BRISBANE WATER ESTUARY PROCESSES STUDY
HYDRAULIC PROCESSES
APPENDIX C

Report Prepared for

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1. INTRODUCTION

This report forms Appendix X of the Brisbane Water Estuary Processes Study report series. It was prepared by Cardno Lawson Treloar for Gosford City Council (GCC) and the Department of Environment and Climate Change (DECC). It describes the purpose, available data, study approach and outcomes of the investigations of the Hydraulic Processes of Brisbane Water, which form an important driver to the overall water quality, sediment distribution and ecological conditions of the waterway. Wave processes are included in these investigations, and like the currents, vary spatially and temporally.

The report describes generally the hydraulic processes that are important drivers for the ecological processes of this large estuary and then the data, methods of investigation and outcomes of this study task. Results were provided progressively to others in the Study Team.

The outcomes need to be considered in both quantitative and qualitative terms.

2. PHYSICAL PROCESSES

2.1 General

The purpose of this section is to describe the physical processes that are important to the overall physiography and state of Brisbane Water, together with ongoing changes to the physical nature of the waterway. These processes are: -

- Waves
- Currents
- Water Levels
- Winds
- Sediment Transport

2.2 Wave Processes

Waves that affect the study area may have energy in two distinct frequency bands. These are principally related to the generation and propagation of ocean swell (up to Ettalong) and local sea (in waterway areas beyond Ettalong, but may occur at Ettalong also). Large waves generated by an ocean storm are generally categorised as sea because wind energy is still being transferred to the ocean.

Water waves are irregular in height and period and so it is necessary to describe wave conditions using a range of statistical parameters. In this study the following have been used: -

- H_{mo} significant wave height (H_s) based on $4\sqrt{M_o}$ where M_o is the 0th moment of the wave energy spectrum (rather than the time domain $H_{1/3}$ parameter).

- H_{max} maximum wave height in a specified time period

- T_p wave energy spectral peak period, that is, the wave period related to the highest ordinate in the wave energy spectrum

- T_z average zero crossing period based on upward zero crossings of the still water line. An alternative definition is based on the zeroth and second spectral moments.

Wave heights defined by zero up-crossings of the still water line fulfil the Rayleigh Distribution in deep water and thereby provide a basis for estimating other wave height parameters from H_s. In shallow water, that is, within Brisbane Water, significant wave height defined from the wave spectrum, H_{mo}, is normally larger (typically 5% to 8%) than $H_{1/3}$ defined from a time series analysis.

Ocean waves also have a dominant direction of wave propagation and directional spread about that direction that can be defined by a Gaussian or generalised cosine ($\cos^n$) distribution (amongst others), and a wave grouping tendency. Directional spread is reduced by refraction as waves propagate into the shallow, nearshore regions and the wave crests become more parallel with each other and the seabed contours. Although neither of these characteristics has been addressed explicitly in this study, directional spreading was included in the numerical wave modelling work. Directional spreading causes the sea surface to have a more short-crested wave structure in deep water.

Waves propagating into shallow water may undergo changes caused by refraction, shoaling, bed friction, wave breaking and, to some extent, diffraction.

Wave refraction is caused by differential wave propagation speeds. That part of the shoreward propagating wave that is in the more shallow water has a lower speed than those parts in deeper water. When waves approach a coastline obliquely these speed differences cause the wave fronts to turn and become more coast parallel. Associated with this directional change there are changes in wave heights. On irregular seabeds wave refraction becomes a very complex process.

Waves propagating shoreward develop reduced speeds in shallow water. In order to maintain constancy of wave energy flux (ignoring energy dissipation processes) their heights must increase. This phenomenon is termed shoaling and leads to a significant increase in wave height near the shoreline.

A turbulent boundary layer forms above the seabed with associated wave energy losses that are manifested as a continual reduction in wave height in the direction of wave propagation - leaving aside further wind input, refraction, shoaling and wave breaking. The rate of energy dissipation increases with greater wave height, that is, it is a non-linear process.

Wave breaking occurs in shallow water when the wave crest speed becomes greater than the wave phase speed. For irregular waves this breaking occurs in different depths so that there is a breaker zone rather than a breaker line. Seabed slope, wave period and water depth are important parameters affecting the wave breaking phenomenon. As a consequence of this energy dissipation, wave set-up (a rise in still water level caused by wave breaking), develops shoreward from the breaker zone in order to maintain conservation of momentum flux. This rise in water level increases non-linearly in the shoreward direction and allows larger waves to propagate shoreward before breaking. Field measurements have shown that the slope of the water surface is normally concave upward. Wave set-up at the shoreline can be in the order of 15% of the equivalent deep-water significant wave height. Lower set-up occurs in estuarine entrances, but the momentum flux remains the same. Wave set-up is smaller where waves approach a beach obliquely, but then a longshore current can be developed. Wave grouping and the consequent surf beats also cause fluctuations in the still water level.

In a random wave field, each wave may be considered to have a period different from its predecessors and successors and the distribution of wave energy is often described by a wave energy spectrum. In fact, the whole wave train structure changes continuously and individual waves appear and disappear until quite shallow water is reached and dispersive processes are reduced. In developed sea states, that is swell, the Bretschneider modified Pierson-Moskowitz spectral form has generally been found to provide a realistic wave energy description. For developing sea states the JONSWAP spectral form, which is generally more ‘peaky’, has been found to provide a better spectral description.

For structural design in the marine environment it is necessary to define the H_{max} parameter related to storms having average recurrence intervals (ARI) of R years. However, the expected H_{max}, relative to H_s in statistically stationary wave conditions, increases as storm/sea state duration increases. Based on the Rayleigh Distribution the usual relationship is: -

$$H_{max} = H_s \sqrt{(0.5 \ell nNz\ )}$$

where Nz is the number of waves occurring during the time period being considered, where individual waves are defined by Tz.

ℓn is the natural logarithm

This relationship has been found to overestimate H_{max} by about 10% in severe ocean storms. In shallow water the relationship is not fulfilled. In very shallow water H_{max} is replaced by the breaking wave height, H_b.

Waves propagating through an area affected by a current field are caused to turn in the direction of the current. The extent of this direction change depends on wave celerity, current speed and relative directions. Wave height is also changed. Opposing currents cause wave lengths to shorten and wave heights to increase and may lead to wave breaking. When the current speed is greater than one quarter of the phase speed the waves are blocked. Conversely, a following current reduces wave heights and extends wave lengths.

Other waves that can cause shoreline damage in an estuarine situation are boat waves, but they are not addressed in this study.

2.3 Currents

Currents within Brisbane Water are caused by a range of phenomena, including: -

- Astronomical Tides
- Winds
- Creek Discharges
- Coastal Trapped Waves and Other Tasman Sea Processes
- Nearshore Wave Processes
- Density Flows

The astronomical tides are caused by the relative motions of the Earth, Moon and Sun, see Section 2.4. The regular rise and fall of the tide level in the sea causes a periodic inflow (flood tide) and outflow (ebb tide) of oceanic water to the Estuary and mixed oceanic and freshwater from the Estuary to the sea, respectively. A consequence of this process is the generation of tidal currents. The volume of sea water that enters the Estuary or leaves the Estuary on flood and ebb tides, respectively, is termed the tidal prism; which parameter varies due to the inequality between tidal ranges and spring/neap tide ranges. The tidal prism is affected by changes in inter-tidal areas, such as areas of reclamation, but not by dredged areas below low tide.

Wind forcing is applied to the water surface as interfacial shear, the drag coefficient and consequent drag force varying with wind speed. Momentum from the wind is gradually transferred down through the water column by vorticity, the maximum depth of this effect being termed the Ekman depth. At the surface, wind caused currents, are in the direction of the wind, but in the southern hemisphere they gradually turn to the left of the wind direction until they flow in the opposite direction at the Ekman depth. Brisbane Water is too shallow for this condition to develop fully and wind driven currents are affected by the seabed boundary layer and seabed form. Wind driven currents diminish with depth. Because wind forcing is applied at the water surface, the relative effect is greater in shallow water where there is less water column volume per unit plan area. Therefore wind driven currents are greater in more shallow areas. Maximum surface current speed is in the order of 1% to 3% of the wind speed, depending on water depth. Where water is piled up against a coastline by wind forcing, a reverse flow develops near the seabed.

Density currents may be caused by freshwater inflows, for example, when Erina Creek is in flood. The freshwater is more buoyant and tends to spread across the Estuary surface until mixing with the ambient saline water occurs. Those flows transport sediment and nutrients into the Estuary and affect their distribution, thereby affecting ecological processes.

Coastal Trapped Waves (CTW) are long period wave phenomena that propagate northward along the continental shelf (Freeland et al, 1986). Their origin is not fully understood, but they are believed to originate from the passage of successive high and low pressure meteorological systems across southern Australia. These systems have inter-arrival times varying from 3 to 7 days, typically, and these are the periods of the observed CTW. These waves are irregular and cause approximate coast parallel currents and variations in water levels. They are trapped on the continental shelf by refraction and the Coriolis force. CTW are known to occur on the continental shelf of NSW and will affect observed water levels in the Brisbane Water region. As they propagate past Broken Bay they cause inflow and outflow currents that are additional to the tidal currents.

The propagation of ocean waves (swell) into the nearshore region leads to wave breaking and energy dissipation. Where waves propagate obliquely to the shoreline this process leads to the generation of a longshore current in the surf zone, and to some extent seaward of that line. These currents are of some importance to shoreline processes in the Ettalong Beach area, where swell propagates to the shoreline from time-to-time. Wave breaking and subsequent wave run-up are discussed further in Section 2.4.

2.4 Water Levels

Water level variations in the Estuary result from one or more of the following natural causes: -

- Eustatic and Tectonic Changes
- Tides
- Wind Set-up and the Inverse Barometer Effect
- Wave Set-up
- Wave Run-up
- Fresh Water Flow
- Tsunamis
- Greenhouse Effect
- Global Changes in Meteorological Conditions

Eustatic sea level changes are long term worldwide changes in sea level relative to the land mass and are generally caused by changes to the polar ice caps. No rapid changes are believed to be occurring at present and this aspect has not been addressed in this study. Nevertheless, a minimum rise of 1mm per annum is now generally accepted. Tectonic changes are caused by movement of the Earth's crust; they may be vertical and/or horizontal

Tides are caused by the relative motions of the Earth, Moon and Sun and their gravitational attractions. While the vertical tidal fluctuations are generated as a result of these forces, the distribution of landmasses, bathymetric variation and the Coriolis force determine the local tidal characteristics.

Wind setup and the inverse barometer effect are caused by regional meteorological conditions. When the wind blows over an open body of water, such as the Broadwater at Gosford, drag forces develop between the air and the water surface. These drag forces are proportional to the square of the wind speed. The result is that a wind drift current is generated. This current may transport water towards the shoreline upon which it piles up causing wind set-up. Wind set-up is inversely proportional to depth.

In addition, the drop in atmospheric pressure, which accompanies severe meteorological events, causes water to flow from high pressure areas on the periphery of the meteorological formation to the low pressure area. This is called the 'inverse barometer effect' and results in water level increases up to 1cm for each hecta-Pascal (hPa) drop in central pressure below the average sea level atmospheric pressure in the area for the particular time of year, typically about 1010 hPa. The actual increase depends on the speed of the meteorological system and 1cm is only achieved if it is moving slowly. The phenomenon causes daily variations from predicted tide levels up to 0.1m. The combined result of wind set-up and the inverse barometer effect is called storm surge.

Wave run-up is the vertical distance between the maximum height a wave runs up the beach or a coastal structure and the still water level, comprising tide plus storm surge. Additionally, run-up level varies with surf-beat, which arises from wave grouping effects.

Tsunamis are caused by sudden crustal movements of the Earth and are commonly, but incorrectly, called 'tidal waves'. They are very infrequent and unlikely to occur during a storm and so have not been included in this study. Nevertheless, in the context of events having recurrence intervals in the order of 100 years, one should keep this point in mind. The largest recorded tsunami in the Central Coast region of NSW was 0.8m (crest to trough) caused by an earthquake in Chile in 1960 (BoM, 1998).

Global meteorological and oceanographic changes, such as the El Nino Southern Oscillation phenomenon in the eastern southern Pacific Ocean, and continental shelf waves, cause medium term variations in mean sea level. The former phenomenon may persist for a year or more. The causes are not properly understood, but analyses of long term data from Australian tide gauges indicate that annual mean sea level may vary up to 0.1m from the long term trend, whilst mean sea level may vary by more than 0.2m over the time scale of weeks as a result of coastal trapped wave activity.

Many scientists believe that global warming of the Earth's atmosphere will lead to a rise in mean sea level. Predictions of global sea level rise due to the Greenhouse effect vary considerably. It is impossible to state conclusively by how much the sea may rise, and no policy yet exists regarding the appropriate provision that should be made in the design of new coastal developments.

Based on a number of global greenhouse models, a guide to future ocean level rises is presented in Table 2.1.

Table 2.1: Predicted Greenhouse Related Mean Sea Level Rises (IPCC, 2001)

	Sea Level Rise (m) to Year 2100		
Greenhouse Scenario	**Min**	**Max**	**Central**
IP92a	0.11	0.77	0.44
SRES	0.09	0.88	0.48

Recent investigations undertaken by CSIRO (1998) advise a mean sea level rise of 0.2m over the 50 years period from 1998 for the NSW coastline. Investigation of the Australia State of the Environment Report 2001 web-site advises a mean sea level rise of 0.09m to 0.88m by 2100. Thus there is considerable uncertainty in this parameter estimate. Figure 2.1 (IPCC, 2001) describes this variation.

Tidal planes derived from long-term records at Middle Harbour (Port Jackson) are shown in Table 2.2 (Manly Hydraulics Laboratory, 2004). Tidal planes for Broken Bay at the entrance to Brisbane Water area are similar to those for Sydney Harbour, but are attenuated further into Brisbane Water. Tides in Broken Bay are semi-diurnal, that is, there are two high and two low tides each day, normally. On rare occasions there may be only one high or low tide because the lunar tidal constituents have a period of about 25 hours. There may also be a significant diurnal difference, that is, a significant difference between successive high tides and successive low tides. Moreover, the higher frequency tides, such as the semi-diurnal components, attenuate more than the lower frequency diurnal tidal components.

Table 2.2: Tidal Planes for Broken Bay

Tidal Plane	Water Level	
	m LAT	m AHD
Mean High Water Springs (MHWS)	1.58	0.65
Mean High Water (MHW)	1.45	0.52
Mean High Water Neaps (MHWN)	1.32	0.39
Mean Sea Level (MSL)	0.95	0.02
Mean Low Water Neaps (MLWN)	0.57	-0.36
Mean Low Water Springs (MLWS)	0.32	-0.61

Appendix 1 presents additional tidal plane information based on Manly Hydraulics Laboratory (2004), including tidal plane variation along various arms of Brisbane Water. Table 2.3 presents extreme water levels for typical Average Recurrence Intervals (ARI), derived from the Fort Denison water level records (Manly Hydraulics Laboratory, 1992). They will be generally applicable to Broken Bay also. These levels exclude wave setup and relate to locations seaward of the breaker zone.

Table 2.3: Extreme Water Levels in Broken Bay

Average Recurrence Interval (years)	Water Level	
	m LAT	m AHD
20	2.28	1.35
50	2.37	1.44
100	2.41	1.48

2.5 Winds

Wind affects both the wave and current climates in Brisbane Water. Wind data has been recorded at Sydney Airport since 1939 (Moneypenny et al, 1997). This is the closest long-term wind data set other than Norah Head lighthouse. Although, on an event-by-event basis, winds in the Brisbane Water region will be different from those at Sydney Airport, they will be similar on a longer term statistical basis.

The location and impact of airport development have changed since records began. From 1939 to 16 August, 1994, a Dines anemometer was used to record 10-minute averages of wind speed and direction. Since the early 1960's, at least, this anemometer was located on a 10m mast near the intersection of the east-west and north-south runways. Recommended WMO clearances from buildings and other obstructions were maintained. During its period of service, the Dines anemometer was maintained well.

Since 16 August, 1994, wind data at the airport has been recorded using a Synchrotec anemometer installed on a 10m mast near the threshold of the main north-south runway, which is more exposed than the previous Dines anemometer site.

Analyses of these wind records (Monypenny and Middleton, 1997) showed that there had been a gradual error (reduction) in wind speed recorded by the Dines anemometer. This reduction amounted to 2.6m/s by August, 1994. Monypenny and Middleton (1997) advise that a simplified linear adjustment be made to Sydney airport wind speeds up to 16 August, 1994 and this adjustment was made for this study. Data to 31 December, 2000 was obtained from the Bureau of Meteorology.

Appendix 2 presents a description of wind speed and direction joint occurrence at Mascot. Note that calms occur for about 17% of the time.

2.6 Sediment Transport - Coastal Stability

The nearshore and shoreline regions of Brisbane Water are formed from marine sands and rocky headlands, with some muddy areas in the more sheltered regions such as Mudflat Creek, Fagans Bay and an area within Correa Bay. Additionally, the perimeters of some existing development works provide hard-edge areas, such as those at the northern end of the broadwater at Gosford, see Figure 2.2.

Natural changes to the shoreline and nearshore areas continue and are caused by storm waves, typically erosion, especially when they occur during periods of higher water level, and by catchment floods that deliver sediments (typically silts and clays, but also sands and other materials such as glass and road-base) to the estuary.

Development within the Brisbane Water region since European settlement has caused an increase in impermeable areas and consequent increases in peak flood flows and runoff volumes, leading to increased sediment yield loads.

Sediment transport is caused by the water particle motions of waves and currents that lead to a shear stress on the seabed sediment particles. In some parts of the Bay, waves and currents cause combined shear stresses. Generally, sediment motion commences when the seabed shear stress exceeds a threshold value, which depends on particle size, density and sediment type – cohesionless (sands) or cohesive (silts and clays). Sediment may be transported as bed load or suspended load. Bed load transport is effected as a series of saltations or hops. Suspended sediment transport occurs when the turbulent mixing of the flow counteracts the fall velocity of the finer sediment particles that disperse upward from the seabed. Transport is initiated only when the shear stress exceeds the threshold.

Where a seabed is disturbed, for example, by dredging, and where the threshold condition for sediment movement is exceeded, wave and current caused sediment transport may act to restore the pre-condition of the seabed. Experience based on historical hydrographic surveys has shown that in Brisbane Water, other than at nearshore locations and in the Ettalong shoals area, the bed of the Estuary is essentially stable.

At shoreline locations sediment transport may be alongshore and/or onshore/offshore. Where waves break obliquely to the shoreline, a longshore current may cause longshore transport. Offshore transport normally occurs during a storm, with a longer term onshore transport following storm abatement. However, onshore transport may not occur in regions that generally have low wave energy, other than during ocean storms, such as Ettalong.

These regions are characterised by a flat inter-tidal area with a steep drop-off near the low tide line, and often a steep back-beach area; for example, the Woy Woy region, see Figure 2.3.

Waterways that enter the Estuary may transport fine silt particles from the catchments to the Estuary. These fine particles eventually settle in the most tranquil regions of the Estuary. From time-to-time they may be disturbed by uncommon strong winds and consequent local sea, and then being transported to other more tranquil areas. Because nutrients may be adsorbed to these fine sediments, this process also affects the distribution of nutrients, affects light penetration and may disturb seabed plants.

3. DATA

A range of data items were required to setup, calibrate and operate the current, wave, sediment/morphological and transport-dispersion models used in this study – see also Appendices Y and Z.

3.1 Bathymetric Data

This data was obtained from a number of sources, namely: -

- Chart AUS 204
- Survey on north-east side of St Huberts Island, August, 2004, Hydrographic Surveys
- 1992 Public Works hydrosurvey extending from Wagstaff Point to Gosford. This is the most recent overall survey of the estuary
- Chart 83042 – Broken Bay. 1989 seabed survey undertaken by NSW Public Works.
- Some cross-sectional data for Narara and Erina Creeks, thereby allowing parts of the downstream reaches of these waterways to be described in the overall hydrodynamic model developed for this study

This data was digitised to provide a digital terrain model (DTM) extending from the 200m depth contour offshore to the Gosford shoreline and throughout the estuary.

3.2 Water Level Data

This data came in a range of forms and from a range of sources. Principal amongst these was the extensive gauging study undertaken by Manly Hydraulics Laboratory, (MHL, 2004).

Water level data was collected from five permanent sites - one in Middle Harbour and four in Brisbane Water, (2, 9, 10 and 22) and seven temporary sites (4, 6, 11, 14, 16, 18 and 20), see Figure 3.1, were established at other strategic locations within the estuary for a period of approximately twelve weeks.

This water level data was used for two aspects of this study. The first was to provide time series data for numerical hydrodynamic model calibration. That data was provided by MHL in digital form. The second was to provide descriptions of the spatial variations of tidal ranges and tidal plans. That data is reproduced in Appendix 1.

Predicted tidal levels and recorded water levels at hourly intervals for Fort Denison, Sydney, was provided by the National Tidal Centre for the May 1974 storm event. Records of indicative peak water levels that were observed in Brisbane Water for that event, other than in isolated locations such as Fagans Bay, remain as the highest recorded water levels in Brisbane Water – Public Works, 1976, see Figure 3.2. These levels have been converted from Standard Datum to AHD.

A second, ocean-water level event that lead to unusually high water levels in Brisbane Water occurred in April 1990 (Public Works, 1991). It arose from a very large low pressure system over the Tasman Sea, but neither significant rainfall nor wave action occurred at that time in the Broken Bay region. A level of 1.4m AHD was recorded in Sydney Harbour, being the third highest recorded water level since 1914. The effects propagated well into Brisbane Water with tidal anomalies up to 0.4m occurring. Peak observed water levels were:-

- Ettalong 1.20m AHD at 2200 27/02/1990
- Koolewong 1.09m AHD at 0000 28/04/1990

- Wharf St, Gosford 1.02m AHD at 0000 28/04/1990

These higher water levels would have caused a temporary increase of influx of ocean water and subsequent outflow. Generally, the highest water levels in Brisbane Water itself, leaving aside local flooding issues in creeks and stormwater flow areas, are caused by ocean storm systems, with little accompanying rainfall.

Water level records from Koolewong and Ettalong were provided by MHL in digital form - up to ten years at Koolewong, but only three months at Ettalong (February to April, 2004).

Tidal constant data for the offshore region of the Brisbane Water hydrodynamic model was taken from Australian National Tide Tables (2006).

3.3 Discharge Data

MHL (2004) also report on discharge measurements taken at a number of strategic locations using Acoustic Doppler Current Profiler (ADCP) instruments, see Figure 3.1. These instruments record current speeds and directions along selected transects across the waterway and through the water column. Typical vertical resolution is in bins of 0.5m. Integration of speed and direction leads to an estimate of discharge. Taking records through the tide cycle leads to an irregular time series of discharge data that can be used for model calibration.

Generally, discharge data is more reliable than current data taken from one location because it enables the tidal prism upstream of the cross-section (transect) to be quantified. A single measurement point on a cross-section does not describe the speed (and direction) variation across the section; where in some circumstances reverse flow may occur over some part of the cross-section.

ADCP's do not record data from the top and bottom 10 to 15% of the water column. This is a consequence of their acoustic beam structure. Account of this characteristic is included in the calculation of discharge.

3.4 Sediment Data

In terms of this study, sediment data has been collected at a number of sites, see Figure 3.3, for purposes of sediment transport and siltation analyses. Other sediment data has been collected as part of seabed contaminant investigations, Appendix F. Some of this data has been collected during the course of this study. Sediments within Brisbane Water display a range of characteristics from sand to cohesive muds, for example, Ettalong and Mud Flat Creek in Hardys Bay, respectively. This information is presented in Appendix D– Estuarine Morphology and Siltation.

3.5 Historical Photographic Data

Some of this data has been provided by GCC, New South Wales Lands Department and other information has been provided by community groups such as the Killcare Pretty Beach & Wagstaffe and the Correa Bay Water Quality Management Committees.

Selected photographs are presented in appropriate sections of this and other appendix reports of this series.

3.6 Wave Data

Both sea and swell are important in different regions of Brisbane Water. Local sea is the more widely spread of the two and occurs throughout the estuary, being most important in the wide expanse of the Gosford Broadwater. On a minor-scale, local sea is important in the region north-east of St Huberts Island to the Cockle Channel, for example, whereas inshore propagating severe ocean-storm swell is important at Ettalong, especially on high tide when larger waves can propagate over the Ettalong Point shoal.

MHL have collected wave data (height, period and direction) since March 1992 from their Long Reef Waverider buoy site. That data was available to this study for the purpose of describing ocean waves at the boundary of the overall Brisbane Water wave modelling system.

3.7 Wind Data

Wind data has been addressed in Section 2.5. This wind data (long term Sydney Airport) was analysed in terms of the standard directional octants to provide peak storm wind speeds at selected average recurrence intervals (ARI), see Table 3.1(a).

Table 3.1(a): Wind Speeds (m/s) by Octant

Octant	Gust Speeds		10 min Average Speeds		3 hour Average Speeds	
	100 yr ARI	20 yr ARI	100 yr ARI	20 yr ARI	100 yr ARI	20 yr ARI
N	28.4	26.1	19.3	17.8	18.5	17.0
NE	23.8	22.9	18.3	17.6	17.6	16.9
E	25.7	22.8	19.8	17.5	19.0	16.8
SE	28.2	25.6	21.7	19.7	20.8	18.9
S	42.1	38.3	31.7	28.8	30.4	27.6
SW	35.1	31.9	25.6	23.3	24.6	22.4
W	38.3	35.0	26.6	24.3	25.5	23.3
NW	33.9	31.3	21.3	21.3	22.1	20.4

This table also includes wind gust speed - generally 2-second gusts. These results are general and do not include any shoreline terrain correction factors. Additional information is presented in Table 3.1(b). These analyses were undertaken by ranking recorded wind speeds in each octant and then undertaking an extremal analysis using the maximum likelihood method, fitting to a Weibull distribution.

Table 3.1(b): Wind Speeds (m/s) at Selected ARI - 10-Minute Average Speeds

Octant	Average Recurrence Interval (years)					
	5	10	20	50	100	1000
N	16.4	17.1	17.8	18.7	19.3	23.5
NE	17.0	17.3	17.6	18.0	18.3	20.3
E	15.4	16.5	17.5	18.8	19.8	26.3
SE	17.9	18.8	19.7	20.8	21.7	27.4
S	26.2	27.5	28.8	30.5	31.7	39.9
SW	21.2	22.3	23.3	24.6	25.6	32.1
W	22.2	23.3	24.3	25.6	26.6	33.1
NW	19.4	19.9	21.3	20.9	21.3	24.1

4. MODEL SYSTEMS

A range of model systems were setup and applied to the estuarine regions of this study. They were: -

- The Delft3D modelling system, including waves – Delft Hydraulics
- LITPACK coastal processes modelling system – Danish Hydraulics Institute

4.1 Model System

4.1.1 General

Investigations of water levels, currents, transport-dispersion and morphological processes required application of a high level model capable of simulating a range of processes – wind field, wave and tidal forcing and then sand and mud siltation modelling, with some confidence.

These simulations were undertaken using the Delft3D modelling system.

The Delft3D modelling system has been applied to current and wave investigations at many international locations, as well as within Australia by Cardno Lawson Treloar – Port Botany (Sydney), Cairns Navy Base (Queensland), Gulf of Papua, Pittwater and Exmouth Gulf in Western Australia, for example.

The Delft3D modelling system includes wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions and is capable of using irregular rectilinear or curvilinear coordinates.

Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

Initially a single model domain of Brisbane Water was developed for this study (Figure 4.1). The model extends offshore to a depth of approximately 70m AHD and features water level boundaries offshore and along the boundaries with the Hawkesbury River and Pittwater. A calibrated MIKE-11 model of the Hawkesbury River system, including Brisbane Water and Pittwater, has been used to determine concurrent water level time series estimates for Pittwater and the Hawkesbury River during selected offshore water level conditions. Sub-model areas have been developed for wave and sediment analyses.

The model has a curvilinear grid with variable resolution. Offshore areas have a grid resolution in the order of 100m x 100m, while areas inside Brisbane Water, where steep hydrodynamic gradients exist, have horizontal grid cells in the order of 10m x 10m.

4.1.2 Hydrodynamic Numerical Scheme

The Delft3D FLOW module is based on the robust numerical finite-difference scheme developed by G. S. Stelling (1984) at the Delft Technical University in The Netherlands. Since its inception the Stelling Scheme has had considerable development and review by Stelling and others.

The Delft3D Stelling Scheme arranges modelled variables on a horizontal staggered Arakawa C-grid. The water level points (pressure points) are designated in the centre of a continuity cell and the velocity components are perpendicular to the grid cell faces. Finite difference staggered grids have several advantages including: -

- Boundary conditions can be implemented in the scheme easily
- It is possible to use a smaller number of discrete state variables in comparison with discretisations on non-staggered grids to obtain the same accuracy
- Staggered grids minimise spatial oscillations in the water levels.

Delft3D can be operated in 2D (vertically averaged) or 3D mode. In 3D mode, the model uses the σ-coordinate system first introduced by N Phillips in 1957 for atmospheric models. The σ-coordinate system is a variable layer-thickness modelling system, meaning that over the entire computational area, irrespective of the local water depth, the number of layers is constant. As a result, a smooth representation of the bathymetry is obtained. Also, as opposed to fixed vertical grid size 3D models, the full definition of the 3D layering system is maintained into shallow water and until the computational point is dried.

Horizontal solution is undertaken using the Alternating Direction Implicit (ADI) method of Leendertse for shallow water equations. In the vertical direction (in 3D mode) a fully implicit time integration method is also applied.

Vertical turbulence closure in Delft3D is based on the eddy viscosity concept.

4.1.3 Wetting and Drying of Intertidal Flats

Many nearshore areas include shallow inter-tidal regions; consequently Delft3D includes a robust and efficient wetting and drying algorithm to handle this process.

4.1.4 Conservation of Mass

Problems with conservation of mass, such as a ‘leaking mesh’, do not occur within the Delft3D system.

However, whilst the Delft3D scheme is unconditionally stable, inexperienced use of Delft3D, as with most modelling packages, can result in potential mass imbalances.

Potential causes of mass imbalance and other inaccuracies include: -

- Inappropriately large setting of the wet/dry algorithm and unrefined inter-tidal grid definition
- Inappropriate bathymetric and boundary definition causing steep gradients
- Inappropriate time step selection (i.e. lack of observation of the scheme’s allowable Courant Number condition) for simulation

4.1.5 Siltation Model

The past ten years have seen the development of a hydrodynamic module that is capable of simultaneous sediment transport modelling and morphological updating while performing the hydrodynamic simulation. This “online sediment version” works by treating sediment as another constituent (in addition to salinity and heat) allowing it to be calculated in three dimensions, and subsequently feeding the density effects of the sediment back into the flow simulation. This version includes linked hydrodynamics, wave processes, sediment transport and morphological changes.

Interaction with the bed for sand fractions is computed and is based upon the sediment pick-up functions of Leo van Rijn; bed-load transport is included. For mud fractions the widely recognised sediment flux expressions of Partheniades and Krone are used (van Rijn, 1993).

This version also includes the ability to model fixed, non-erodible areas. To bridge the gap between morphological and hydrodynamic time-scales a morphological acceleration factor can be used. Significant is the inclusion of improved formulations that describe the effects of waves on the three-dimensional flow pattern. These features make the version particularly suitable for modelling morphological changes in areas with complex three-dimensional flow patterns, such as river bends, dredged trenches, coastal regions and estuaries, including lateral erosion. Five vertical layers were applied to the siltation (mud) analyses undertaken for this study. In sandy areas 2D modelling is applied because the algorithms have been developed in terms of depth averaged flow.

It is often necessary to undertake a range of siltation simulations for a range of combined wave and current conditions – including creek inflows. Nested finer grid models were used for some sediment transport investigations in order to provide the necessary spatial resolution over a smaller area of interest. Generally, the boundaries of siltation models are set where there is likely to be no seabed change.

4.2 Wave Model Systems

Wave modelling for this study was based on the SWAN wave model, which is integrated into the Delft3D modelling system. SWAN was developed at the Delft Technical University and includes wind input, (local sea cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking.

Wave modelling was undertaken for six purposes, namely: -

- To describe the propagation of ocean waves into the estuary. Generally, swell is not important upstream of about Snapper Road at Ettalong
- To describe local sea waves throughout the study area. This required a range of sub-models, see Section 7, in order to develop sufficient resolution in individual areas such as Woy Woy Bay
- To describe the effect of severe ocean storm waves on elevated water levels in the estuary
- As part of tide/wave sediment transport processes in the Ettalong area
- To describe the likely frequency of seabed disturbance/sediment movement caused by near seabed shear stresses
- To investigate shoreline erosion caused by offshore transport in elevated water level and storm wave conditions

The model layouts prepared for this study ensured that the development of wave conditions arising from the complex bathymetry and variable wind cases were included in the wave parameter descriptions.

4.3 Short Term Erosion

Storm erosion transports sediment from the beach-face and dune, where there is one, into the offshore area to form a bar. This process would occur relatively quickly over a period of less than half a day, typically, because storm winds will change direction rapidly. In areas exposed to swell the shoreline/beach may gradually recover over a period of several months as swell causes onshore transport of sand. On the other hand, in areas affected by sea only, then onshore transport following storm abatement generally does not occur.

This process has been addressed using the LITPACK coastal processes modelling system in areas such as Green Point where there is a natural sandy beach.

5. MODEL CALIBRATION

Model calibration increases confidence that the model system provides a realistic description of the estuarine processes described by it in complex forcing conditions – for example, current speeds (process) caused by a spring tide (forcing condition). Brisbane Water is a complex hydraulic system featuring: -

- Several branches, some of which are interconnected,
- Generally shallow (water depths < 10m),
- Significant mangrove and intertidal areas,
- Mobile sand shoals, and a
- Major hydraulic control at 'The Rip'.

'The Rip' is a major control on tidal range in the upper estuary and the volume of water exchange between Brisbane Water and Broken Bay. This feature, located between Ettalong and Woy Woy, is described in Figure 5.1. Figure 5.1 also includes MHL water level data for locations 500m upstream (red line) and 500m downstream (black line) of 'The Rip'. There is a significant reduction in the tidal range upstream of 'The Rip' and a phase change of approximately 1-hour in the tidal signal. 'The Rip' features large holes, up to 30m deep, upstream and downstream of the main rocky constriction. The depth in the narrowest section of 'The Rip' is generally less than 4m at datum AHD.

The calibration of the Delft3D hydrodynamic model was undertaken in two main stages. The first stage involved calibrating the water levels by adjusting the bed friction factor. Water level calibration is generally controlled by bed friction. The second stage of the calibration was to ensure that the discharges through each section of the model agreed with available flow data. Discharge rate is influenced by two key factors: bed friction and the conveyance, which in turn is affected by bed level and cross-sectional area. The discharge calibration ensures that the correct storage is defined in each branch of the model, thereby ensuring reliable velocity descriptions. It is possible to have a good water level calibration yet a poor discharge calibration if the correct storage is not provided within the model. The Brisbane Water bathymetric data is reasonably comprehensive; however, important areas such as Kincumber Broadwater and Cockle Channel have large inter-tidal areas that are relatively unsurveyed. During the discharge calibration, bed levels of unsurveyed areas were adjusted to provide the correct storage.

During the calibration process it became evident that relatively large (local) friction values would be required to achieve the observed hydraulic loss across 'The Rip'. Higher roughness values (Manning's 'n') were also specified for mangrove and oyster lease areas. The final friction values adopted in the model were: -

- General model roughness – n=0.03
- Mangrove areas – n=0.05
- Oyster leases – 0.1, and
- 'The Rip' – 0.075.

Figure 3.1 presents the locations of the MHL water level and discharge data collection sites. Figures 5.2 and 5.3 present modelled and measured water level time series at a number of MHL sites. The agreement between modelled and measured water levels is very good at all locations.

Figure 5.4 presents modelled and measured discharge at locations along the main branch of Brisbane Water. The calibration is generally very good including across 'The Rip' (Site 5). Figure 5.5 presents modelled and measured discharge across the Woy Woy Channel and near the railway bridge at the entrance to Woy Woy Bay. The calibration at the railway bridge is generally good, although the model underestimates the discharge in Woy Woy channel.

Figure 5.6 presents modelled and measured discharge across Cockle Channel and at the entrance to Kincumber Broadwater. The modelled peak discharge through the Cockle Channel cross-section is of lower magnitude than the measured data; however, the calibration across Humphrey's Channel is very good. There are large inter-tidal areas upstream of the Cockle Channel that are not well surveyed and this lack of detail influences the modelled result.

Overall the calibration in this region of the model is good. Figure 5.7 presents modelled and measured discharge at the entrance to Fagan's Bay and Narara Creek. At these locations, the hydrodynamic calibration is also very good.

The overall hydrodynamic calibration of the model is very good. The region of the model where there is the largest relative difference between the model and measured data is the region near Woy Woy Channel. This area is highly influenced by tidal flow through the surrounding mangrove areas. In this region of the model, the density of survey data is relatively low. Additional survey data of intertidal areas near the Woy Woy Channel could improve the hydrodynamic model performance in this region; however, the additional data would have very little influence on the outcomes of the overall modelling investigations. The overall description of estuarine hydraulics in the Woy Woy region is reproduced well by the Delft3D model.

5.1 Hydrodynamic Processes at 'The Rip'

Figures 5.8 to 5.10 show depth-averaged tidal currents near 'The Rip' at 2-hourly intervals. The upper plot in Figure 5.8 is just before 'slack' water. The lower plot in Figure 5.8 shows flood tide vectors. Figure 5.9 shows the transition from the flood to ebb tide. Figure 5.10 is a plot of the peak ebb tide currents. Key features of these plots are the rapid spatial acceleration in flow over 'The Rip' sill and the large eddy structures that are evident upstream and downstream of 'The Rip'. The modelled eddies are similar in structure to those that are observed when looking over 'The Rip' bridge during the peak of the flood or ebb tide.

Appendix 3 of this report contains typical tidal and wind driven depth-averaged currents at a number of locations. They are:-

- Figures A3-1 – A3-3: Tidal currents of Woy Woy and Paddy's Channel
- Figures A3-4 – A3-6: Tidal currents of St Huberts Island area
- Figures A3-7 – A3-9: Tidal currents of Cockle Channel
- Figures A3-10 – A3-12: Tidal currents of Ettalong and Wagstaff
- Figures A3-13 – A3-17: Tidal and wind (NE @ 5m/s) currents of Broadwater area

5.2 Dispersion Coefficient Calibration

The horizontal dispersion coefficient influences the lateral dispersion of substances dissolved or suspended in the water column, for example, suspended sediments or nutrients. The dispersion coefficient can be considered to be a calibration parameter that is influenced by the level of turbulent mixing and the horizontal grid spacing. In an estuarine system, the dispersion coefficient has a strong influence on the salinity gradient along the estuary.

Salinity is a conservative tracer that can be used to calibrate the model dispersion coefficient. Data from a real-time salinity probe deployed at Koolewong (Figure 3.1) between 1996 and 2001 was provided by MHL. Analysis of the data identified several occasions when salinity in Brisbane Water dropped significantly in response to freshwater inflows and then gradually recovered to the normal levels (average ≈ 33.4 ppt). A period was identified in August 1998 when salinity recovered at a uniform rate following significant freshwater inflows. The data indicated that tidal forcing dominated estuarine hydraulics during this recovery time – little wind and no further rainfall. On average, the recorded salinity recovery between 20 August 1998 and 20 September 1998 was approximately 0.3ppt per day.

The calibrated Delft3D model was setup with predicted tides from the time of identified commencement of salinity recovery and an initial uniform salinity of 20ppt throughout the estuary. This set up included the preparation of the Hawkesbury and Pittwater model boundaries. Salinity recovery in an estuary is a three-dimensional process due to the vertical density gradient. Therefore the model was configured with 5-vertical sigma layers (each layer represented 20% of the water column). Although the whole Estuary would not have had an initial salinity of 20ppt, the simulation was designed to replicate the observed rate of salinity recovery. A range of dispersion coefficients were investigated, including spatial variation having higher values in the region between Paddy's Channel and Ettalong to reflect the higher level of turbulent mixing expected there. The dispersion coefficient which produced the closest match to the recorded data was a uniform value of $2m^2/s$. Figure 5.11 presents a plot of modelled and measured mid-depth salinity at Koolewong during the simulation period. Overall the model appears to provide a good representation of the observed rate of salinity recovery and hence, within the limited extent of suitable salinity data, confirms that it behaves in an overall physically realistic manner.

6. ESTUARINE FLUSHING

The concept of estuarine flushing refers to the rate of water exchange due to tidal and catchment flows. Quantitative investigations into flushing can be used to describe the likely character of water quality responses of an estuarine system. For example, flushing rates can be used to assess the time it takes for a particular pollutant to disperse in various sections of an estuary. Then, considering flushing times, nutrient loads and biological response rates for a particular estuary, an assessment of the possible water quality outcomes can be investigated.

The 'flushing' of Brisbane Water is a complex process due to the geometry and scale of the water body. A wide range of valid approaches can be adopted to investigate flushing depending on the focus of a particular investigation. In terms of the Brisbane Water Estuary Processes Study, a general description of estuarine flushing throughout Brisbane Water was required. Due to the scale and complexity of the system, flushing has been investigated in a number of sections of Brisbane Water. Figure 6.1 is a plot of the six sub-regions which have been adopted for this study. They are: -

- Gosford – Broadwater (Dark Blue),
- St Huberts Island – Paddys Channel (Magenta)
- Ettalong (Light Blue)
- Kincumber (Yellow),
- Fagans Bay (Red), and
- Woy Woy Bay (Green).

A simulation using the Delft3D model (2D depth-averaged) was undertaken for each region with a tracer dispersed initially uniformly (concentration 100) over the specific investigation region. The initial tracer concentration outside the investigation area was defined as zero. Water level boundaries were prescribed for the ocean, Hawkesbury River and Pittwater model boundaries. The simulations were undertaken for up to 2 consecutive spring-neap tide cycles (28-days). No catchment flows were supplied to the models; that is, the flushing times determined by these analyses were maxima because catchment flows reduce flushing times by causing a net transport through a region.

Note that the outcome in terms of flushing times depends upon the initial model set up and distribution of tracer. If initial tracer were introduced throughout the whole estuary at the commencement of a simulation, then flushing times in the upper estuary, for example, Fagans Bay, would be much greater than those determined by this analysis. Hence the purpose has been to address the flushing times in terms of 'sub-regional spills'.

Flushing times have been defined in terms of e-folding times. The e-folding time refers to the time taken for a tracer to reach 1/e or 0.3679 of its initial concentration. At any location in an estuary subject to dynamic equilibrium forcing, the concentration of a particular tracer can be described by Equation 6.1.

$$
\begin{aligned}
&C_i = C_0 e^{-kt_i} \\
&\textit{where} \\
&\quad C_i = \text{concentration at time i}, \\
&\quad C_0 = \text{initial concentration at time } 0, \\
&\quad t_i = \text{time i}, \\
&\quad k = \text{dispersion constant},
\end{aligned}
\qquad (6.1)
$$

Following-on from Equation 6.1, k can be calculated by Equation 6.2.

$$k = \frac{\ln\left(\frac{C_i}{C_0}\right)}{-t_i} \qquad (6.2)$$

The e-folding time is then the inverse of k shown in Equation 6.3.

$$e-folding = \frac{1}{k} \qquad (6.3)$$

For each sub-model, e-folding times have been calculated using Equations 6.2 and 6.3.

Figure 6.2 presents e-folding times throughout the Gosford – Broadwater region. Flushing times range from 30 days in the south, up to 42 days near Erina Creek. Figure 6.3 presents flushing times in the St Huberts Island – Paddys Channel region. The flushing gradient upstream of 'The Rip' is steep with flushing times at 'The Rip' of approximately 5 days rising to 25 days in the Paddys Channel area. Note that there are some inconsistencies between the results presented for the area near Saratoga in Figures 6.2 and 6.3, this outcome being a result of the selection of specific regions for these analyses.

Figure 6.4 presents e-folding times downstream of 'The Rip' towards Ettalong. In this region flushing times vary between 2 and 3 days. There is a significant variation between the flushing times in the middle of the channel compared to nearby embayments, such as Hardys Bay.

Figure 6.5 presents the e-folding time for the Kincumber region of Brisbane Water. Flushing varies between 2 days in the western area of the main channel, to up to 28 days near Kincumber Creek. Again, these are relative to the selected sub-region.

E-folding times in Fagans Bay are presented in the upper section of Figure 6.6. Flushing times vary between 2 to 3 days. In Woy Woy Bay (lower section Figure 6.6) the flushing times are significantly longer than compared to Fagans Bay, varying between 10 and 15 days.

Note the apparent inconsistency between the 2 and 3 days flushing time for Fagans Bay to the approximate 30 days in the Gosford Broadwater. The outcome is related to the method of definition. If Fagans Bay and the Gosford Broadwater were considered as one region in terms of flushing time, then Fagans Bay would have a flushing time greater than 30 days. Hence the outcome depends upon the way in which the question is posed.

Water quality issues are considered further in Cardno Lawson Treloar (2007c), wherein the distribution of nutrients is considered in some detail, and although flushing processes are included implicitly, no initial sub-regional definition and tracer distribution is required, rather natural creek flows and nutrient loads are investigated.

7. WAVE PROCESSES

7.1 Model Setup

Wave processes in Brisbane Water have been investigated using the SWAN wave model. Due to the complexity and extent of the waterway system, a series of separate model domains have been developed to cover the whole study area and to allow local sea and swell to be investigated. Swell wave conditions typically affect coastal areas and locations near Ettalong – seaward of about Schnapper Road. The overall Delft3D model grid (Figure 4.1) has been used to propagate swell from deep water into the study area. The grid was truncated at 'The Rip' because swell energy does not propagate past that point.

Due to the complex physiography of the region, a total of 5 high-resolution domains were defined to investigate local sea inside Brisbane Water. Figure 7.1 describes the extent of all the individual local sea model domains. These wave model layouts mean that there are some shoreline locations that lie within two grid areas. Results were taken from the most appropriate grid (complete fetch definition for a specific wind direction).

For each of the local sea wave models, a matrix of predefined cases was prepared at 22.5^{o} direction intervals (16 directions) and 2.5m/s wind speed intervals up to 27.5m/s. A time series of wave conditions at each selected output location was then prepared from those basic model results by combining the model results with the time series of the fifty-nine years of recorded wind data at Mascot.

For the swell wave model, a matrix of predefined cases was simulated using 22.5^{o} direction intervals (9-directions, north through east to south) and 1s period intervals from 3 to 11s (T_z-9 wave periods). Time series of swell wave conditions were then prepared by transferring 9 years of recorded offshore directional wave data from Sydney (MHL Long Reef Waverider buoy data) to selected locations within the Ettalong area.

Wave propagation was undertaken at water levels of 1m and 1.6m AHD, these being typical, high storm-tide water levels within Brisbane Water, even though they would be more likely to occur during a severe east coast low ocean storm with onshore winds than with northerly winds, for example. Wave generation is sensitive to water level in the more shallow areas of Brisbane Water because of the relatively large increase in water depth that high water levels cause.

For both the sea and swell cases, extremal wave conditions for selected average recurrence intervals (ARI) have been estimated by undertaking Type-1 (Gumbel) extremal analyses on the top 50 wave height results in each directional sector (as appropriate) at each selected location; though generally, swell only has one nearshore direction at each location.

7.2 Local Sea Wave Climate

Figure 7.2 presents the 5-years ARI near-shore local sea wave conditions – based on wave modelling at 1m AHD. The largest waves occur in the Broadwater areas that are exposed to the south-easterly to south-westerly fetches. Figure 7.3 is a similar plot for the 100-years ARI conditions – based on wave modelling at 1.6m AHD. Compared with Figure 7.2, wave heights have generally increased, particularly at exposed Broadwater locations. Near some protected areas there is little difference between 5-years ARI and 100-years ARI conditions because wave generation is fetch limited.

7.3 Swell Wave Climate

Figure 7.4 presents the 5-years ARI swell wave conditions in lower Brisbane Water. Near Ettalong, swell wave conditions up to 1m (H_s) are observed. Figure 7.5 is a similar plot for the 100-years ARI conditions. Compared to Figure 7.4, wave heights are generally similar. Swell propagation to Ettalong is limited by water depth on the Ettalong Point shoal.

7.4 Detailed Wave Climate

Figure 7.6 (sea) and Figure 7.7 (swell) present the locations where detailed wave climate parameters have been prepared. Wave conditions for selected ARI's between 5 and 500-years are presented in Table 7.1 (local sea) and Table 7.2 (swell).

