28, with release flows (Table 2), ambient current velocities (Table 3) and release hydraulic design (Table 4) remaining the same as previously stated.

Table 2

Ebb Tide Release Design Flow Rates

Design Flow	Iluka	Yamba
ML/day	1.95	7.92
L/sec over 3 hour release window	91	367

Table 3

Ebb Tide Current Velocity

Percentile	Velocity for entire ebb tide at Xth percentile (in m/s)	Velocity for 3 hour ebb tide at Xth percentile (in m/s)
50th	0.40	0.50
90th	0.09	0.24
99th	0.02	0.13

Table 4

Iluka Ebb Tide Release Design: Duckbill Ports

Number of Ports	DUCKBILL Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	100	0.0910	0.0455		
4	100	0.0910	0.0228		
6	100	0.0910	0.0152	4.60	1.10
8	100	0.0910	0.0114	3.90	0.75
10	100	0.0910	0.0091	3.20	0.60
2	150	0.0910	0.0455	5.40	1.50
4	150	0.0910	0.0228	4.20	0.90
6	150	0.0910	0.0152	2.90	0.45
8	150	0.0910	0.0114	2.4	0.3
10	150	0.0910	0.0091	2.2	0.25
2	200	0.0910	0.0455	4.00	0.85
4	200	0.0910	0.0228	3.20	0.50
6	200	0.0910	0.0152	2.20	0.25
8	200	0.0910	0.0114	1.80	0.15
10	200	0.0910	0.0091	1.70	0.12
2*	**300**	**0.0910**	**0.0455**	**2.65**	**0.36**
4	300	0.0910	0.0228	1.85	0.17
6	300	0.0910	0.0152	1.50	0.12
8	300	0.0910	0.0114	1.30	0.09
10	300	0.0910	0.0091	1.15	0.07

*Selected design for Iluka ebb tide release

Near-field modelling was undertaken using CORMIX, with the site conditions outlined in Tables 1 to 4. An ambient water depth of -4.0 m IPD was assumed and a release depth of -3.0 m IPD was applied. Due to the distance of the location from the ocean, a 3 hour ebb tide release window was assumed. This 3 hour operational timeframe will be confirmed with subsequent hydrological modelling. 50th percentile and 90th percentile flows over this 3 hour period were used to calculate near-field dilutions are shown in Table 5.

Table 5

Iluka: Two Port Diffuser Near-field Dilutions

Port Angle	Dilution for 3 hour ebb discharge (50th %ile velocity)	Dilution for 3 hour ebb discharge (90th %ile velocity)
90/270	91	58