Table 7.1: Local Sea Wave Conditions – Significant Wave Height (m)

X (MGA94)	Y (MGA94)	Location	Average Recurrence Interval (Years)						
			1	5	10	20	50	100	500
346140.2	6290086	4	0.35	0.4	0.41	0.43	0.45	0.46	0.5
346531.4	6290146	5	0.38	0.44	0.45	0.47	0.49	0.51	0.54
346814.3	6290433	6	0.31	0.37	0.39	0.41	0.44	0.46	0.50
346624.0	6290797	7	0.32	0.37	0.38	0.40	0.42	0.43	0.47
346315.9	6290870	8	0.26	0.29	0.3	0.31	0.33	0.34	0.36
346378.4	6291209	9	0.30	0.34	0.36	0.38	0.40	0.41	0.44
345856.0	6291448	10	0.35	0.39	0.41	0.42	0.44	0.45	0.48
345487.1	6291838	11	0.33	0.37	0.38	0.40	0.42	0.43	0.46
344949.1	6292194	12	0.22	0.25	0.26	0.26	0.28	0.28	0.30
345132.0	6292974	13	0.36	0.42	0.44	0.47	0.49	0.52	0.56
345465.5	6293770	14	0.37	0.45	0.48	0.51	0.55	0.58	0.64
344864.0	6293720	15	0.20	0.23	0.25	0.26	0.27	0.28	0.30
344349.9	6293890	16	0.17	0.19	0.20	0.21	0.22	0.22	0.24
344328.5	6294957	17	0.28	0.32	0.33	0.34	0.36	0.37	0.39
343900.4	6295952	18	0.45	0.48	0.50	0.51	0.53	0.54	0.57
343289.9	6296327	19	0.42	0.47	0.49	0.51	0.54	0.56	0.60
343527.8	6296846	20	0.42	0.46	0.47	0.48	0.49	0.51	0.53
343775.9	6297334	21	0.40	0.43	0.44	0.45	0.46	0.47	0.49
344657.1	6297358	22	0.64	0.78	0.83	0.88	0.94	0.99	1.10
344949.3	6298639	23	0.44	0.46	0.47	0.48	0.49	0.50	0.52
345347.0	6299850	24	0.48	0.57	0.60	0.62	0.66	0.68	0.75
345785.3	6298782	25	0.41	0.44	0.45	0.46	0.48	0.49	0.51
345877.0	6297514	26	0.67	0.76	0.79	0.82	0.86	0.89	0.96
346412.1	6298614	27	0.39	0.41	0.41	0.42	0.43	0.44	0.45
346733.4	6298078	28	0.53	0.56	0.57	0.58	0.59	0.60	0.62
347305.1	6298430	29	0.38	0.45	0.48	0.5	0.53	0.55	0.60
347990.7	6298680	30	0.33	0.35	0.36	0.36	0.37	0.38	0.40
347686.0	6297990	31	0.39	0.43	0.44	0.45	0.47	0.48	0.51
347283.2	6297526	32	0.42	0.46	0.47	0.49	0.50	0.51	0.54
346965.6	6296546	33	0.60	0.69	0.73	0.76	0.80	0.83	0.89
347308.2	6295946	34	0.39	0.41	0.42	0.43	0.44	0.44	0.46
347249.8	6295326	35	0.45	0.48	0.48	0.49	0.50	0.51	0.53
346331.5	6295203	36	0.43	0.46	0.47	0.48	0.50	0.51	0.53
345574.8	6295170	37	0.37	0.39	0.39	0.40	0.40	0.41	0.42
345413.6	6294669	38	0.35	0.42	0.44	0.46	0.49	0.52	0.57
345956.5	6294134	39	0.47	0.57	0.6	0.63	0.68	0.71	0.78
346781.6	6293998	40	0.27	0.32	0.33	0.35	0.37	0.39	0.42
346934.2	6293300	41	0.29	0.34	0.36	0.38	0.40	0.42	0.46
347697.0	6293542	42	0.32	0.40	0.43	0.45	0.48	0.51	0.56
348104.8	6293095	43	0.29	0.35	0.37	0.39	0.41	0.43	0.48
348576.6	6292968	44	0.14	0.16	0.17	0.18	0.19	0.19	0.21
348978.7	6293228	45	0.28	0.32	0.33	0.35	0.36	0.38	0.41
348749.4	6293486	46	0.28	0.31	0.32	0.33	0.35	0.36	0.38
348145.1	6294238	47	0.31	0.35	0.36	0.37	0.39	0.40	0.42
348520.3	6295122	48	0.36	0.38	0.39	0.40	0.41	0.41	0.43
349482.3	6295292	49	0.34	0.36	0.36	0.37	0.38	0.38	0.40
349332.6	6294332	50	0.36	0.39	0.40	0.41	0.42	0.43	0.45
348881.8	6293720	51	0.31	0.34	0.35	0.35	0.37	0.37	0.39
349157.8	6293205	52	0.33	0.36	0.37	0.38	0.40	0.41	0.43
349572.7	6293083	53	0.31	0.35	0.36	0.37	0.38	0.39	0.41
349381.5	6292585	54	0.33	0.39	0.41	0.43	0.45	0.47	0.51
348877.8	6292149	55	0.27	0.29	0.30	0.30	0.31	0.32	0.34
348616.3	6292646	56	0.26	0.30	0.31	0.33	0.34	0.35	0.38
348537.2	6292804	57	0.22	0.27	0.28	0.29	0.31	0.32	0.35
347937.7	6292934	58	0.22	0.26	0.27	0.29	0.30	0.32	0.35
347534.6	6293317	59	0.22	0.26	0.27	0.28	0.3	0.31	0.33
347031.3	6293053	60	0.16	0.18	0.19	0.20	0.21	0.21	0.23
346901.5	6292464	61	0.26	0.31	0.33	0.34	0.36	0.38	0.41

X (MGA94)	Y (MGA94)	Location	Average Recurrence Interval (Years)						
			1	5	10	20	50	100	500
346941.4	6291950	62	0.30	0.36	0.38	0.40	0.43	0.45	0.50
346459.3	6291724	63	0.37	0.45	0.48	0.50	0.54	0.56	0.62
346485.6	6291375	64	0.43	0.52	0.55	0.58	0.62	0.65	0.72
346936.4	6291329	65	0.37	0.45	0.47	0.50	0.53	0.56	0.61
346941.3	6290828	66	0.42	0.50	0.53	0.56	0.59	0.62	0.68
347549.2	6290737	67	0.32	0.35	0.36	0.37	0.38	0.39	0.42
347514.9	6290224	68	0.31	0.34	0.35	0.36	0.38	0.39	0.41
347650.8	6289410	69	0.27	0.28	0.29	0.29	0.30	0.31	0.32
347091.3	6289796	70	0.31	0.34	0.35	0.36	0.38	0.39	0.41
346530.0	6289107	71	0.26	0.28	0.29	0.29	0.30	0.31	0.32
346039.7	6289850	72	0.28	0.32	0.34	0.36	0.37	0.39	0.42
345886.6	6289878	73	0.28	0.00	0.00	0.00	0.00	0.00	0.00
345520.6	6289590	74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
344845.4	6299864	b75	0.10	0.11	0.11	0.11	0.12	0.12	0.12
345145.0	6299895	b76	0.24	0.27	0.28	0.29	0.30	0.31	0.33
345048.8	6299481	b77	0.21	0.25	0.26	0.27	0.29	0.30	0.33
344838.8	6299138	b78	0.11	0.13	0.13	0.14	0.15	0.15	0.17
344455.1	6299203	b79	0.11	0.11	0.12	0.12	0.12	0.12	0.13
344057.1	6299284	b80	0.16	0.17	0.17	0.17	0.18	0.18	0.19
343699.5	6299635	b81	0.17	0.19	0.20	0.21	0.22	0.23	0.25
344117.8	6299528	b82	0.16	0.17	0.18	0.18	0.18	0.19	0.20
344508.0	6299448	b83	0.15	0.17	0.17	0.18	0.19	0.20	0.21
344753.3	6299650	b84	0.20	0.24	0.25	0.26	0.28	0.29	0.33
348227.9	6292146	c75	0.13	0.14	0.14	0.14	0.14	0.14	0.15
348423.9	6292055	c76	0.14	0.15	0.15	0.16	0.16	0.17	0.17
348297.1	6291881	c77	0.10	0.10	0.11	0.11	0.11	0.11	0.12
348149.0	6291978	c78	0.12	0.13	0.13	0.13	0.14	0.14	0.15
345922.4	6293276	s75	0.34	0.41	0.43	0.46	0.49	0.51	0.56
346475.7	6292922	s76	0.25	0.29	0.31	0.32	0.34	0.36	0.39
346253.8	6292688	s77	0.18	0.20	0.21	0.21	0.22	0.23	0.24
346754.1	6292611	s78	0.24	0.30	0.32	0.34	0.36	0.38	0.43
346533.6	6292482	s79	0.14	0.16	0.17	0.18	0.18	0.19	0.20
346629.7	6292371	s80	0.15	0.20	0.21	0.23	0.25	0.26	0.30
346730.9	6292166	s81	0.14	0.19	0.20	0.22	0.24	0.26	0.29
346856.8	6292037	s82	0.19	0.23	0.25	0.26	0.28	0.29	0.32
346822.6	6291938	s83	0.34	0.41	0.44	0.46	0.49	0.51	0.56
346585.9	6291987	s84	0.25	0.28	0.29	0.30	0.31	0.32	0.34
346534.4	6292234	s85	0.22	0.28	0.30	0.32	0.35	0.37	0.41
346191.4	6292036	s86	0.42	0.51	0.54	0.56	0.60	0.63	0.69
346050.1	6292460	s87	0.23	0.26	0.27	0.27	0.28	0.29	0.31
346353.0	6292392	s88	0.18	0.22	0.23	0.25	0.26	0.28	0.31
345994.7	6292842	s89	0.20	0.21	0.22	0.22	0.23	0.23	0.24
344185.0	6294642	w1	0.20	0.23	0.24	0.24	0.25	0.26	0.28
344248.8	6294171	w2	0.25	0.26	0.27	0.27	0.28	0.29	0.30
344207.3	6293777	w3	0.34	0.39	0.40	0.41	0.43	0.45	0.48
343681.8	6293178	w4	0.21	0.23	0.23	0.24	0.24	0.25	0.26
343127.1	6292908	w5	0.23	0.25	0.26	0.27	0.28	0.29	0.31
342651.2	6292657	w6	0.28	0.32	0.34	0.36	0.38	0.39	0.43
343033.9	6293348	w7	0.25	0.28	0.29	0.30	0.32	0.33	0.35
343752.4	6293588	w8	0.25	0.30	0.31	0.33	0.35	0.36	0.40
343419.9	6293942	w9	0.25	0.26	0.27	0.28	0.29	0.29	0.31
342912.5	6294176	w10	0.27	0.29	0.30	0.31	0.32	0.32	0.34
342283.1	6294721	w11	0.23	0.27	0.28	0.29	0.31	0.32	0.34
342858.0	6294653	w12	0.35	0.43	0.46	0.49	0.52	0.55	0.61
342797.1	6295532	w13	0.29	0.34	0.36	0.38	0.40	0.42	0.46
343393.3	6294407	w14	0.43	0.52	0.56	0.59	0.63	0.66	0.74
343896.8	6294196	w15	0.40	0.49	0.52	0.55	0.59	0.62	0.69
343911.2	6294408	w16	0.24	0.29	0.31	0.32	0.34	0.36	0.39

Table 7.2: Swell Conditions – Significant Wave Height (m)

X (MGA94)	Y (MGA94)	Location	Average Recurrence Interval (Years)						
			1	5	10	20	50	100	500
343302.2	6285985	1	3.15	3.78	4.05	4.32	4.67	4.94	5.55
343308.6	6286522	2	2.89	3.47	3.72	3.97	4.30	4.54	5.12
343308.6	6286995	3	3.89	4.64	4.96	5.28	5.70	6.01	6.75
343141.0	6287145	4	4.07	4.92	5.28	5.64	6.11	6.47	7.30
343230.9	6287396	5	4.31	5.20	5.57	5.95	6.44	6.81	7.68
343430.0	6287691	6	4.57	5.46	5.84	6.21	6.70	7.08	7.94
343712.6	6288064	7	4.24	5.02	5.35	5.68	6.11	6.44	7.20
343609.0	6288312	8	3.65	4.33	4.61	4.90	5.28	5.56	6.22
343494.0	6288497	9	3.69	4.37	4.66	4.95	5.33	5.62	6.29
343685.7	6288759	10	4.10	4.84	5.15	5.47	5.88	6.19	6.91
343966.9	6288913	11	3.85	4.53	4.82	5.11	5.49	5.78	6.45
344369.6	6289047	12	2.89	3.39	3.60	3.82	4.09	4.30	4.79
344753.1	6289117	13	2.41	2.85	3.03	3.22	3.46	3.65	4.08
345138.6	6289311	14	2.18	2.65	2.85	3.05	3.31	3.51	3.97
345137.3	6289487	15	1.00	1.21	1.29	1.38	1.50	1.59	1.79
345161.6	6289772	16	0.45	0.53	0.56	0.59	0.63	0.66	0.73
345286.7	6290046	17	0.22	0.24	0.25	0.26	0.27	0.28	0.30
345554.8	6290332	18	1.00	1.22	1.31	1.40	1.52	1.60	1.81
345816.9	6290243	19	0.36	0.43	0.46	0.5	0.54	0.57	0.64
346114.7	6290076	20	0.24	0.29	0.31	0.33	0.35	0.37	0.42
346430.4	6290052	21	0.07	0.08	0.08	0.09	0.10	0.10	0.12
346680.7	6290183	22	0.11	0.13	0.14	0.15	0.16	0.17	0.20
346835.5	6290439	23	0.02	0.03	0.03	0.03	0.04	0.04	0.05
346680.7	6290803	24	0.00	0.00	0.00	0.00	0.01	0.01	0.01
346865.3	6290880	25	0.01	0.02	0.02	0.02	0.03	0.03	0.03
347461.0	6290761	26	0.03	0.03	0.04	0.04	0.05	0.05	0.06
347467.0	6290290	27	0.04	0.05	0.05	0.06	0.06	0.06	0.07
347610.7	6290009	28	0.01	0.02	0.02	0.02	0.02	0.02	0.02
347615.9	6289480	29	0.01	0.02	0.02	0.02	0.02	0.02	0.02
347335.9	6289528	30	0.03	0.03	0.04	0.04	0.05	0.05	0.06
347067.8	6289826	31	0.06	0.08	0.08	0.09	0.10	0.10	0.12
346752.1	6289570	32	0.03	0.04	0.05	0.05	0.06	0.06	0.07
346537.7	6289176	33	0.03	0.04	0.04	0.05	0.05	0.06	0.06
346273.2	6289390	34	0.01	0.01	0.02	0.02	0.02	0.02	0.02
346150.5	6289683	35	0.07	0.08	0.09	0.10	0.11	0.11	0.13
345954.4	6289925	36	0.28	0.34	0.36	0.39	0.42	0.45	0.51
345673.9	6289820	37	0.62	0.75	0.81	0.87	0.94	1.00	1.13
345382.0	6289528	38	1.66	2.00	2.15	2.29	2.49	2.63	2.97
345673.9	6289123	39	1.90	2.24	2.38	2.52	2.71	2.85	3.19
345751.3	6288664	40	0.50	0.59	0.63	0.66	0.71	0.75	0.83
345558.2	6288247	41	1.50	1.77	1.88	1.99	2.14	2.26	2.52
345574.7	6287938	42	3.40	3.95	4.19	4.42	4.73	4.96	5.50
346032.4	6287510	43	1.29	1.50	1.58	1.67	1.78	1.87	2.06
346382.8	6286780	44	5.78	6.79	7.22	7.65	8.22	8.64	9.63
346558.8	6287163	45	5.13	6.05	6.44	6.83	7.34	7.73	8.63
346916.2	6287608	46	5.64	6.60	7.01	7.42	7.95	8.36	9.30
347371.6	6287890	47	5.73	6.71	7.12	7.53	8.08	8.49	9.44
347645.8	6288151	48	5.66	6.64	7.06	7.47	8.02	8.43	9.39
347973.2	6288414	49	5.92	6.95	7.39	7.83	8.40	8.84	9.84
348267.9	6288532	50	5.23	6.14	6.52	6.90	7.41	7.79	8.67
348450.7	6288591	51	5.21	6.13	6.51	6.90	7.41	7.80	8.69
348822.0	6288567	52	4.44	5.24	5.58	5.92	6.37	6.71	7.49

Wave periods (T_z) are generally less than 3 seconds for local sea - 1.5 seconds at 5-years ARI to 2.5 seconds at 100-years ARI. For swell, T_z varies from 8 to 10.5 seconds for 5 to 100-years ARI, typically. Case specific investigations would be needed for project design.

7.5 Wave Forces on the Estuary Bed

The seabed shear forces caused by waves have significant impacts on the ecology of estuarine systems. In addition to an influence on shoreline circulation (wave breaking processes generate a longshore current) within an estuary, waves have impacts on the estuary bed. Bed forces induced by waves have the ability to mobilise sediment and impact on biological function, for example, to disturb seagrass areas.

Brisbane Water is comprised of sandy bed regions and other areas that principally are formed from silts or muds. The manner in which bed forces induced by waves are normally described depends on the bed material. For example, sandy regions typically have bed forces described by the near-bed current speed while mud areas are described by the bed shear stress. In both cases the point is to describe the parameter value above which bed movement is initiated.

The SWAN model has been used to determine spatial maps of near-bed velocity and bed shear stress to identify regions where bed forces may be significant. Seabed plants and other organisms are disturbed when seabed sediment motion is initiated. On sandy beds this threshold occurs at about 0.3m/s (van Rijn, 1993) – that is, the near bed wave orbital particle speed. On silty beds the bed shear stress needs to exceed about 0.2 to 0.5N/m^2, depending upon the degree of consolidation (van Rijn, 1993). Where there are sea grasses, the root system increases the current speed or shear stress needed to initiate sediment motion. However, there is no substantial data available for that assessment, but based on observation of storm caused seagrass damage in Botany Bay, a near seabed velocity of about 1m/s would be required, or a shear stress of 1N/m^2, approximately.

Figure 7.8 presents the 1-year ARI near-bed velocity map in the Broadwater area and Figure 7.9 presents the bed shear stress map. In both figures, yellow identifies regions were sediment suspension and transport is likely to occur. Figures 7.10 and 7.11 present similar plots for the 5-years ARI wave conditions. Comparing the 1-year and 5-years ARI results, significantly larger areas are subject to re-suspension forces for the 5-years ARI case. From a biological perspective, common conditions, such as an event which occurs every year, have a more significant influence on the ecology than conditions which occur less frequently.

Figures 7.12 and 7.13 present the 1-year ARI bed forces in ‘The Rip’ region. The deeper water depths and smaller fetch length act to produce lower bed forces compared to the Broadwater area. However, shear stresses caused by the tidal flow will be much greater and have acted to erode the bed to bedrock or equilibrium levels. Figures 7.14 and 7.15 present the bed force description in the eastern St Huberts Island area. High bed forces are concentrated in the intertidal areas and near oyster leases.

Figures 7.16 and 7.17 present the 1-year ARI bed forces in the Cockle Channel area. Although the fetch lengths in the region are not as large as those in the Broadwater region, the shallow depths contribute to relatively high bed forces during relatively large wave conditions. Figures 7.18 and 7.19 present the 1-year ARI bed forces in the Woy Woy Bay area. This relatively deep branch is also somewhat protected from high wave conditions and the area exposed to high near-bed forces is much less than other areas in Brisbane Water.

7.6 Shoreline Erosion

Much of the shoreline of Brisbane Water is protected by rock walls, see, for example, Figure 2.2. However, more natural shorelines are found at locations such as those indicated on Figure 7.20. Those locations have been selected for storm 'bite' analyses – the loss of sand from the beach face through offshore sediment transport processes caused by waves and high water levels.

Morphological response of the shoreline due to storm wave conditions occurs over relatively short periods (hours). This response primarily involves the erosion of the normal subaerial beach face through offshore transport and deposition near the storm wave break point to form an offshore bar – small in the case of local sea in Brisbane Water. On open sea coasts the beach face slowly rebuilds as sand in the bar is transported shoreward under swell wave conditions with lower steepness. However, at these sites there is generally no swell.

An assessment of storm erosion was made for the six locations shown on Figure 7.20 using the LITPROF model. A site visit was undertaken in June 2004 and sediment samples taken at each site, as well as estimates of the inter-tidal and back-beach slopes. Other parts of the lower profile were determined from the digital terrain model established for this study. Particle size analysis results are provided in Cardno Lawson Treloar 2007c.

LITPROF is a semi-empirical, dynamic equilibrium storm onshore/offshore erosion prediction model developed at the Danish Hydraulics Institute and is a module of the LITPACK coastal processes system. The bed level is determined by the continuity equation of sediment mass coupled with onshore/offshore transport. The model can be run with constant or time varying wave height and still water level.

All simulations were undertaken at a water level of 1.6m AHD over a period of three hours using the respective peak storm Hs at 100-years ARI – see Table 7.1 and Figure 7.6. Results are presented in Figure 7.21. Typically there would be from 1 to 2m of horizontal shoreline recession at levels between 1.5 and 2m AHD. This erosion would occur at a lower level should these wave conditions occur at a lower water level. In that case, though, the overall smaller water depths would lead to lower wave heights and less shoreline recession.

These beach areas would recover very slowly, or not at all, because of the lack of swell waves at those sites.

8. WATER LEVEL ISSUES

This section of the report describes the spatial and temporal variation of water level throughout the estuary. These characteristics are described also in Appendix 1 for tidal conditions alone.

The dominant water level forcing phenomenon is the astronomical tide. However, the highest recorded water levels in the estuary occurred during the severe ocean storm of May 1974 (Public Works 1976), though levels may be higher in Fagans bay in a severe creek flood. Although flood levels within the estuary are the subject of a separate and on-going study (as at January 2007), it is important to discuss water levels and the increments that make up a total water level within the context of this processes study and to include some quantitative data.

The following analyses may be directed also towards developing realistic risk-based downstream boundary water levels to be applied to creek flood studies. Previously, Cardno Lawson Treloar have adopted a boundary water level based on long term recorded data (Fort Denison and Newcastle) and selected a level so that one can be 99% confident that the level will not be exceeded during any flood. This criterion can be adopted when there is little or no correlation between the boundary water levels and rainfall events in the subject catchment.

This approach is sound and works well where there is long term recorded water level data that can be subjected to a joint occurrence analysis of tidal and meteorological processes, as is the case for Port Jackson. Note that Manly Hydraulics Laboratory have about ten years of recorded water level data at Koolewong, with a shorter record at Ettalong. There is a period of three months of concurrent data from their Middle Harbour, Koolewong and Ettalong sites. Analysis of three months of data provides reliable tidal constituents; one year is required for a Standard Port. Unfortunately, it is understood that the Koolewong gauge has been de-commissioned. Where additional site-specific estuarine processes would affect this relationship (water level versus probability of exceedance) the Fort Denison result may not be directly applicable; as is the case in Brisbane Water. Hence it is necessary to undertake other investigations.

The questions then are: -

- Can the Port Jackson long-term-based extreme water levels analysis be applied to Brisbane Water in some way, or some regions of Brisbane Water, it being the longest record available?
- Can the recorded Koolewong water level data be applied to the selection of appropriate water level boundary criteria in the Gosford Broadwater, at Koolewong itself, and more generally in the whole Gosford Broadwater?
- More broadly, can the Koolewong data itself, processed in terms of probability of exceedance, or more likely, in terms of joint occurrence of astronomical tide and meteorologically caused variations, be applied to Brisbane Water?
- If the responses are at least partially no, then what other analyses must be undertaken to develop these criteria?

Note that planning levels, in general, must be formed from envelopes of estuary water levels near creek mouths and water levels formed from individual creek flood studies themselves at selected ARI. Estuary planning levels may include wave run-up also.

The definition of detailed planning levels does not form part of this study. Nevertheless, the processes have been investigated.

8.1 Study Approach

A number of types of water level investigation have been undertaken. They include: -

- Hindcast investigations of the May 1974 storm event,
- Simulation of events with selected approximate return periods (i.e. 10 and 20 years ARI events), and
- Analyses of recorded water level data.

The calibrated hydrodynamic model developed for this study can also be coupled with a whole of Brisbane Water SWAN wave model to allow the simultaneous simulation and interaction of hydrodynamic (tide and wind) and wave processes (manifested as wave set-up) throughout the estuary.

This model has been used to undertake hindcast investigations of the May 1974 storm event. This severe storm event caused elevated water levels along the mid-NSW coast and water level data was 'recorded' within Brisbane Water (PWD, 1976). The elevated water levels were caused by a combination of processes, including: -

- A high astronomical tide,
- Inverse barometer effect,
- Wind setup,
- Wave setup,
- Possible propagation of coastal trapped waves along the continental shelf, and
- Possible ocean basin processes – such as the el Nino southern oscillation

The May 1974 ocean storm was particularly severe because peak wave conditions coincided near the time of peak astronomical tide in the Sydney region. The impact of the May 1974 event on Brisbane Water is documented in Department of Public Works (1976) and Foster et al (1975). Lord and Kulmar (2000) also discuss this event. The average recurrence interval (ARI) of an event like the May 1974 storm is generally considered to be greater than 100-years in terms of combined wave and elevated water level processes and hence coastal impact. However, the ARI of this storm depends upon the method of assessment (peak wave height/duration/direction), location (open coast/estuarine) and type of impact (inundation/erosion), for example. Where joint occurrence between wave height and water level affects the impact, then the ARI may be much longer than that of peak storm wave height itself.

The May 1974 storm event was simulated using the following boundary conditions: -

- Measured Fort Denison tide (provided by National Tidal Centre),
- Peak wave conditions (Foster et al, 1975): -
    - H_s=9.0m,
    - T_p=16s,
    - Direction = 112.5^{o}TN
- Peak wind conditions: -
    - W_s=27m/s, and
    - Direction = 135^{o}TN,

A simulation using the same parameters was undertaken on a calibrated Sydney Harbour model as well and the modelled water level at Fort Denison determined. This procedure allowed the difference between the boundary tide (Fort Denison measured water level) and modelled Fort Denison water level to be determined. That is, a true ocean tide is not available at Sydney or for offshore Broken Bay. This difference was then subtracted from the Brisbane Water sites model output water level results so that any wave and wind setup within Sydney Harbour, and already included in the Fort Denison tide gauge record, was removed from the model tidal boundary condition at Broken Bay. Atmospheric pressure effects would be included in the recorded Fort Denison water levels, but for this analysis can be taken to be the same at both sites. Note that these are dynamic simulations in which the ocean tide varies – not a constant water level.

Simulations for approximate 10 and 20-years ARI events conditions were undertaken also. The basis for their selection as representing these ARI was the analysed Fort Denison water level data, analyses of long term offshore Botany Bay wave data and Sydney Airport wind data, all in terms of probability of exceedance. Although these events were selected to represent 10 and 20-years ARI events, the joint probability of all factors contributing to elevated water levels may result in the return period for the combined selected met-ocean parameters being greater, especially in Brisbane Water; even though there is some correlation between them. For the waves and wind, it was assumed that peak conditions must persist for six hours to ensure that water levels could propagate into the estuary. This is because an elevated ocean water level of short duration will not have time to 'fill' Brisbane Water. Table 8.1 describes the boundary conditions for each simulation. Boundary conditions were developed from the following data sets: -

- Water Levels – Fort Denison (MHL, 1992) Table 53,
- Waves – Willoughby (1995), and
- Wind – Mascot 1939-1997 record.

Table 8.1: Severe Event Boundary Conditions

	10 Years ARI	20 Years ARI	May 1974
Peak Ocean Water Level	1.30m AHD	1.35m AHD	1.47m AHD
Peak Wind Conditions	20.5m/s, Dir = 135	22m/s, Dir = 135	27m/s, Dir = 135
Peak Wave Conditions	H_s=8m, T_p=13.5s, Dir=112.5deg	H_s=8.5m, T_p=14, Dir=112.5deg	H_s=9m, T_p=16s, Dir=112.5deg

The purpose of these analyses was to determine whether or not very severe ocean storms cause elevated water levels that 'sit-on' or overlie the extrapolated Koolewong water level data probability of exceedance relationship based on ten years of recorded data. If this outcome were the result, then one could accept that the ten years of Koolewong recorded data provided a realistic basis for estuary planning levels analysis in that region of Brisbane Water and also for creek-flood model boundary data.

Similar analyses would then be used for other estuarine locations from Gosford to Broken Bay, with the long term Fort Denison results possibly being appropriate at Ettalong, for example.

As with the May 1974 investigations, the boundary conditions for the typical 10 and 20-years ARI events were applied also to the Sydney Harbour model to remove the wave setup and wind setup included implicitly in the Fort Denison water level result applied to the Brisbane Water model offshore boundary. The recorded Fort Denison water level data for May 1974 was provided by the National Tidal Centre. Wave and wind directions are based on the available synoptic data for the May, 1974 storm – Foster et al (1975). It is quite possible that other storm scenarios could produce the same peak water level at Fort

Denison, but those selected are typical of the most common very severe ocean storm conditions and consistent with the meteorology of May 1974.

Water level data was collected at Koolewong by MHL on behalf of Gosford City Council between 1993 and 2003 at 15 minute intervals. It has been analysed and plotted in terms of probability of exceedance. Water level data for a number of sites around Brisbane Water was recorded between February and April 2004, including Koolewong and Ettalong (MHL, 2004). Data for Middle Harbour was also available for this period. This data was analysed also on a probability of exceedence basis.

8.2 Results

8.2.1 Delft3D Storm Simulations

The results of these simulations are presented as time series in the first instance at a number of selected sites. Peak water levels at these sites have then been tabulated. Figure 8.1 shows the water level (m AHD) at Ettalong, Woy Woy, Koolewong and Gosford for the May 1974 simulations. Figures 8.2 and 8.3 show similar plots for the 10-years ARI and 20-years ARI events. Table 8.2 summarises the peak water levels for each event at Ettalong, Woy Woy, Koolewong and Gosford.

Table 8.2: Peak Water Levels

	Ettalong	Woy Woy	Koolewong	Gosford
10-years ARI	1.41	1.37	1.43	1.47
20-years ARI	1.47	1.47	1.51	1.55
May 1974	1.62	1.64	1.75	1.80

Figure 8.4 shows time series plots of water level at Ettalong for the simulated May 1974 storm for the following combinations of boundary conditions: -

- Tide only (black line),
- Tide and wind (red line),
- Tide and waves (green line), and
- Tide, wind and waves (blue line).

A similar plot for Gosford is presented as Figure 8.5. Figure 8.4 shows that at Ettalong wave set-up is a larger contributor than wind to the elevation above the ocean tide there. However, at Gosford wind setup contributes more than wave setup, and for the higher level observed at Gosford the wave set-up increment between Broken Bay and Ettalong has increased only a little. Moreover, these model simulation peak water level results are very similar to the observed water levels for that storm (PWD, 1976), see Figure 3.2

8.2.2 Water Levels – Koolewong

Figure 8.6 shows a plot of the Koolewong water level curve (red line and asterisks) based on 10 years of recorded water level, in terms of probability of exceedance. Figure 8.6 also shows: -

- Koolewong based on February – April 2004 data (blue triangles), and

- Koolewong extreme levels based on Delft3D simulations (mauve circles 10 and 20-years ARI) and the May 1974 storm (green box)

For plotting purposes, the probability of exceedance for the 10 and 20-years ARI and the May 1974 peak water levels was based on a duration of 1 hour in each ARI (10, 20 and 100-years – assumed). Figure 8.6 shows that the simulated extreme water levels which influence estuarine planning levels at Koolewong are consistent with, but a little higher than, the Koolewong water level probability of exceedance curve based on the 10 years of recorded data. Note that the correct plotting position, in terms of probability of exceedance, of these points is not known – it is likely that they occur less frequently than the nominal 10 and 20-years ARI. The probability of exceedance distribution for the February – April 2004 data is a good match compared with the 10-years dataset for the more frequently occurring water levels. The distribution based on three months of data only begins to fall below the 10-years distribution for exceedance probabilities less than about 5%.

8.2.3 Water Levels – Ettalong

Ettalong does not have a longterm water level record like that for Sydney Harbour, or even a medium-term record (10 years) as there is at Koolewong. The May 1974 storm event indicates that extreme water levels at Ettalong may be higher than for Sydney Harbour. This is principally a product of wave set-up, which may occur at Ettalong due to the presence of the sandbars at the entrance to Brisbane Water from Broken Bay, despite the tidal attenuation between the sea and Ettalong, in the order of 15% (MHL, 2004). This attenuation of the astronomical tide is caused by the sandbar and estuarine form. However, the Delft3D simulations have shown that for very severe storms typical of the 10 and 20-years ARI, but less severe than the May 1974 storm, water levels at Ettalong are a little lower than those at Fort Denison. Hence wave parameters, and consequentially wave set-up, are an important influence on total water level.

A probability of exceedance water level curve for Ettalong has been developed by modifying the design water level curve for Sydney Harbour (Fort Denison) (MHL, 1992) to reflect the differences between the sites. Water level data was available for Middle Harbour and Ettalong for the February – April 2004 period. The differences between Middle Harbour and Ettalong were determined for defined probabilities using an interpolation routine. The differences between the Ettalong and Middle Harbour water level probability of exceedance distributions during this period were then applied to the long-term Sydney Harbour water level probability of exceedance distribution. Additionally, note was taken of the 10 and 20-years ARI simulations. Note that the May 1974 result lies marginally above this developed probability of exceedance water level distribution indicating that that storm caused a peak water level at Ettalong of much slightly lower frequency than the 100-years ARI.

The probability of exceedance distributions for Middle Harbour and Fort Denison water level data recorded during February – April 2004 were compared to verify that Middle Harbour and Fort Denison have similar water level probability of exceedance distributions. Figure 8.7 presents a plot of the Middle Harbour (Red Asterisks) and Fort Denison (Blue Triangles) water level probability of exceedance distributions and clearly shows that the two distributions are very similar. The Ettalong distribution for the period between February – April 2004 is shown also (Mauve Circles) and is clearly lower.

Figure 8.8 presents an adjusted water level curve for Ettalong based on the Sydney Harbour curve and Brisbane Water model results. The modelled extreme water level cases presented in Table 8.2 are also shown.

8.3 Discussion

These water level investigations have been undertaken for storm and normal conditions. They have highlighted that there are differences between the water levels experienced inside Sydney Harbour and Broken Bay and within the study area.

The Delft3D May 1974 simulation and the data available for the May 1974 storm in Brisbane Water (PWD, 1976) have demonstrated that water levels at Ettalong and further upstream in Brisbane Water may exceed the water level observed at Fort Denison during the same very severe event. Nevertheless, more commonly, water levels in Brisbane Water are lower than those in Broken Bay.

Recorded water level data from a number of sites within Brisbane Water indicate that normal tide range is lower than at Middle Harbour and Fort Denison. This causes an apparent discontinuity between the normal and extreme water levels distributions within Brisbane Water. Continued water level data collection at Koolewong would allow further refinement of design water level distribution using measured data in the future, for example in 10 or 20 years time. Based on current measured data it is difficult to define a realistic return period for an event like the May 1974 storm at Koolewong. Inside Brisbane Water the return period for water levels associated with the May 1974 storm are probably much longer than in Sydney Harbour because the combined influences of storm duration, wave setup and wind setup are more significant at Brisbane Water.

No potential MSL rise as a result of climate change has been included.

9. HYDRAULIC PROCESSES INVESTIGATIONS

The Delft3D hydraulic model of Brisbane Water (Section 5) has been applied to a range of hydraulic processes investigations initiated to investigate ecological phenomena. Details of these ecological investigations are provided as separate reports and technical appendices. The hydraulic processes investigations that support this work are described below.

9.1 Maximum Shear Index

Discussions amongst Dr Peter Freewater (GCC), Cardno Lawson Treloar and Dr Iain Suthers of the University of NSW led to the decision to describe the horizontal gradient of current speed to investigate the influence of hydrodynamics to larval fish settlement in seagrass beds. In particular, Dr Suthers tested the hypothesis that seagrass beds in low flow areas adjacent to high flow areas in the main flood channels are of critical importance as drop off zones for larval recruits. The research was also designed to investigate whether or not there are particular seagrass beds that are of a higher priority for conservation and protection effort than others. Investigations at other sites have shown that the index of maximum shear index (MSI) is a useful correlate. The MSI is defined by Equation 9.1.

$$MSI = \frac{v_{\text{deepest channel section}} - v_{\text{1m depth}}}{\text{distance}} \qquad (9.1)$$

MSI have been determined at selected locations to assist with these analyses and are presented in Figures 9.1 and 9.2.

9.2 Drogue Track Simulations – Larval Transport

9.2.1 Invertebrate Larvae

The movement of invertebrate larvae following spawning has been identified as an important process in the Brisbane Water ecosystem. Observations have indicated that large spring tides provide a cue for the release of large volumes of invertebrate larvae from saltmarsh habitats. The movement of crab larvae from the main saltmarsh habitats over successive tide cycles has been investigated using the drogue tracking feature in Delft3D. Dr Peter Freewater (GCC) identified fifteen saltmarsh locations for investigation. Figures 9.3a to 9.3f present the drogue tracks for larvae released in Paddy's Channel at high tide on the higher high tide of the day. Figure 9.3a is near the first release (10:00 27/2/2006), and the subsequent plots (Figures 9.3b to 9.3f) are the completed tracks at successive higher high tides. Note, a second set of drogues was released at approximately 10:00 28/2/2006. After 5 successive tide cycles (Figure 9.3f) the drogues have moved between the Gosford Broadwater and Broken Bay, but not into Woy Woy Bay and the Kincumber Broadwater, for example. At many locations, the drogues indicated that the larvae are dispersed significant distances from the saltmarsh at which they were spawned (Figures 9.4 to 9.10). However, it was also noted that drogues at other locations (e.g. Correa Bay and Fagans Bay) did not move very far at all (Figures 9.10 and 9.11). This suggested limits to connectivity between particular habitats that implied consideration of a raft of new management issues. Dr Freewater and Cardno Lawson Treloar undertook further hydraulic processes investigations to address these issues (see 9.5 Larval Dispersion).

9.2.2 Fish Larvae

Drogue simulations were also used to simulate the transport of fish larvae (Figures 9.12 to 9.14). This was undertaken to support the research of Dr Iain Suthers (UNSW) into larval recruitment patterns (see also 9.1 Maximum Shear Index and 9.3 Tidal Volumes).

9.3 Tidal Volumes

Following discussions between Dr Iain Suthers (UNSW) and Cardno Lawson Treloar, tidal volumes that pass the eight sites of interest identified in Figure 9.2 were determined for ecological and MSI analyses. These volumes were determined for a spring tide on the 9th March 2004 from the same simulation as the MSI calculations (Section 9.1). Calculations were made across the appropriate channel transects between the channel centre and the 1m depth contour (at datum AHD) at the eight nominated locations; time series are presented in Figures 9.15 and 9.16. These results show a significantly larger flood volume (positive discharge) compared to the ebb volume. Total flood volumes across these site transects are summarised in Table 9.1. This outcome also demonstrates that flood and ebb flow paths are different because the durations of flood and ebb flow are similar, see Figure 5.4, for example. Any diurnal difference in tide range also affects the flood/ebb discharge relationship in the short term. Also, during periods of spring tides water levels within the estuary are pumped up, slightly, and drain during periods of neap tides.

Table 9.1: Spring Tidal Volumes (m^3)

	Flood	Ebb
Location 1	5 281 508	3 773 406
Location 2	1 335 334	652 798
Location 3	2 275 890	1 501 083
Location 4	8 556 024	9 914 911
Location 5	7 543 207	5 690 056
Location 6	7 844 767	7 621 086
Location 7	6 287 600	6 169 357
Location 8	3 746 354	2 917 732

9.4 Wave Induced Near Bed Velocities

Investigations into seabed shear forces caused by waves are described in detail in section 7. 5. These investigations were also used to support research into processes that influence patterns of distribution and abundance of macrobenthic invertebrate community assemblages. Discussions amongst Dr Peter Freewater (GCC), Cardno Lawson Treloar and Dr William Gladstone of the University of Newcastle led to the inclusion of outcomes of these investigations with other environmental variables to investigate the relative influence wave induced near bed velocities have on macrobenthic invertebrate community assemblages. It was demonstrated that their influence was highly significant.

9.5 Larval Dispersion

The spawning crab larvae from fifteen saltmarsh locations within Brisbane Water was simulated using the advection-dispersal mode of the Delft3D hydraulic model. This was done to investigate ecological patterns of connectivity between saltmarshes and other estuarine habitats as well as opportunities for larvae to be exported out of Brisbane Water for potential recruitment to other locations.

The model was based on the assumption that approximately 2000 larvae m^{-2} was released during the ebbing of three consecutive diurnal spring high tides between the 27th February 2006 and the 1st March 2006. The model included a simple decay algorithm to account for approximately 50% loss of larvae per day from fish predation. Larvae were introduced into the model as a source point. To provide a realistic spatial description of the larvae a total of 2000 source points were specified over the fifteen saltmarsh locations. Discharge rates for each source point were individually specified based on the geometry of the computational cell of the discharge location. Very low flow rates, less than $10^{-3}m^3s^{-1}$, were applied to eliminate any influence on the hydrodynamic processes within the model.

The model was run for a two-week period to reflect the period that crabs spend as planktonic larvae before settling out of the water column as juveniles. Figures 9.11 to 9.15 present larvae concentrations at 12 hour intervals over a 48-hour period. Figure 9.11 (Hour 0) corresponds to the approximate end of the final larvae release period (1st March 2006) and represents the highest concentration of larvae during the simulation period. Note that a log scale is applied to Figures 9.11 to 9.15. The results indicate that advection and dispersion via tidal currents alone provides an adequate vehicle for transporting larvae throughout the estuary and that some are exported from the system into Broken Bay (Figures 9.11 to 9.15).

10. CONCLUDING REMARKS

The purpose of this report has been to describe a range of hydraulic processes that are important to the understanding of water quality, sedimentary and ecological processes within Brisbane Water. The results of this work have been applied by other Process Study participants to assist in their understanding of them and the underlying hydrodynamic forces that affect the processes.

Sedimentary and Water Quality matters are discussed in Appendices D and E of this report series, respectively.

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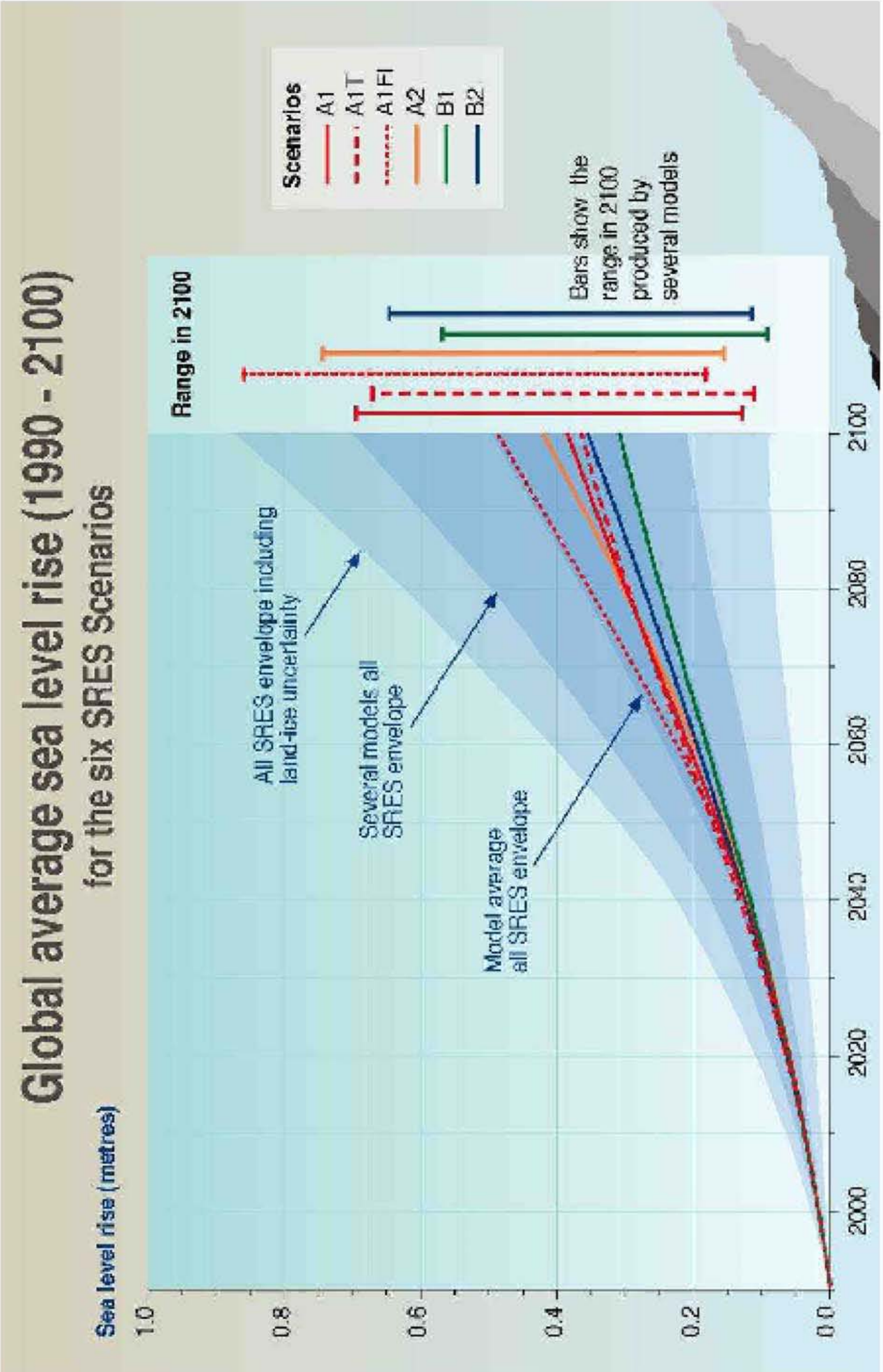
FIGURES



Global average sea level rise (1990 - 2100)
for the six SRES Scenarios
Sea level rise (metres)
1.0
0.8
0.6
0.4
0.2
0.0
2000
2020
2040
2060
2080
2100
Range in 2100
Scenarios
A1
A1T
A1FI
A2
B1
B2
Bars show the range in 2100 produced by several models
All SRES envelope including land-ice uncertainty
Several models all SRES envelope
Model average all SRES envelope

Figure 2.1

Brisbane Water Estuary Processes Study - Hydraulic Processes

HARD EDGE TREATMENT - GOSFORD ROCKWALL

Figure 2.2

Cardno Lawson Treloar

LJ2255/R2312 January 2007
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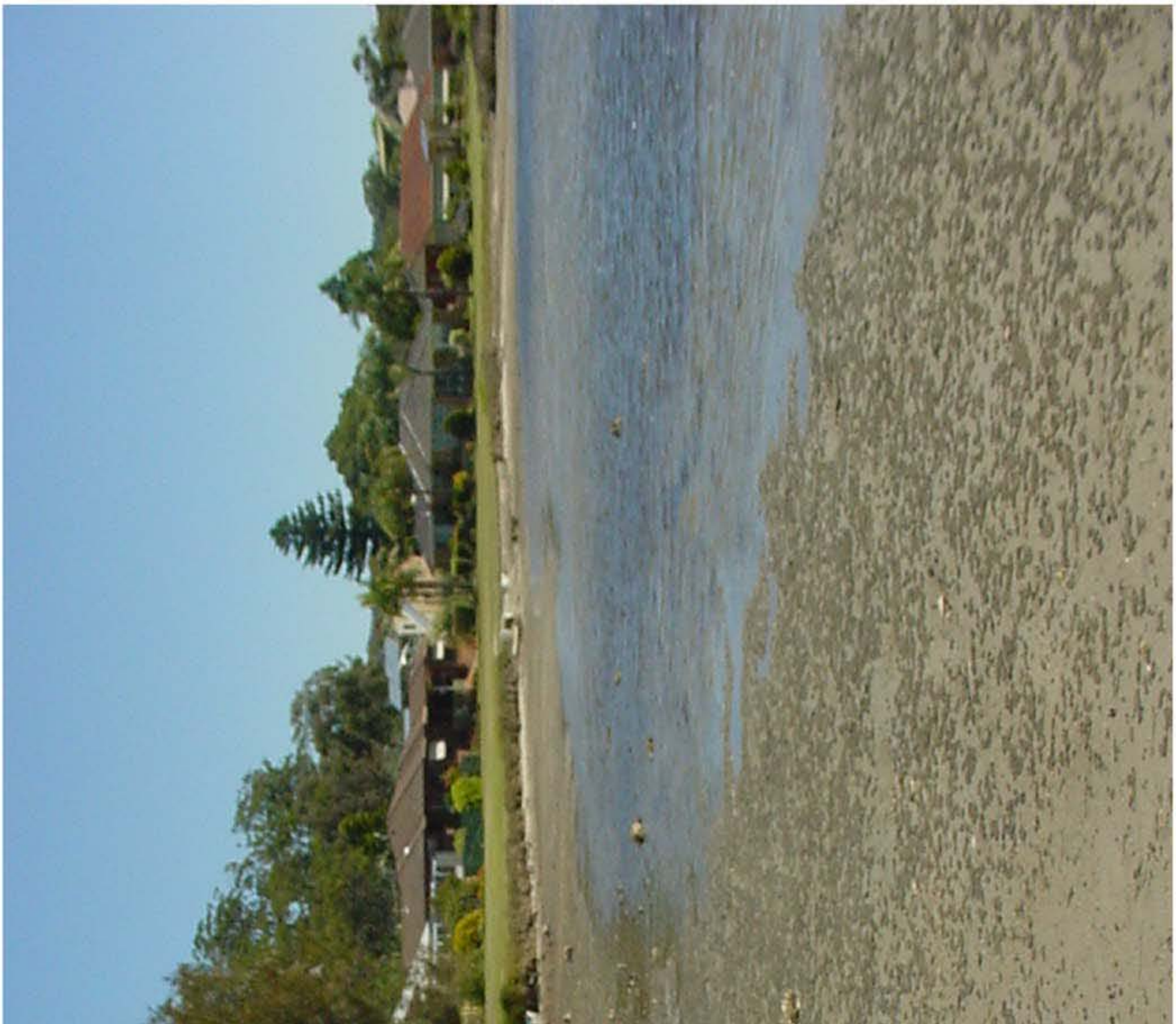

Cardno Lawson Treloar

LJ2255/R2312 January 2007
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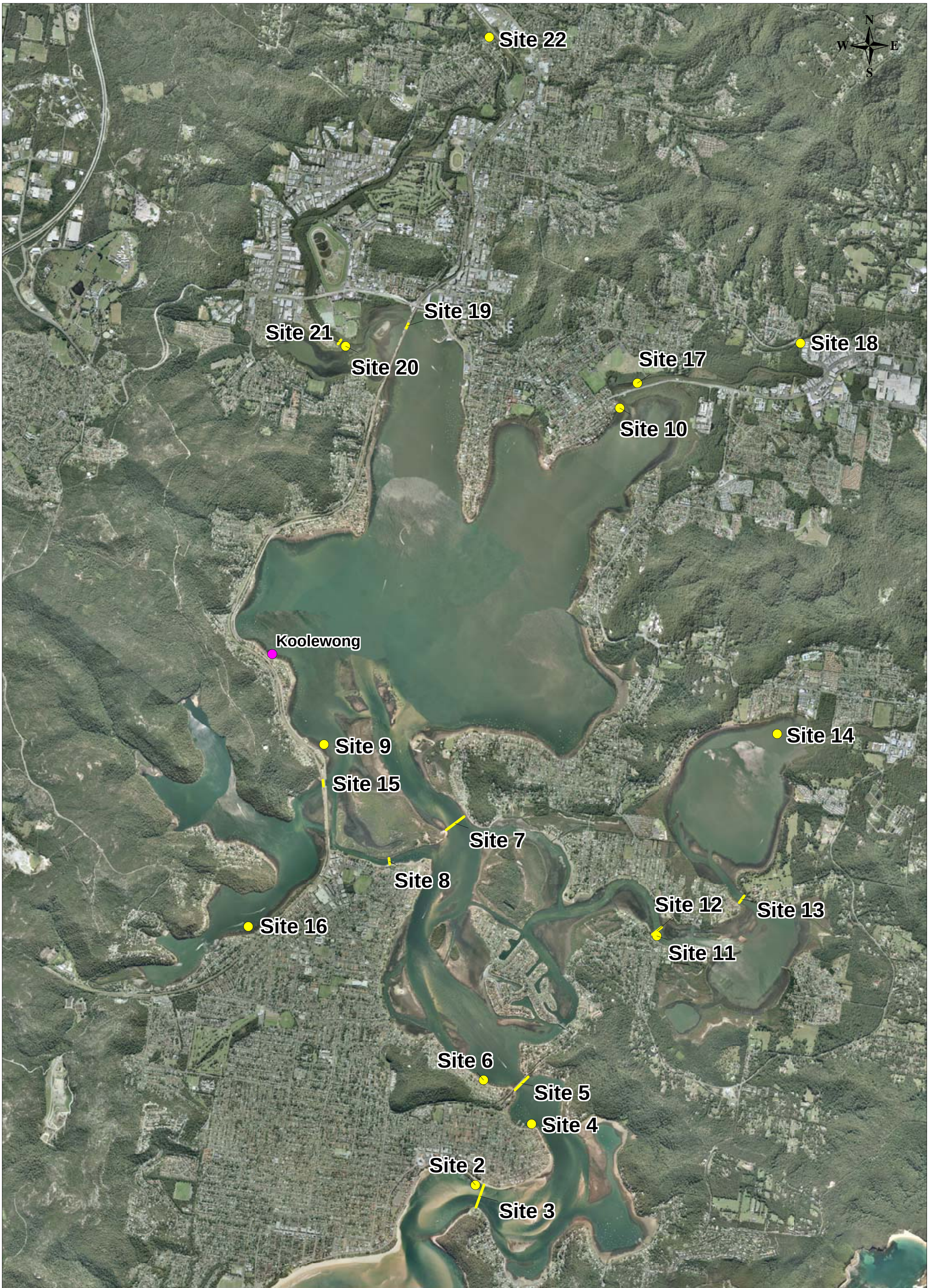
Brisbane Water Estuary Processes Study - Hydraulic Processes
FLAT INTER-TIDAL AREA - WOY WOY REGION

Figure 2.3



Cardno Lawson Treloar

Brisbane Water Estuary Processes Study

MHL DATA LOCATIONS

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Figure 3.1

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Brisbane Water Estuary Processes Study

OBSERVED AND SIMULATED WATER LEVELS (mAHD)
MARCH 1974 EVENT
Figure 3.2

LJ2255/R2312 January 2007
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Cardno Lawson Treloar

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SHORELINE SEDIMENT SAMPLE LOCATIONS

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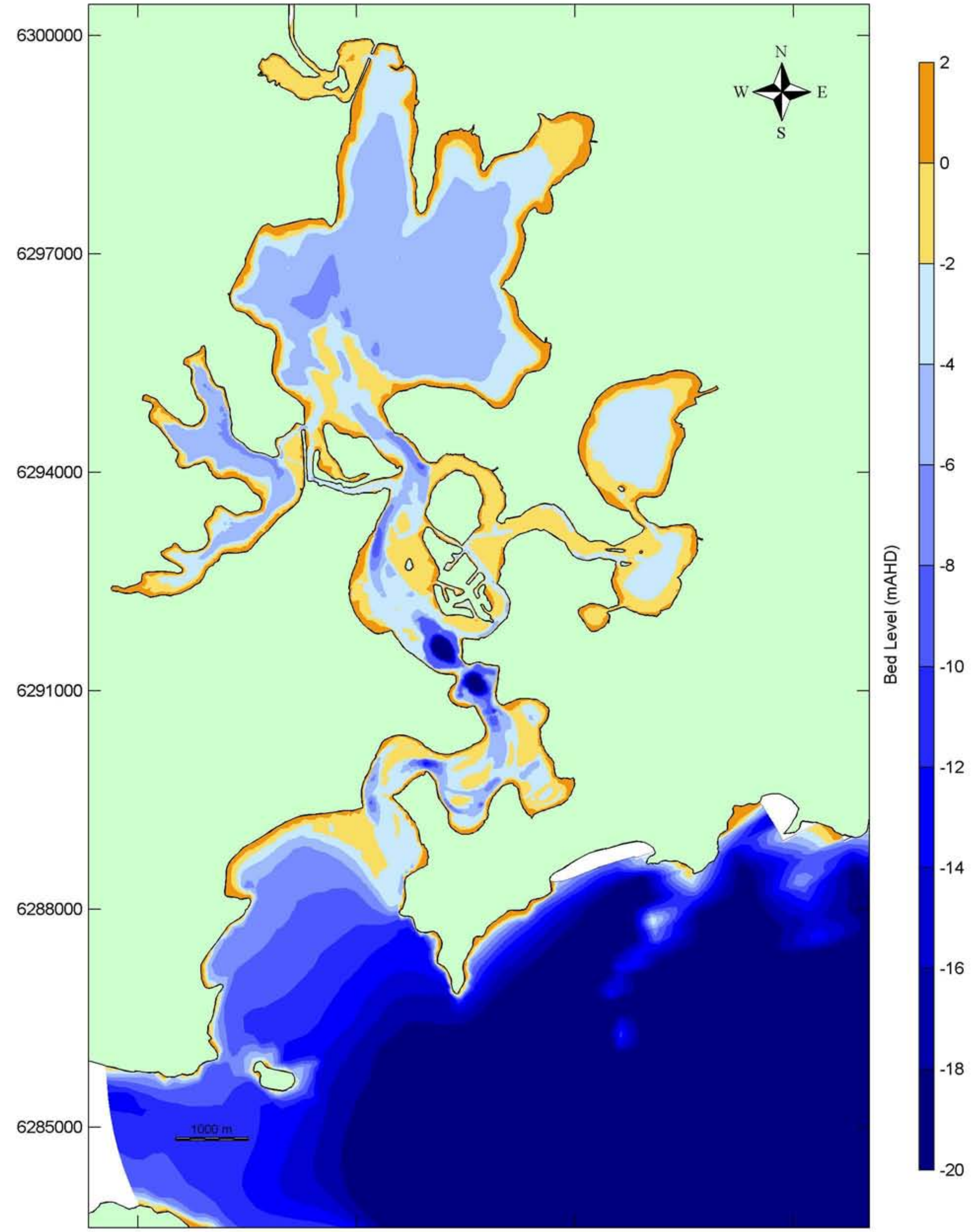
Figure 3.3



Cardno Lawson Treloar

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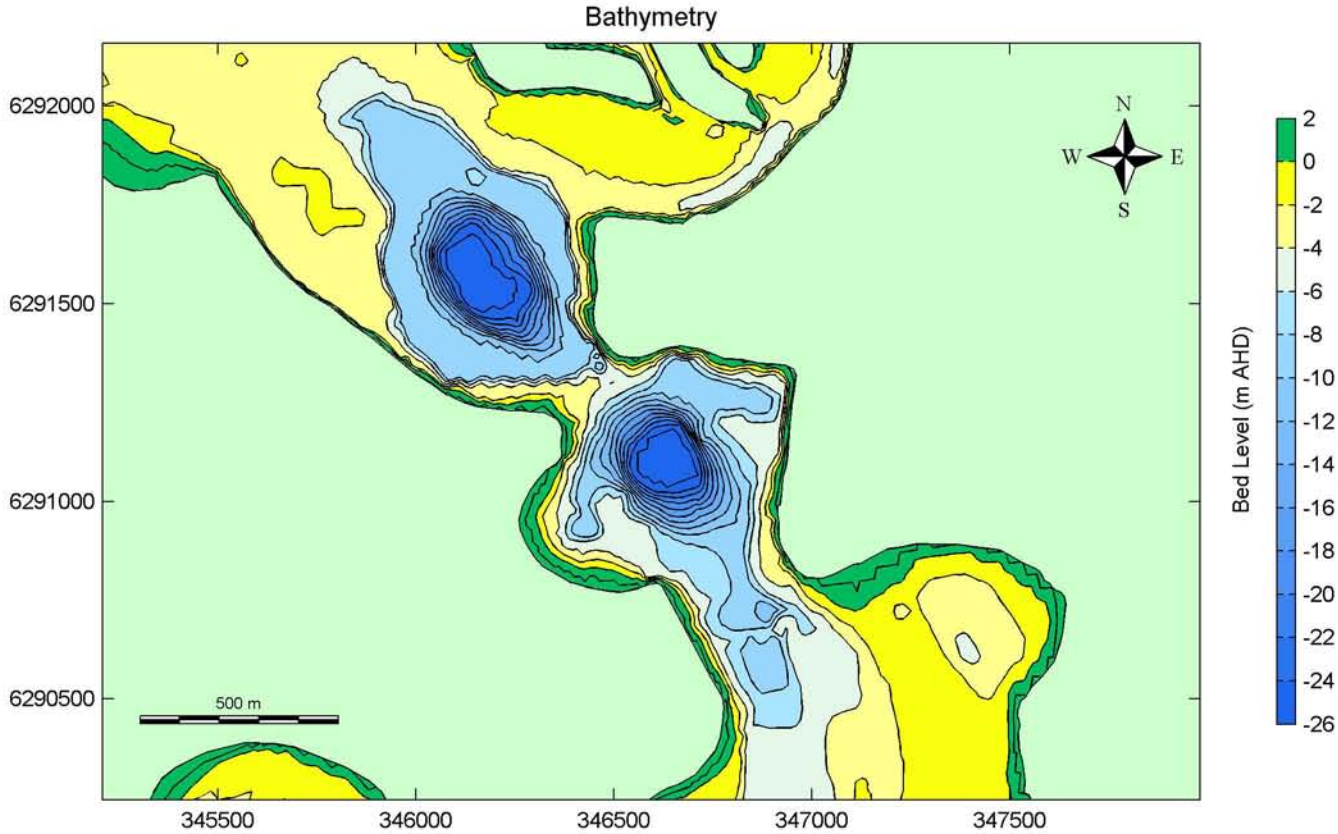
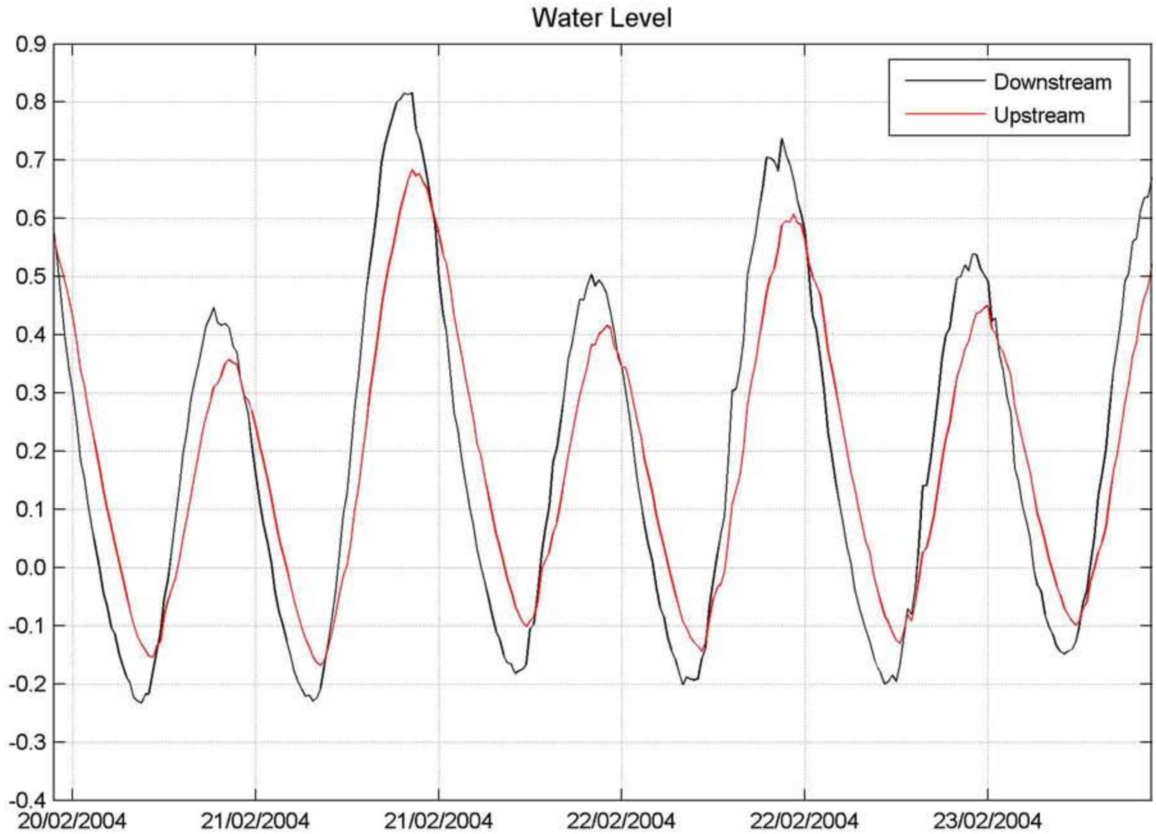
Brisbane Water Estuary Processes Study - Hydraulic Processes
DELFT3D MODEL

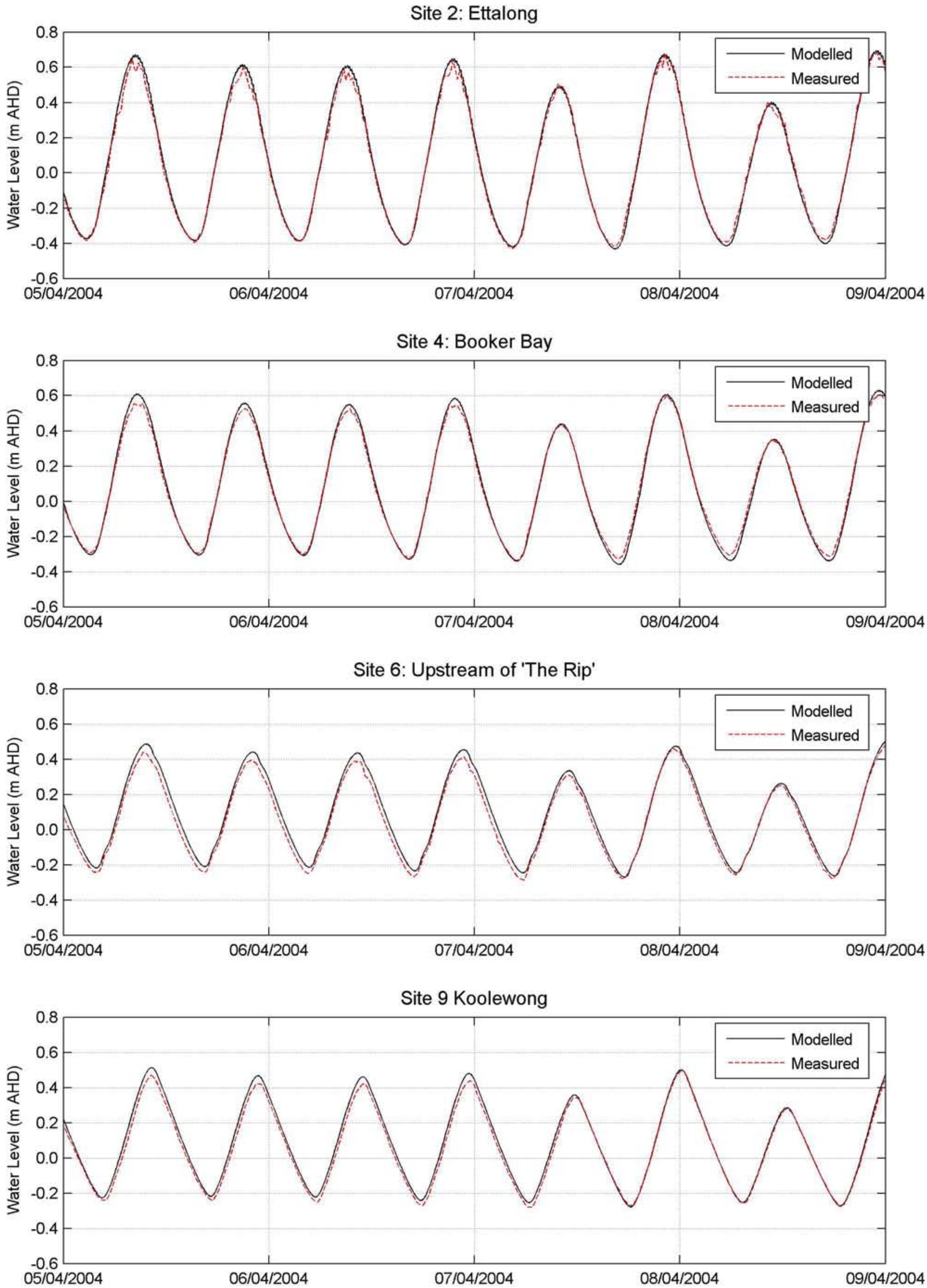
Figure 4.1





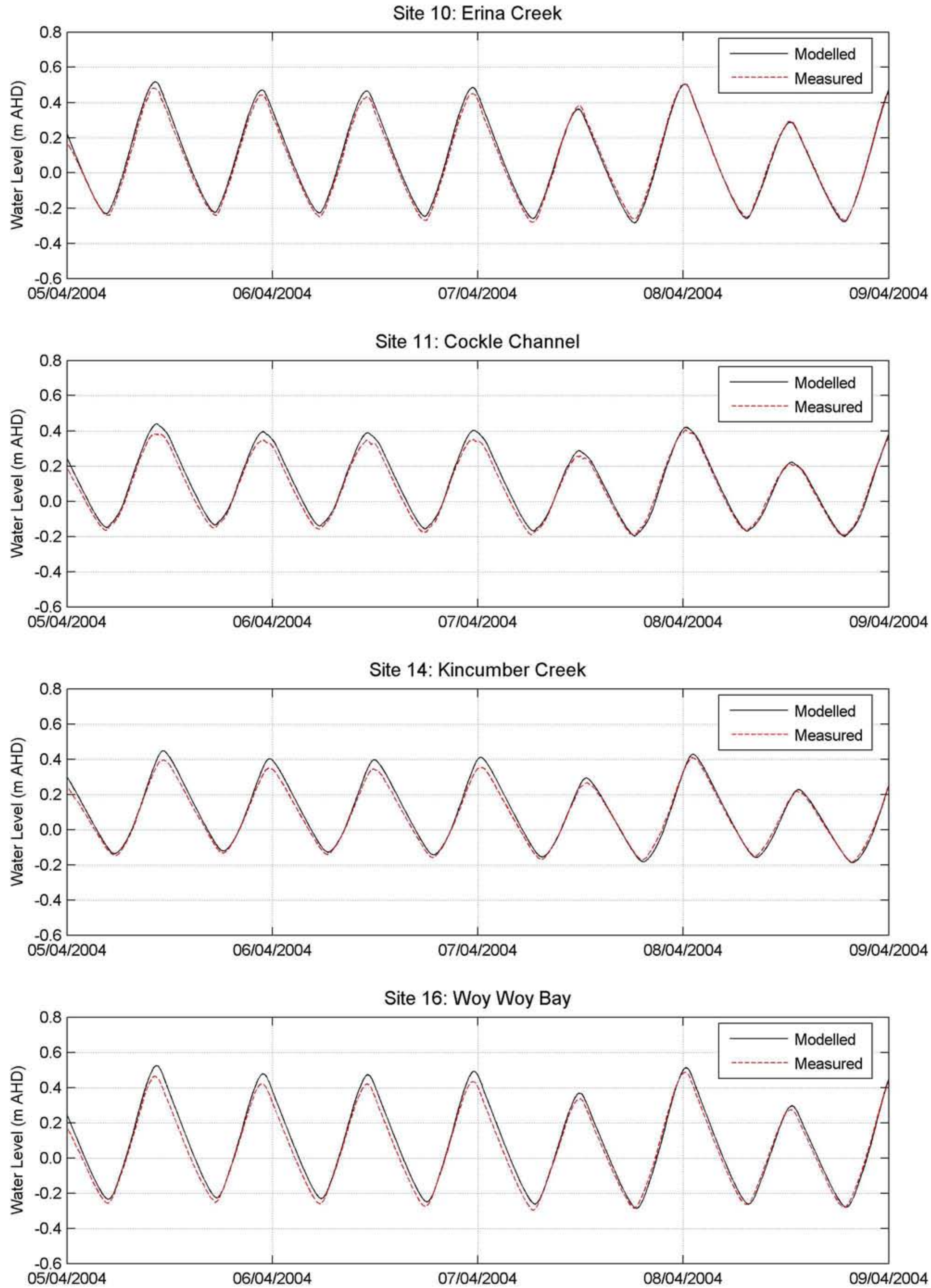
HYDRAULIC GRADIENT ACROSS 'THE RIP'

Figure 5.1



WATER LEVEL CALIBRATION

Figure 5.2

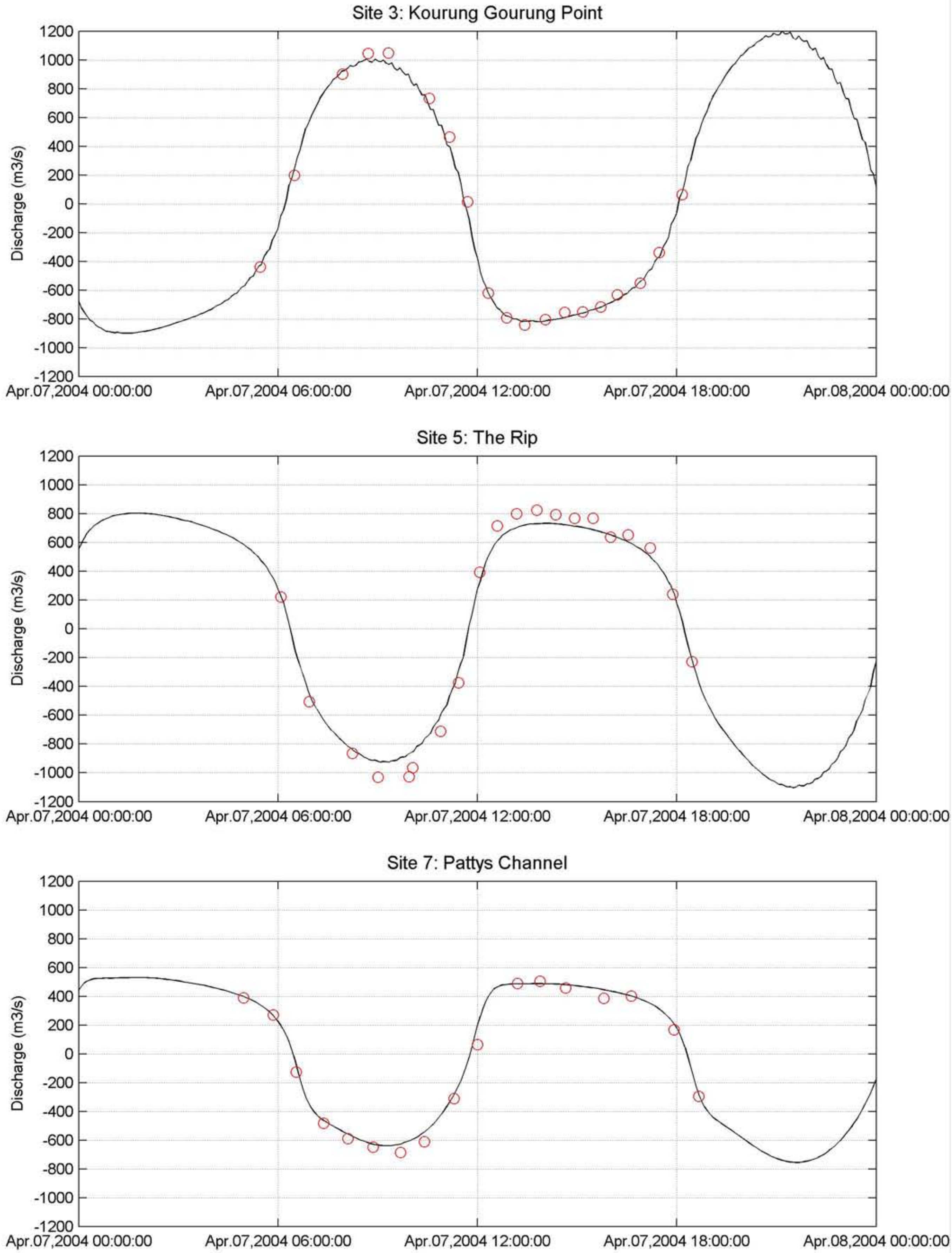


Cardno Lawson Treloar

Brisbane Water Estuary Processes Study - Hydraulic Processes

WATER LEVEL CALIBRATION

Figure 5.3



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Brisbane Water Estuary Processes Study - Hydraulic Processes

DISCHARGE CALIBRATION

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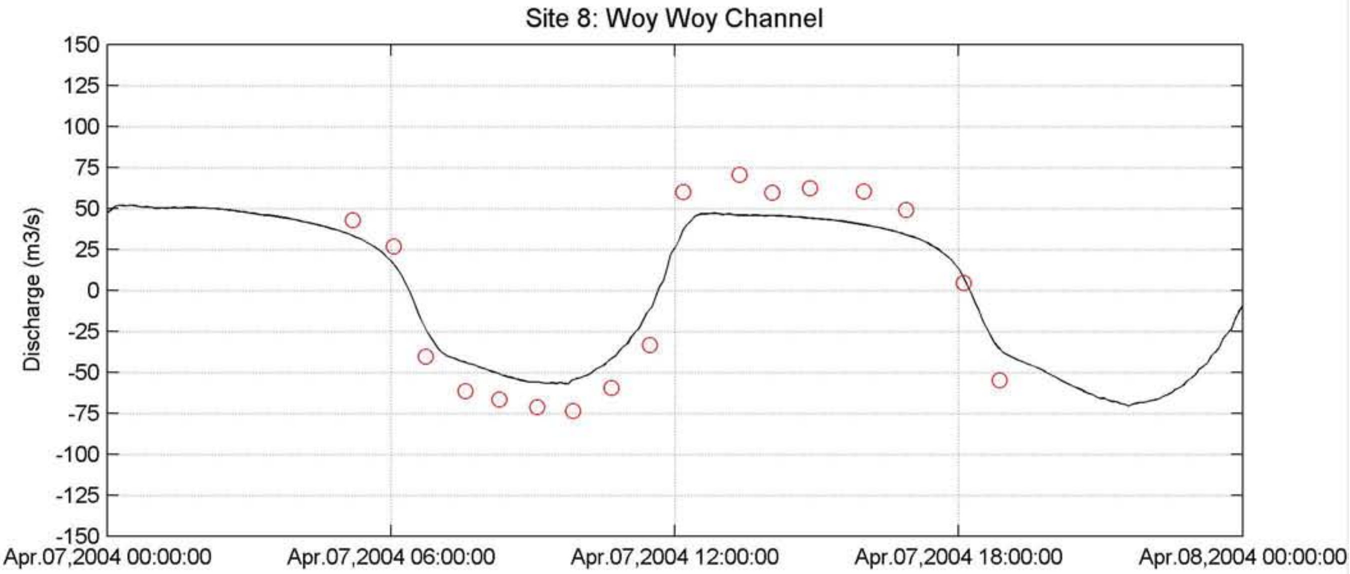
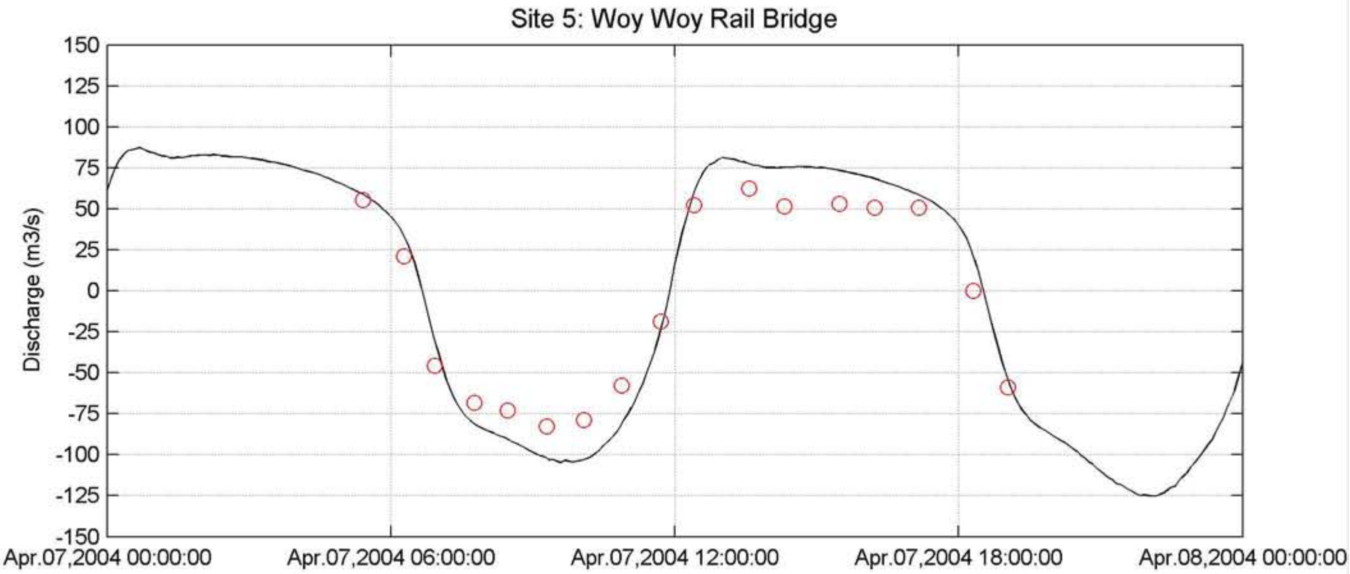
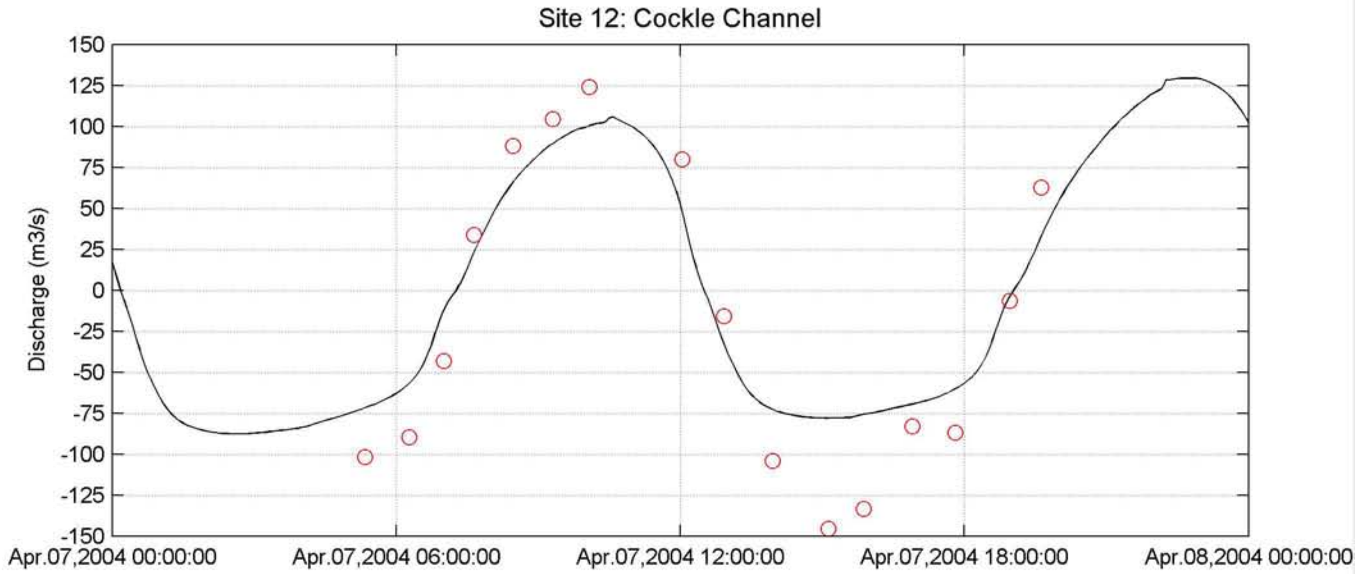
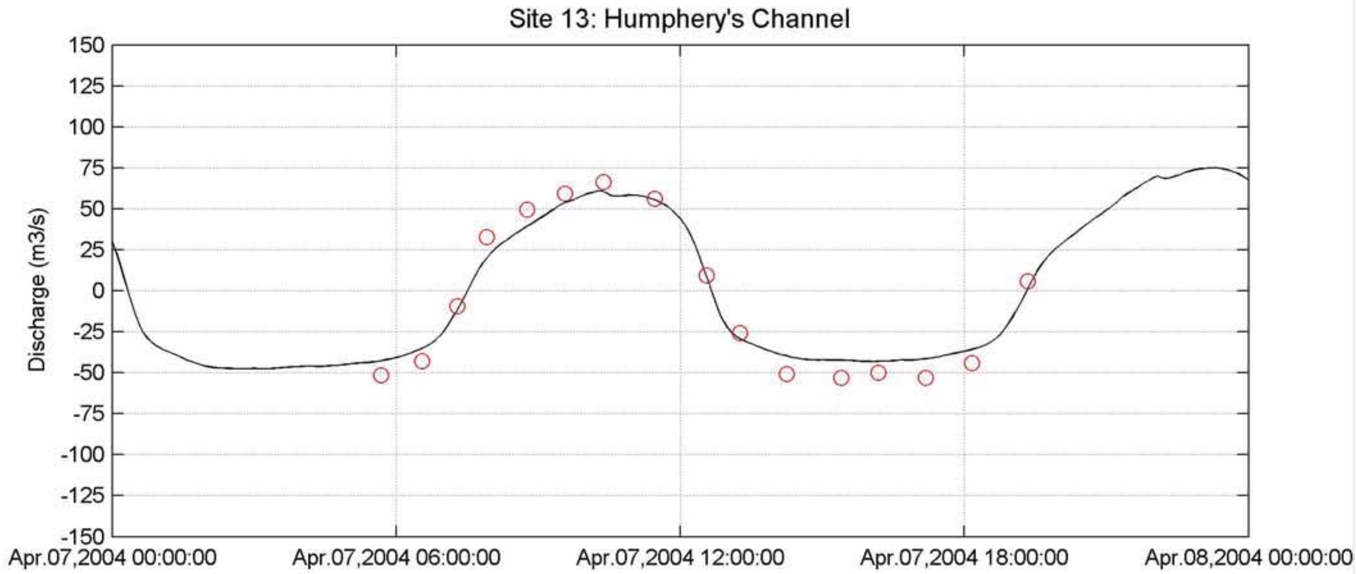
Figure 5.4


Site 8: Woy Woy Channel
Discharge (m3/s)
150
125
100
75
50
25
0
-25
-50
-75
-100
-125
-150
Apr.07,2004 00:00:00
Apr.07,2004 06:00:00
Apr.07,2004 12:00:00
Apr.07,2004 18:00:00
Apr.08,2004 00:00:00

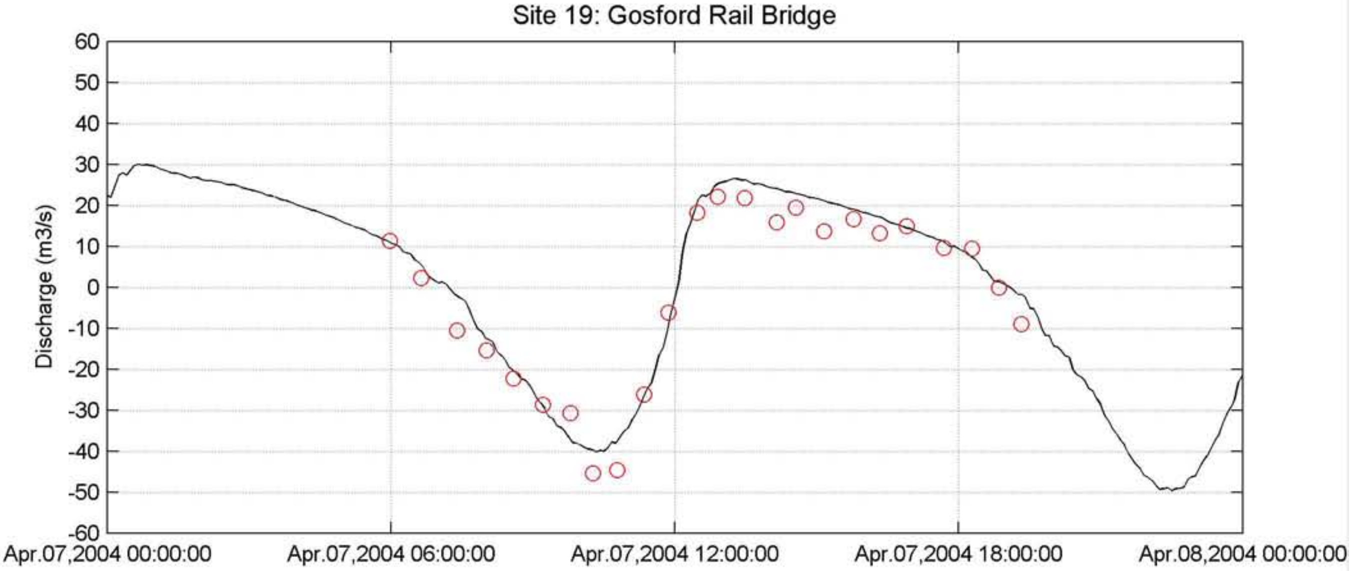

Site 5: Woy Woy Rail Bridge
Discharge (m3/s)
150
125
100
75
50
25
0
-25
-50
-75
-100
-125
-150
Apr.07,2004 00:00:00
Apr.07,2004 06:00:00
Apr.07,2004 12:00:00
Apr.07,2004 18:00:00
Apr.08,2004 00:00:00

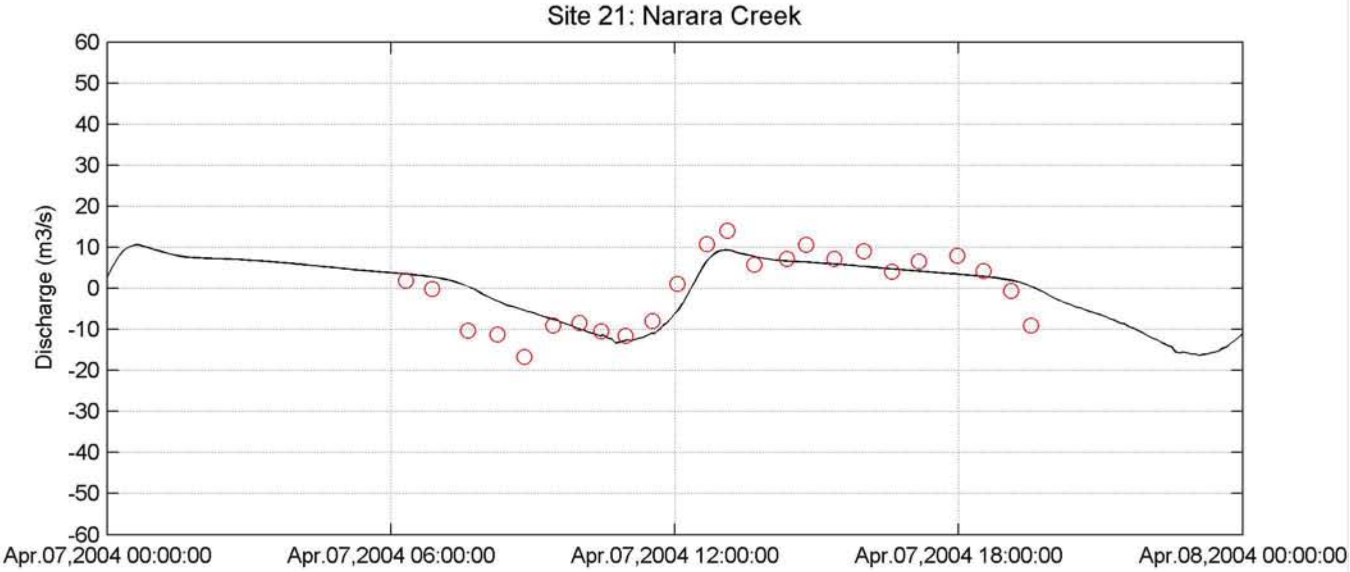




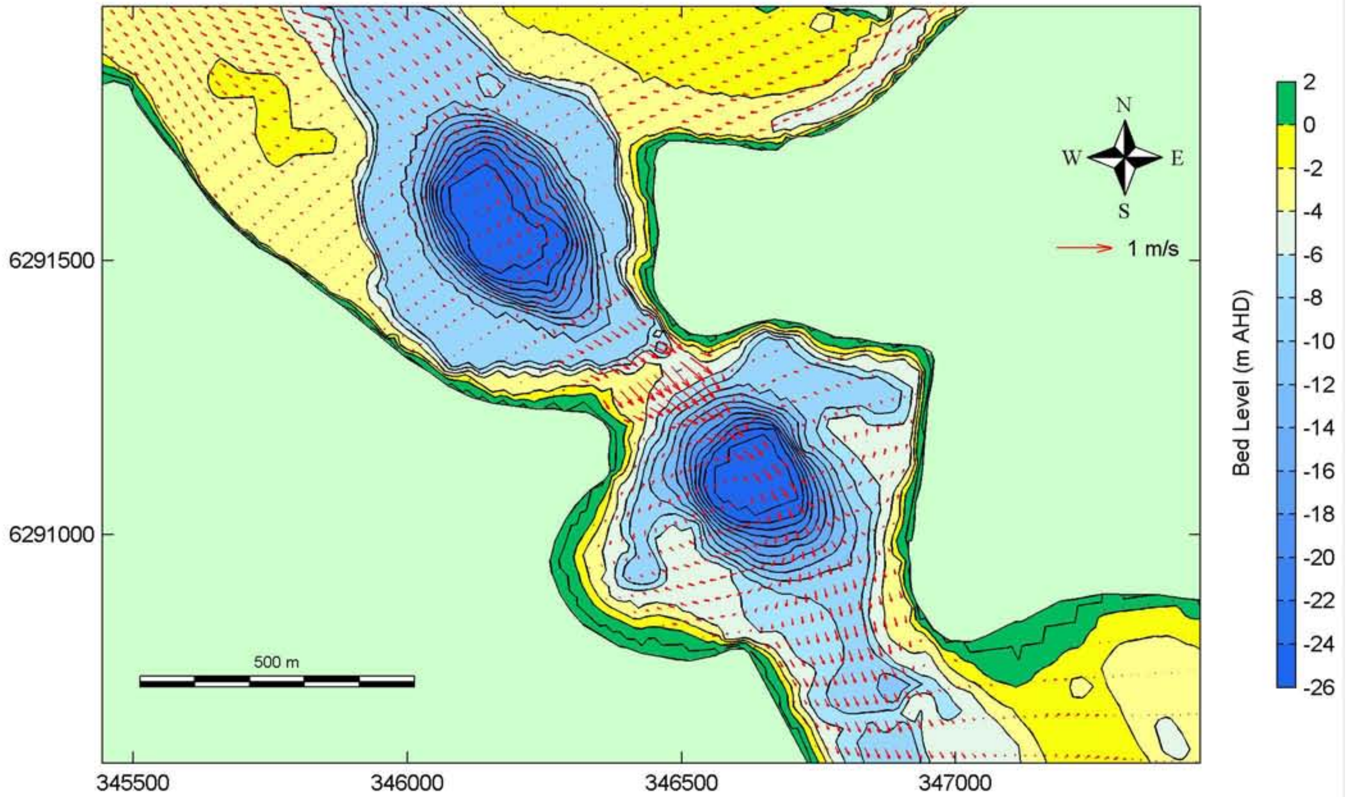
DISCHARGE CALIBRATION

Figure 5.6

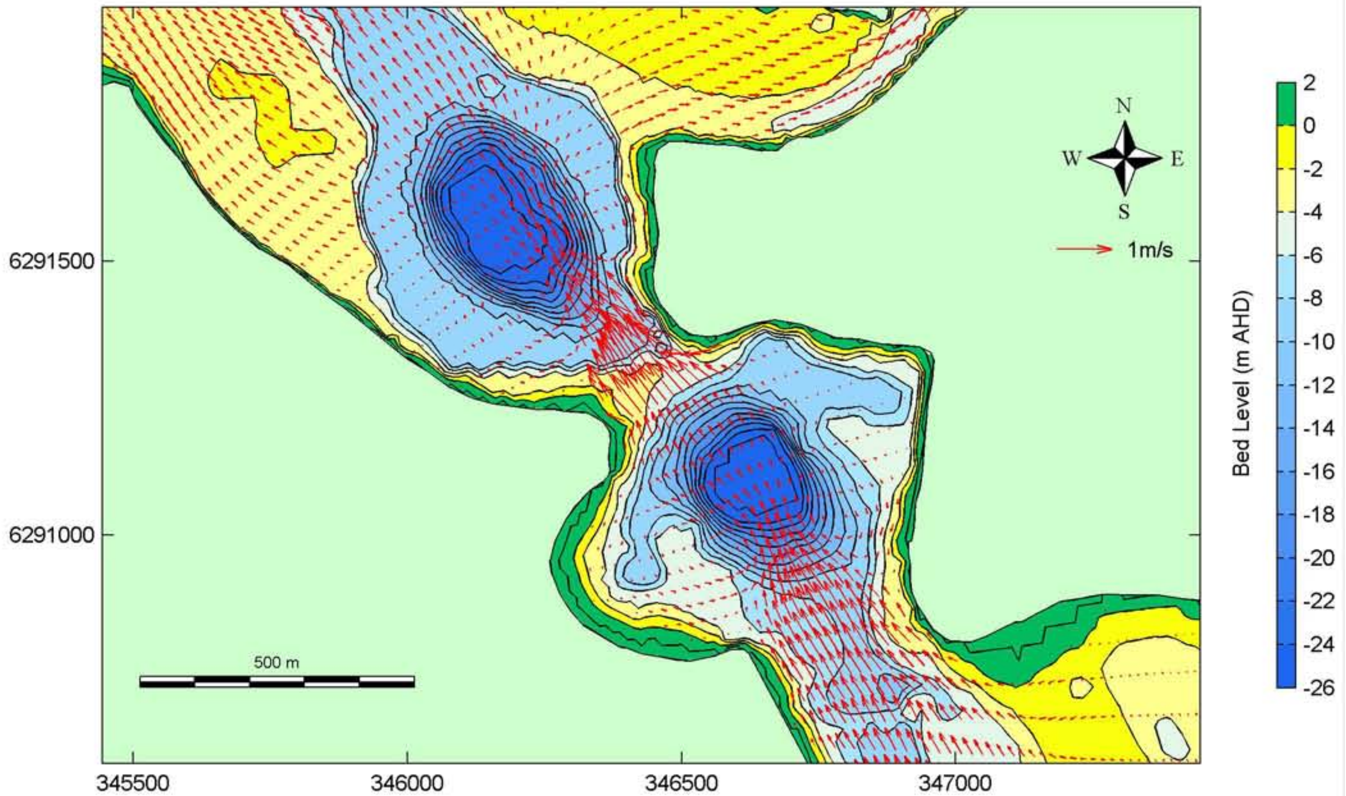

Site 19: Gosford Rail Bridge
Discharge (m3/s)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Apr.07,2004 00:00:00
Apr.07,2004 06:00:00
Apr.07,2004 12:00:00
Apr.07,2004 18:00:00
Apr.08,2004 00:00:00