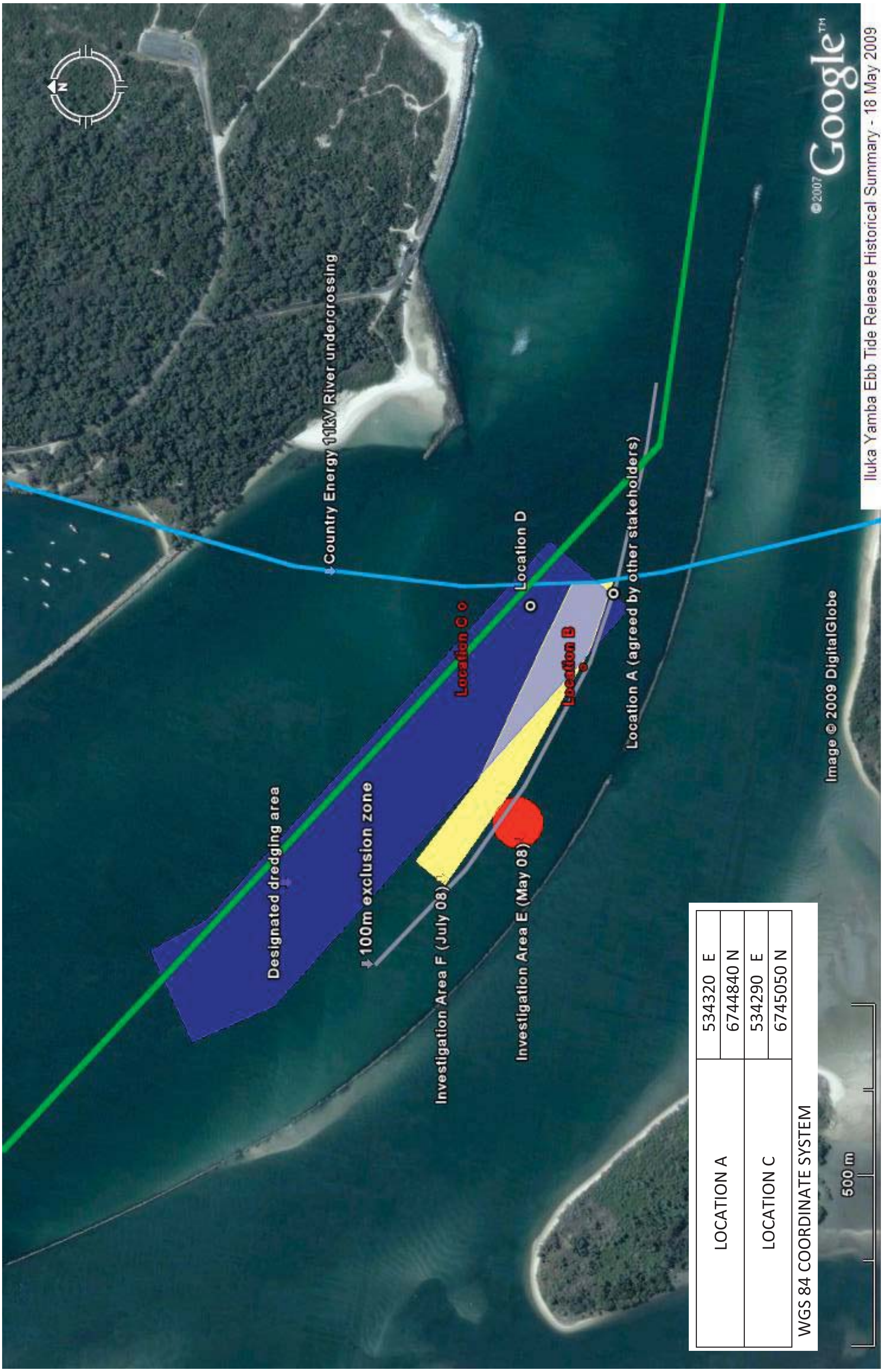
Based on the dilutions calculated above, all analytes except for Total N and ammonia would satisfy water quality guidelines to meet the requirements for minimum dilution within the near-field zone. To satisfy the criteria for Total N (65 times dilution) and ammonia (~200 times dilution), additional dilutions are required. The distance from the release location required to meet ~200 times dilution was calculated as 97 m for 50th percentile ambient velocities, and 193 m for 90th percentile ambient velocities (Table 5 and Figure 2). It is worth noting that the dilution required for ammonia is highly conservative as it assumes that no chemical transformations would occur.

Table 6

Distance to 200 Times Dilution for Iluka: Two Port Diffuser

Port Angle	Distance to 200x dilution for 3 hour ebb discharge (50th %ile velocity)	Distance to 200x dilution for 3 hour ebb discharge (90th %ile velocity)
90/270	97m	193m

The dilutions achieved in the near-field, and distances to ~200 times dilution, for the revised Iluka ebb tide release location are significantly lower than those predicted for the previous Iluka location (Figure 1, Location A). The distances required to meet these dilutions are graphically displayed in Figure 2.



WRL Memo No. M090529	EBB TIDE RELEASE LOCATIONS (SOURCE: DoC)	Figure 1

(a) Plume extent during 50% percentile flows

(b) Plume extent during 90% percentile flows

WRL Memo No. M090529	ILUKA EBB TIDE RELEASE PLUME EXTENTS	Figure 2

Appendix C

Feasibility assessment of revised Yamba ebb tide release location (January 2010)

M E M O R A N D U M

WATER RESEARCH LABORATORY

School of Civil and Environmental Engineering

TO: Tom Blow and Greg Mashiah

DATE: 04 January 2010

FROM: William Glamore

REF: 08069 WCG:DSR M040110

SUBJECT: FEASIBILITY ASSESSMENT OF REVISED YAMBA EBB TIDE RELEASE LOCATION

This memorandum contains preliminary findings regarding the feasibility assessment of a revised Yamba ebb tide release location. The proposed site (E534320 N6744840) is located on the southern side of the NSW Maritime dredge channel (Location A, Figure 1).