Site 21: Narara Creek
Discharge (m3/s)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Apr.07,2004 00:00:00
Apr.07,2004 06:00:00
Apr.07,2004 12:00:00
Apr.07,2004 18:00:00
Apr.08,2004 00:00:00

Slack Water 06:00 07/04/2004



Flood Tide 08:00 07/04/2004



Cardno Lawson Treloar

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL CURRENTS - THE RIP

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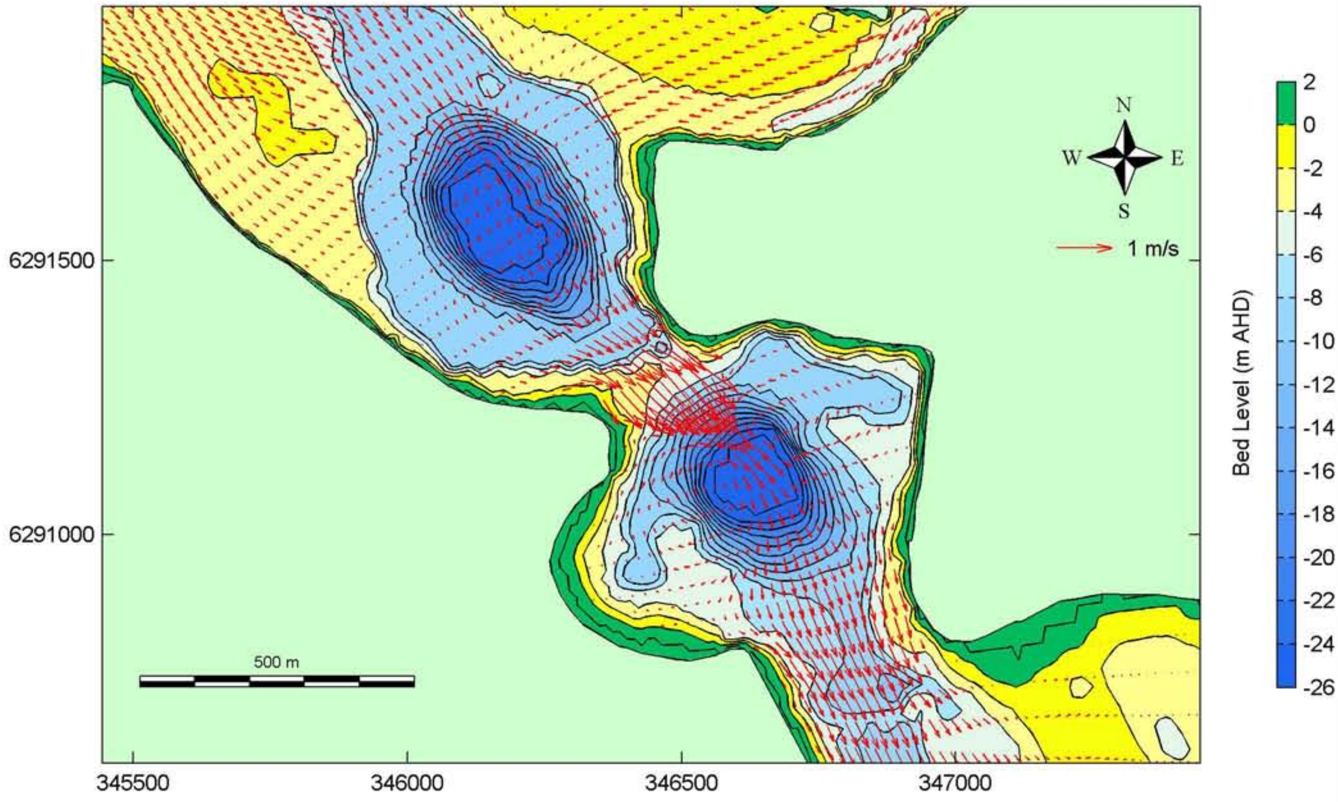
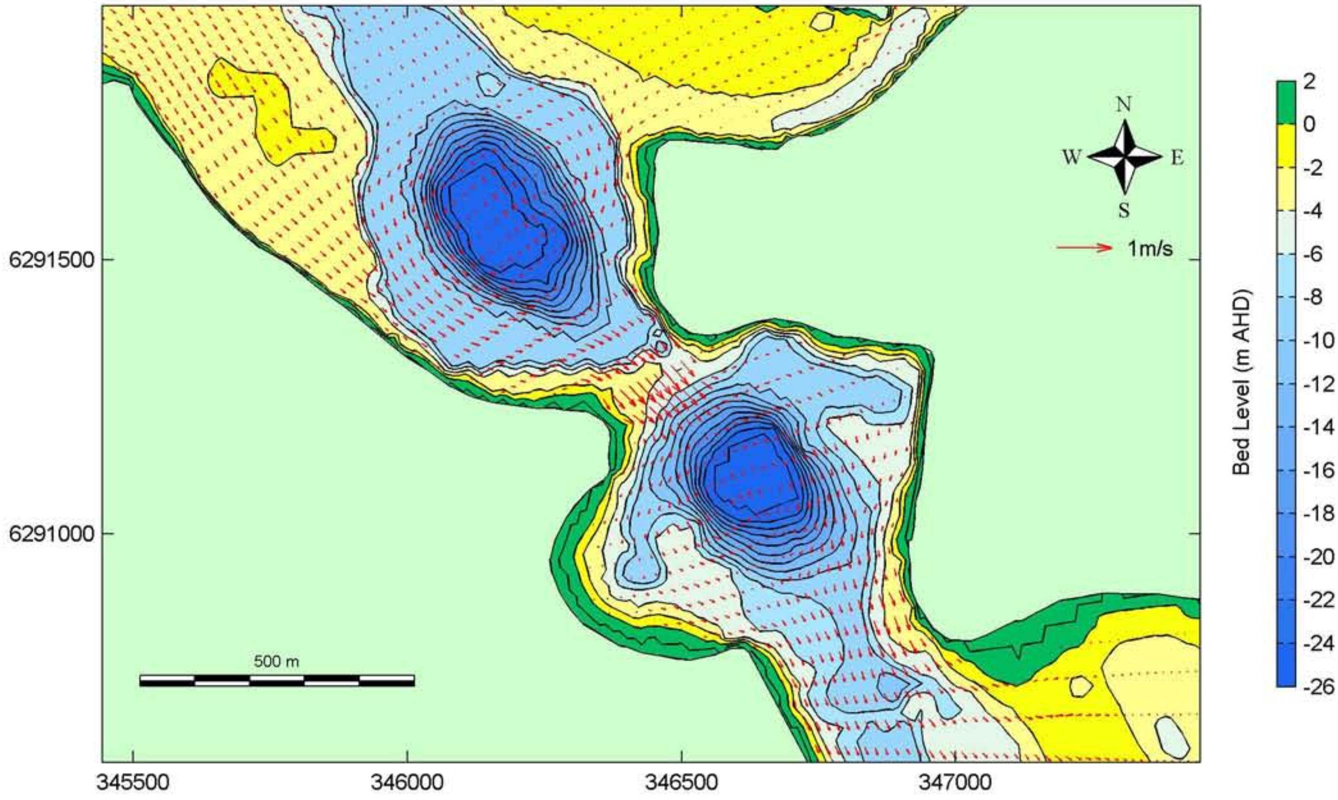
Figure 5.8

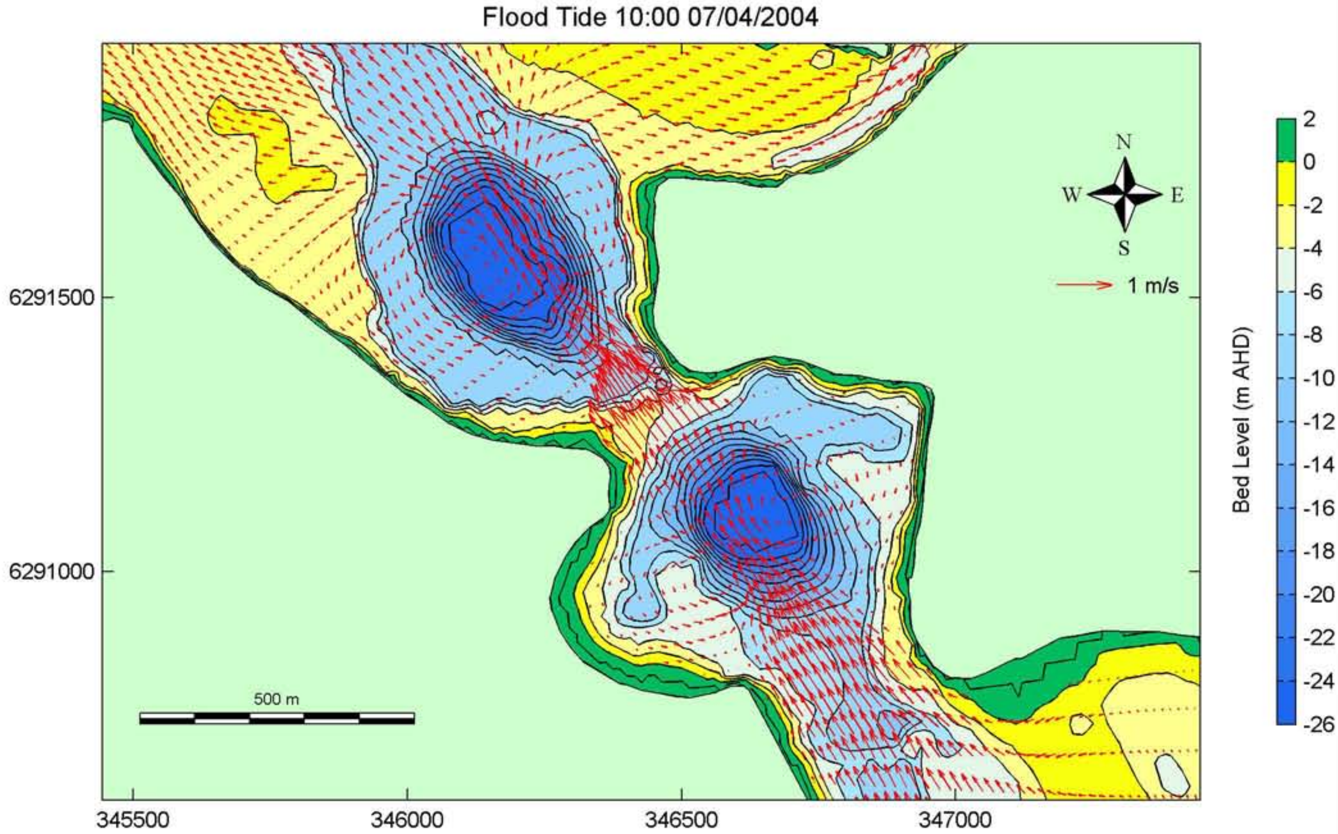
Ebb Tide 14:00 07/04/2004

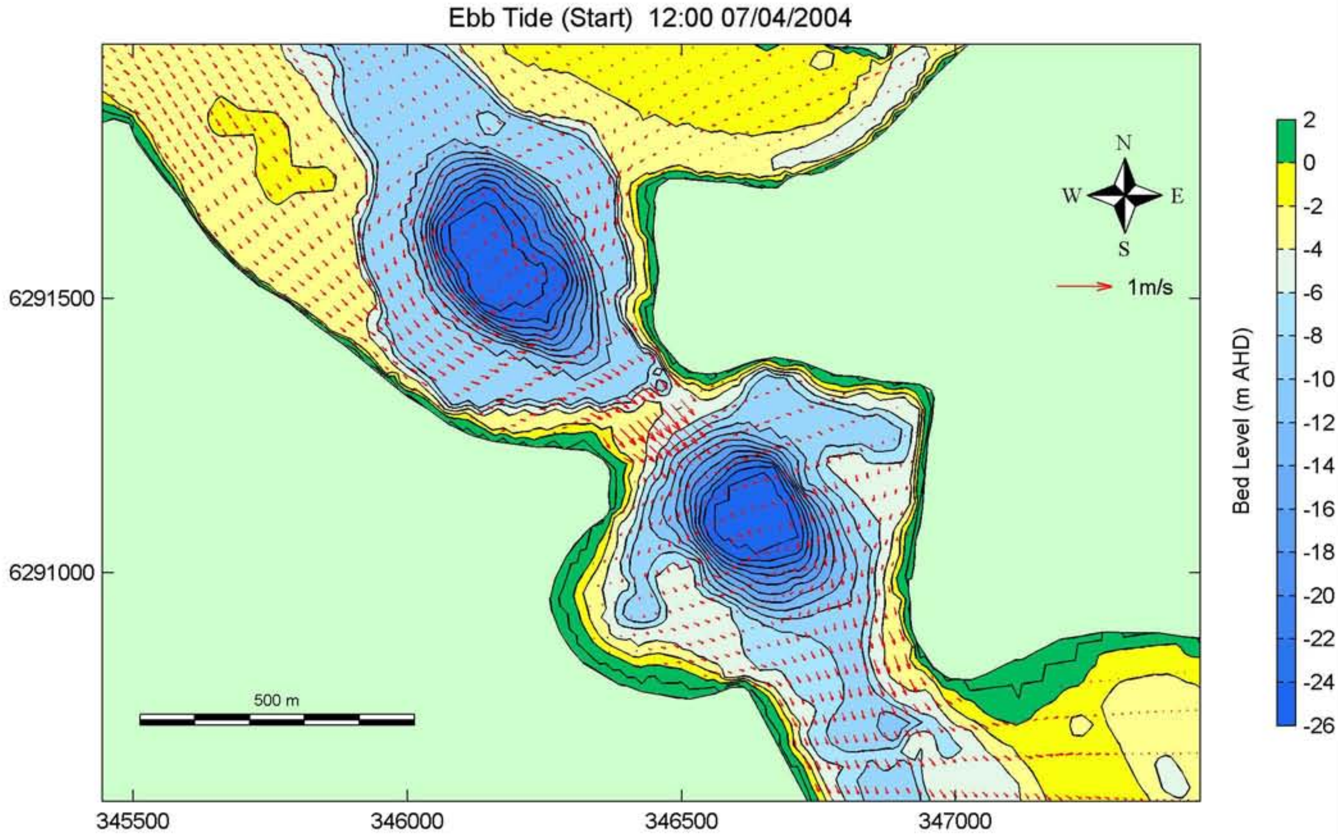


Ebb Tide (Start) 12:00 07/04/2004



TIDAL CURRENTS - THE RIP
DEPTH-AVERAGED
Figure 5.10





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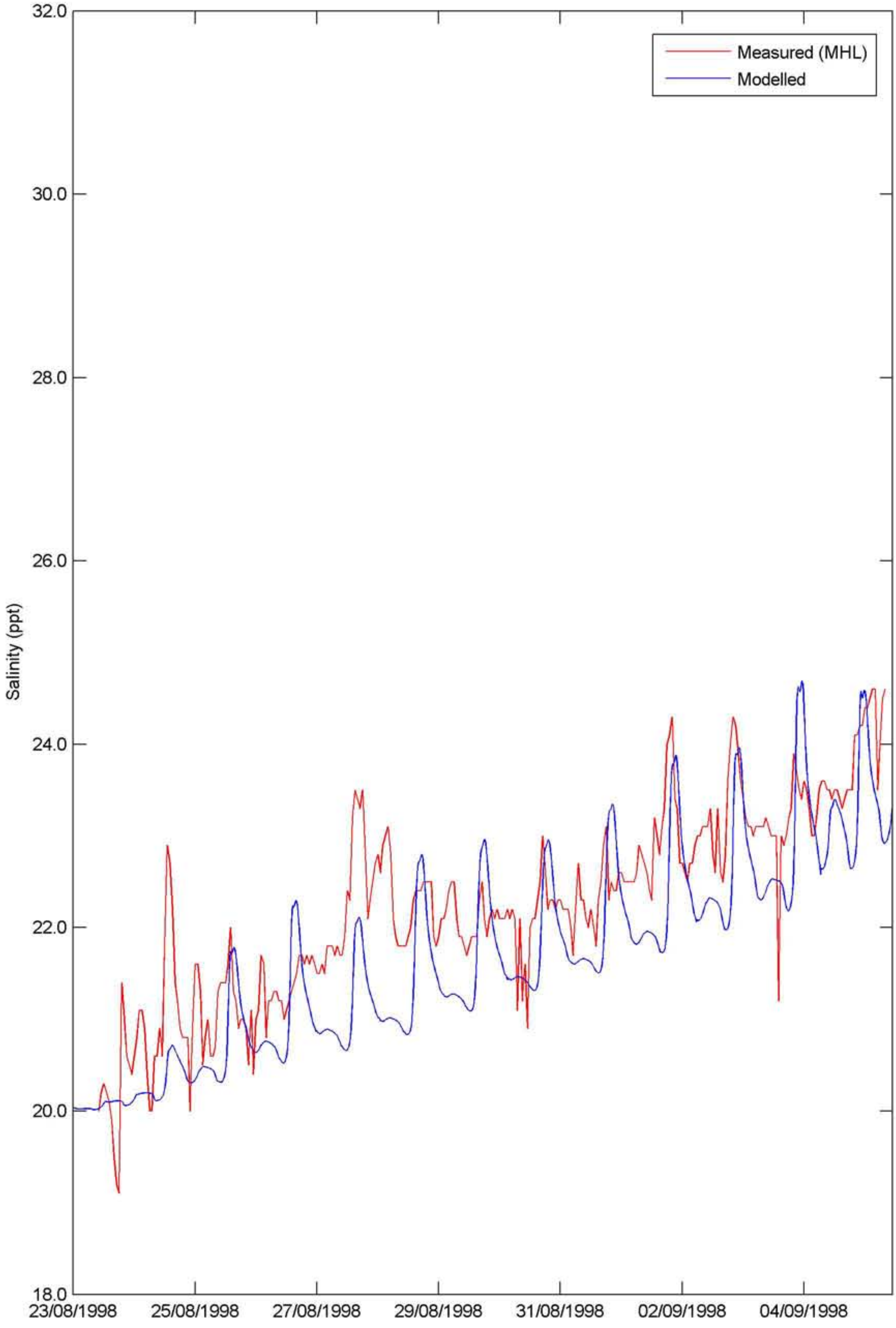
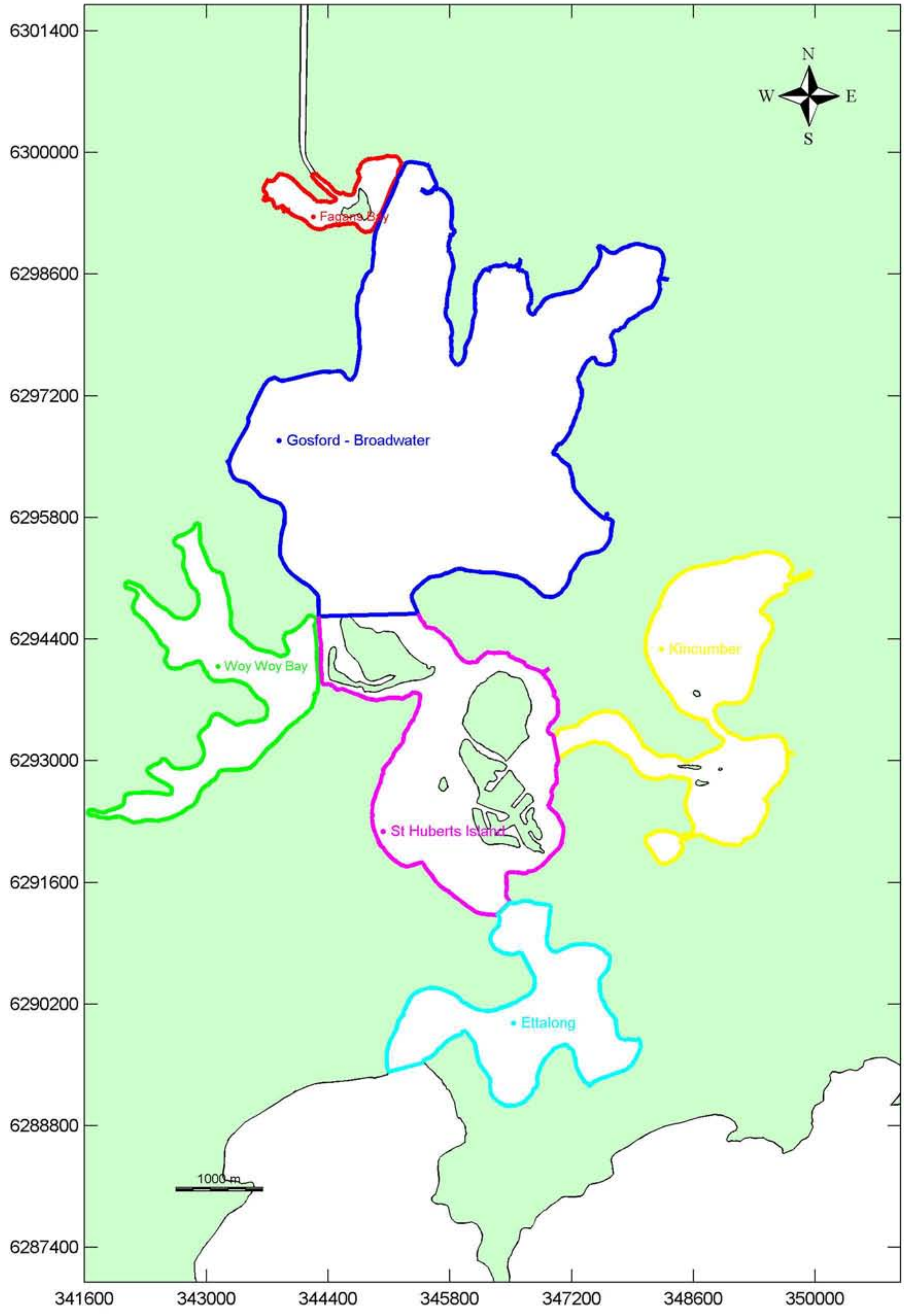
Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - THE RIP
DEPTH-AVERAGED
Figure 5.9

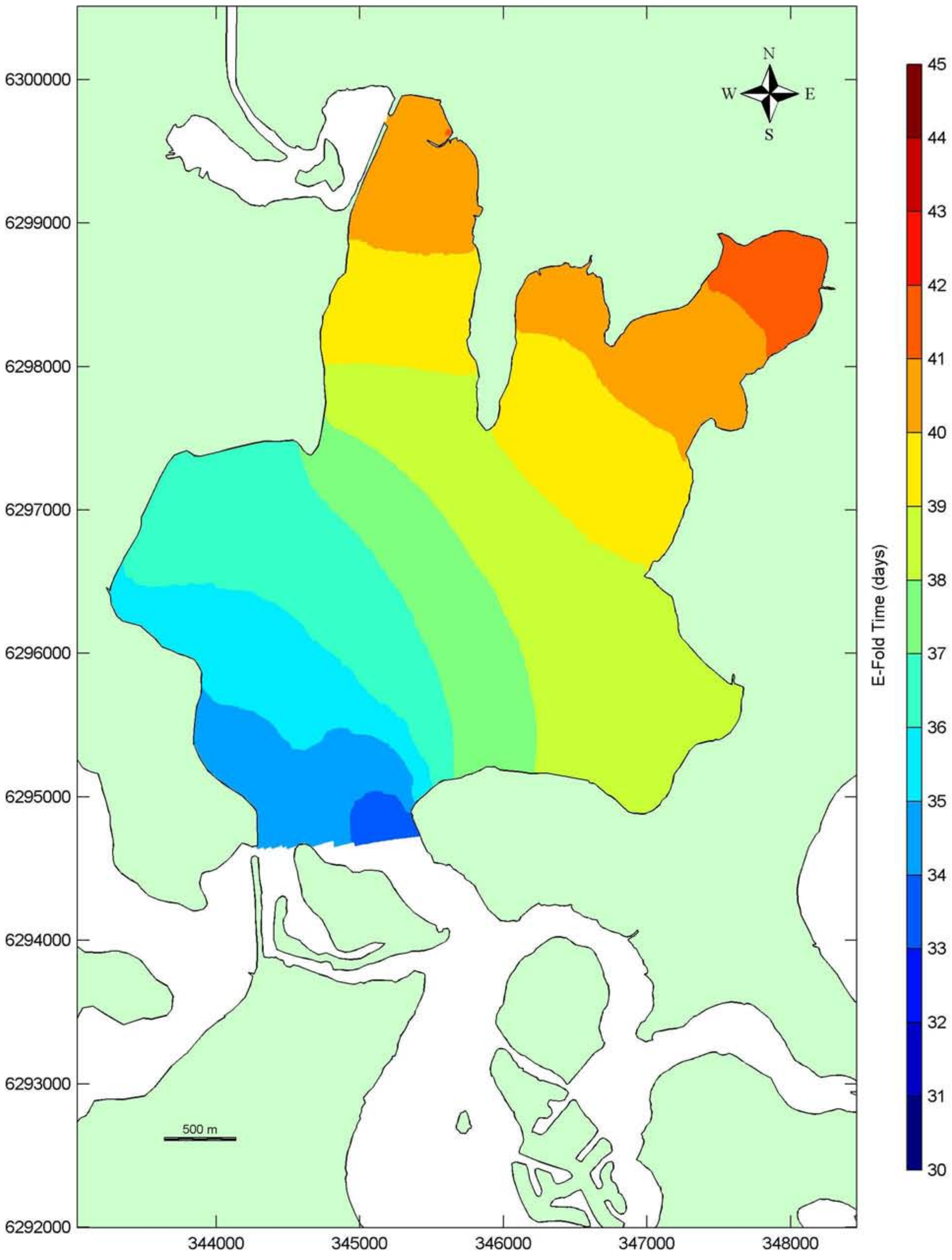


Brisbane Water Estuary Processes Study - Hydraulic Processes
MODELLED AND MEASURED SALINITY
KOOLEWONG
Figure 5.11



Brisbane Water Estuary Processes Study - Hydraulic Processes
EXTENT OF FLUSHING MODELS

Figure 6.1



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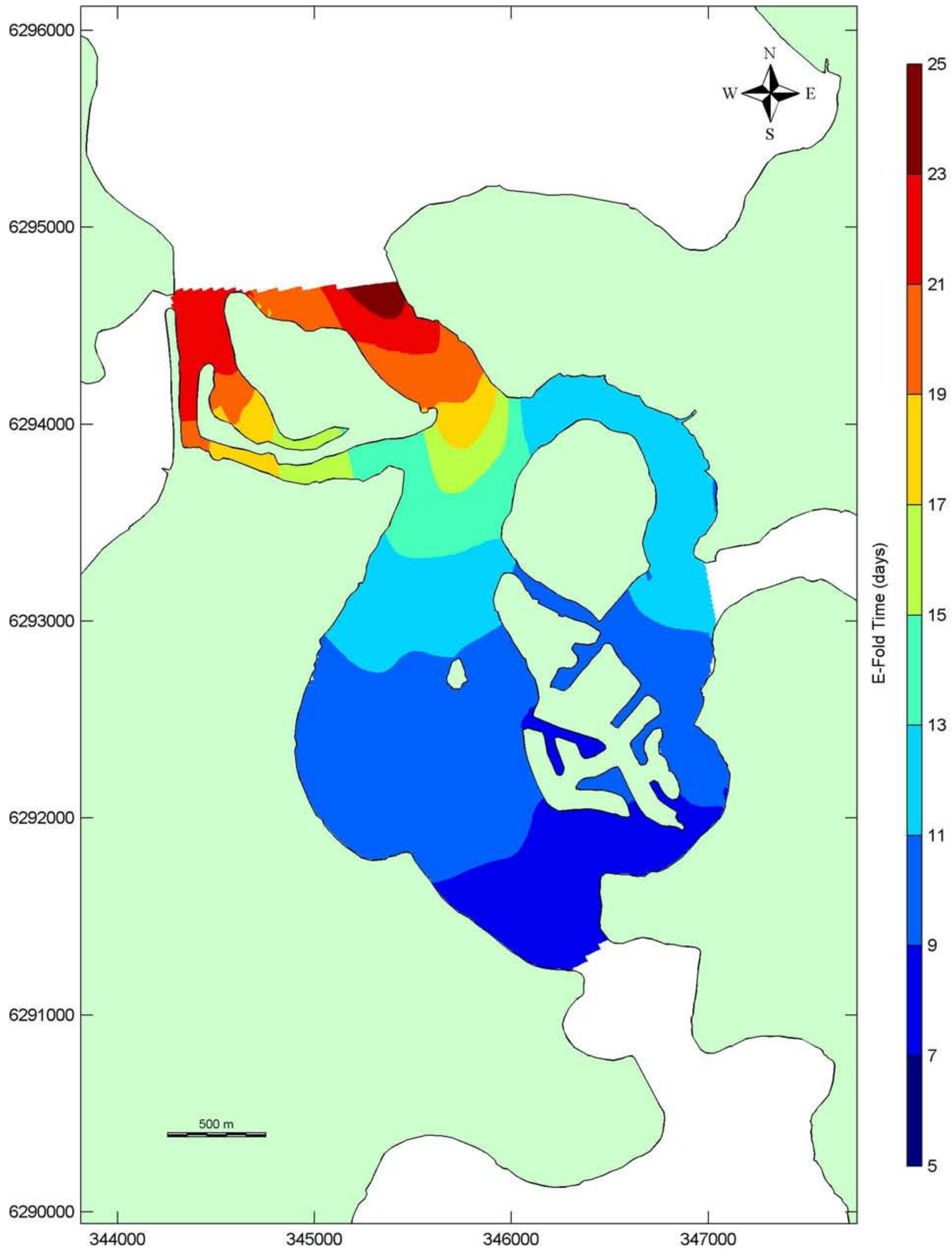
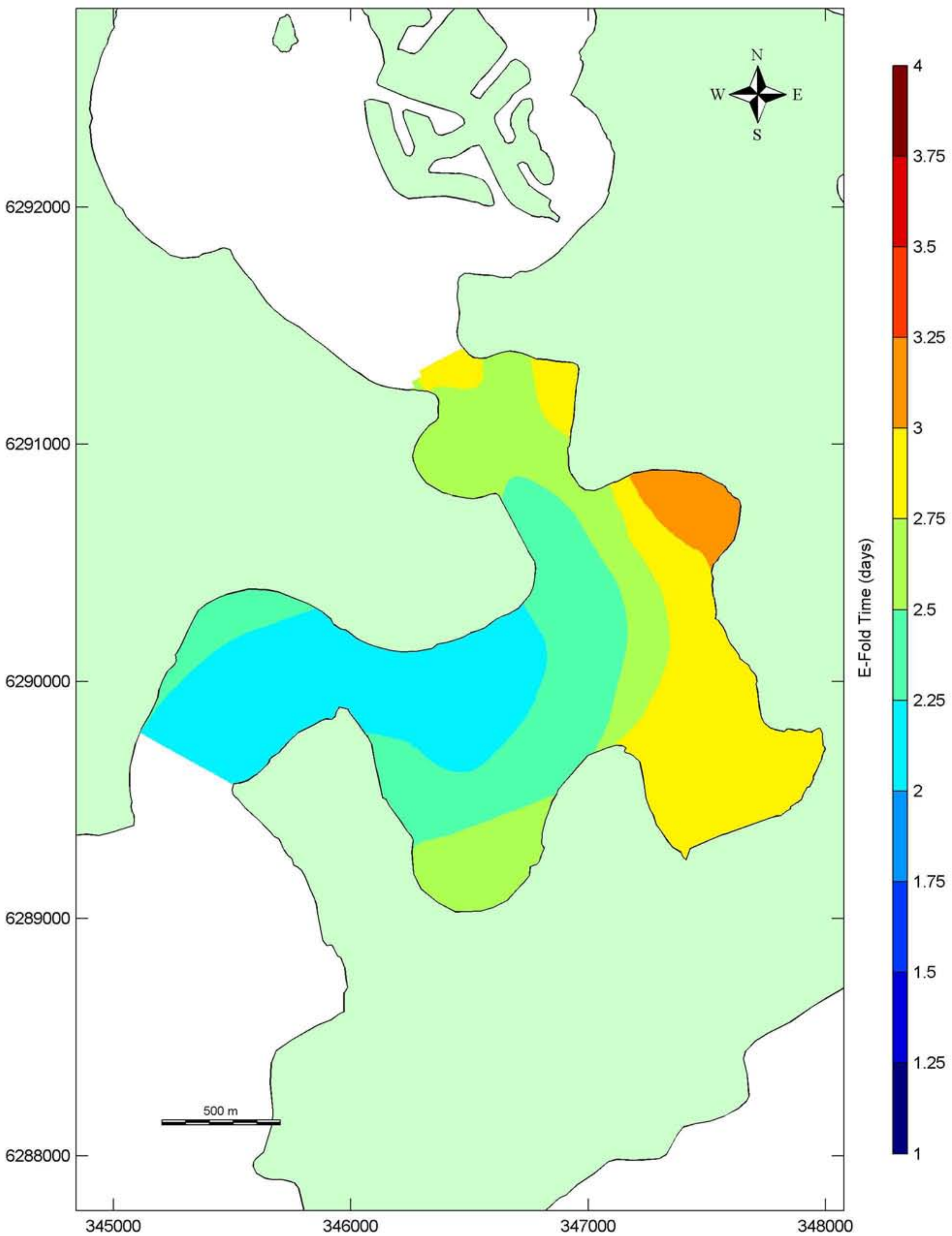
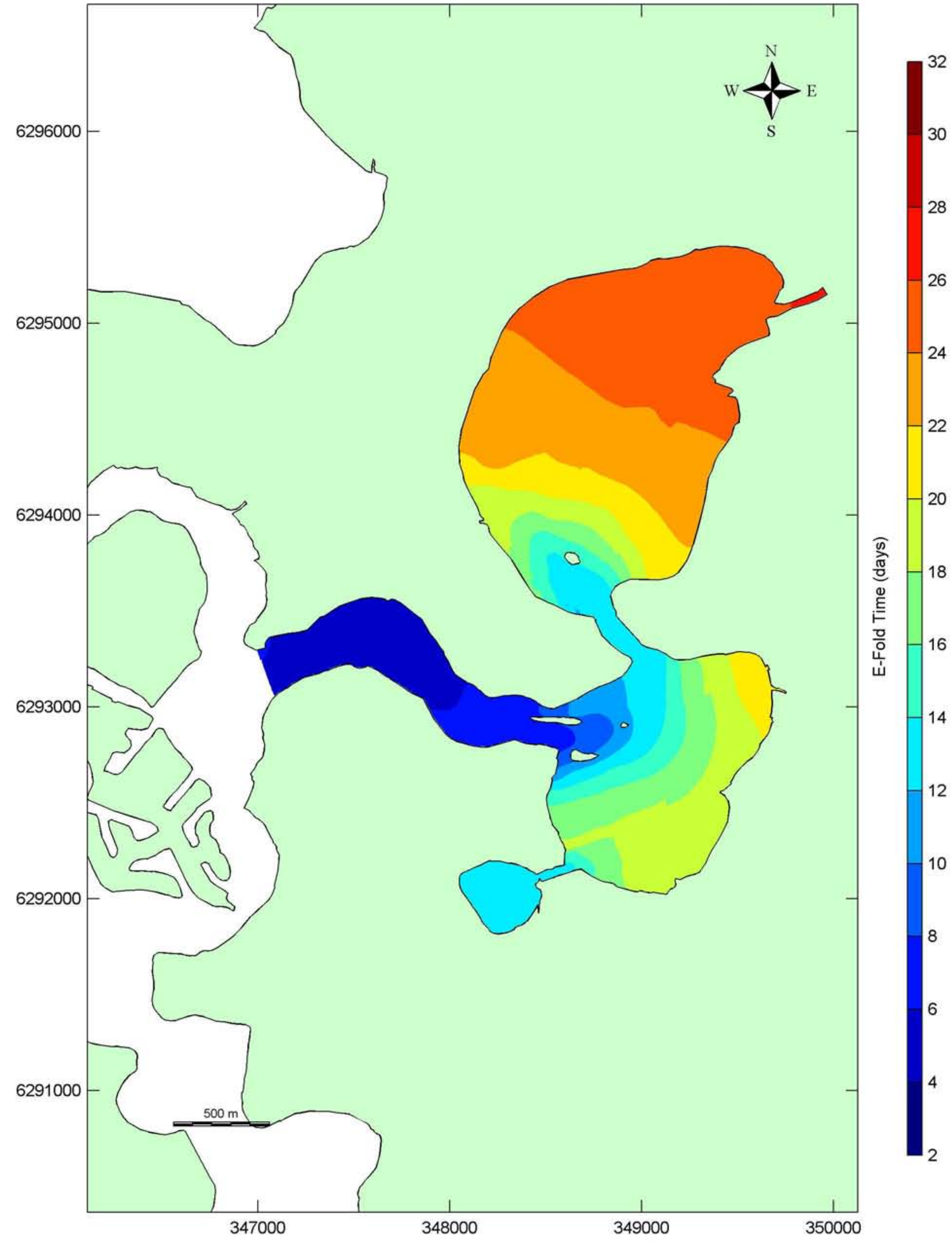
Brisbane Water Estuary Processes Study - Hydraulic Processes
FLUSHING TIME
GOSFORD - BROADWATER
Figure 6.2



Brisbane Water Estuary Processes Study - Hydraulic Processes
FLUSHING TIME
ST HUBERTS ISLANDS - PADDYS CHANNEL
Figure 6.3



FLUSHING TIME
ETTALONG
Figure 6.4



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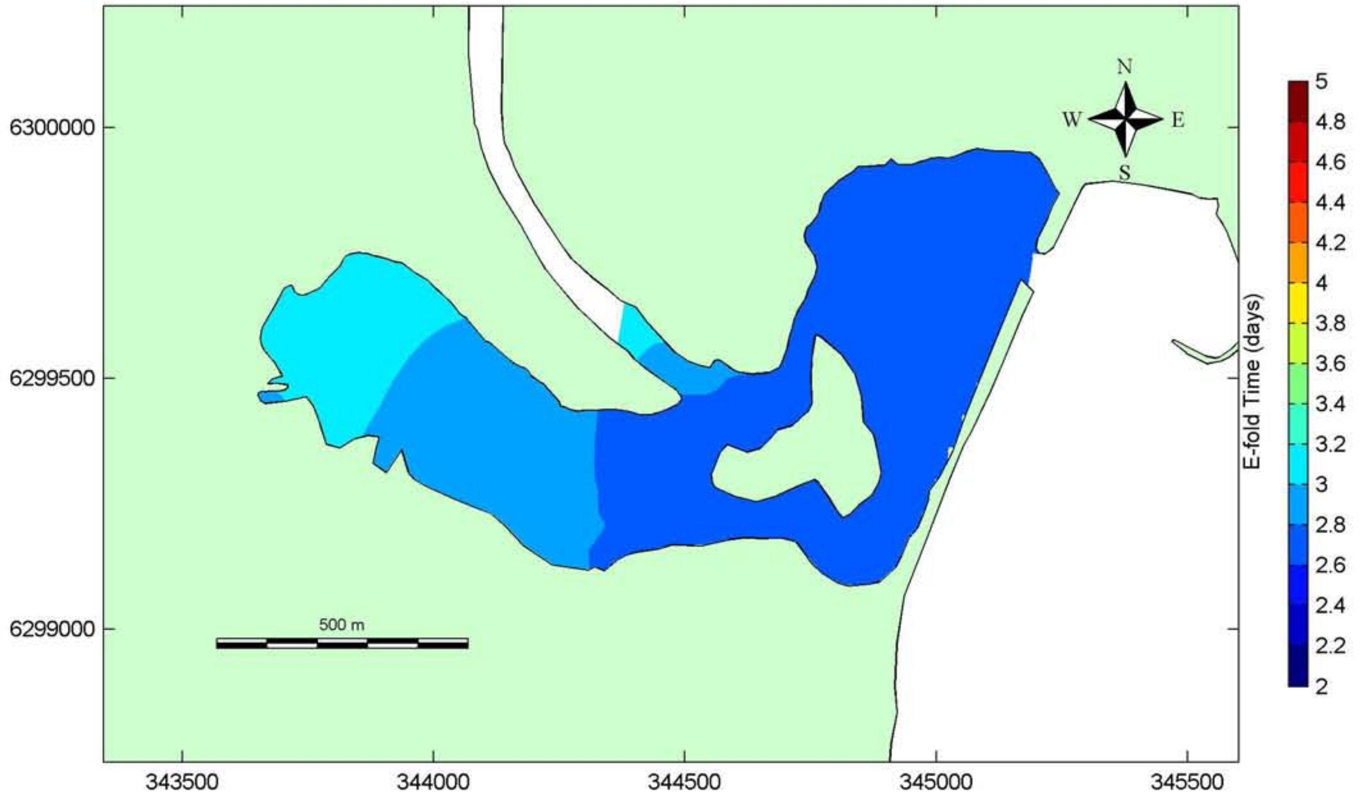
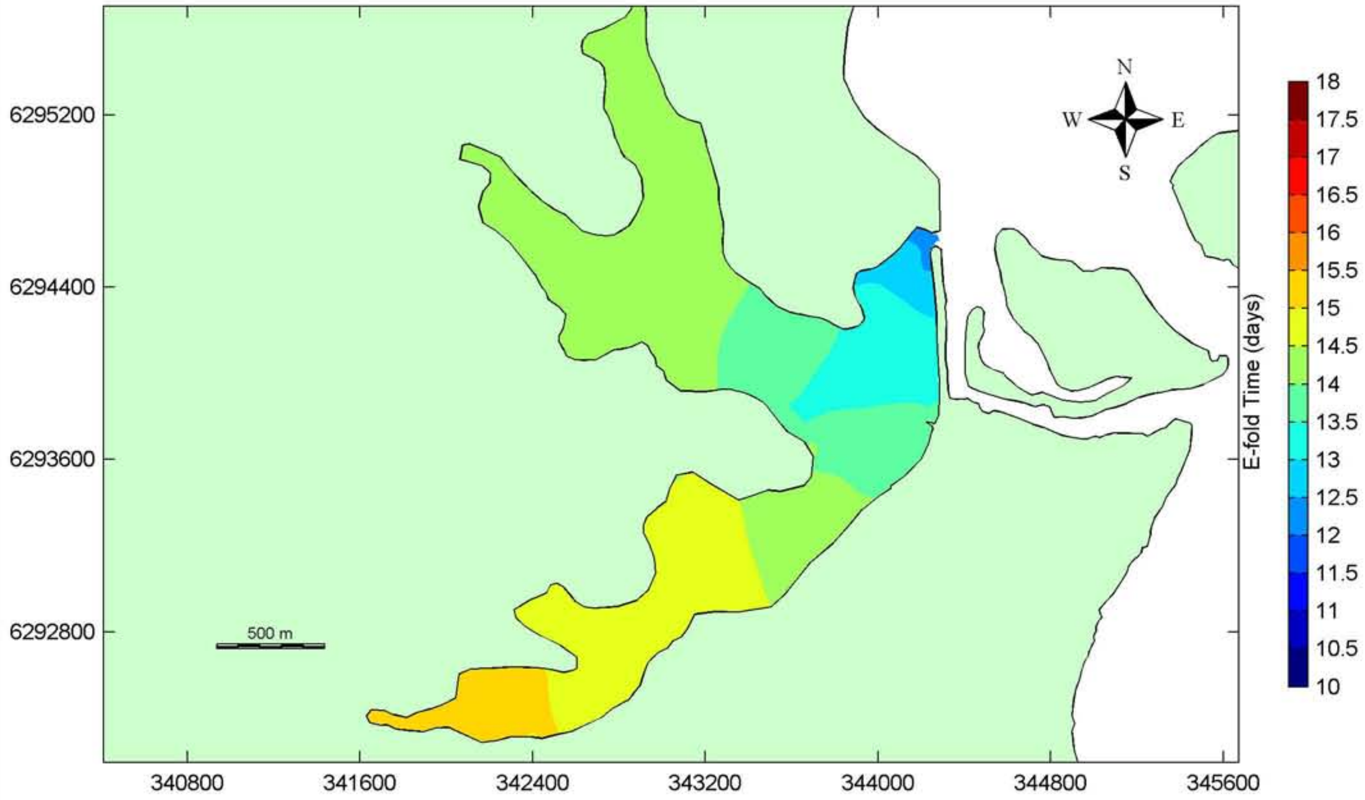
J/CM/J2255bw/Figures/R2312/Figure65.png

Brisbane Water Estuary Processes Study - Hydraulic Processes
FLUSHING TIME
KINCUMBER
Figure 6.5