DIFFUSER DEPTH

NSW Maritime accepted the proposed coordinates for Yamba (Location A) subject to meeting a number of constraints:

1. The highest point of the diffuser structure must be a minimum of 6m IPD, with a preference for 7m or similar (if found to be technically feasible).
2. No marker buoy at the location, and
3. If Maritime were to proceed in the future with deep dredging that Council would be liable for the removal and relocation of the diffuser structure.

Historical surveys (Table 1) indicate that depths and sediment movement at location A are constantly changing. As such, a diffuser structure would be required to be constructed at a conservative depth to ensure the structure does not become buried. However, a diffuser structure with the highest point at 6 m IPD is unlikely. WRL recommend the bottom of the structure be placed at 6 m below IPD with the diffuser ports at approximately 5.5 m below IPD. Constructing a structure at a deeper depth is likely to increase dilutions, but increase the risk of diffuser blockage and/or scour surrounding the structure.

The Yamba Dredging REF (2007) states that:

- Dredging is undertaken “to ensure that the depth of the entrance and channel is maintained at approximately 4 metres”; and,
- That “the Port of Yamba accommodates vessels in excess of 100 metres in length with a maximum draught of 5.4 metres”.

Therefore, a diffuser structure with a highest point at approximately 5.0 m below IPD would still enable vessels with the deepest draught (5.4 m) to safely navigate at higher tidal water levels.

The depth at the previous location (Location D, Figure 1) was approximately -7.5 m IPD (Iluka Port Datum), with the Yamba diffuser positioned at -6 m IPD. Based on the results of this investigation, the depths at the revised Yamba location are approximately -6.46 m IPD and -5.5 m IPD respectively, with depths varying over time from -5.8 m IPD to -7.8 m IPD (Table 1).

Table 1

Recorded Depths at the Proposed Release Location A

Survey	Yamba Location A E:534320 N:6744840 (m IPD)#
1986 - Maritime Services Board of NSW (April)	7.40
1988 - Maritime Services Board of NSW (21-23 June)	7.03
1993 - Australian Army (15 September)	7.6 (approx)
1999 - Sydney Ports (digital data, month unknown)	6.46
2002 - Department of Land and Water Conservation (May)	5.8
2004 - NSW Waterways Authority (March)	not covered
2006 -NSW Maritime (November)	not covered
2007 - DECC Coastal Unit (May)	not covered
2007 - Water Research Laboratory (July)	7.73
2008 - Water Research Laboratory (October)	7.10
2009 - Water Research Laboratory (October)	6.46

Note Iluka Port Datum (IPD) is 0.92 m below local Australian Height Datum (AHD)

DILUTION MODELLING

Design conditions for the ebb tide release have varied from those assessed in WRL Technical Report 2008/28. Release flows (Table 2) have decreased from 367 L/s to 334 L/s resulting in an increase in the release window from 3 hours to 3 hours 18 minutes per ebb tide (daily discharge volume of 7.92 ML/day). Ambient current velocities (Table 3) have remained similar and the release hydraulic design (Table 4) has changed to a 6 x 300 mm duckbill valve diffuser from the previous dual 4 x 300 mm configuration.

Table 2

Ebb Tide Release Design Flow Rates

Design Flow	Iluka	Yamba
ML/day	1.95	7.92
L/sec over 3 hour release window	91	-
L/sec over 3.5 hour release window	-	334

Table 3

Ebb Tide Current Velocity

Percentile	Velocity for entire ebb tide at X^{th} percentile (in m/s)	Velocity for 3.5 hour ebb tide at X^{th} percentile (in m/s)
50^{th}	0.40	0.52
90^{th}	0.09	0.24
99^{th}	0.02	0.13