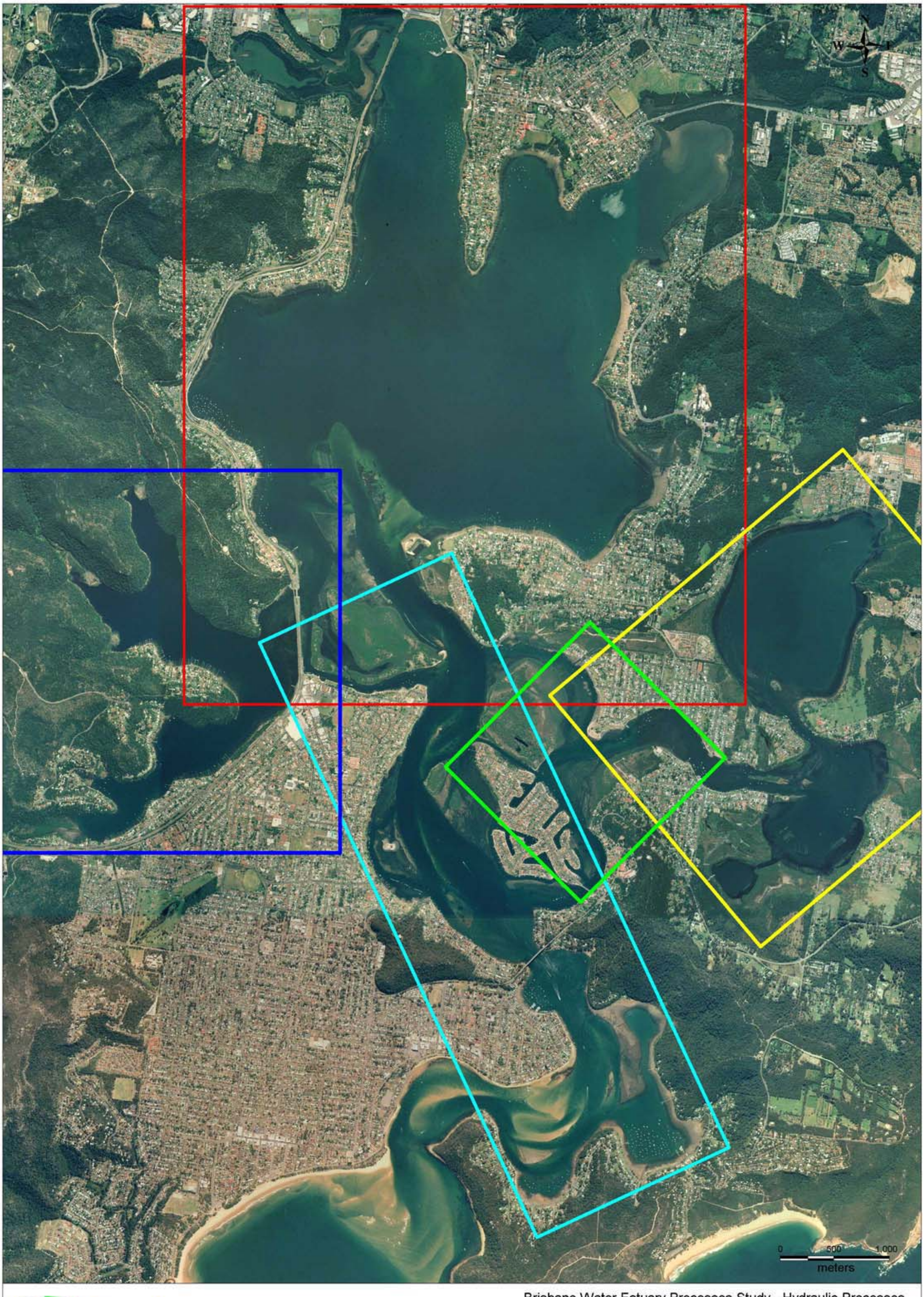




FLUSHING TIME

FAGANS BAY AND WOY WOY BAY

Figure 6.6



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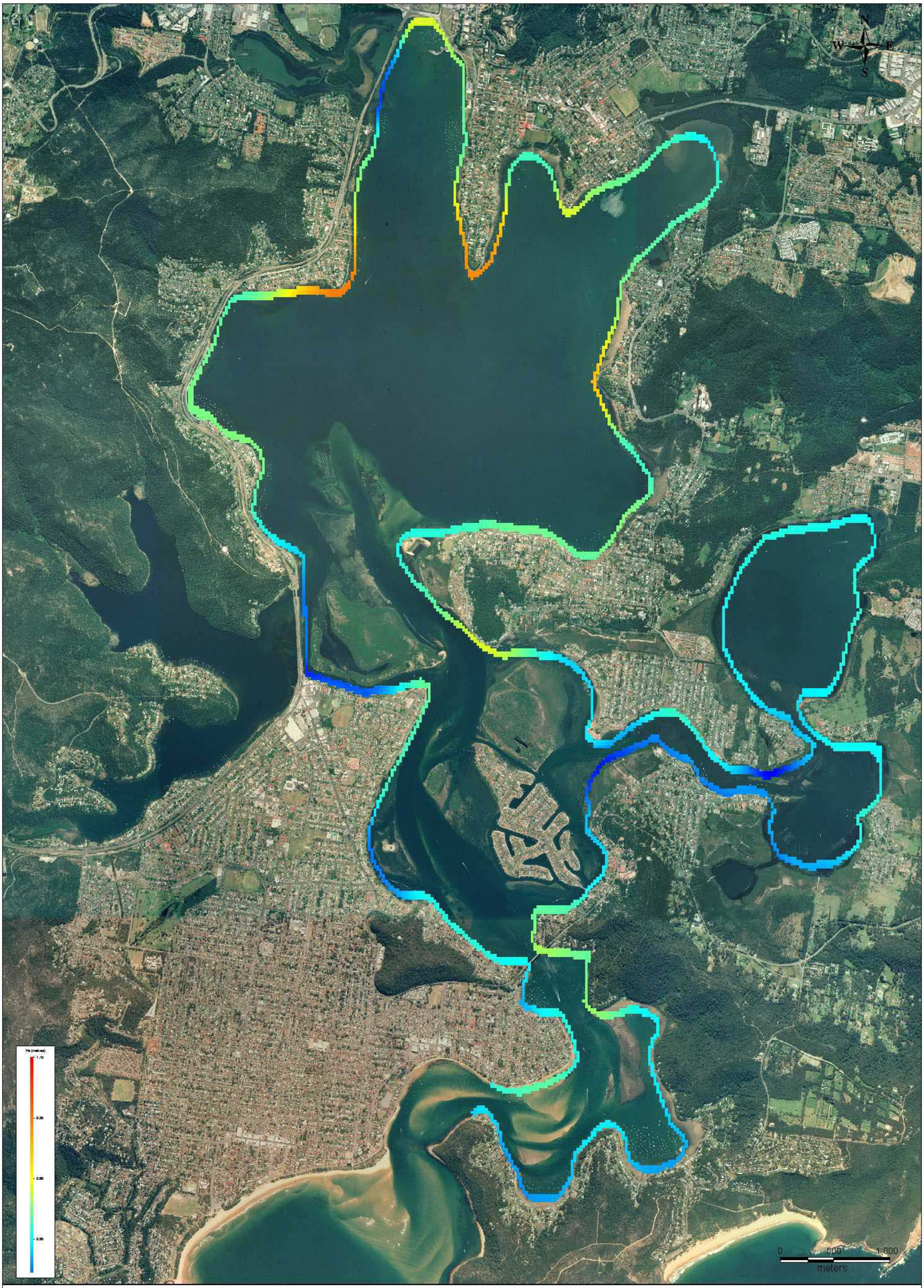
SUB-REGION SWAN MODELS

LJ2255/R2312 January 2006
J/CM/J2255bw/Figures/R2312/Figure7.1.wor

Figure 7.1



Brisbane Water Estuary Processes Study - Hydraulic Processes

5-YEARS ARI WAVE CONDITIONS
LOCAL SEA DOMINATED AREAS

Figure 7.2

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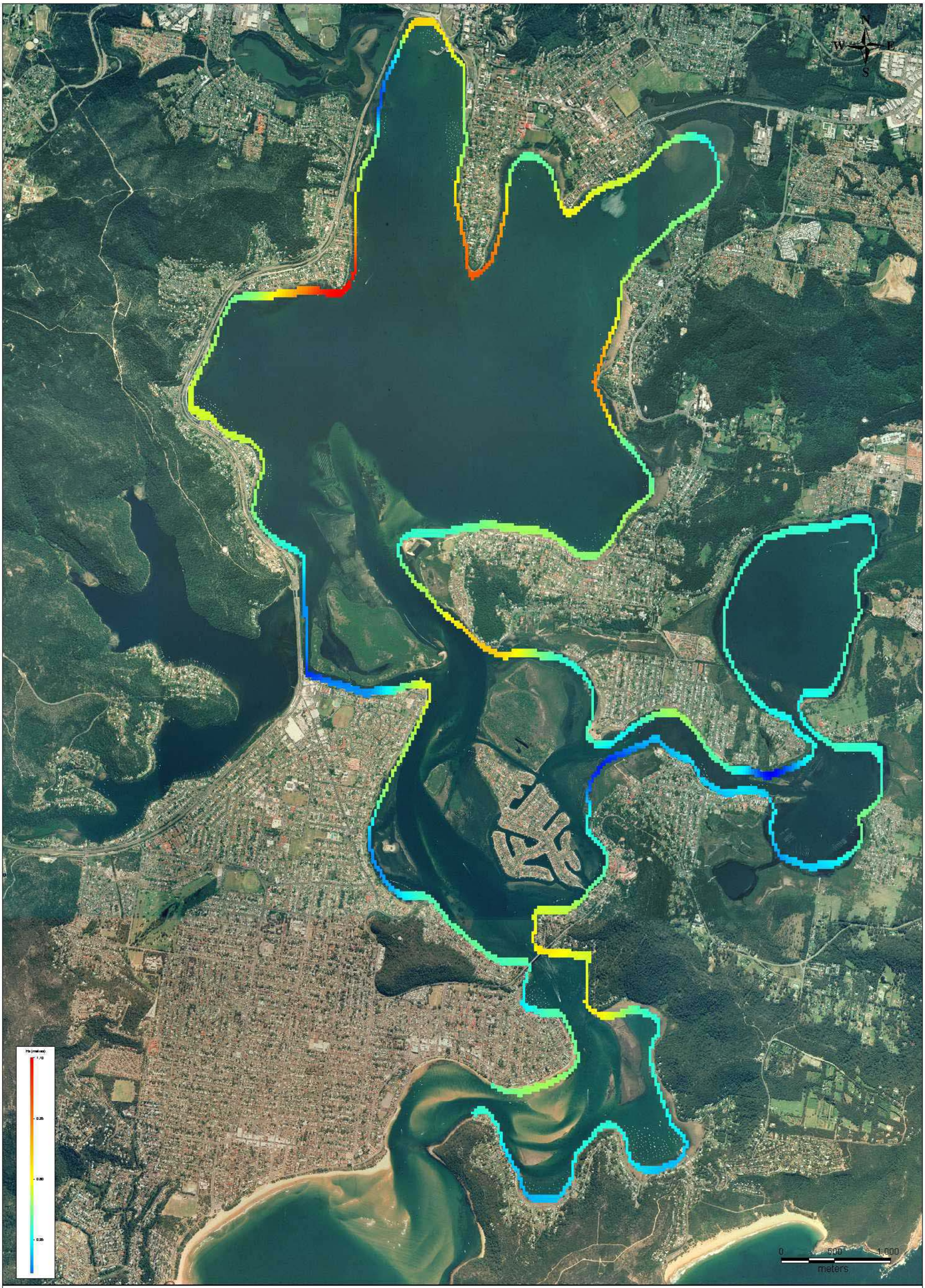
LJ2255/R2312 January 2006
J/CM/J2255bw/Figures/R2312/Figure7.2.wor



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LJ2255/R2312 January 2006
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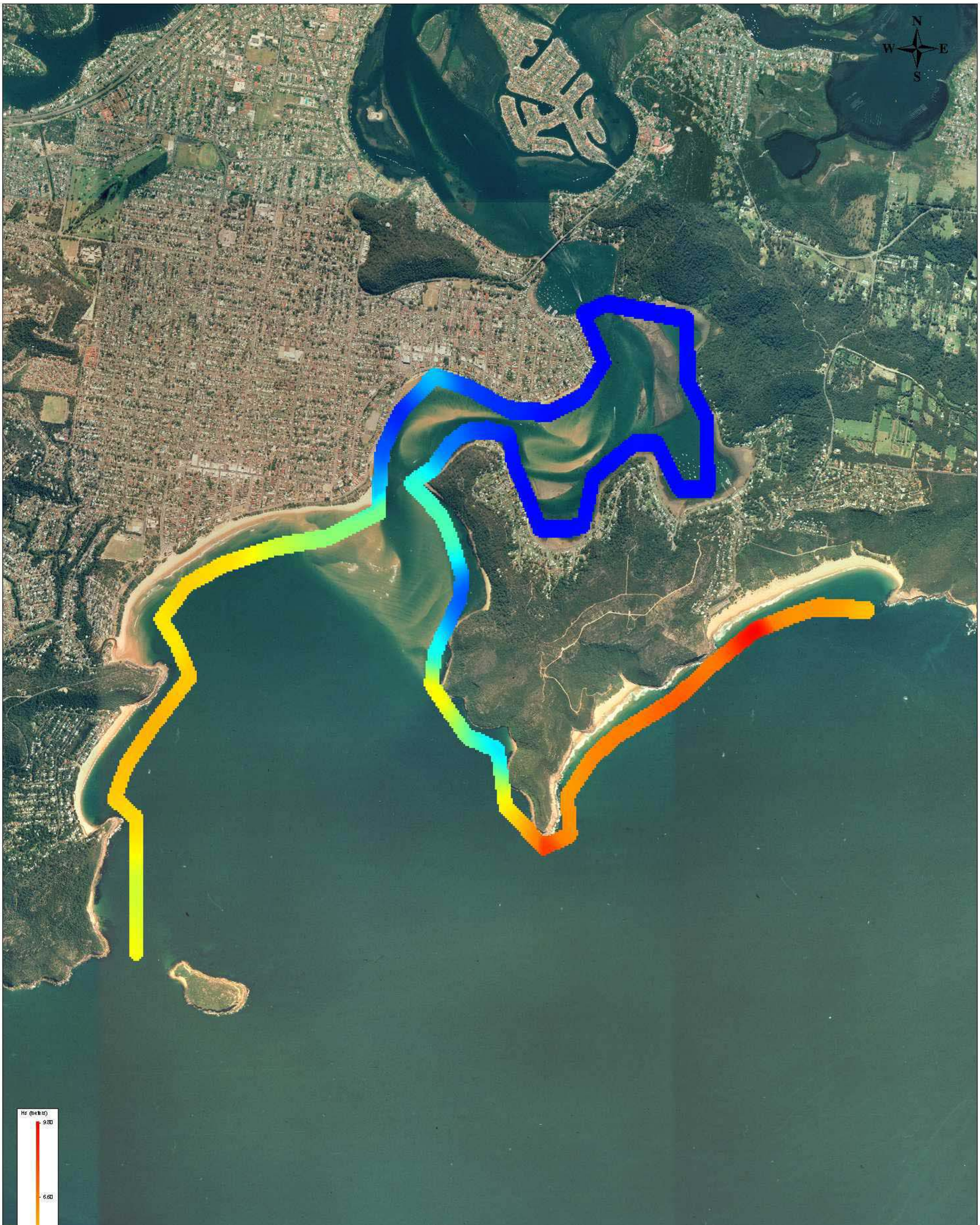
Brisbane Water Estuary Processes Study - Hydraulic Processes

100-YEARS ARI WAVE CONDITIONS
LOCAL SEA DOMINATED AREAS

Figure 7.3



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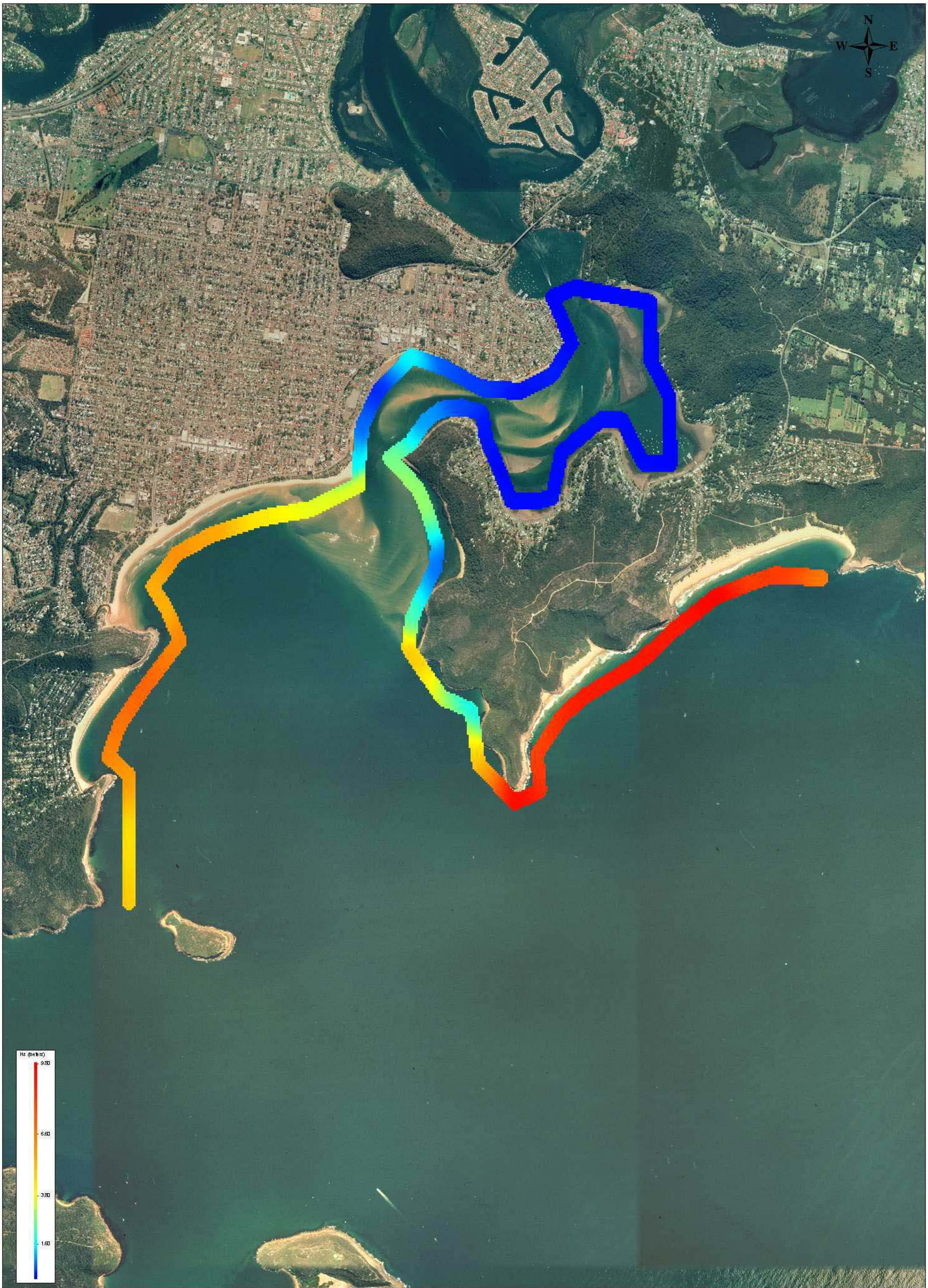
LJ2255/R2312 January 2006
J/CM/J2255bw/Figures/R2312/Figure7.4.wor

Brisbane Water Estuary Processes Study - Hydraulic Processes

5-YEARS ARI WAVE CONDITIONS
SWELL EXPOSED AREAS

Figure 7.4



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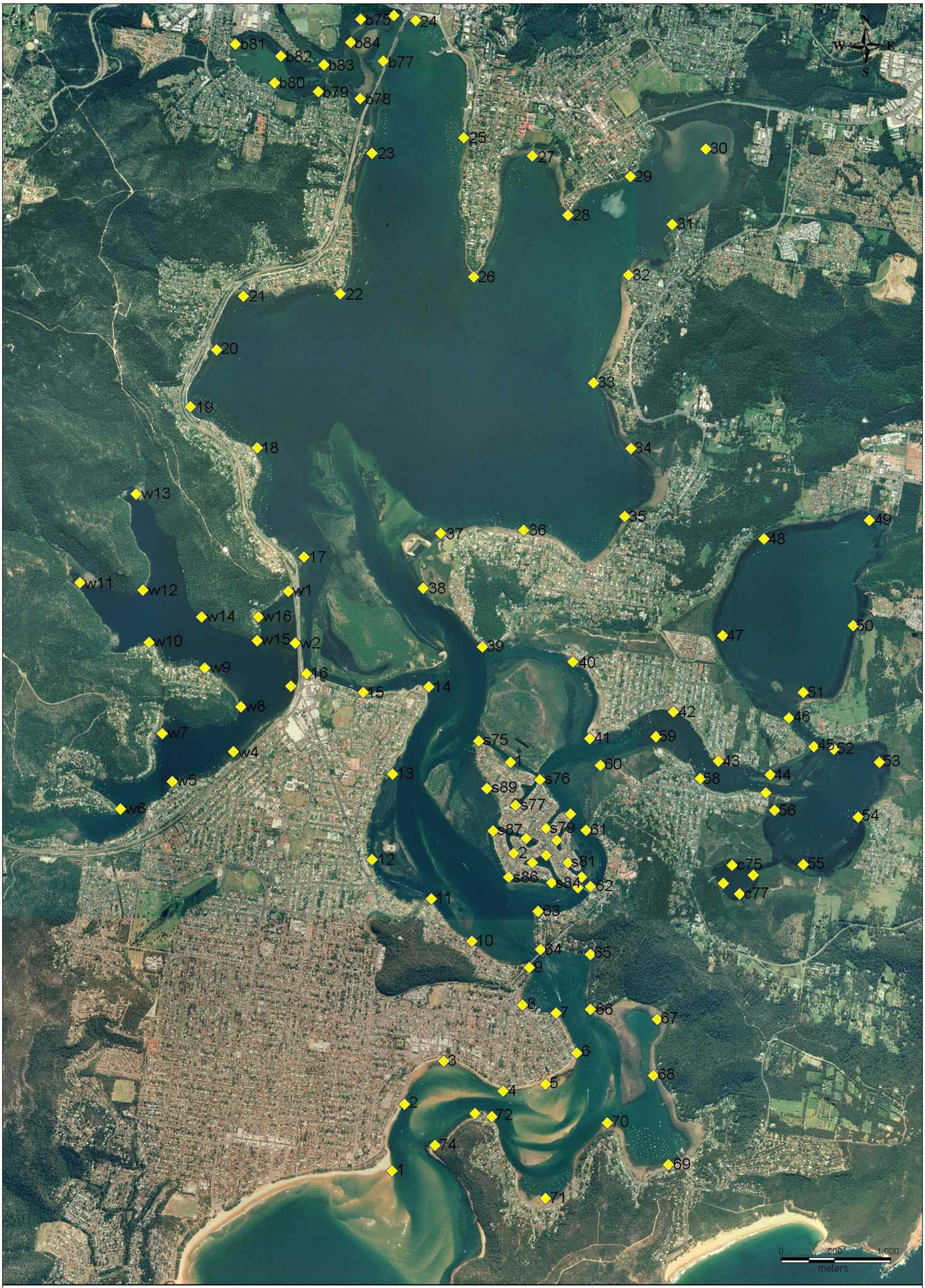
LJ2255/R2312 January 2006
J/CM/J2255bw/Figures/R2312/Figure7.5.wor

Brisbane Water Estuary Processes Study - Hydraulic Processes

100-YEARS ARI WAVE CONDITIONS
SWELL EXPOSED AREAS

Figure 7.5



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LJ2255/R2312 January 2006
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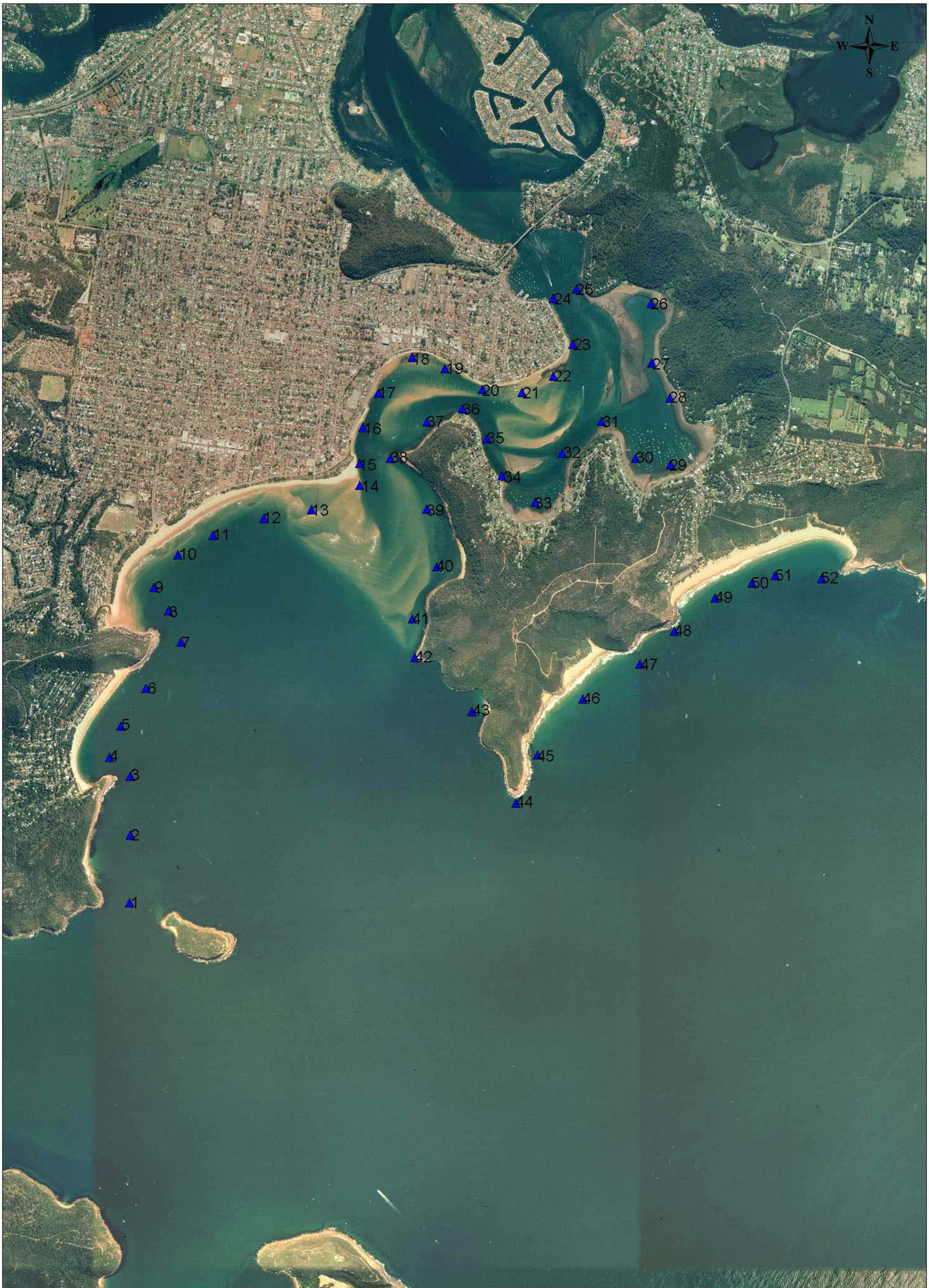
Brisbane Water Estuary Processes Study - Hydraulic Processes

OUTPUT LOCATIONS
LOCAL SEA
Figure 7.6



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LJ2255/R2312 January 2006
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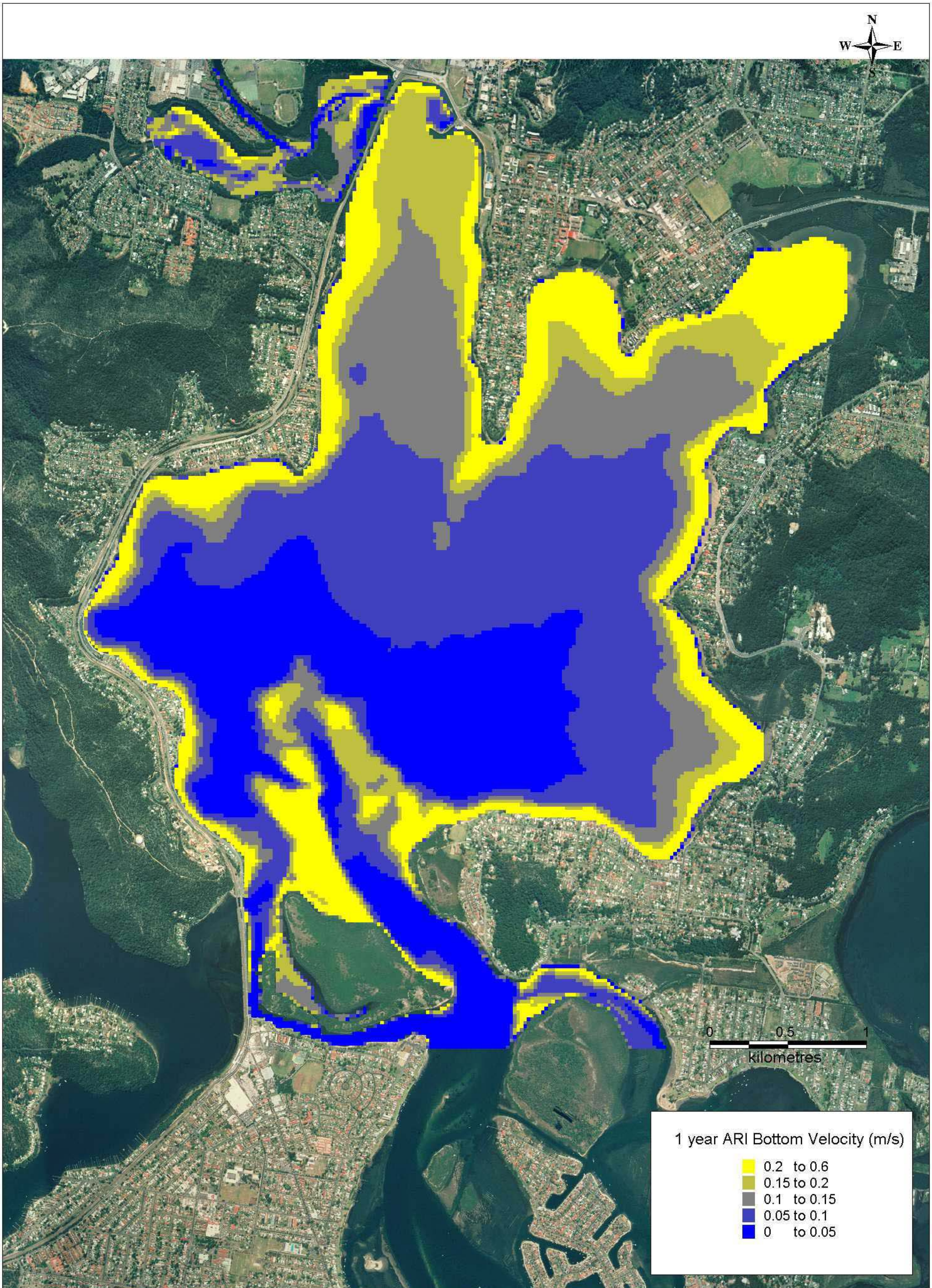
Brisbane Water Estuary Processes Study - Hydraulic Processes

OUPUT LOCATIONS
SWELL EXPOSED AREAS

Figure 7.7



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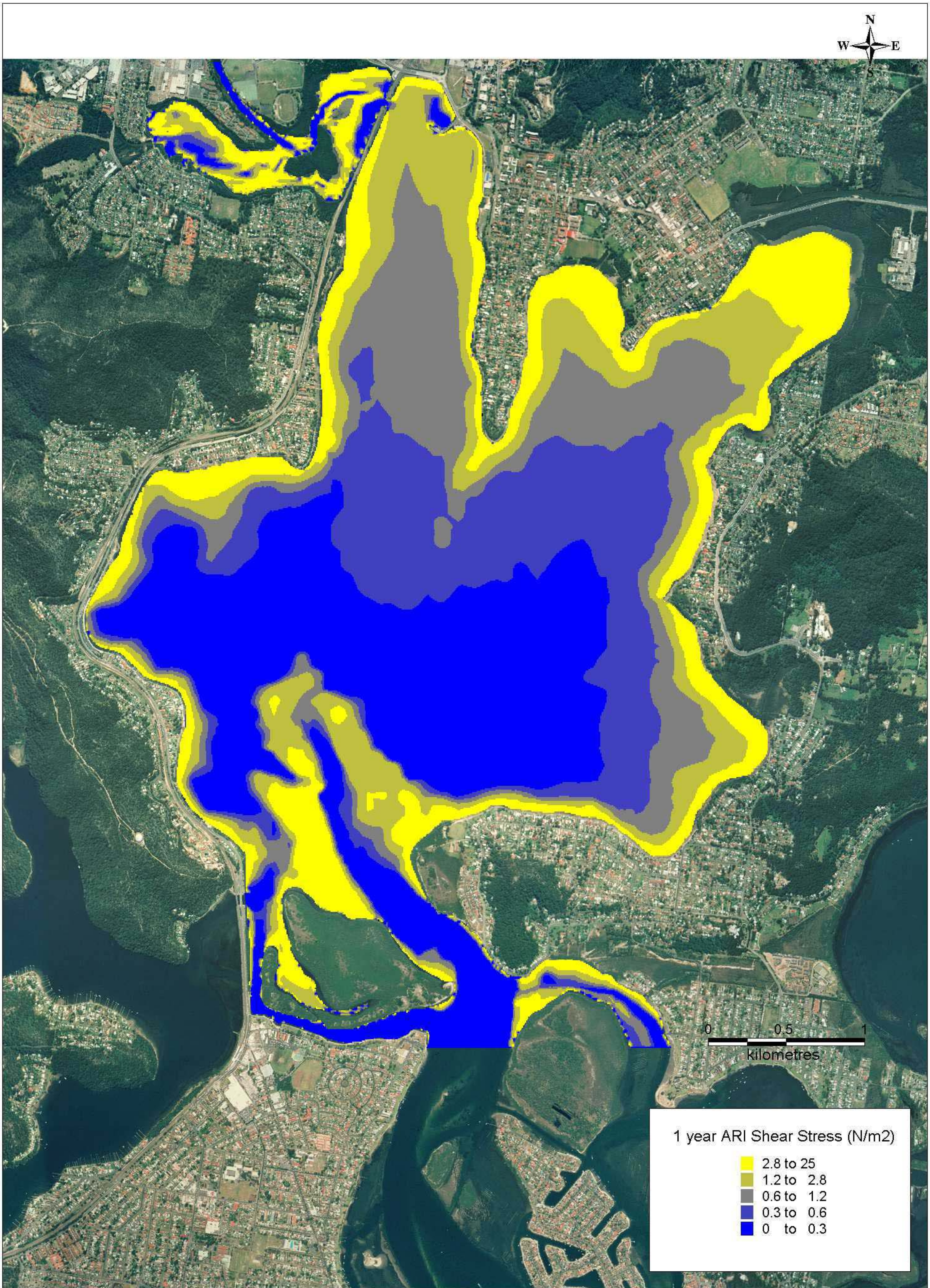
BRISBANE WATER - 1 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
J/CM/J2255bw/Figures/R2312/Figure 7.8.Wor

Figure 7.8



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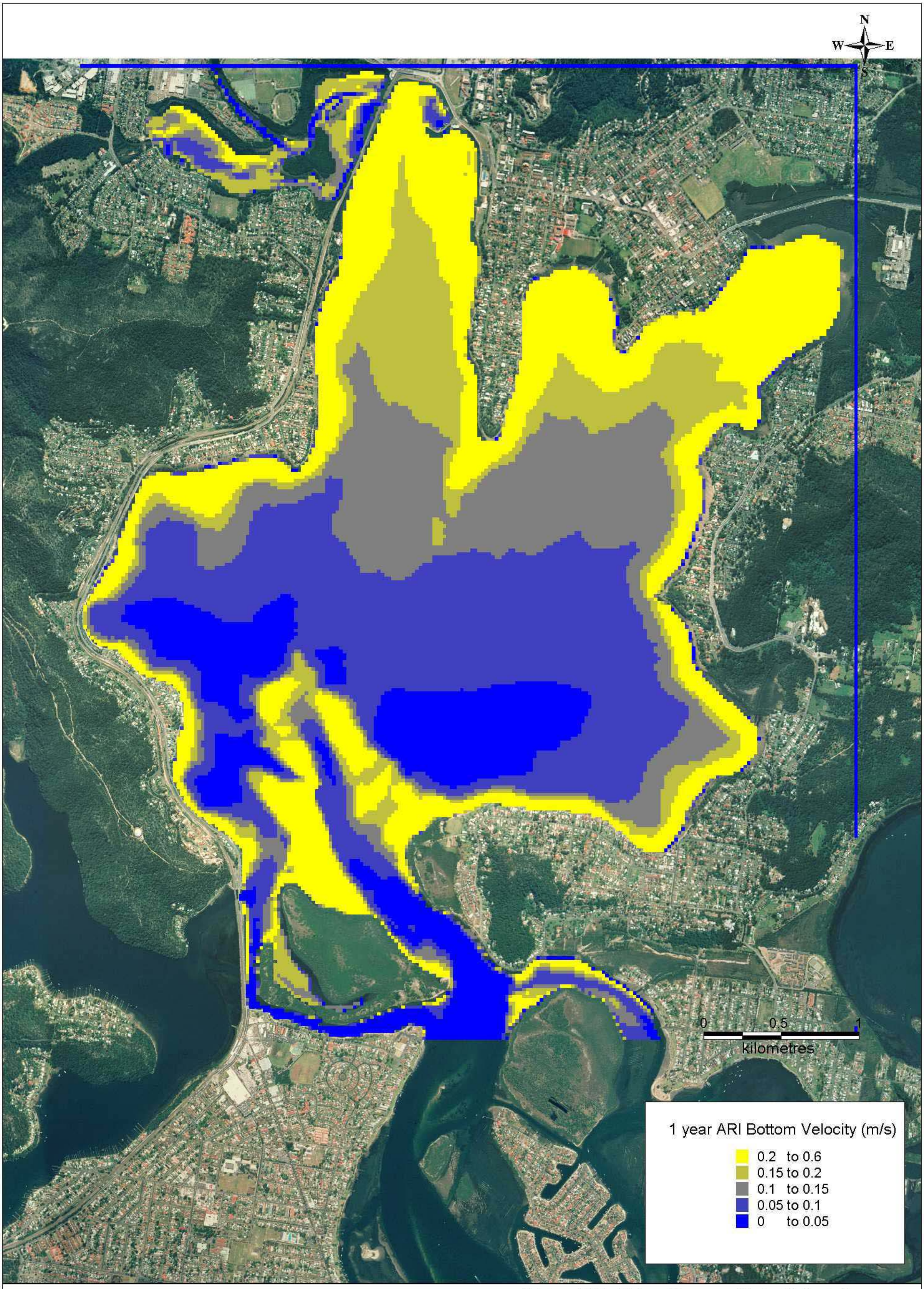
Brisbane Water Estuary Processes Study - Hydraulic Processes

BRISBANE WATER - 1 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
J/CM/J2255bw/Figures/R2312/Figure 7.9.Wor

Figure 7.9



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Brisbane Water Estuary Processes Study - Hydraulic Processes

BRISBANE WATER - 5 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
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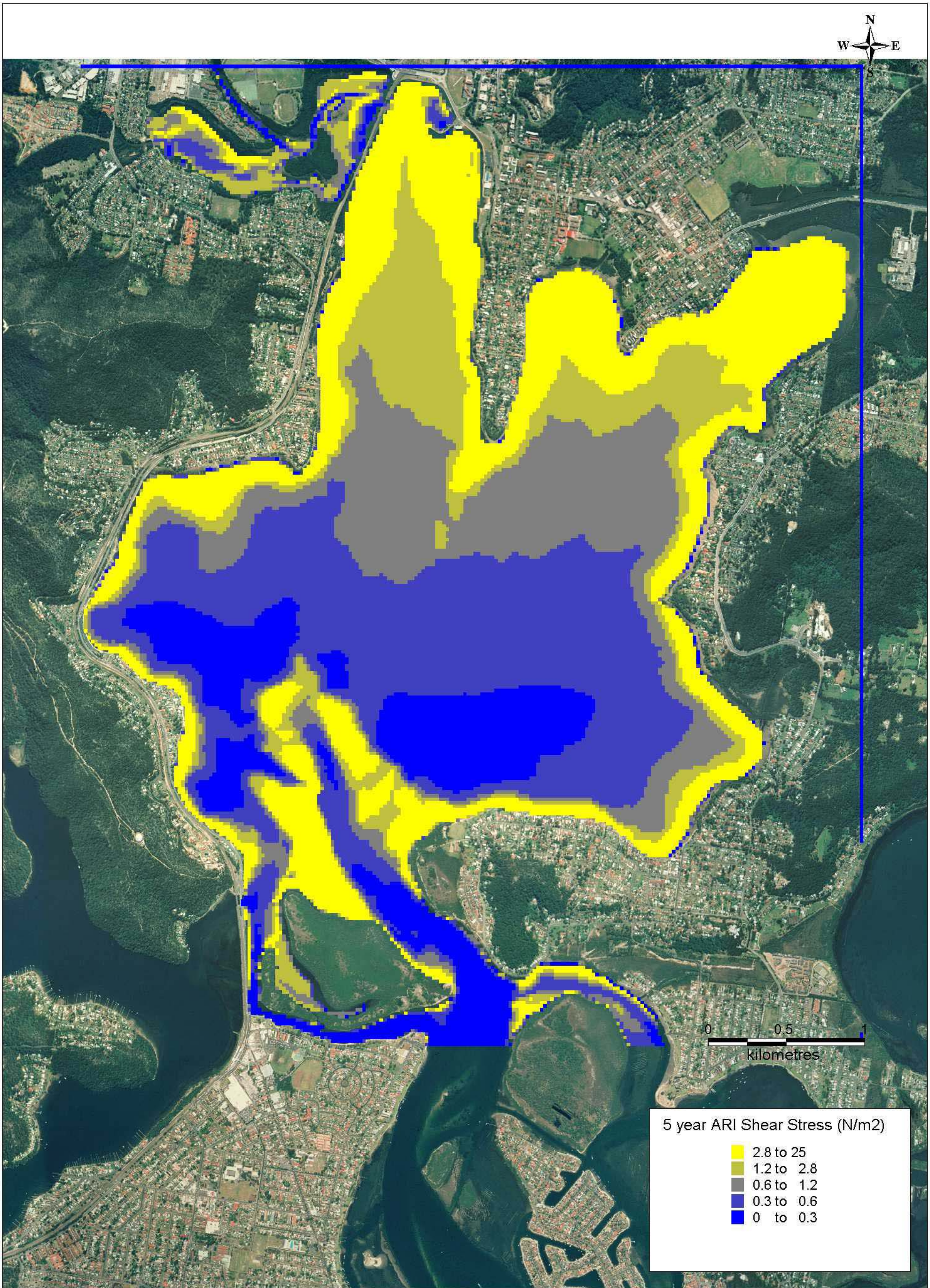
Figure 7.10



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BRISBANE WATER - 5 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
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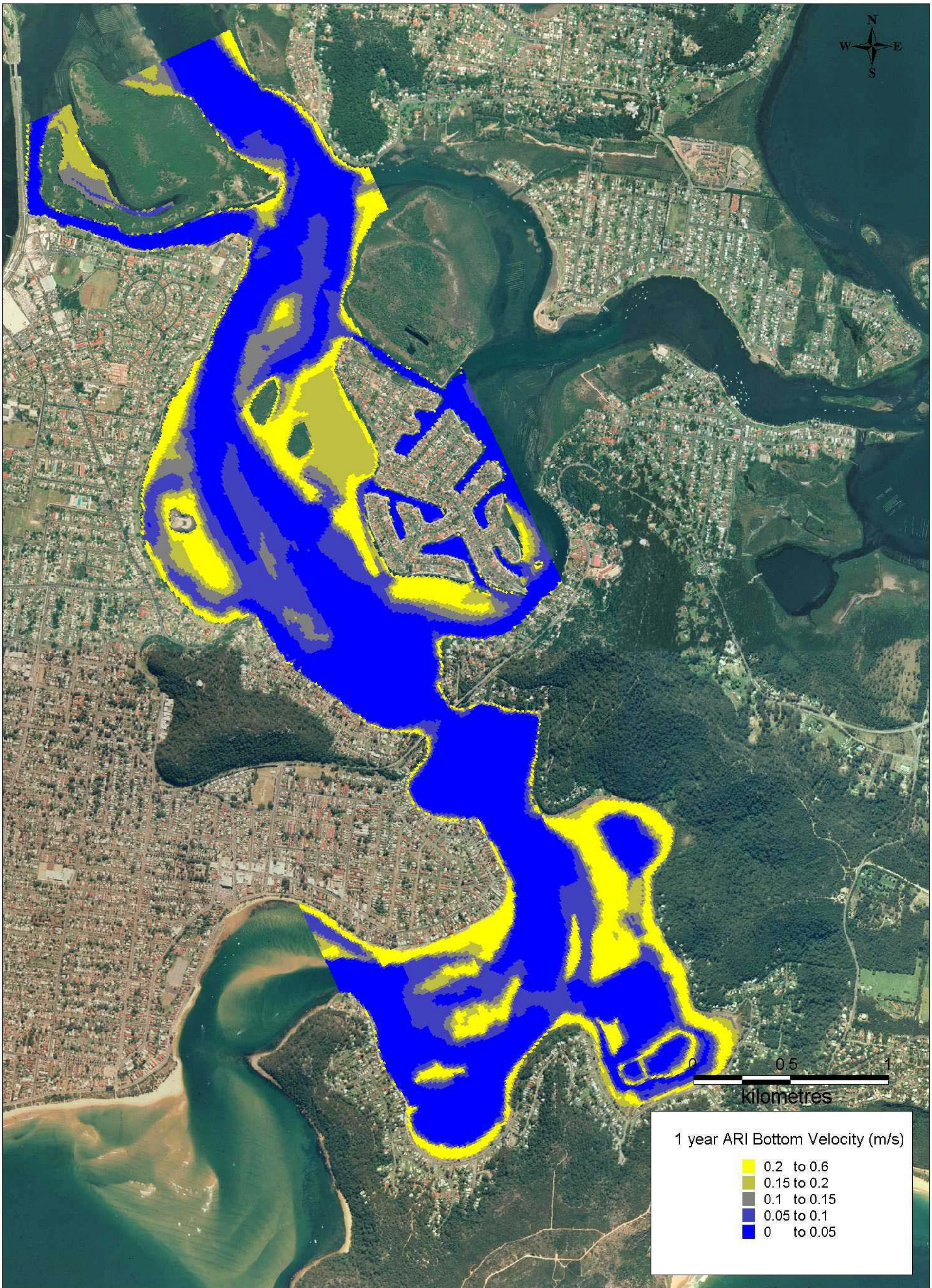
Figure 7.11



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THE RIP - 1 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
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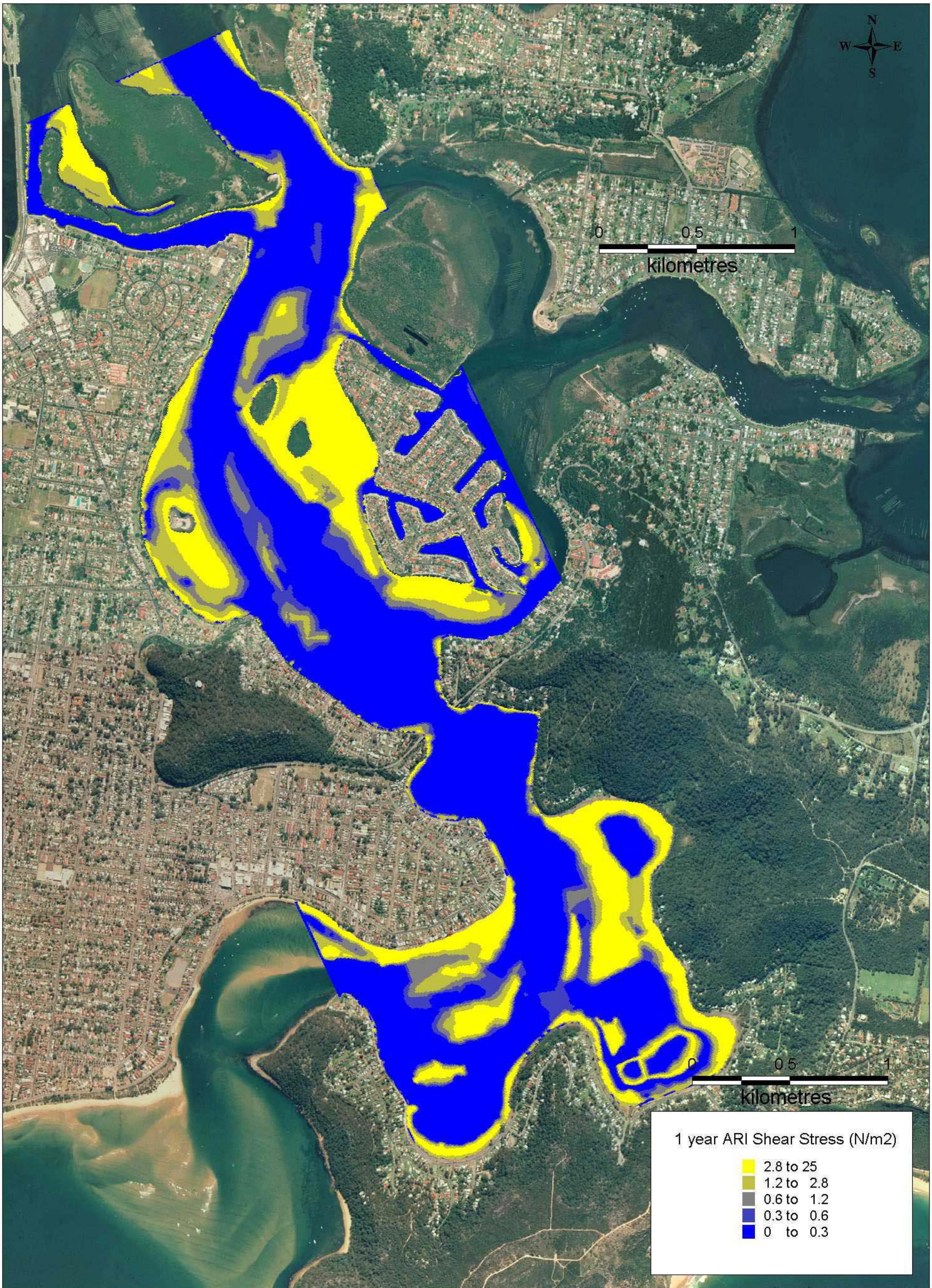
Figure 7.12