Table 4

Yamba Ebb Tide Release Design: Duckbill Ports

Number of Ports	DUCKBILL Port Diameter (mm)	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
2	**100**	0.3340	0.1670	16.1	13.2
4	**100**	0.3340	0.0835	11.3	6.5
6	**100**	0.3340	0.0557	9.1	4.3
8	**100**	0.3340	0.0418	7.9	3.2
10	**100**	0.3340	0.0334	7.0	2.5
2	**150**	0.3340	0.1670	10.6	5.7
4	**150**	0.3340	0.0835	7.4	2.8
6	**150**	0.3340	0.0557	6.0	1.8
8	**150**	0.3340	0.0418	5.2	1.4
10	**150**	0.3340	0.0334	4.6	1.1
2	**200**	0.3340	0.1670	7.9	3.2
4	**200**	0.3340	0.0835	5.5	1.5
6	**200**	0.3340	0.0557	4.5	1.0
8	**200**	0.3340	0.0418	3.9	0.8
10	**200**	0.3340	0.0334	3.4	0.6
2	**300**	0.3340	0.1670	5.2	1.4
4	**300**	0.3340	0.0835	3.6	0.7
6*	**300**	0.3340	0.0557	2.9	0.4
8	**300**	0.3340	0.0418	2.5	0.3
10	**300**	0.3340	0.0334	2.3	0.3

*Selected design for Yamba ebb-tide release

Near-field modelling was undertaken using CORMIX, with the site conditions outlined in Tables 1 to 4. An ambient water depth of -6.0 m IPD was assumed and a release depth of -5.5 m IPD was applied. A 3.5 hour ebb tide release window was assumed. This 3.5 hour operational timeframe will be confirmed with subsequent hydrological modelling. 50^{th} percentile and 90^{th} percentile flows over this 3.5 hour period were used to calculate near-field dilutions are shown in Table 5.

Table 5

Yamba: Six Port Diffuser Near-field Dilutions

Port Angle	Dilution for 3.5 hour ebb discharge (50th %ile velocity)	Dilution for 3.5 hour ebb discharge (90th %ile velocity)
0	169	87
60/300	195	107
120/240	197	102
180	170	84

Based on the dilutions calculated above, all analytes except for ammonia would satisfy water quality guidelines to meet the requirements for minimum dilution within the near-field zone. To satisfy the criteria for ammonia (~200 times dilution), additional dilutions are required. The distance from the release location required to meet ~200 times dilution was calculated as 60 m for 50^{th} percentile ambient velocities, and 175 m for 90^{th} percentile ambient velocities (Table 5 and Figure 2). It is worth noting that the dilution required for ammonia is highly conservative as it assumes that no chemical transformations would occur.

Table 6

Distance to 200 Times Dilution for Yamba: Six Port Diffuser

Port Angle	Distance to 200x dilution for 3.5 hour ebb discharge (50th %ile velocity)	Distance to 200x dilution for 3.5 hour ebb discharge (90th %ile velocity)
0	60	175
60/300	43	140
120/240	40	145
180	53	170