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THE RIP - 1 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
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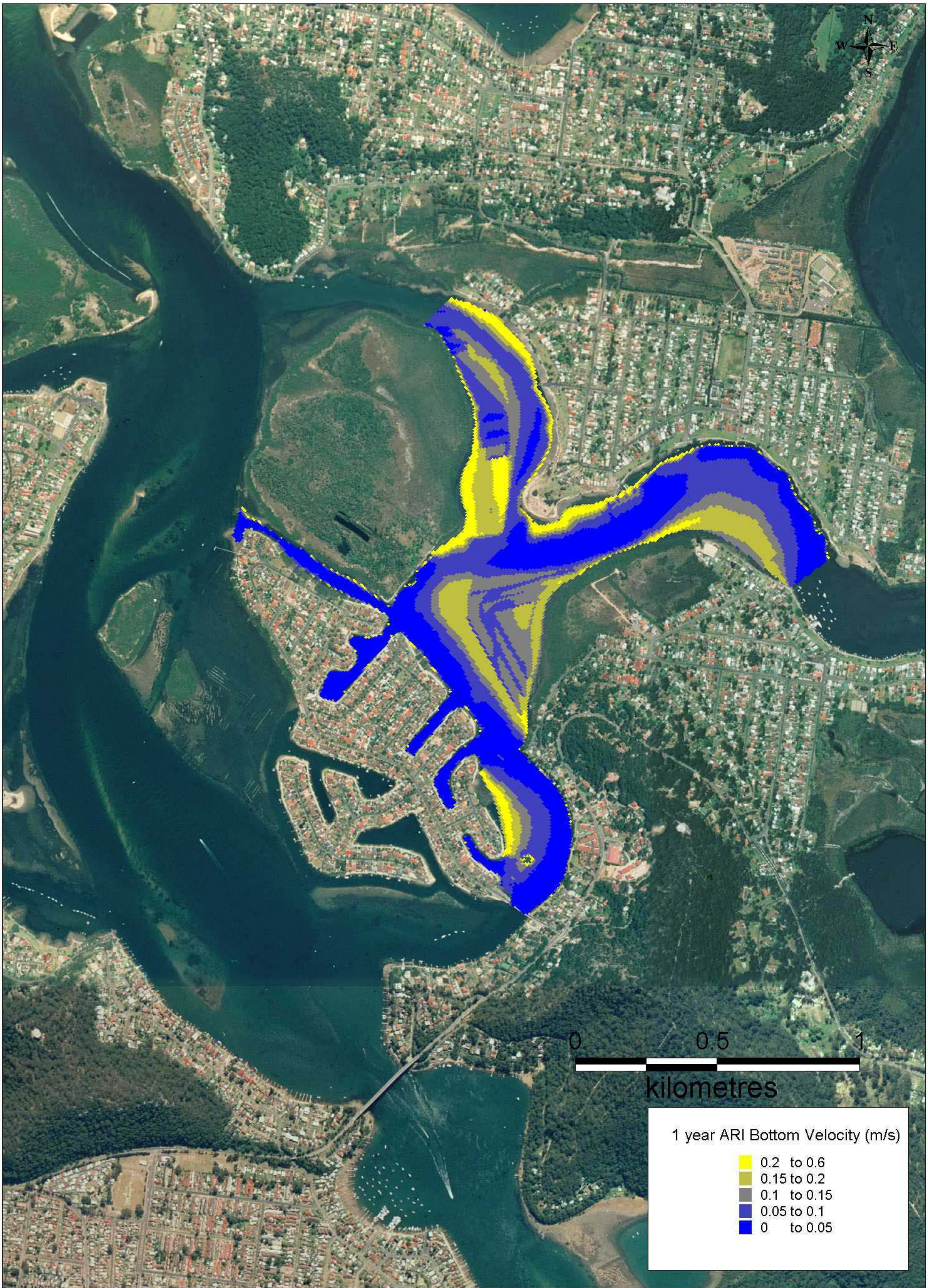
Figure 7.13



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ST HUBERTS ISLAND - 1 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
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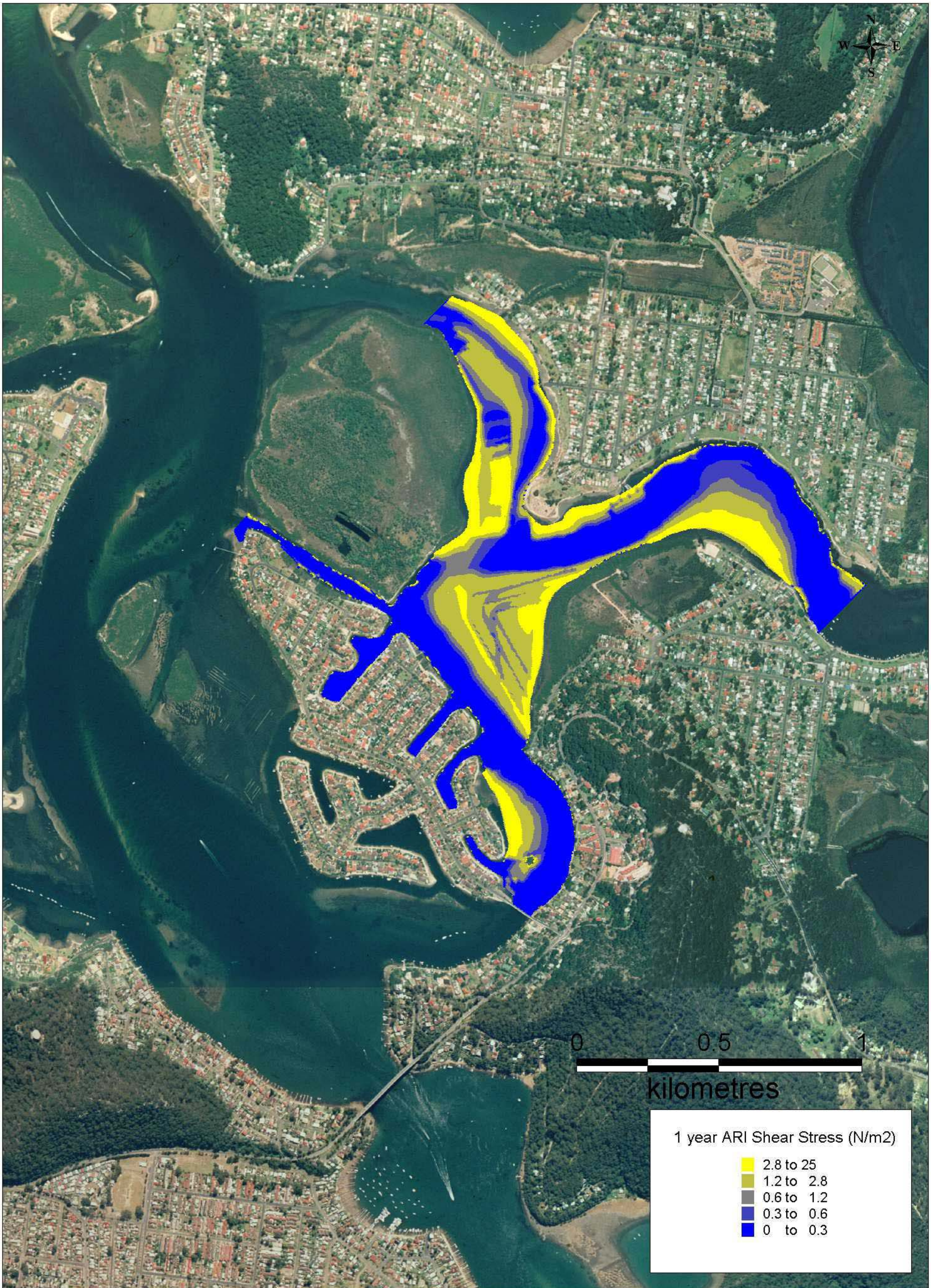
Figure 7.14



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ST HUBERTS ISLAND - 1 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
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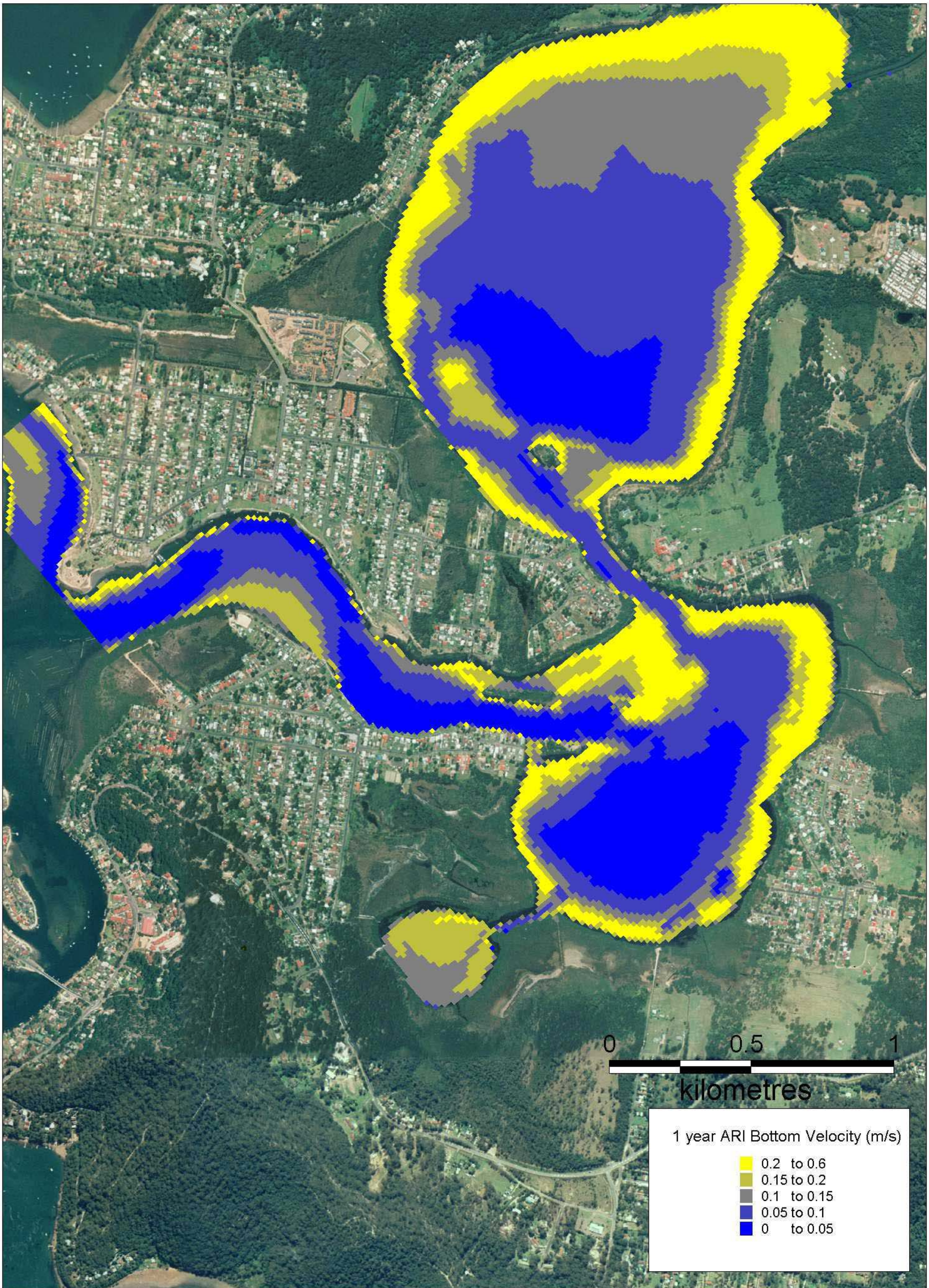
Figure 7.15



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COCKLE CHANNEL - 1 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
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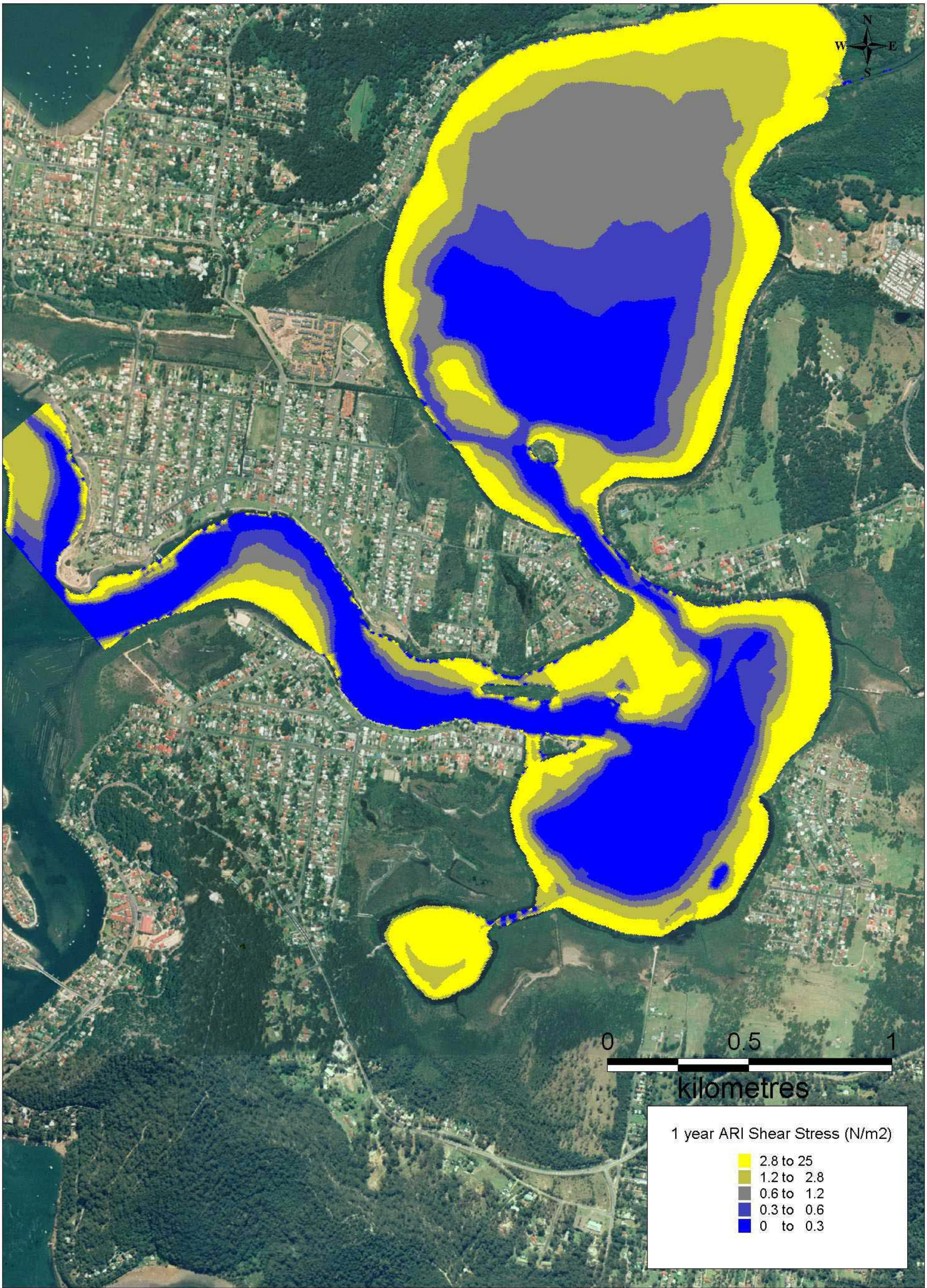
Figure 7.16



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COCKLE CHANNEL - 1 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
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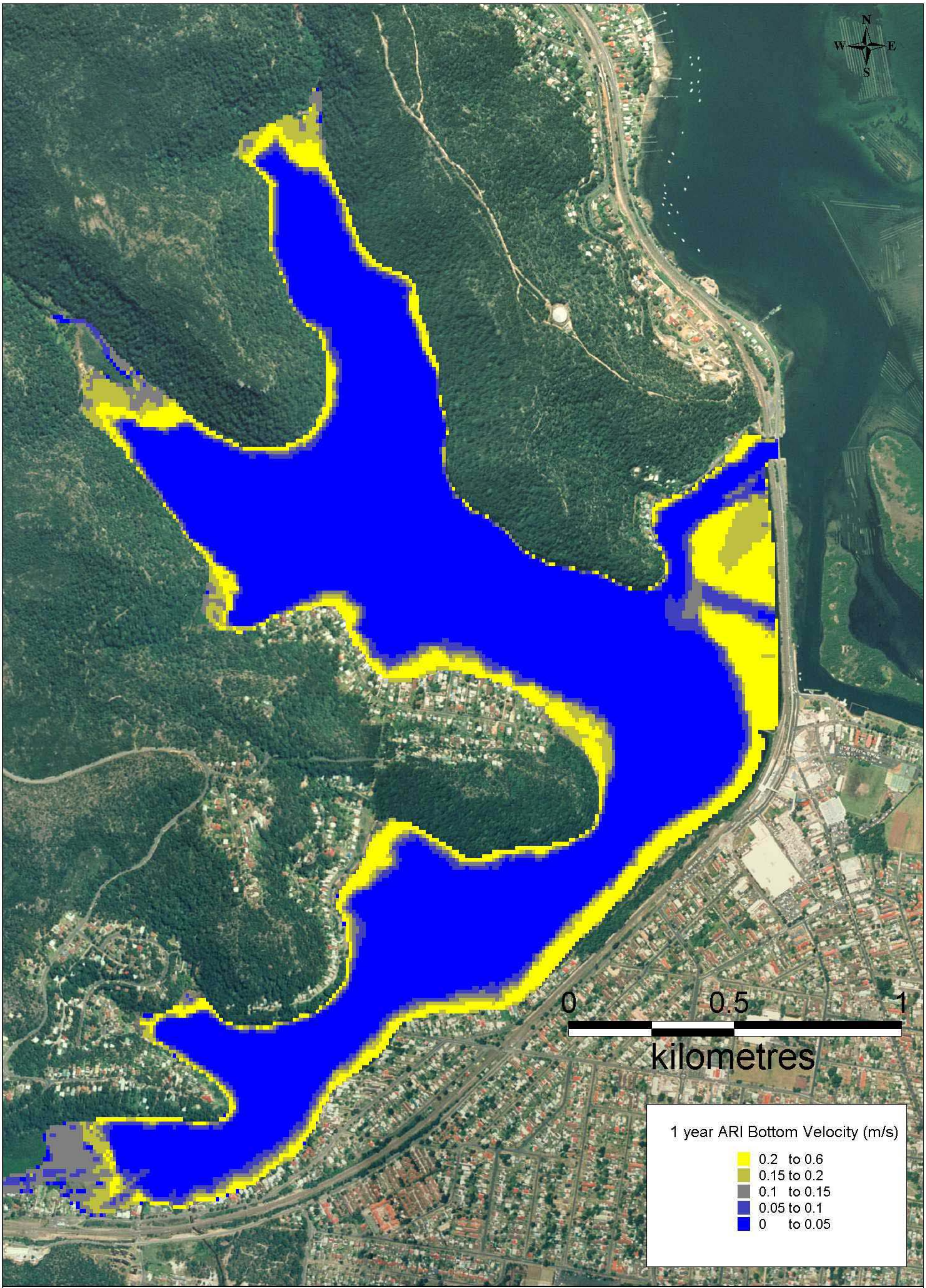
Figure 7.17



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WOY WOY BAY - 1 YR ARI WAVE INDUCED NEAR BED VELOCITIES

J2255/R2312 January 2007
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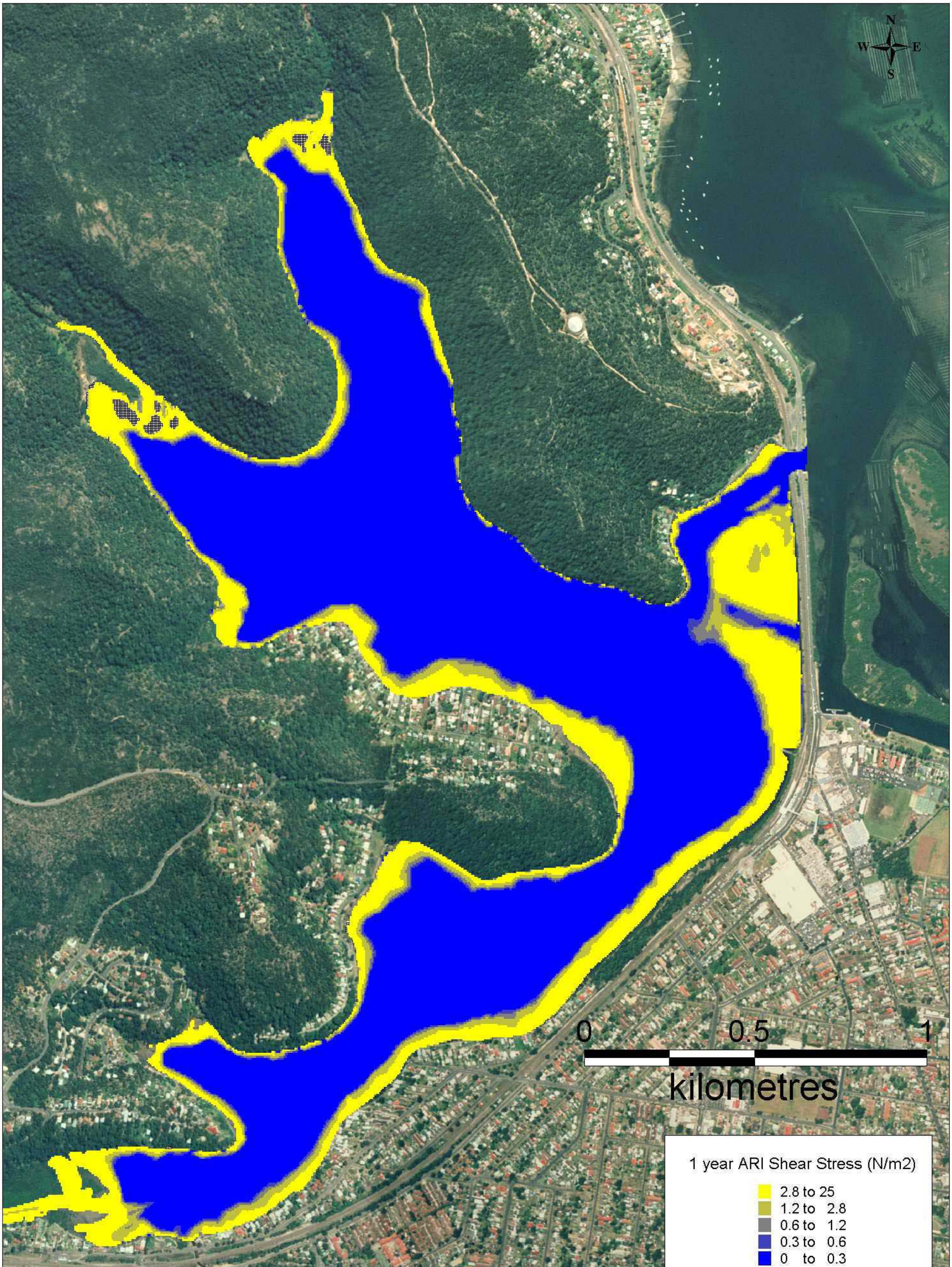
Figure 7.18



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Brisbane Water Estuary Processes Study - Hydraulic Processes

WOY WOY BAY - 1 YR ARI MAXIMUM BOTTOM SHEAR STRESS

J2255/R2312 January 2007
J/CM/J2255bw/Figures/R2312/Figure 7.19.Wor

Figure 7.19

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Brisbane Water Estuary Processes Study - Hydraulic Processes

SHORE NORMAL STORM EROSION SECTIONS

LJ2255/R2312 January 2007
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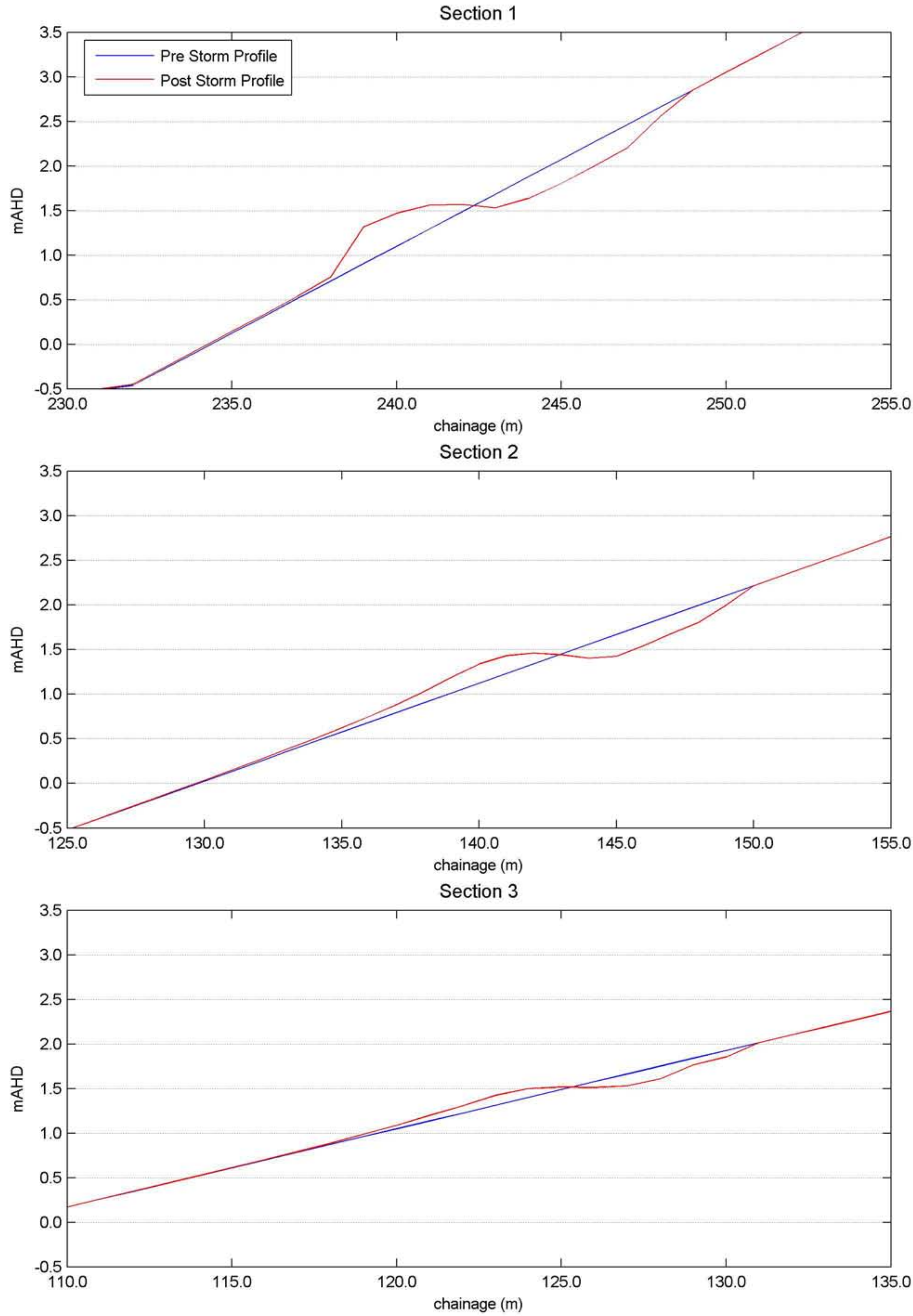
Figure 7.20

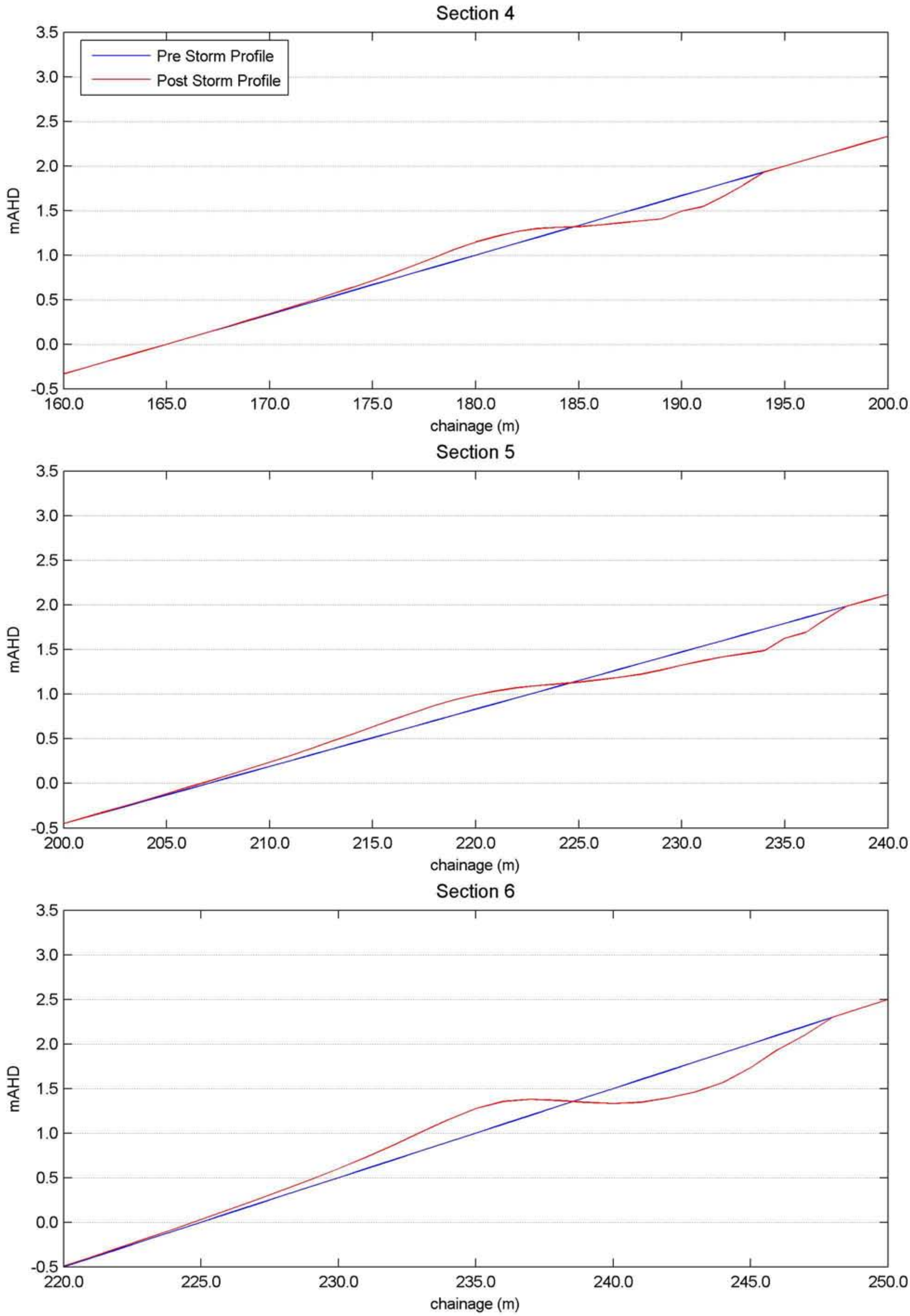


Brisbane Water Estuary Processes Study - Hydraulic Processes

SHORE NORMAL STORM BITE

100-YEARS ARI WAVE CONDITIONS

Figure 7.21a



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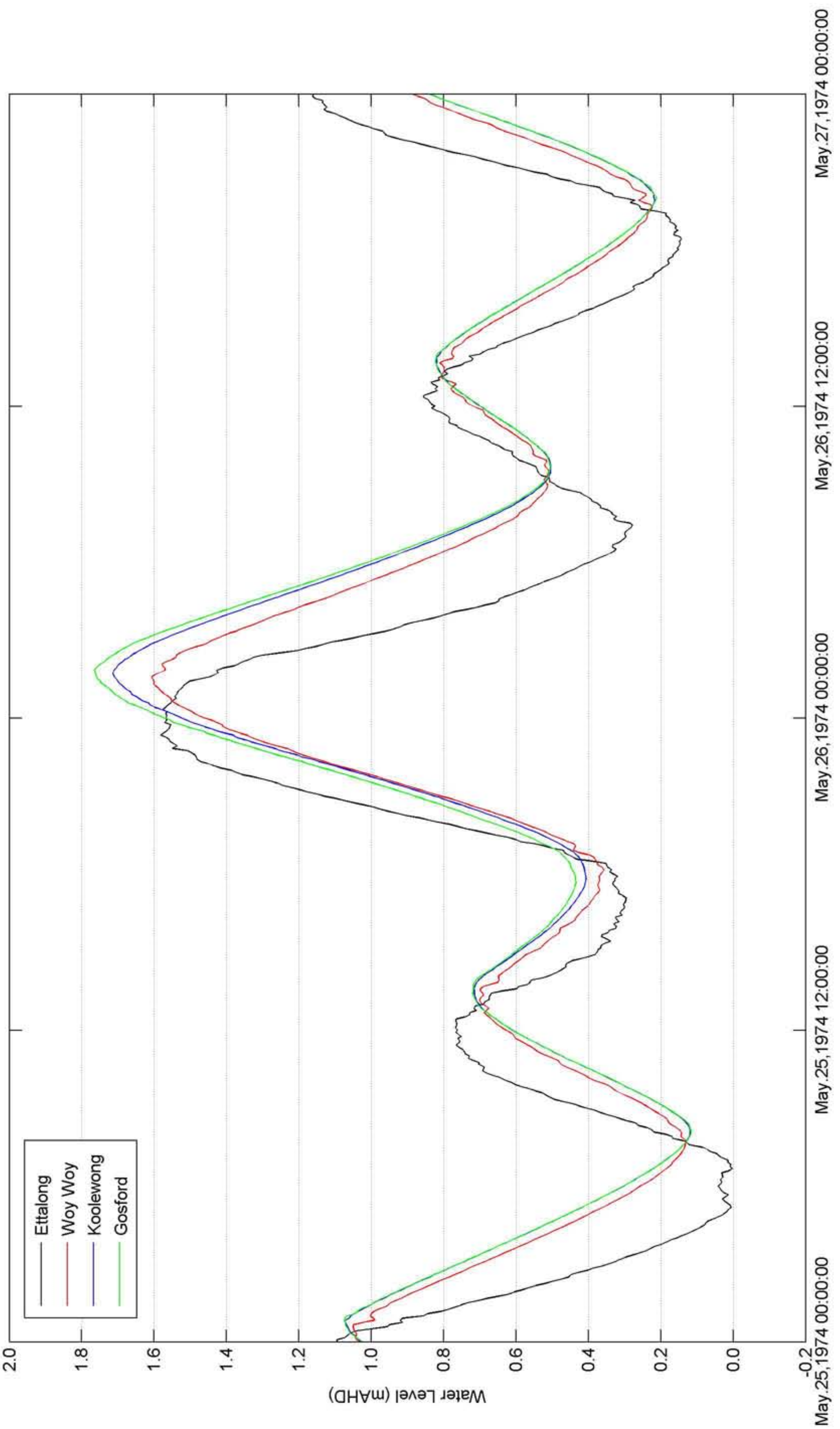
Brisbane Water Estuary Processes Study - Hydraulic Processes
SHORE NORMAL STORM BITE
100-YEARS ARI WAVE CONDITIONS
Figure 7.21b



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LJ2255/R2312 January 2007
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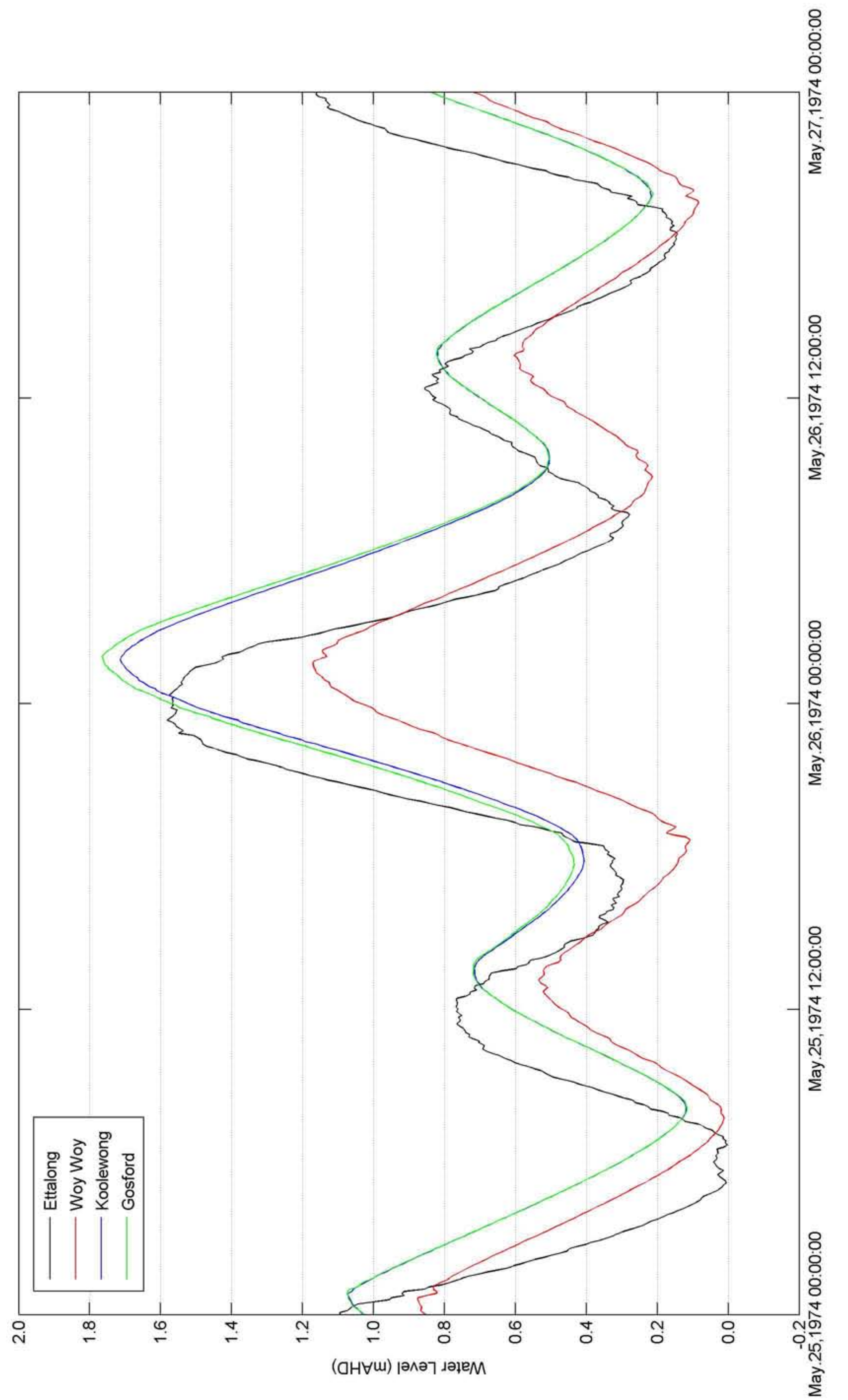
Brisbane Water Estuary Processes Study - Hydraulic Processes
HINDCAST MAY 1974 WATER LEVELS
BRISBANE WATER
Figure 8.1



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LJ2255/R2312 January 2007
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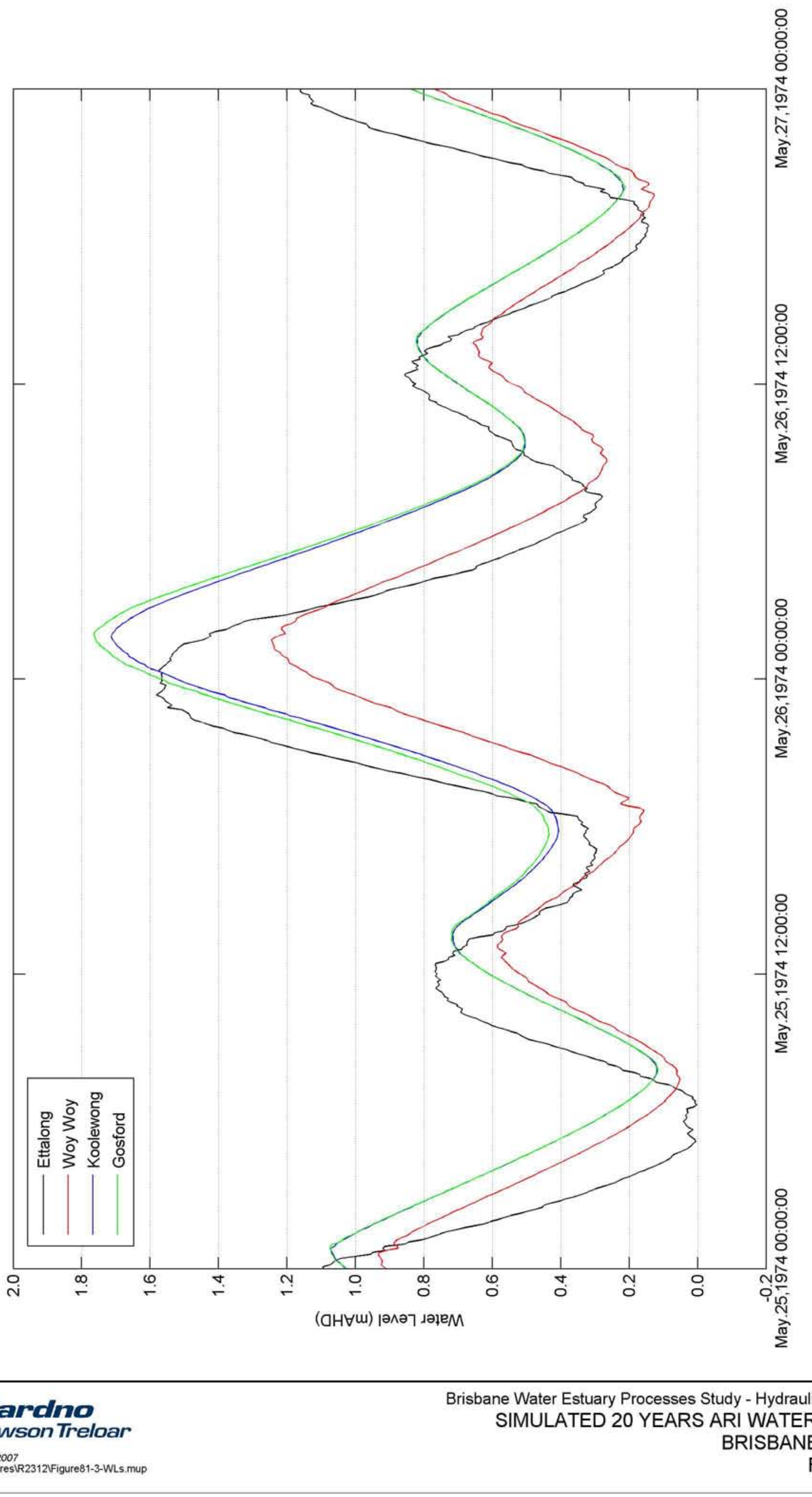
Brisbane Water Estuary Processes Study - Hydraulic Processes
SIMULATED 10 YEARS ARI WATER LEVELS
BRISBANE WATER
Figure 8.2



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SIMULATED 20 YEARS ARI WATER LEVELS
BRISBANE WATER

Figure 8.3

LJ2255/R2312 January 2007
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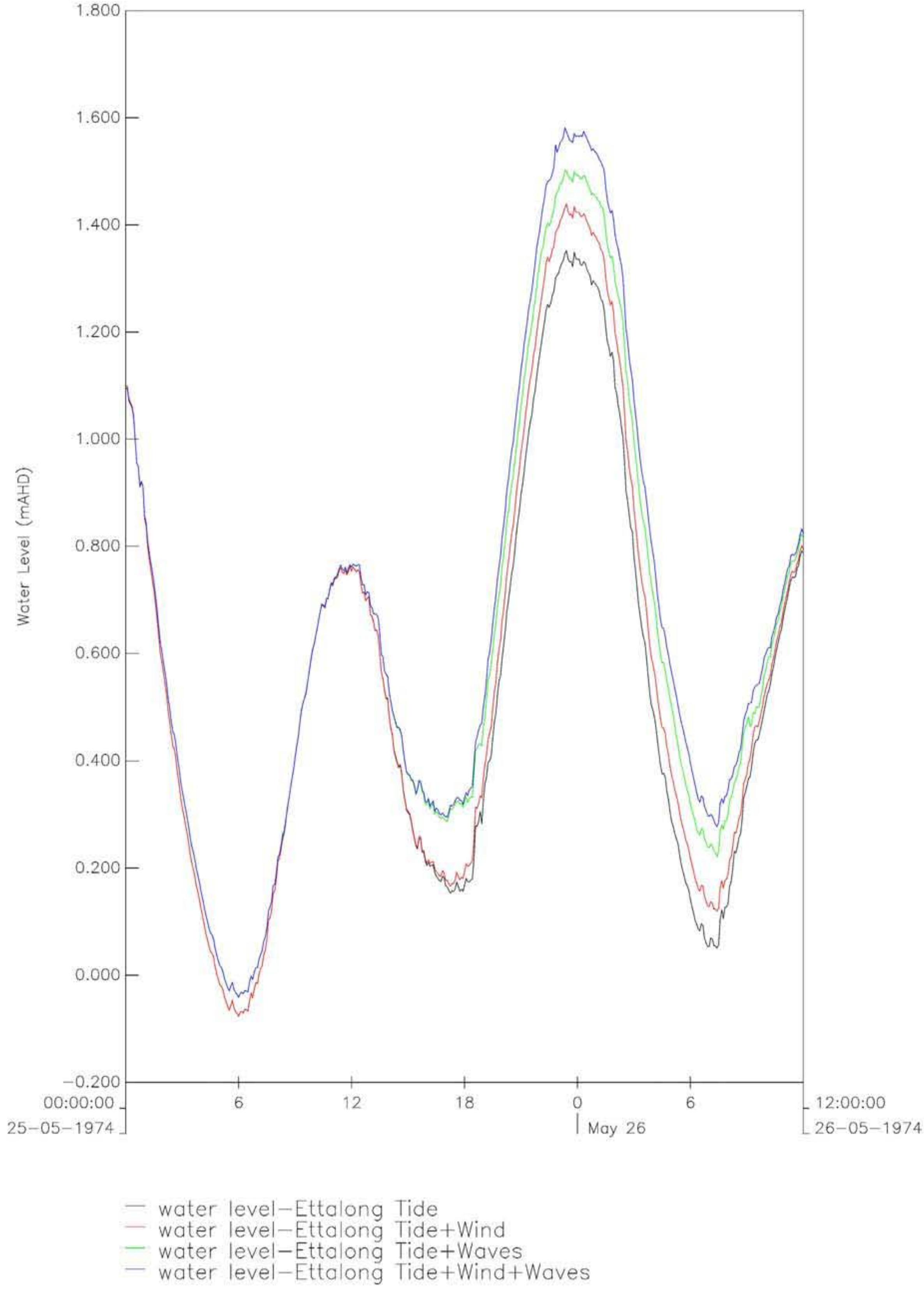

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J2255/R2312 January 2007
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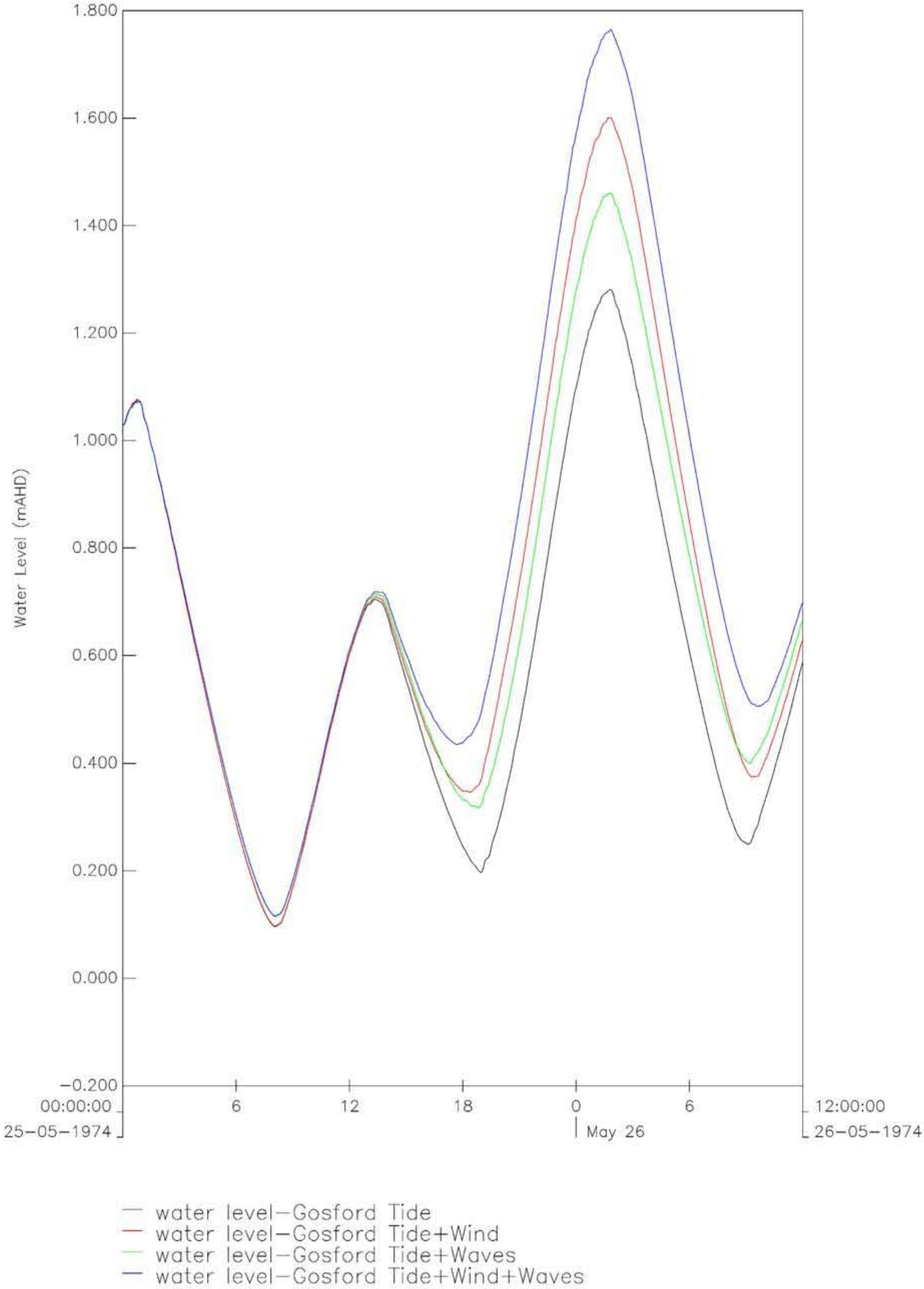
Brisbane Water Estuary Processes Study - Hydraulic Processes
SIMULATED MAY 1974 WATER LEVELS
ETTALONG
Figure 8.4



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J2255/R2312 January 2007
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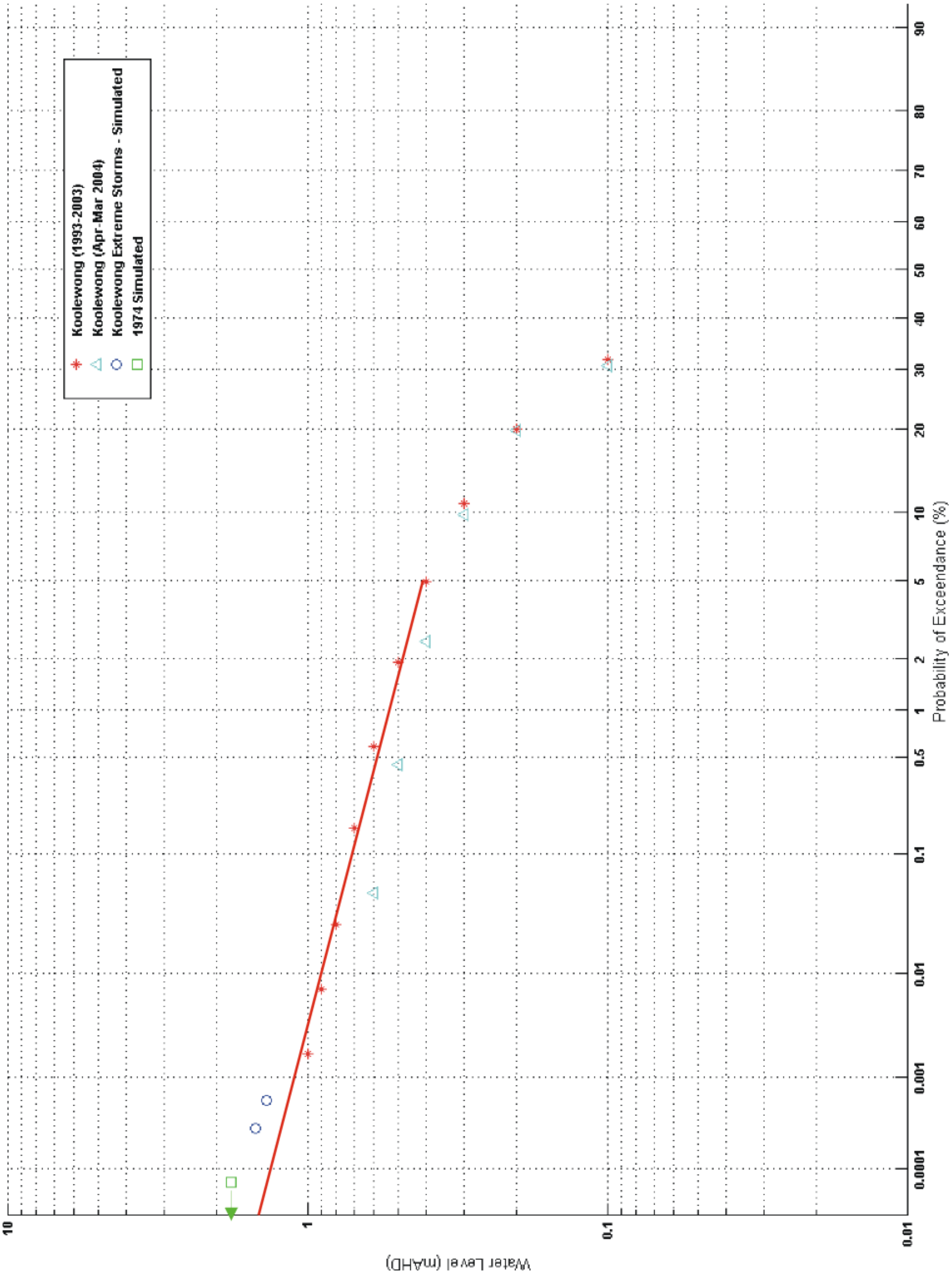
Brisbane Water Estuary Processes Study - Hydraulic Processes

SIMULATED MAY 1974 WATER LEVELS
GOSFORD

Figure 8.5



Brisbane Water Estuary Processes Study - Hydraulic Processes

KOOLEWONG WATER LEVEL CURVES

Figure 8.6

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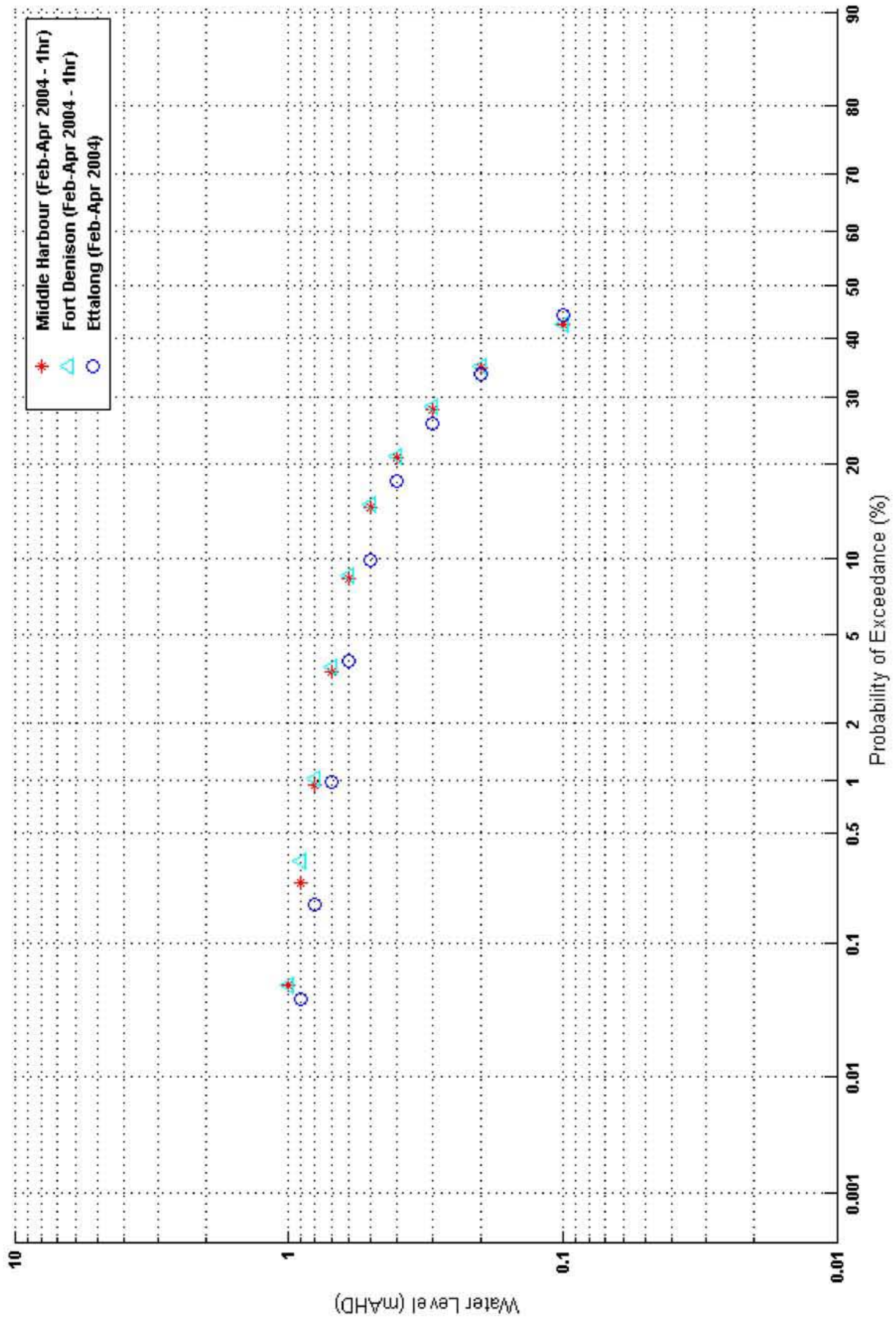

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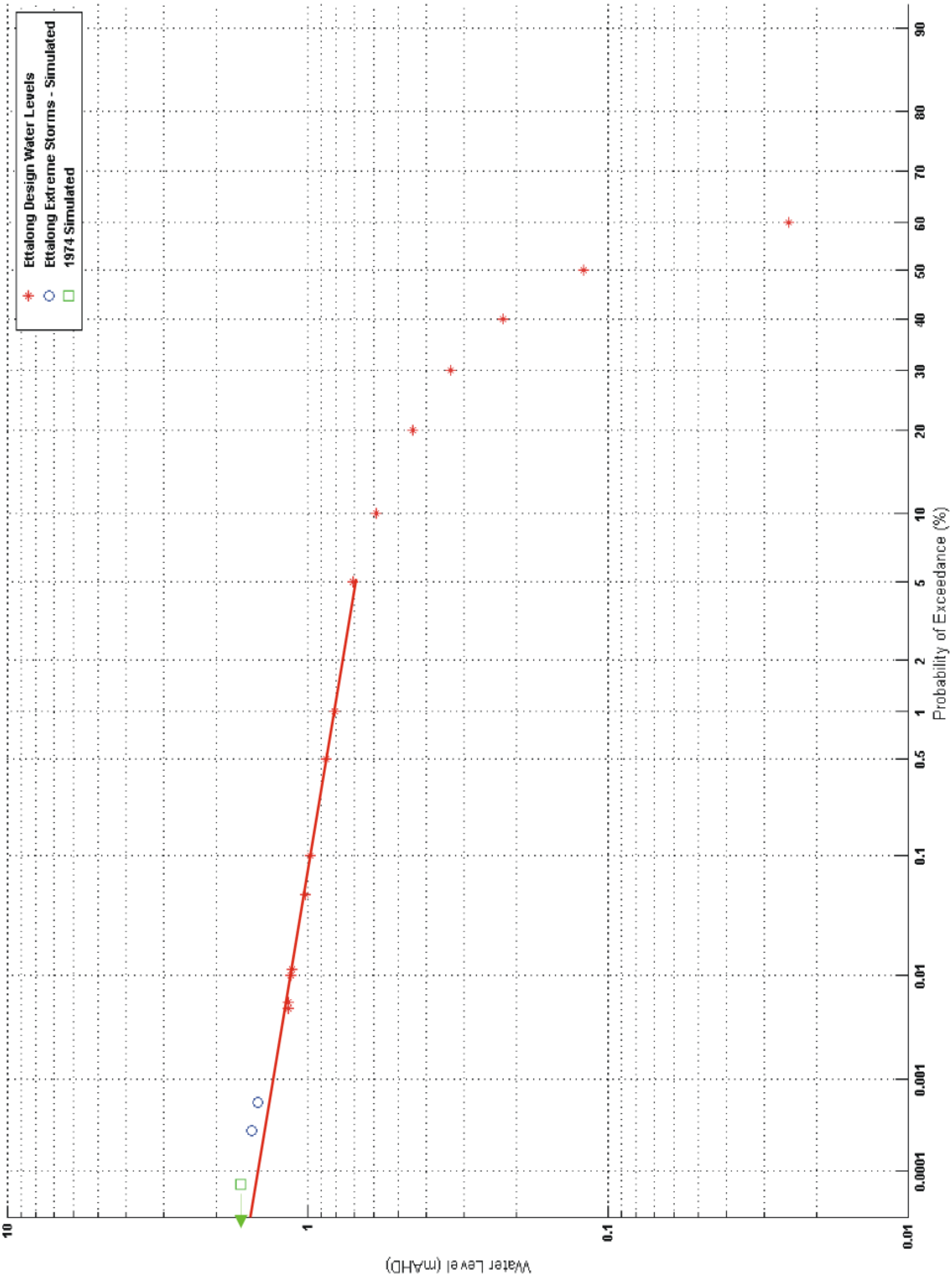
FORT DENISON, MIDDLE HARBOUR AND ETTALONG WATER LEVEL DISTRIBUTIONS

LJ2255/R2312 January 2007

File: J:\CM\J2255bw\Figures\R2310\Figure 8.7 - Sydney, MH and Ettalong.cdr

Figure 8.7



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Lawson Treloar

LJ2255/R2312 January 2007
File: J:\CM\J2255bw\Figures\R2310\Fig8.8_Ettalong_Design_WL.cdr

Brisbane Water Estuary Processes Study - Hydraulic Processes

ETTALONG DESIGN WATER LEVEL CURVES

Figure 8.8

Transect	Location	MSI
1	E	0.00296496
2	E	0.00331763
3	E	0.000916251
4	E	0.000816211
5	E	0.000800039
6	E	0.00158215
7	E	0.0023806
8	E	0.00747401
9	E	0.000725066
10	E	0.00133475
11	E	0.00102097
12	E	0.000548494
13	E	0.00122497
14	E	0.00136189
15	E	0.00550991
16	E	0.00261144
17	E	0.000685026
18	E	0.000842677
19	E	0.00035802
20	E	0.00152215
21	E	0.000795295
22	E	0.000970349
23	E	0.00116004
1	W	0.0040375
2	W	0.00190116
3	W	0.00326319
4	W	0.00130901
5	W	0.00150366
6	W	0.00179265
7	W	0.00190313
8	W	0.00640969
9	W	0.00088777
10	W	0.000732459
11	W	0.00117234
12	W	0.00251571
13	W	0.00252783
14	W	0.00161703
15	W	0.00154849
16	W	0.00264641
17	W	0.000782464
18	W	0.00205584
19	W	0.0021356
20	W	0.00309107
21	W	0.00222441
22	W	0.000341048
23	W	0.000623049

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Brisbane Water Estuary Processes Study - Hydraulic Processes

MAXIMUM SHEAR INDEX - 9 MARCH 2004

Figure 9.1

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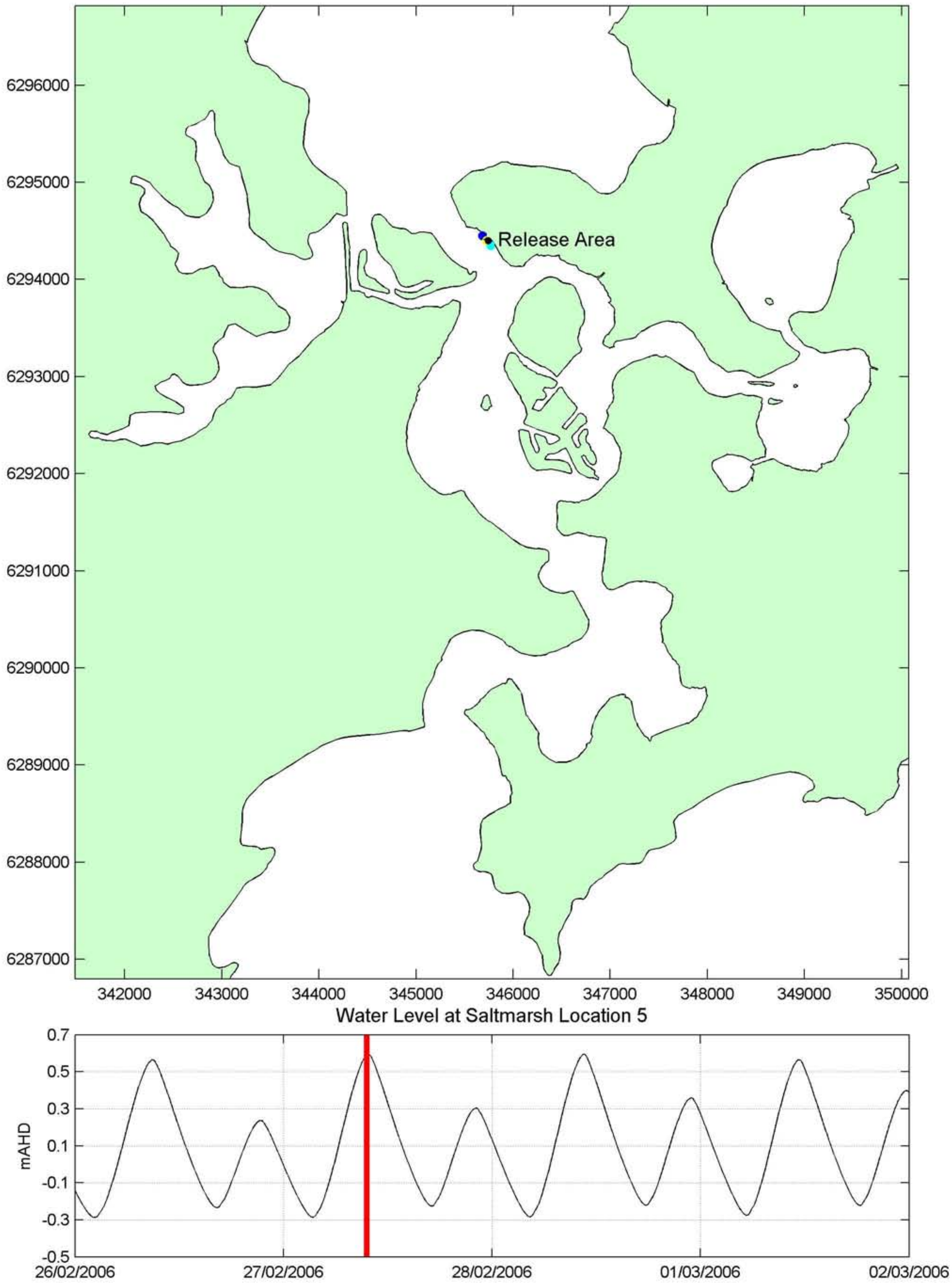
Brisbane Water Estuary Processes Study - Hydraulic Processes

MAXIMUM SHEAR INDEX - 9 MARCH 2004

J2255/R2312 January 2007
J/CM/J2255bw/Figures/R2312/Figure 9.2.Wor

Figure 9.2



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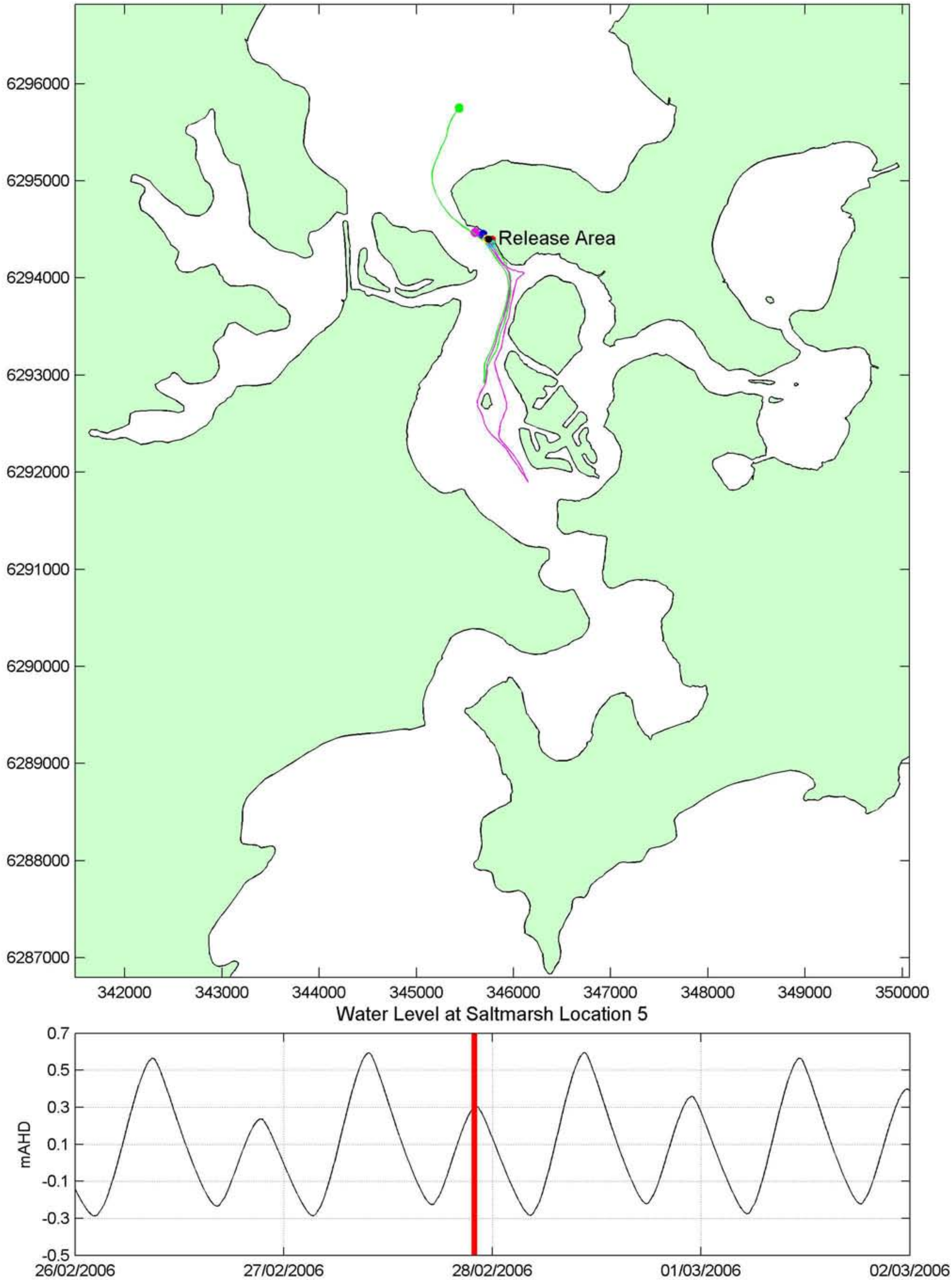
LARVAE MOVEMENTS FROM SALTMARSH LOCATION 5

Figure 9.3a



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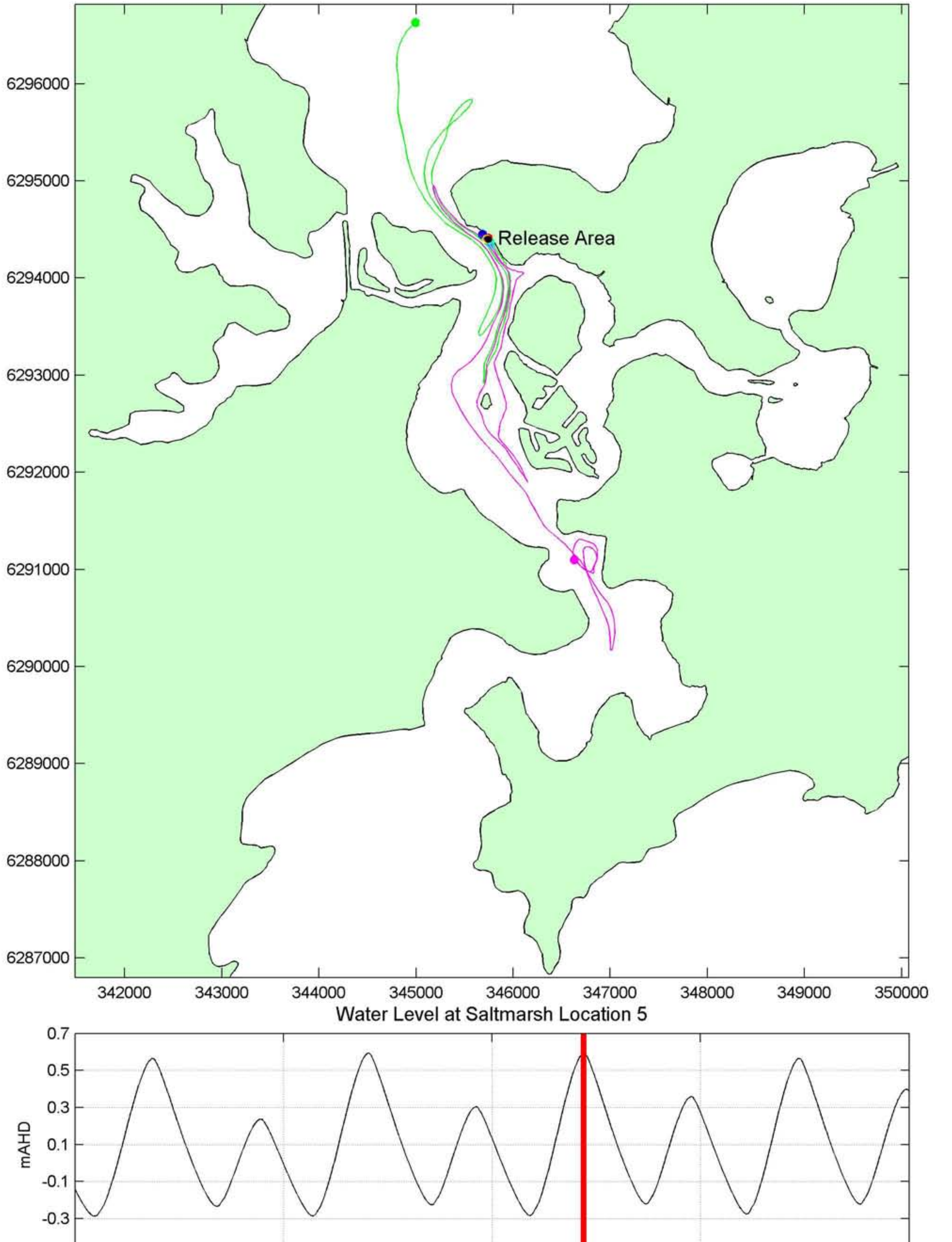
Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 5

LJ2255/R2312 January 2006

J/CM/J2255bw/Figures/R2312/Figure 9.3b.png

Figure 9.3b



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Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 5

LJ2255/R2312 January 2006

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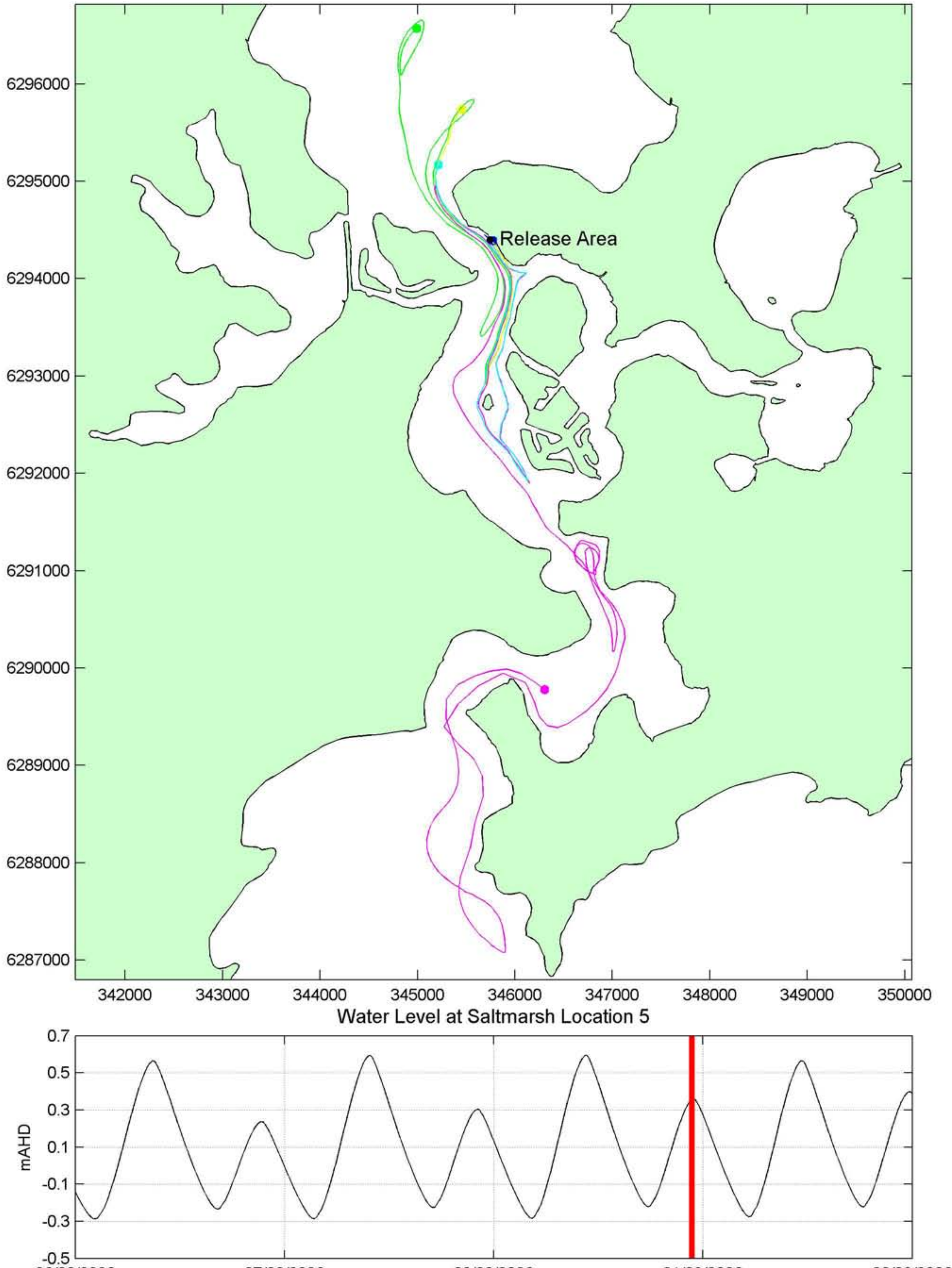
Figure 9.3c



Cardno Lawson Treloar

Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 5

LJ2255/R2312 January 2006

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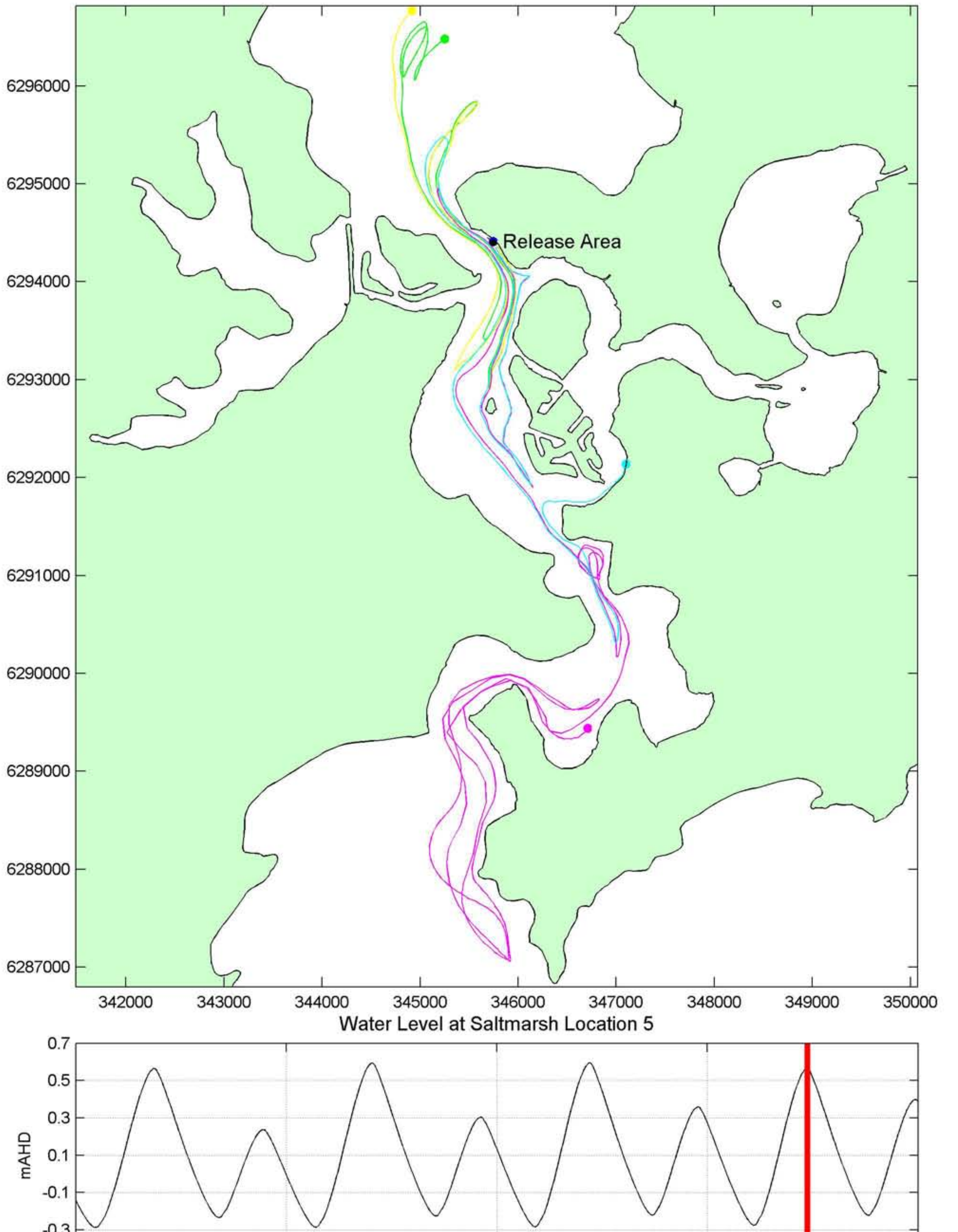
Figure 9.3d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346000
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349000
350000
Water Level at Saltmarsh Location 5
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0.3
0.1
-0.1
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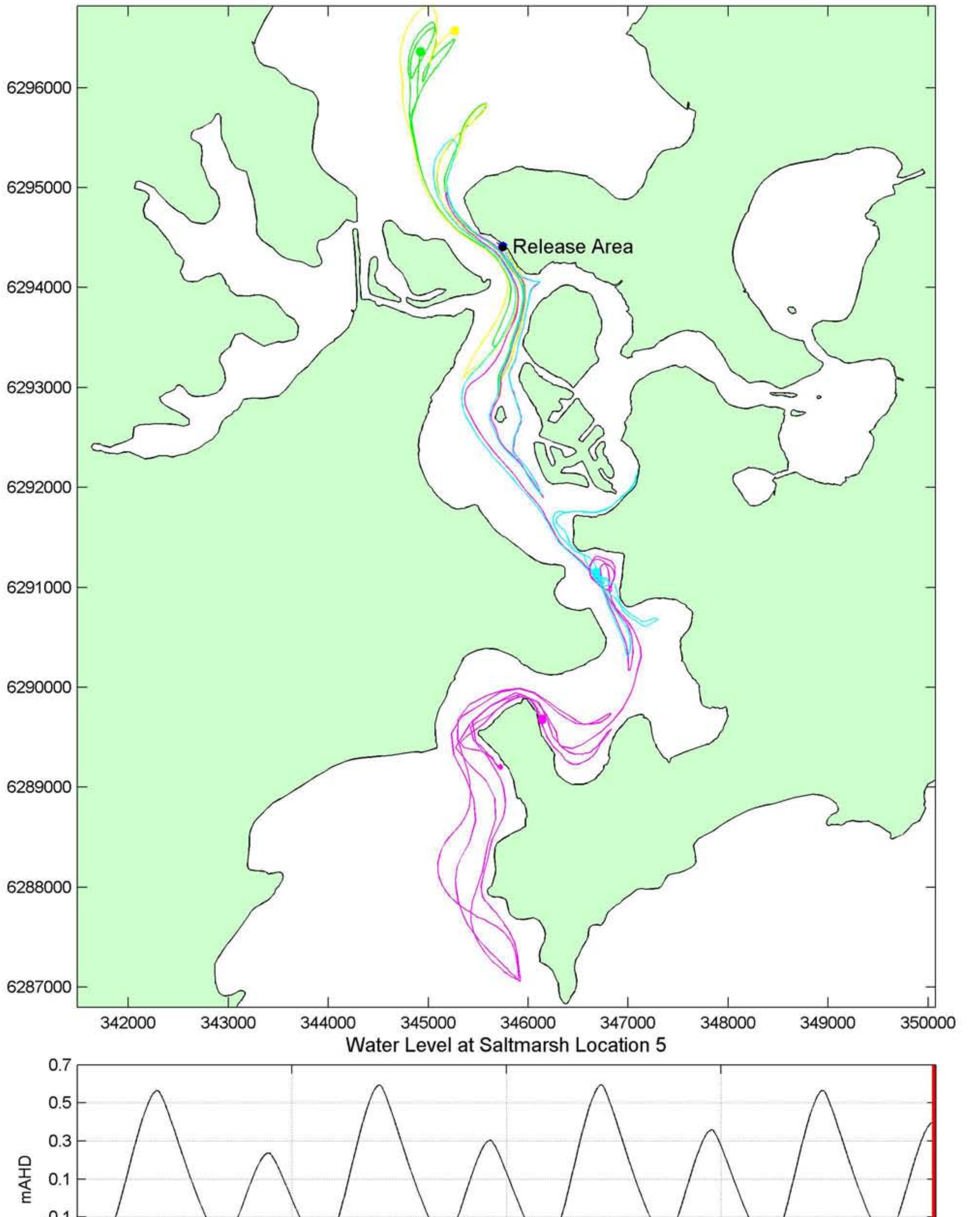
mAHD
26/02/2006
27/02/2006
28/02/2006
01/03/2006
02/03/2006

Figure 9.3e



Cardno Lawson Treloar

Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 5

LJ2255/R2312 January 2006

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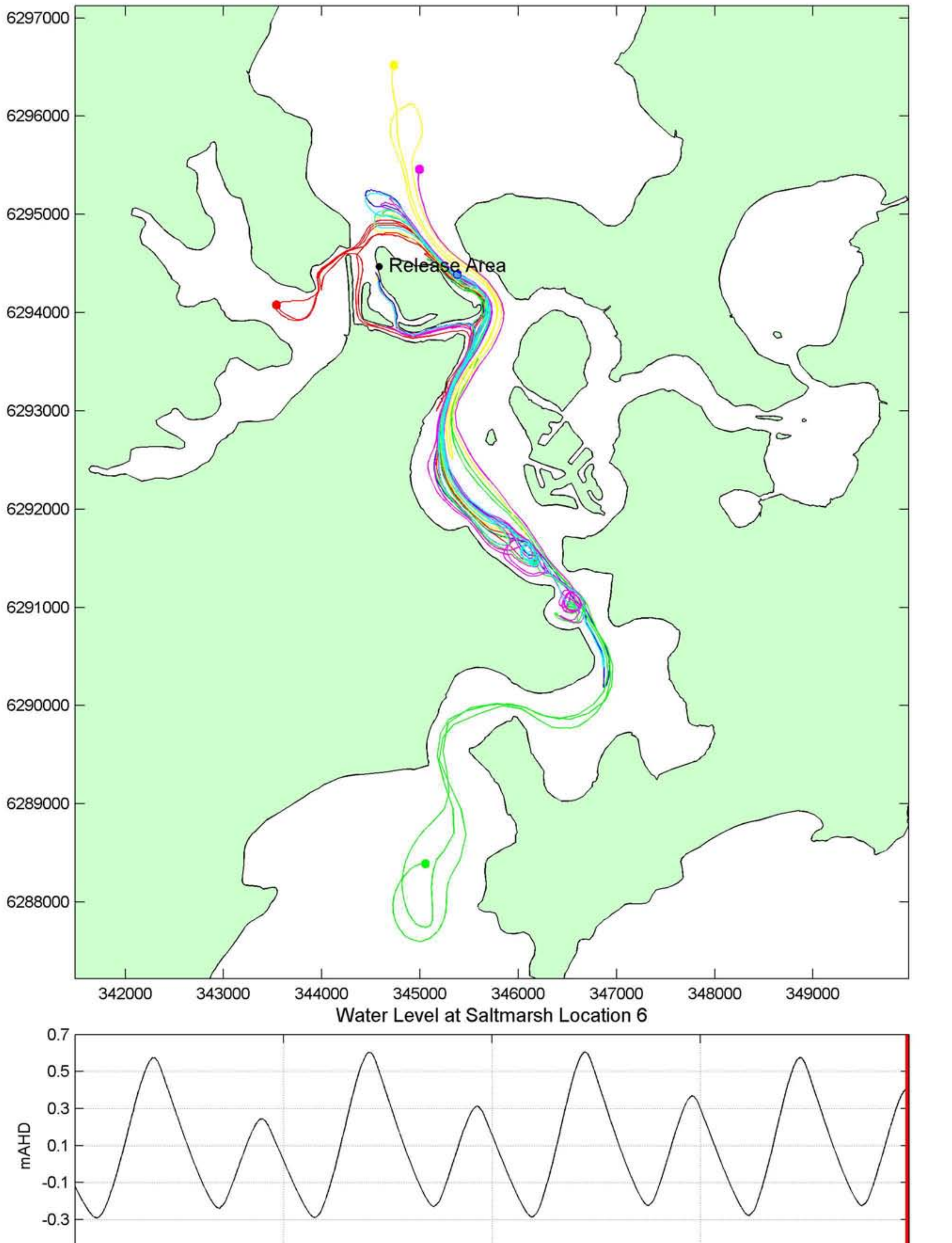

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Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 6

LJ2255/R2312 January 2006
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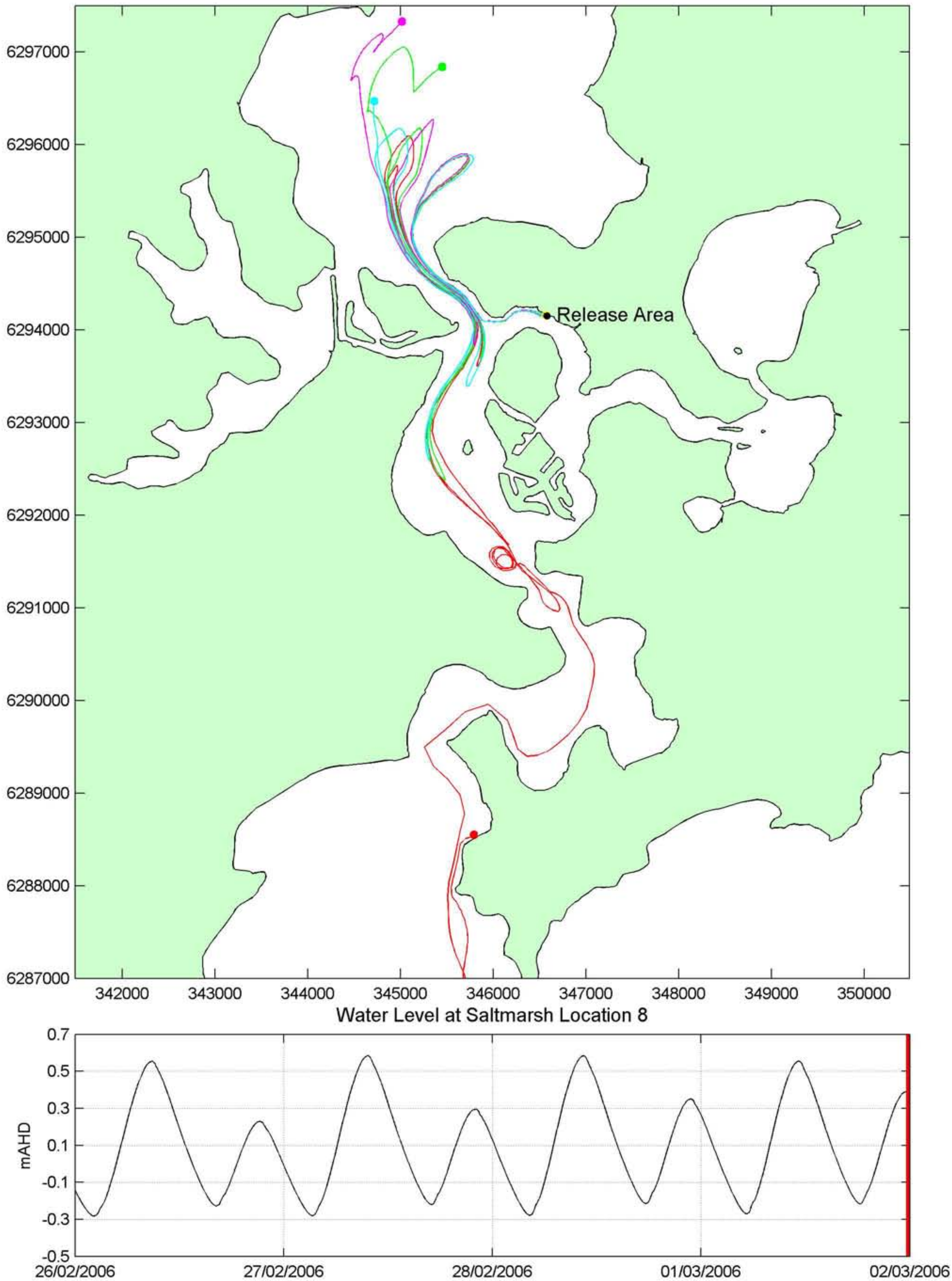
Figure 9.4



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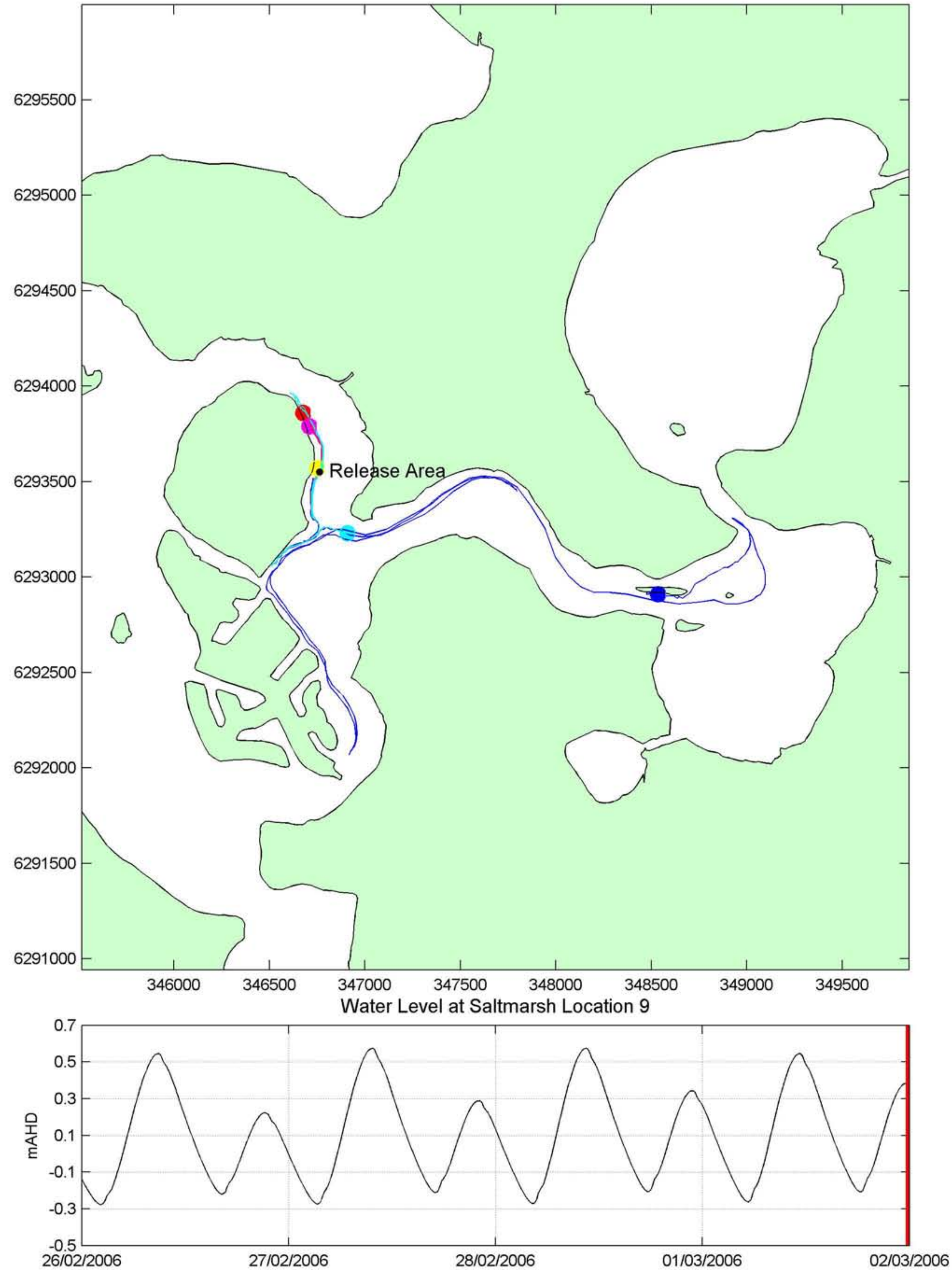
Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 8