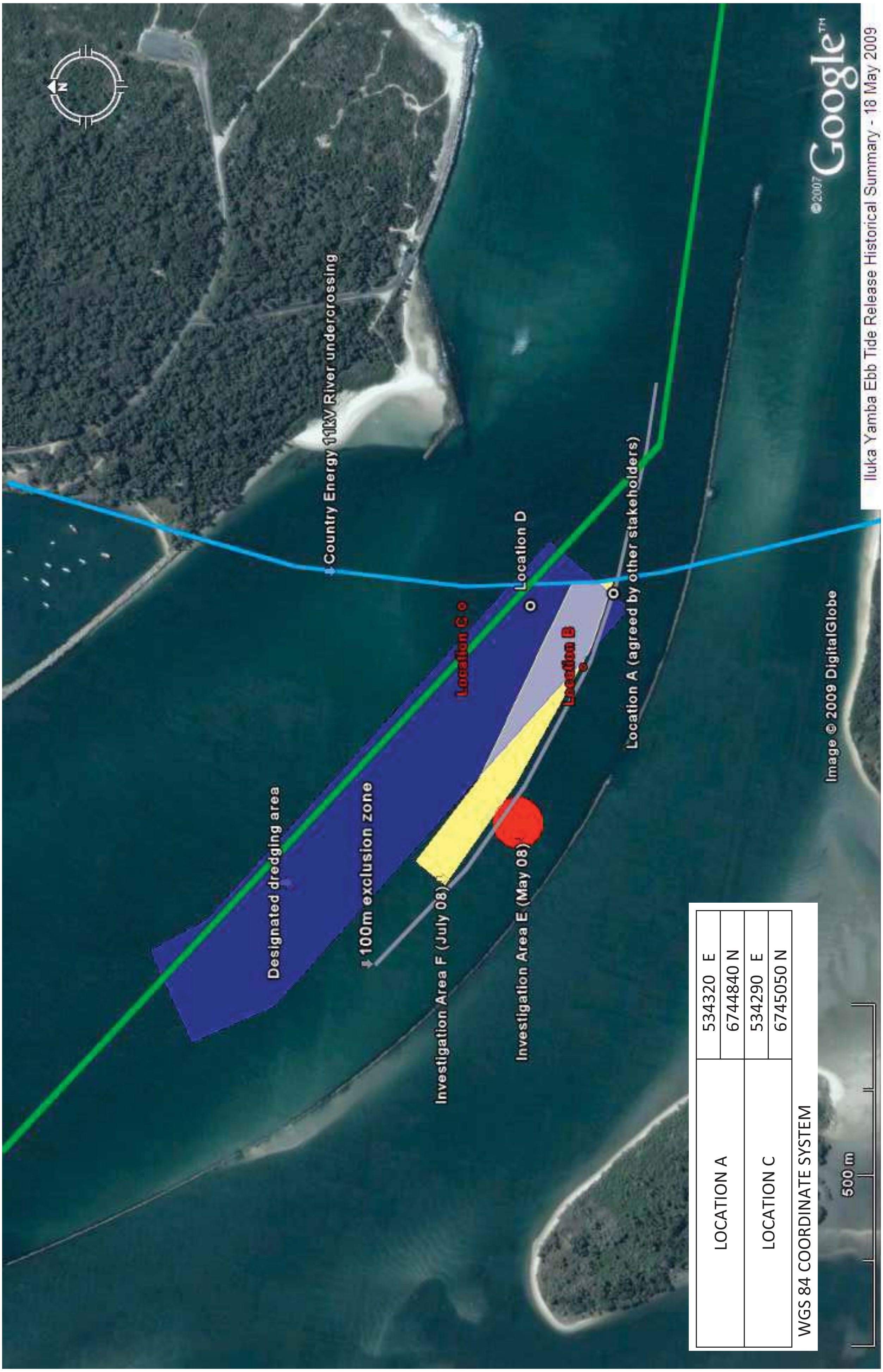
The dilutions achieved in the near-field, and distances to ~200 times dilution, for the revised Yamba ebb tide release location are similar to those predicted for the previous Yamba location (Figure 1, Location A). The distances required to meet these dilutions are graphically displayed in Figure 2.

RELEASE WINDOW DISCUSION

The impact of an extended release window (3.5 hours compared to 3 hour window) is likely to be minimal as the modelling detailed above assumes the worst case conditions. Previous investigation into release window duration (see WRL Technical Report 2008/28, section 5.4.4 p27) noted that a longer release window, such as 4 hours, resulted in the release plume being transported through the gap in the middle wall and into the Oyster Channel. This predominantly occurred during periods when a small amplitude tide was followed by a large amplitude tide (i.e. large tidal inequity). This typically occurs during the change between spring and neap tide cycles. In these situations the lag in the ebb-tide discharge, combined with the quickly rising amplitude tide, results in a short release window. Note that the release window is defined as beginning 30 minutes after the change in ambient water velocity direction.

For the entire 3.5 hour release window to be utilised, a discharge of 3 x ADWF (average dry weather flow) would have to occur 2.5 days per year based on the previous 4.5 years of flow records. The conjunctive probability of large tidal inequity and a 3 x ADWF release occurring co-currently is very low.

WRL recommends that the impacts of a 3.5 hour release window be confirmed with subsequent hydrodynamic modelling.



WRL Memo No. M091027	EBB TIDE RELEASE LOCATIONS (SOURCE: DoC)	Figure 1

(a) Plume extent during 50% percentile ambient velocities

(b) Plume Extent during 90% percentile ambient velocities

WRL Memo No. M091027	YAMBA EBB TIDE RELEASE PLUME EXTENTS	Figure 2

Appendix D

Revision of Yamba ebb tide release diffuser concept design (April 2014)

5. References

Brooks, N.H. (1960) Diffusion of Sewage Effluent in an Ocean Current, *Proceedings of International Conference of Waste Disposal in the Marine Environment*, 1st 246-367. Pergamon, Oxford.

Fischer, H.B., List, E.Y., Koh, R.C.Y., Imberger, J. and Brooks, N.H. (1979) Mixing in Inland and Coastal Waters, Academic Press, New York.

Glamore, W.C., Rayner, D.S. and Miller, B.M. (2009) Draft: Detailed Concept Design of Yamba-Iluka Ebb Tide Release, WRL Technical Report 2008/28, Water Research Laboratory, UNSW.

Lee, H.W., Karandikar. J. and Horton, P.R. (1998) Hydraulics of Duckbill Elastomer Check Valves, Journal of Hydraulic Engineering, 24(4), 394-405.

Appendix D

Revision of Yamba ebb tide release diffuser concept design (April 2014)

30 April 2014

WRL Ref: WRL2008069 DSR:WCG L20140430

Mr Geoff Gorton
NSW Department of Commerce
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Water Research Laboratory

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Dear Geoff,

Re: Revision of Yamba Ebb Tide Release Diffuser Concept Design

1. Introduction

This letter contains a preliminary feasibility assessment of a revised Yamba ebb tide release location. The proposed site (E:534258, N:6745100) is located on the northern side of the NSW Maritime dredge channel and approximately 60 m to the north west of the recently constructed Iluka ebb tide release diffuser (Figure 1).

The revised location is considerably shallower than the locations previously assessed for the Yamba ebb tide release. Due to the close proximity of the proposed Yamba diffuser location to the constructed Iluka diffuser, the Iluka design conditions for depth and ambient velocities were adopted. Note that 0.0 m Iluka Port Datum (IPD) is equal to -0.92 m Australian Height Datum (AHD).

Key parameters for the design of the revised Yamba ebb tide release diffuser include:

- Average assumed bed elevation = -4.0 m IPD
- Assumed discharge elevation = -3.0 m IPD
- Minimum Discharge depth = 3.0 m
- Diffuser port centreline above bed = 1.0 m
- Revised flow rate = 0.267 m^3/s
- Required dilutions = 200 times for ammonia; 65 times for all other analytes

Note that dilution in the near-field is highly dynamic and near-field model results should be considered accurate to ± 30%. The near-field models used for this study only consider single plumes. Complex near-field plume interactions are not considered. The impact of far-field interaction between the Yamba and Iluka outfalls is assessed.

The assumed water quality parameters and required dilutions are presented in Table 1.

Figure 1: Yamba and Iluka ebb-tide release locations and example measured ebb-tide currents

Table 1: Key water quality parameters

Analyte	Discharged Water Quality*	ANZECC Trigger Value	Background Concentration	Dilution Required
Faecal Coliforms	<200 cfu/100mL[#]	14 cfu/100mL	5 cfu/100mL	22
DO	2 mg/L	5 mg/L	6 to 9 mg/L	2
BOD	10 mg/L	15 mg/L	n/a	1
TSS	10 mg/L	10 mg/L	9 mg/L	1
Oil and grease	10 mg/L	0.3 mg/L	n/a	33
pH	6.5 - 8.5	n/a	n/a	1
Ammonia	2 mg/L	0.03 mg/L	0.02 mg/L	198
Total N	1 mg/L	0.45 mg/L	0.3 mg/L	65
Total P	0.3 mg/L	0.045 mg/L	0.03 mg/L	18

*Values are 90th percentile values for accepted modern technology; mean values will be lower.

[#]Flows for reuse will be treated to < 10 cfu/100mL.

2. Yamba Ebb-Tide Release Dilution Modelling

This section considers a Yamba ebb-tide release scenario in isolation with no discharge from the Iluka diffuser included. Near-field modelling was undertaken for the environmental conditions listed above, in conjunction with the 50th and 90th percentile exceedance ambient ebb-tide current velocities detailed in Table 2.

Table 2: Ebb Tide Current Velocity

Percentile	Velocity for 3 hour ebb tide at Xth percentile (in m/s)
50th	0.50
90th	0.24
99th	0.13

Table 3: Yamba Ebb Tide Release Design: Duckbill Ports

Number of Ports	DUCKBILL Port Diameter (mm)*	Total Flow Rate (m3/s)	Flow Rate per Port (m3/s)	Exit Velocity (m/s)	Head Loss Riser (m)
4	200	0.267	0.067	5.1	1.33
6	200	0.267	0.045	4.1	0.86
8	200	0.267	0.033	3.4	0.59
10	200	0.267	0.027	2.8	0.40
2	300	0.267	0.134	4.8	1.17
4	300	0.267	0.067	3.4	0.59
6	300	0.267	0.045	2.8	0.40
8	300	0.267	0.033	2.4	0.29
10	300	0.267	0.027	2.2	0.25

* 200 mm duckbill hydraulic code 297. 300 mm duckbill design curves Lee et al. (1998).

Various diffuser configurations are presented in Table 3. Near-field modelling was undertaken using both Corjet and Jetlag numerical models. Predicted distances to 65 times and 200 times dilutions were calculated in a uniform current as developed by Brooks (1960). Near-field model results for 50^{th} and 90^{th} percentile ambient velocities are presented in Tables 4 and 5. respectively.

Far-field dilutions (i.e. distance to 65 times and 200 times dilution) were assessed using the analysis of Brooks (1960) as described in Fischer et al. (1979). Using the $4/3^{rd}$ power law for eddy diffusivity, Brooks's analysis of dilution in a uniform current is:

$$\frac{C_0}{C_{max}} = \left\{erf\left[\frac{3/2}{(1+8\varepsilon_0 t/w^2)^3-1}\right]\right\}^{-\frac{1}{2}} \tag{1}$$

Where: ε_0 is the initial value of the horizontal turbulent diffusion coefficient corresponding to plume width (w) at the end of the near-field region, C_0 is the effluent concentration at the end of the near-field region, and C_{max} is the centreline concentration after travel time t. ε_0 was assumed to be $0.05w^{4/3}$. In comparison, the open ocean has a ε_0 value of $0.01w^{4/3}$, and a river with a straight, rectangular cross-section has a value of $0.15w^{4/3}$.

Near-field model results indicate that many different diffuser configurations are capable of producing dilutions in excess of 65 times within a 60 metre proximity under 50^{th} percentile currents (Table 4). Six and eight port configurations of the 200 mm duckbill valves, and 8 and 10 port diffusers with 300 mm duckbill valves achieve dilutions in excess of 65 times by the end of the near-field region. Although not included in this modelling, a similar configuration of 250 mm duckbills may also be a viable design option. All diffuser configurations assessed, except a 4 port diffuser configuration, achieve the required 65 times dilution within 60 m during 50^{th} percentile ambient currents.

Table 4: Near-field model results (50^{th} %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilution (m)#
			Corjet	Jetlag				
200	4	0.0668	39	71	55	19	47	137
200	6	0.0445	66	92	79	13	13	91
200	8	0.0334	70	110	90	13	13	75
300	4	0.0668	45	62	54	11	40	128
300	6	0.0445	56	82	69	12	12	99
300	8	0.0334	59	102	81	12	12	79
300	10	0.0267	65	121	93	12	12	66

#Calculated using Brooks (1960) and based on adopted near-field results.
* Calculated from Corjet.

As expected, dilutions are lower under 90th percentile ambient currents (Table 5). However, the required 65 times dilutions are achieved before reaching the Iluka diffuser location.

Overall, Jetlag predicted higher dilutions than Corjet. For both models, dilutions were predicted for a range of port discharge angles (with respect to ambient currents) based on a rosette configuration and averaged. A single dilution was assumed by adopting the average of the Corjet and Jetlag model predictions.

Far-field analysis indicates that the 200 times dilution required to dilute ammonia is not likely to occur within 60 metres (Tables 4 and 5). The experiments that Brooks (1960) used to form the basis of the above formulation were for comparatively large ocean outfall plumes. The 50th percentile distances calculated using Brooks (1960) matched well with distances predicted by the Cormix modelling software. The 90th percentile distances calculated using Brooks (1960) however, were less than those predicted by Cormix.

Table 5: Near-field model results (90th %ile ambient velocities)

Duckbill Diameter (mm)	Ports	Flow per port (m^3/s)	Near-field dilution (times)		Adopted Mean Dilution	Distance to end of near-field*	Distance to 65 times dilution (m)#	Distance to 200 times dilutions (m)#
			Corjet	Jetlag				
200	4	0.0668	27	42	35	9	31	79
200	6	0.0445	32	53	43	10	28	71
200	8	0.0334	30	57	44	6	19	50
300	4	0.0668	20	32	26	6	34	86
300	6	0.0445	25	47	36	7	25	64
300	8	0.0334	29	65	47	6	17	48
300	10	0.0267	41	63	52	7	20	59

#Calculated using Brooks (1960) and based on adopted near-field results. *Calculated from Corjet.

3. Mixing of Yamba and Iluka Plumes

Modelling of Yamba ebb-tide release diffuser configurations indicates that dilutions of 200 times will not be achieved within 60 m from the proposed Yamba diffuser location. Although the Yamba diffuser location is not directly upstream from the constructed Iluka diffuser, minor changes in ebb-tide current directions (Figure 1) may result in the ebb-tide release plumes mixing. Subsequently, an assessment of ebb-tide release plume mixing between the Yamba and Iluka ebb-tide release diffusers and the resulting impact on dilution is required. The assessment conservatively assumes that ebb-tide release plumes from both outfalls will directly overlap one another.

The dilution of the merged outfall plume was assessed by mixing the centreline concentration of both the Yamba and Iluka plumes at the end of the Iluka near-field region. This plume mixing essentially increases the Yamba plume concentration, (while lowering the Iluka plume concentration). A revised distance to 200 times dilution was calculated using Brooks (1960) (Equation 1) based on the merged plume concentration (or dilution), in conjunction with the assumed ambient background ammonia concentration (Tables 6 and 7).

Table 6: The impact of Yamba and Iluka plume mixing on 200 times dilution for a selection of potential diffuser configurations (50th %ile ambient velocities)

Number of Ports	Duckbill Port Diameter (mm)	Approximate dilution of Yamba at 60 m	Approximate dilution of Iluka (as constructed) at end of near field (most conservative)	Approximate distance to 200 times dilution with no plume interaction (m from Yamba location)	Approximate distance to 200 times dilution with plume interaction (m from Yamba location)
6	200	132	54	91	355
8	200	160	54	75	339
8	300	151	54	79	344
10	300	182	54	66	330

Table 7: The impact of Yamba and Iluka plume mixing on 200 times dilution for a selection of potential diffuser configurations (90th %ile ambient velocities)

Number of Ports	Duckbill Port Diameter (mm)	Approximate dilution of Yamba at 60 m	Approximate dilution of Iluka (as constructed) at end of near field (most conservative)	Approximate distance to 200 times dilution with no plume interaction (m from Yamba location)	Approximate distance to 200 times dilution with plume interaction (m from Yamba location)
6	200	162	25	50	297
8	200	248	25	86	287
8	300	268	25	48	286
10	300	202	25	59	291

The mixing of Yamba and Iluka plumes increases the distance to achieve 200 times dilution by approximately 400% from (during 50th percentile receiving water velocities as shown in Table 6). A 500% increase in distance from was predicted for the 90th percentile receiving water velocities (Table 7). Note that these are approximations and provide an indication of the impact of mixing plumes on dilution distances.

4. Summary

An assessment of the revised Yamba ebb-tide release location and discharge rate was undertaken. A range of diffuser configurations were analysed and near field plume dynamics assessed. Diffuser designs were assessed against the dilution criteria required before the Yamba ebb tide release potentially interacts with the constructed Iluka ebb tide release (approximately 60 m). An assessment of the far-field interactions between the Yamba and Iluka releases was also undertaken.

The study results indicate that the new Yamba ebb tide release site can achieve the required dilutions with a range of diffuser configurations. Various port size (200 and 300 mm) and numbers (6, 8 or 10 duckbills/port) were tested and several options achieved the required dilutions prior to interacting with the downstream Iluka diffuser. Far-field tests indicate that the Yamba and Iluka releases may intermix and relevant dilution distances are presented. As a multiport diffuser design is recommended (6 - 10 ports; 200-300 mm duckbill diameter), the relative effectiveness of various port configurations is provided. The final diffuser design, compliant with the dilutions outlined in this report, should be determined during the detailed design and construction phase of the project. Please refer to WRL Technical Report 2008/28 for further information regarding the detailed concept design of the Yamba/Iluka ebb-tide release (Glamore et al., 2009).

Yours sincerely,

G P Smith
Manager

5. References

Brooks, N.H. (1960) Diffusion of Sewage Effluent in an Ocean Current, *Proceedings of International Conference of Waste Disposal in the Marine Environment*, 1st 246-367. Pergamon, Oxford.

Fischer, H.B., List, E.Y., Koh, R.C.Y., Imberger, J. and Brooks, N.H. (1979) Mixing in Inland and Coastal Waters, Academic Press, New York.

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