Figure 9.5

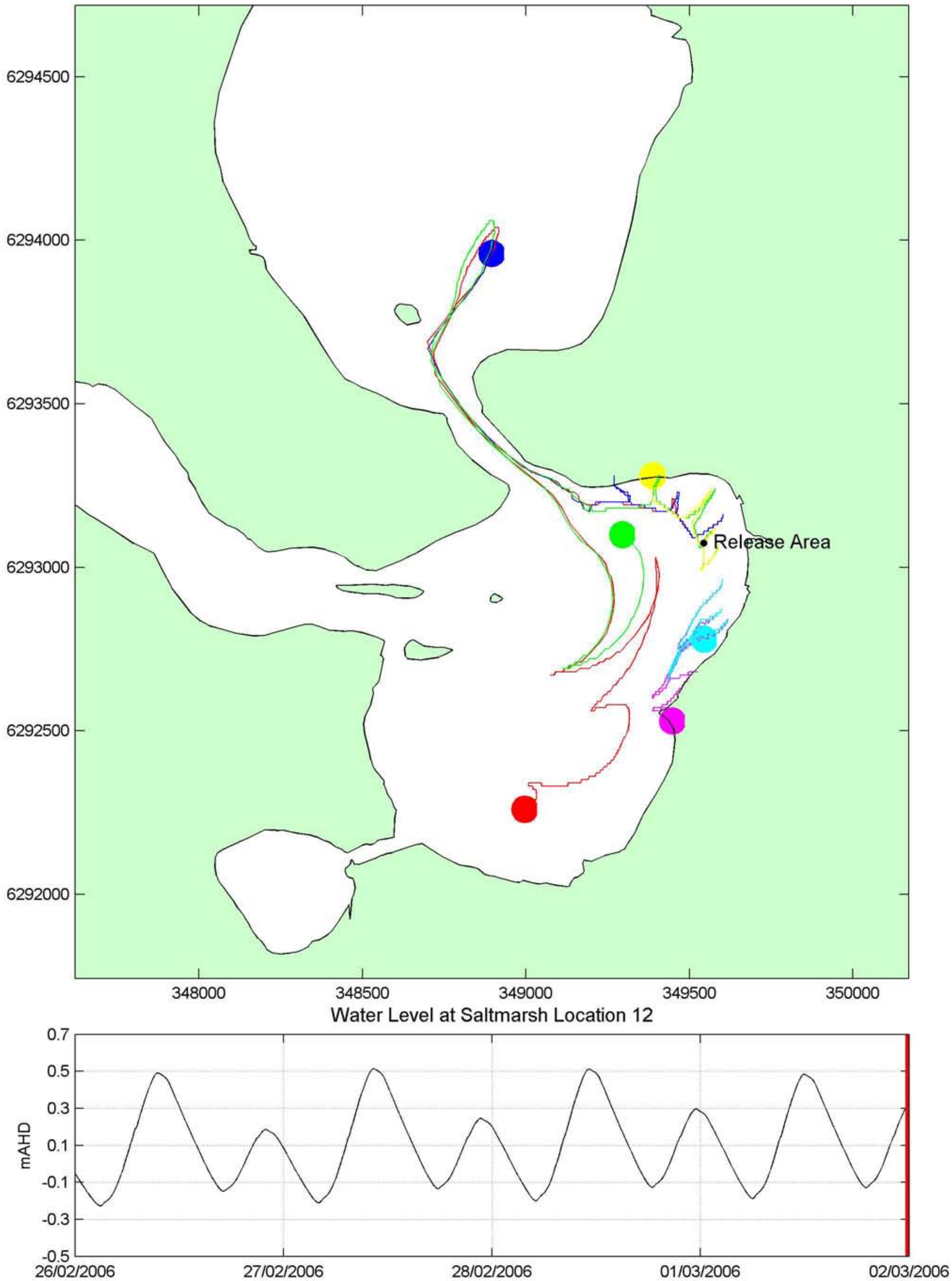


Cardno Lawson Treloar

Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 9

Figure 9.6



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Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 12

LJ2255/R2312 January 2006

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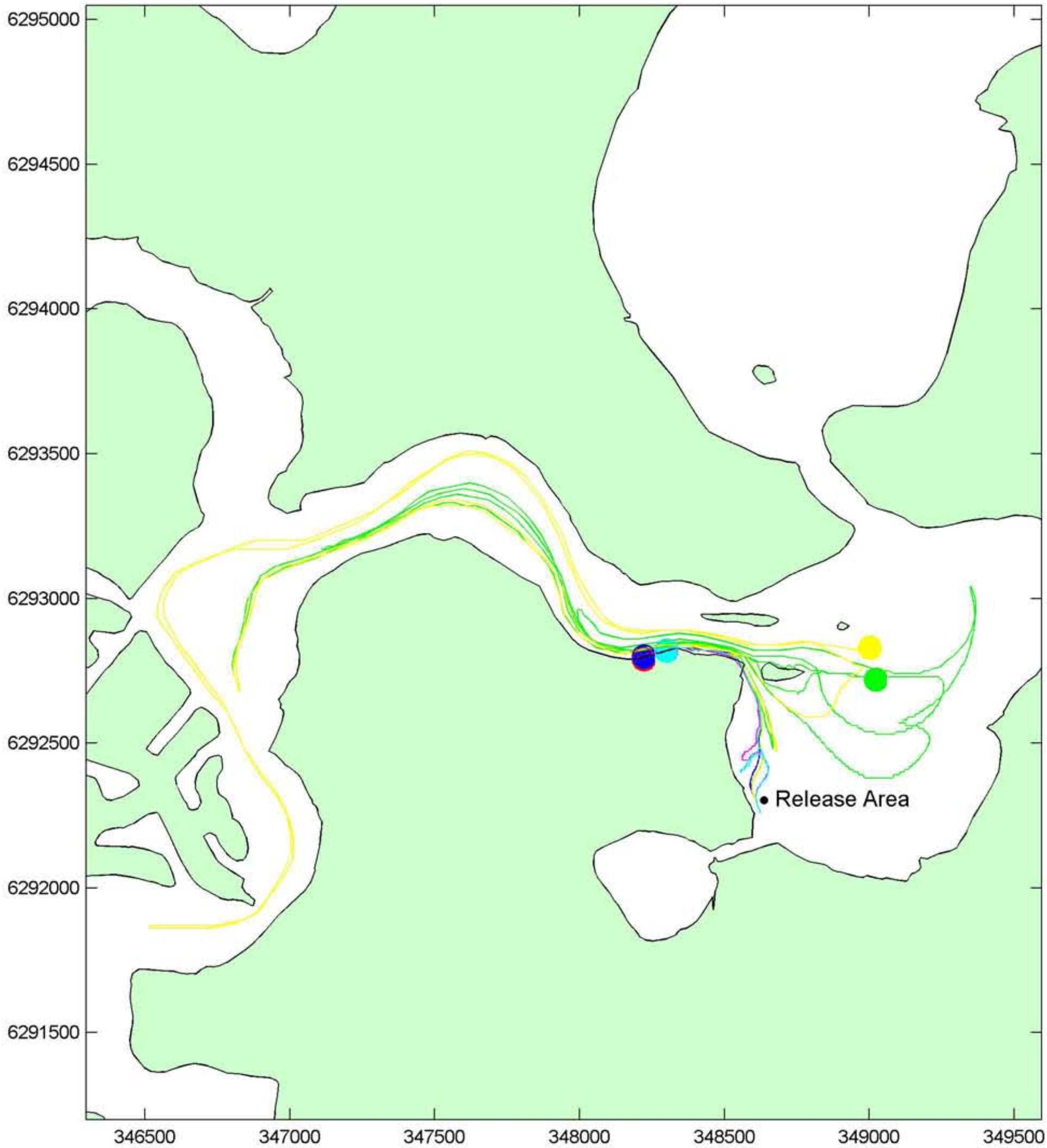
Figure 9.7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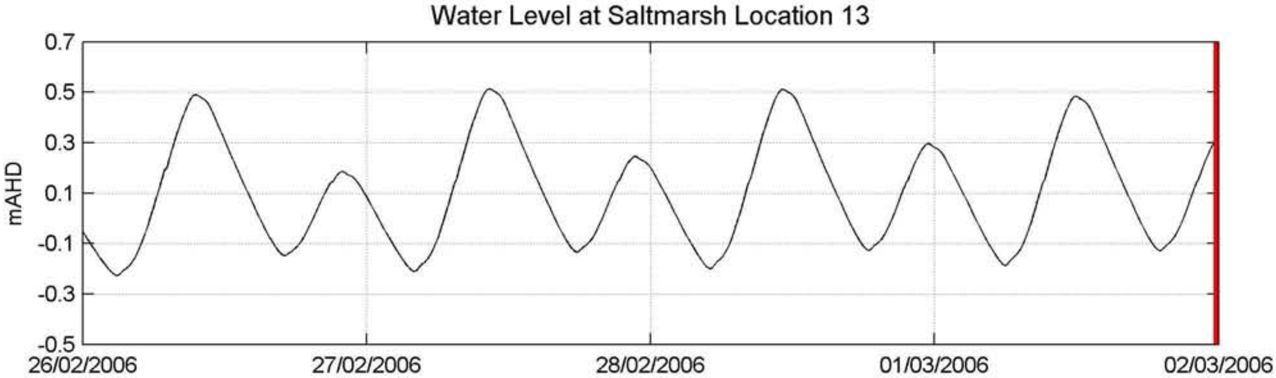
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0.1
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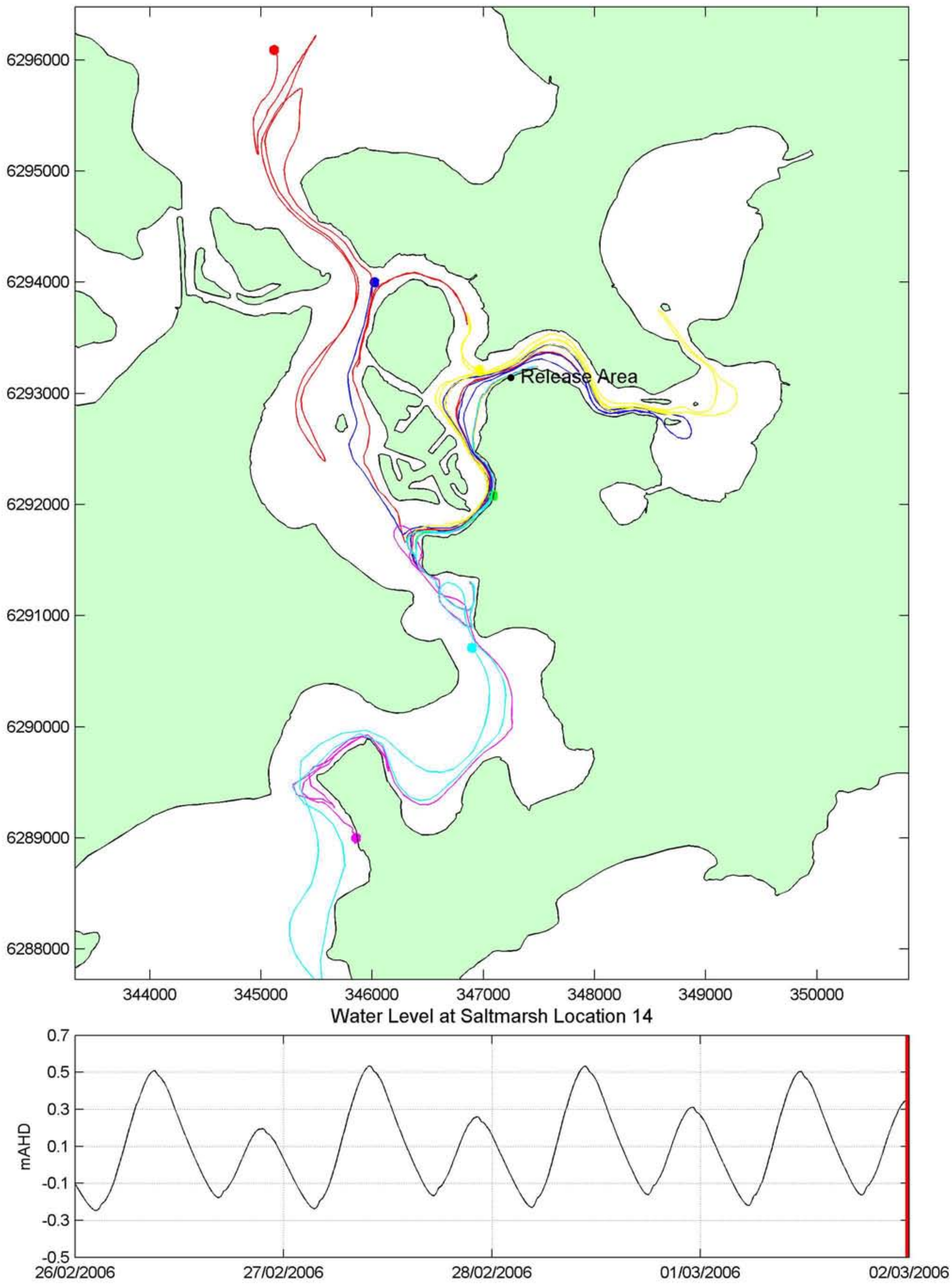
26/02/2006
27/02/2006
28/02/2006
01/03/2006
02/03/2006

Figure 9.8



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Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE MOVEMENTS FROM SALTMARSH LOCATION 14

LJ2255/R2312 January 2006

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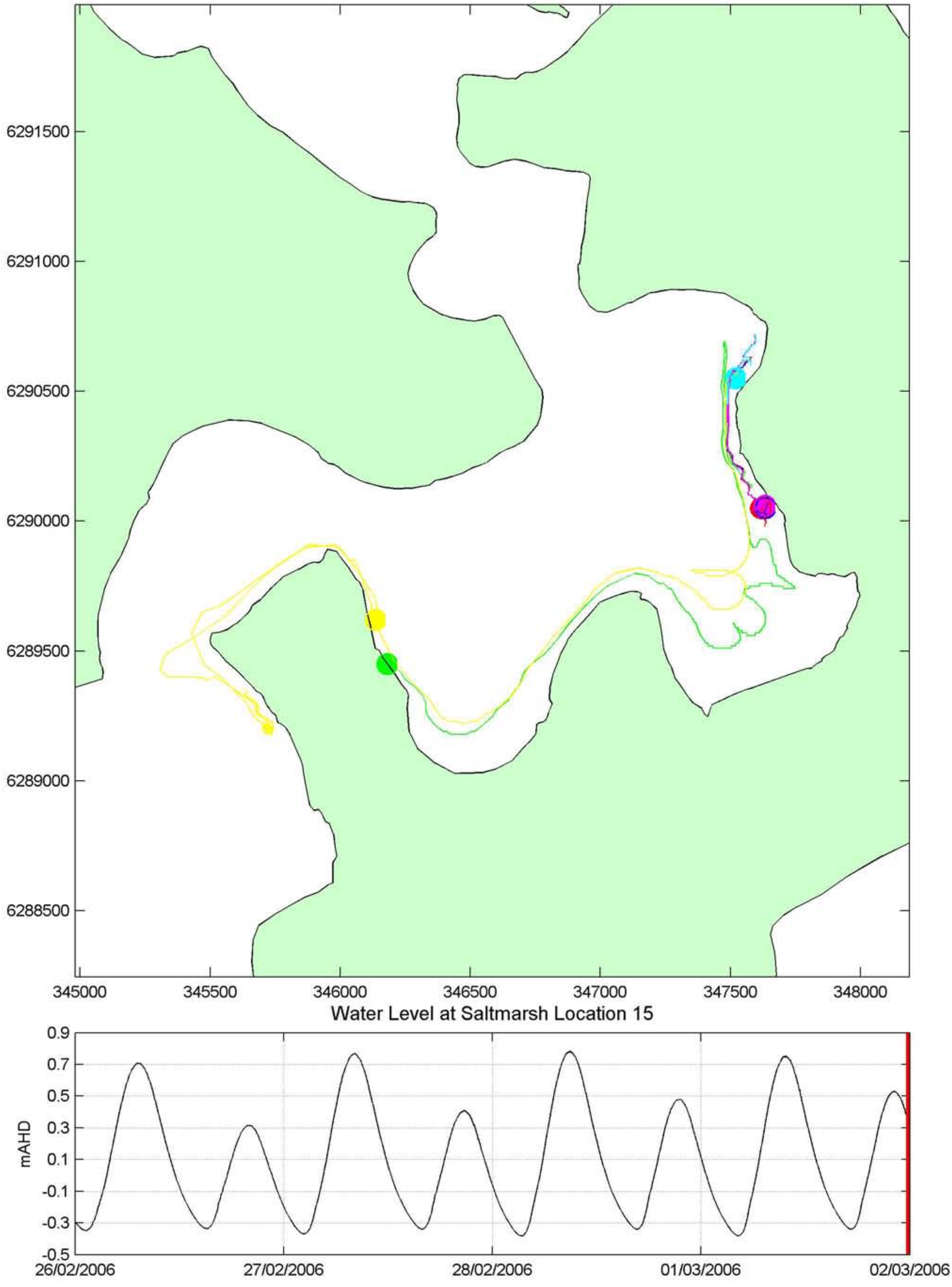
Figure 9.9



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348000
Water Level at Saltmarsh Location 15
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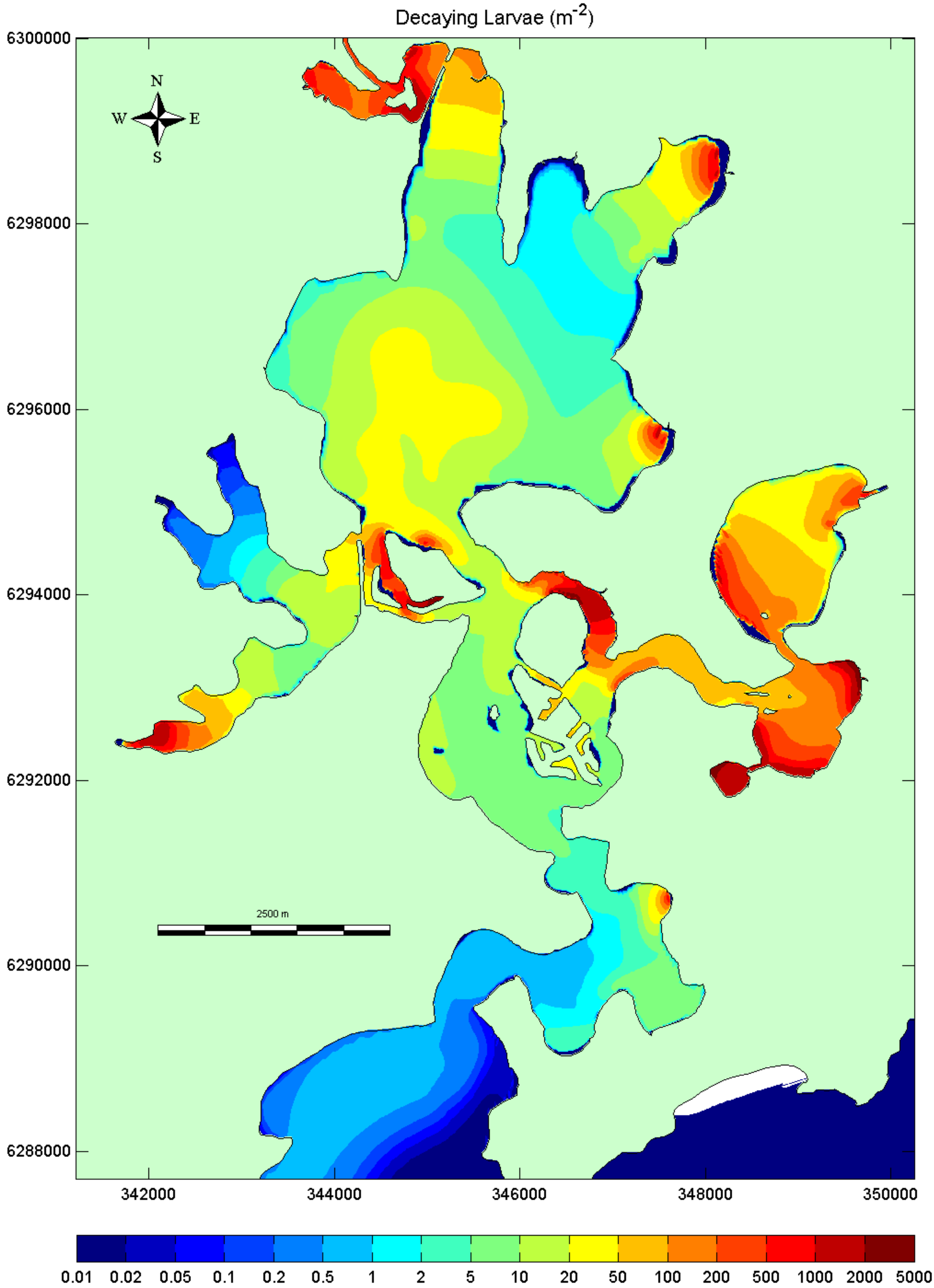
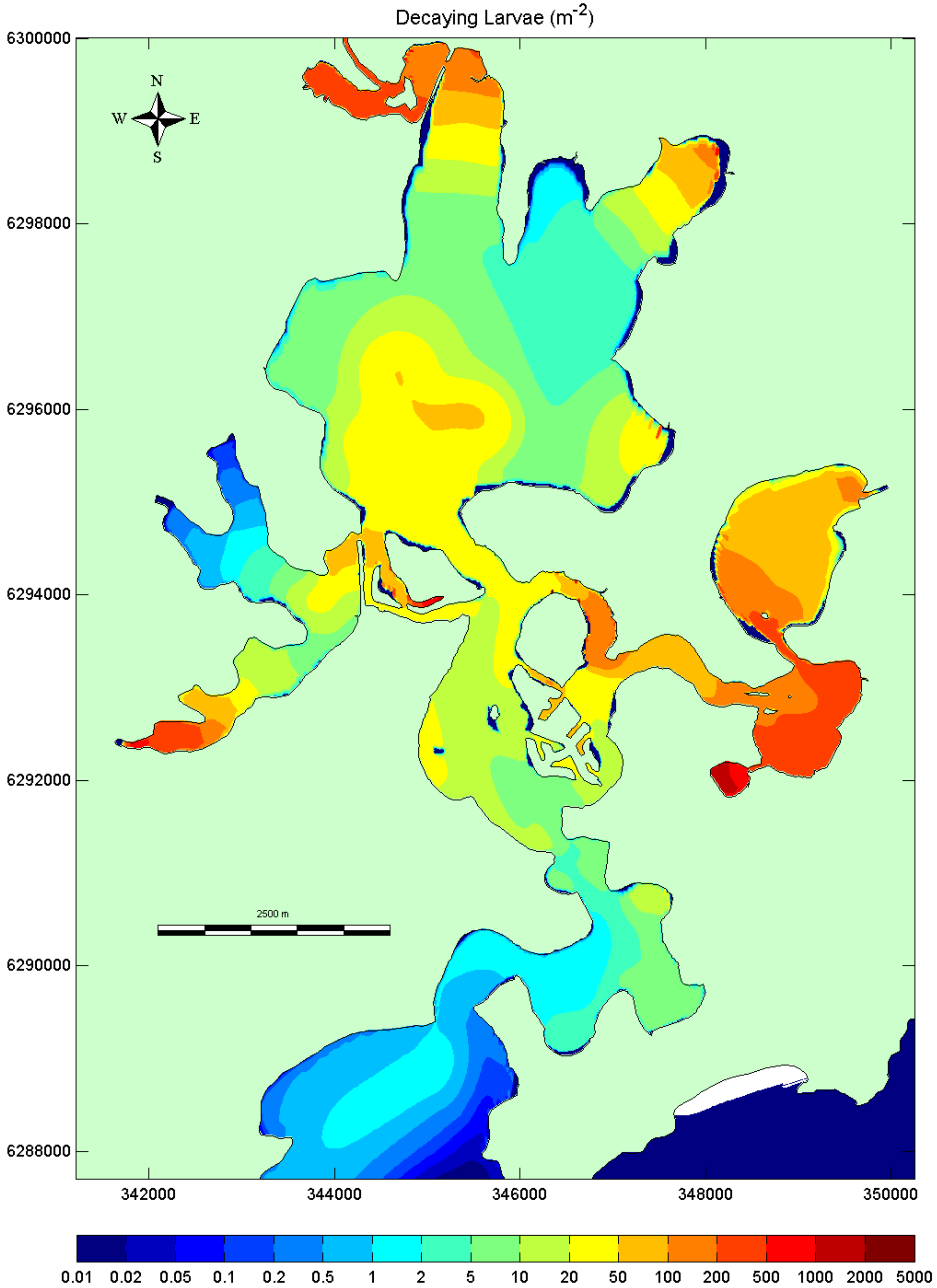
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
mAHD
26/02/2006
27/02/2006
28/02/2006
01/03/2006
02/03/2006

Figure 9.10



Brisbane Water Estuary Processes Study - Hydraulic Processes
LARVAE TRANSPORT - DECAYING TRACER MODELLING
HOUR: 0
Figure 9.11



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LJ2255/R2312 January 2006

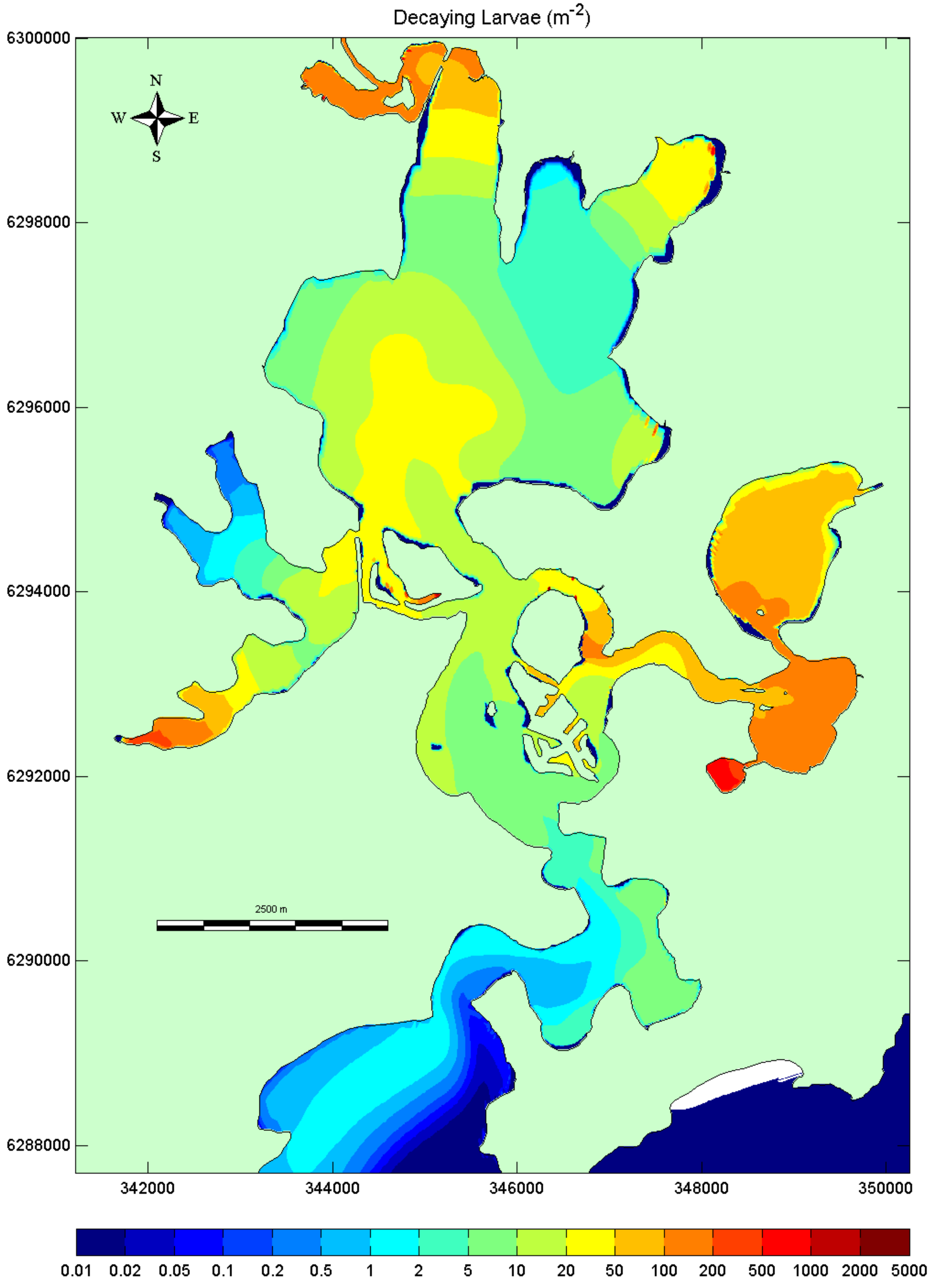
J/CM/J2255bw/Figures/R2312/Figure9.12.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE TRANSPORT - DECAYING TRACER MODELLING

HOUR: 12

Figure 9.12



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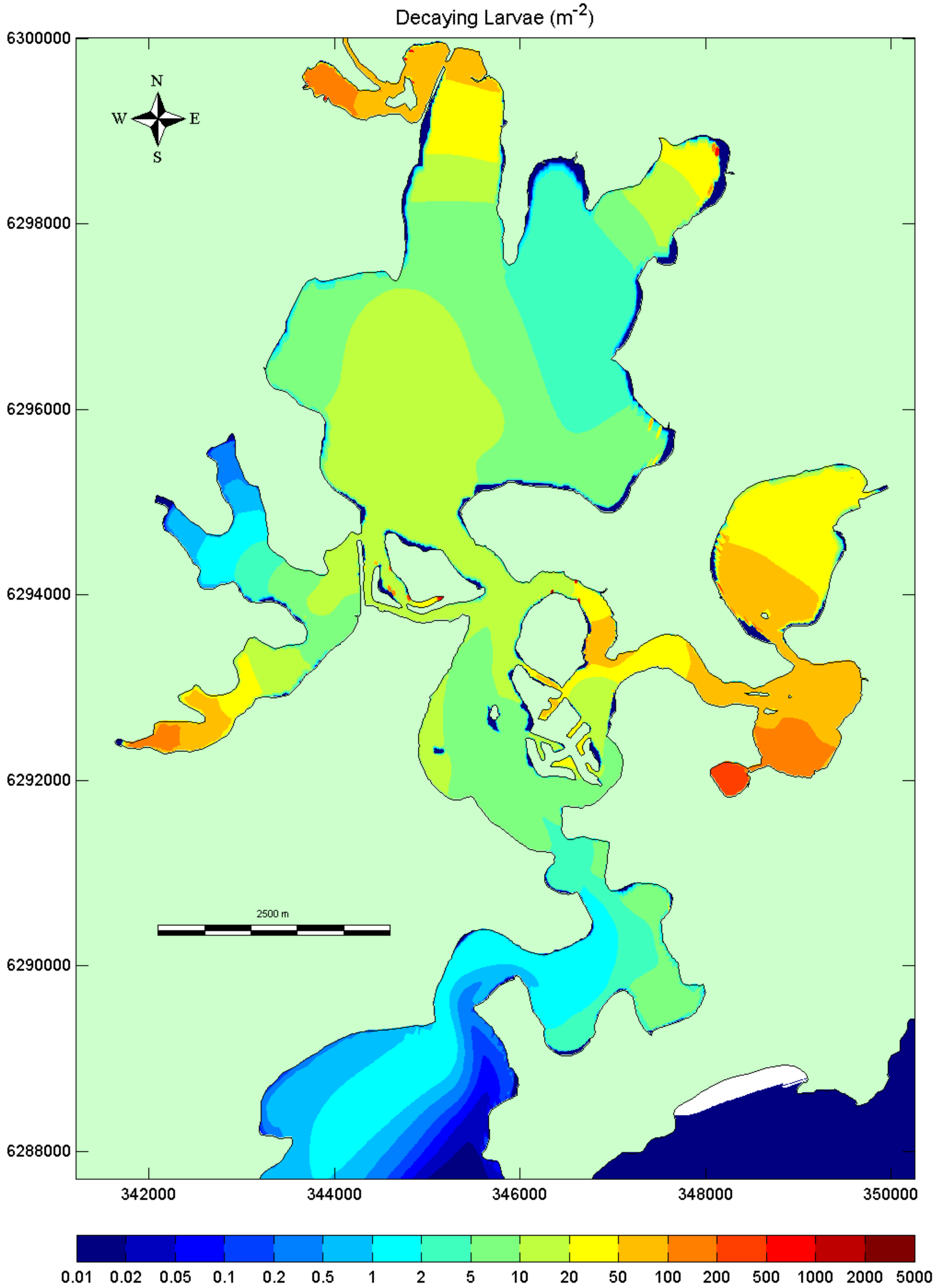
Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE TRANSPORT - DECAYING TRACER MODELLING

HOUR: 24

Figure 9.13



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LJ2255/R2312 January 2006

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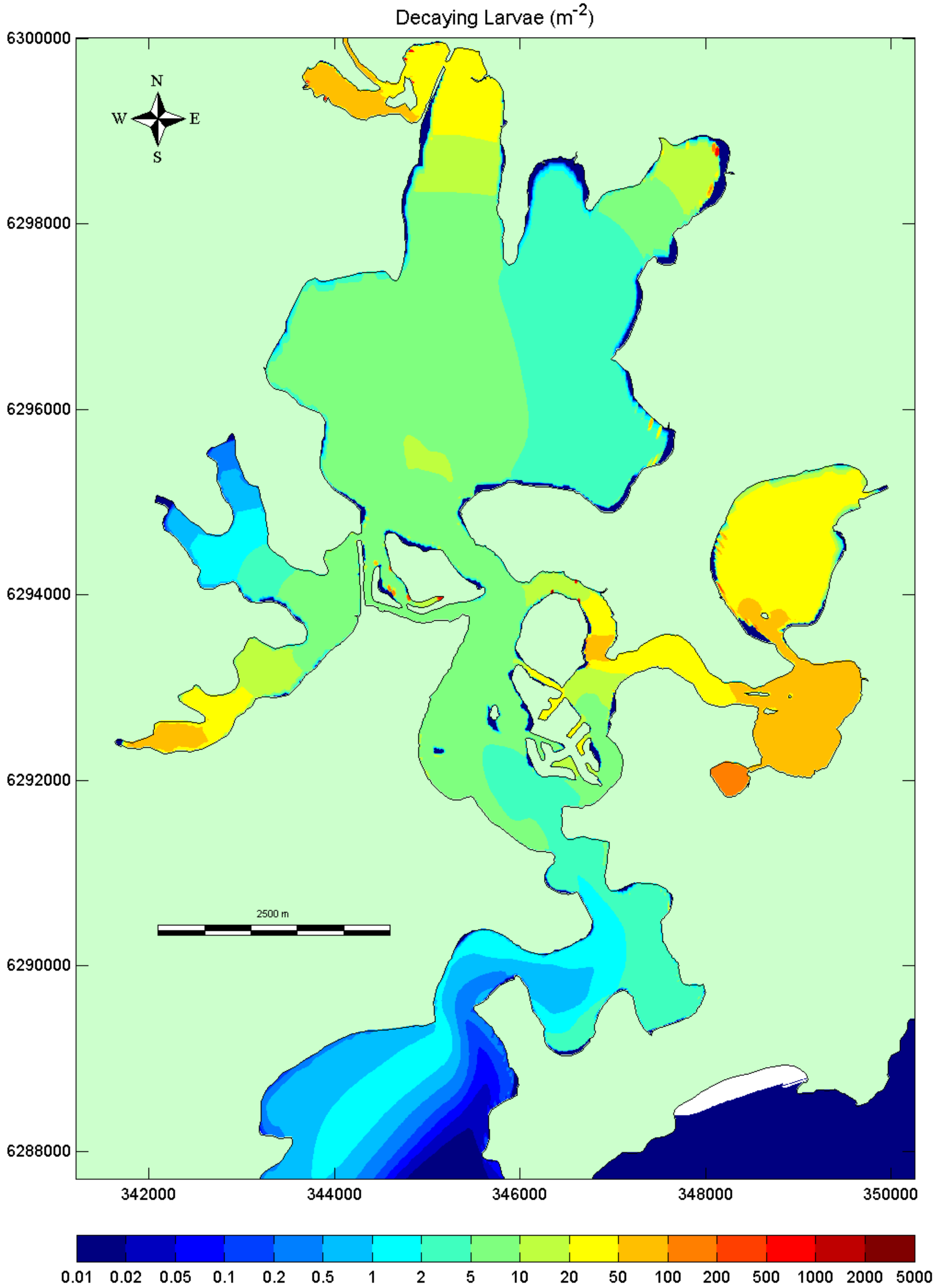
Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE TRANSPORT - DECAYING TRACER MODELLING

HOUR: 36

Figure 9.14



Cardno Lawson Treloar

LJ2255/R2312 January 2006

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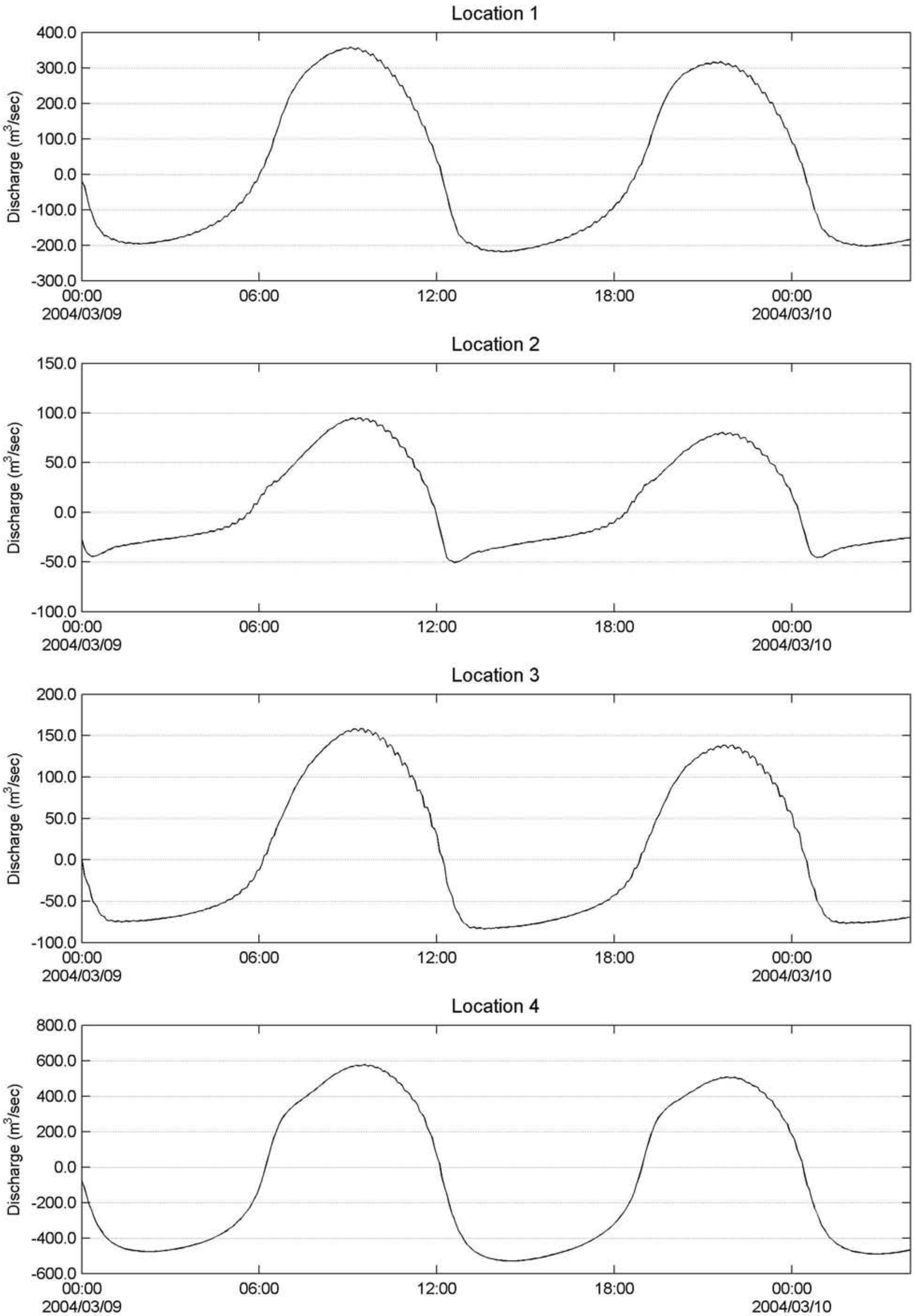
Brisbane Water Estuary Processes Study - Hydraulic Processes

LARVAE TRANSPORT - DECAYING TRACER MODELLING

HOUR: 48

Figure 9.15



Cardno Lawson Treloar

LJ2255/R2312 January 2006
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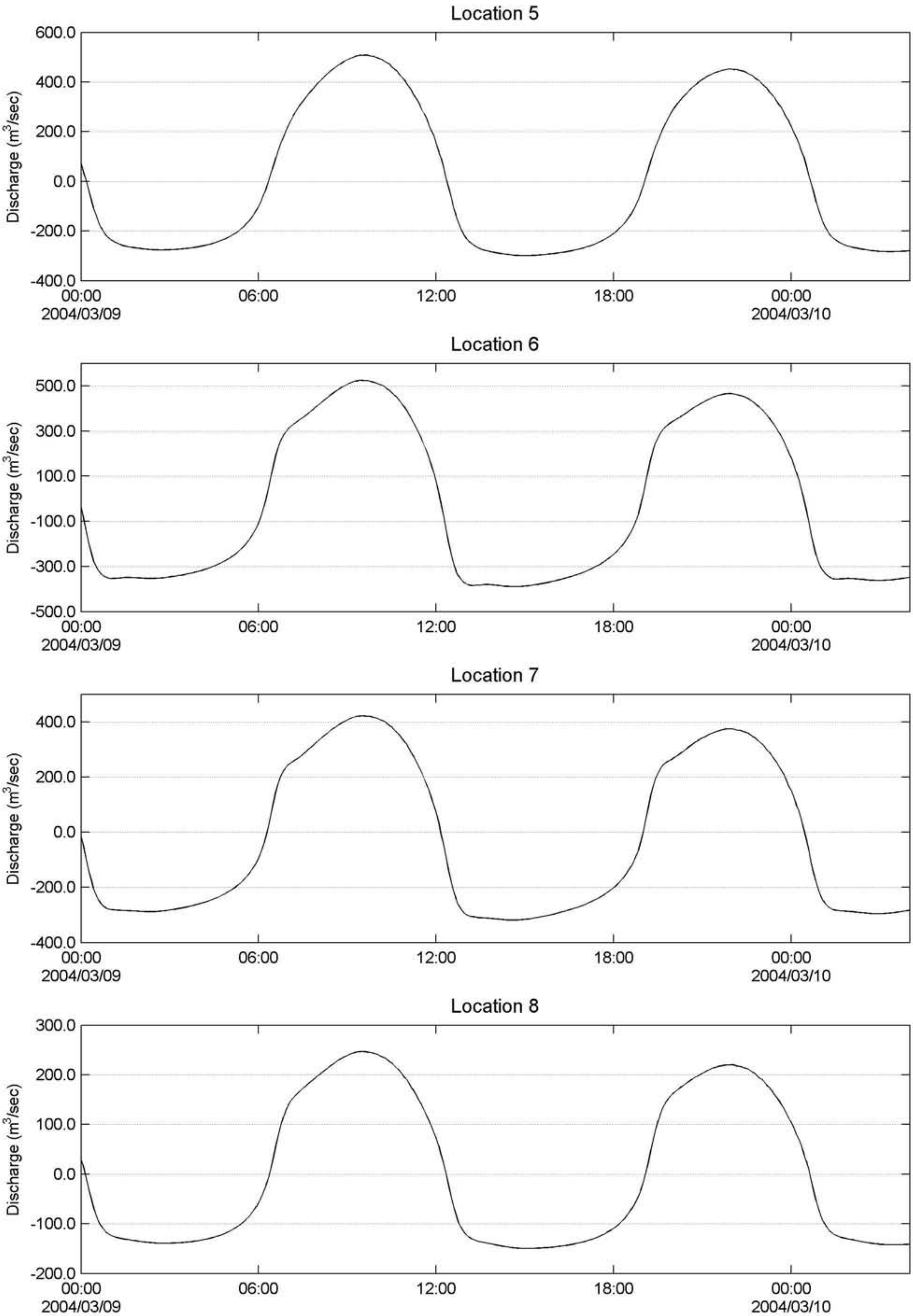
Brisbane Water Estuary Processes Study - Hydraulic Processes
SPRING TIDE DISCHARGE TIMESERIES
LOCATIONS 1 - 4
Figure 9.16



Cardno
Lawson Treloar

LJ2255/R2312 January 2006
File: J:\CM\J2255bw\Figures\R2312\Muppet-plots\Figures_911-12.mup

Brisbane Water Estuary Processes Study - Hydraulic Processes
SPRING TIDE DISCHARGE TIMESERIES
LOCATIONS 5 - 8
Figure 9.17

APPENDIX 1

Tidal Plane and Range Data
(from Manly Hydraulics Laboratory Report MHL1319)

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Woy Woy Inlet
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 16 (m AHD)
HHW(SS)	0.980	0.796	0.736	0.610	0.623	0.614
MHWS	0.646	0.519	0.471	0.369	0.384	0.376
MHW	0.518	0.435	0.400	0.318	0.331	0.322
MHWN	0.389	0.350	0.329	0.267	0.278	0.269
MTL	0.016	0.077	0.089	0.071	0.076	0.068
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.133
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.186
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.240
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.410

Table 2.1: Comparison of Tidal Planes – Woy Woy Inlet

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Narara Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 20 (m AHD)	Site 22 (m AHD)
HHW(SS)	0.980	0.796	0.736	0.610	0.623	0.621	0.727
MHWS	0.646	0.519	0.471	0.369	0.384	0.385	0.362
MHW	0.518	0.435	0.400	0.318	0.331	0.333	0.325
MHWN	0.389	0.350	0.329	0.267	0.278	0.280	0.288
MTL	0.016	0.077	0.089	0.071	0.076	0.089	0.077
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.102	-0.133
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.155	-0.171
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.207	-0.208
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.375	-0.469

Table 2.2: Comparison of Tidal Planes – Narara Creek

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water				Erina Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 10 (m AHD)	Site 18 (m AHD)
HHW(SS)	0.980	0.796	0.736	0.610	0.623	0.628	0.644
MHWS	0.646	0.519	0.471	0.369	0.384	0.391	0.398
MHW	0.518	0.435	0.400	0.318	0.331	0.338	0.343
MHWN	0.389	0.350	0.329	0.267	0.278	0.285	0.288
MTL	0.016	0.077	0.089	0.071	0.076	0.081	0.082
MLWN	-0.357	-0.196	-0.150	-0.124	-0.126	-0.123	-0.125
MLW	-0.485	-0.280	-0.221	-0.175	-0.179	-0.176	-0.180
MLWS	-0.614	-0.364	-0.292	-0.227	-0.232	-0.229	-0.235
ISLW	-0.852	-0.562	-0.482	-0.398	-0.403	-0.398	-0.410

Table 2.3: Comparison of Tidal Planes – Erina Creek

Tidal Planes	Ocean Site 0 (m AHD)	Brisbane Water			Kincumber Broadwater	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 11 (m AHD)	Site 14 (m AHD)
HHW(SS)	0.980	0.796	0.736	0.610	0.558	0.508
MHWS	0.646	0.519	0.471	0.369	0.334	0.293
MHW	0.518	0.435	0.400	0.318	0.293	0.257
MHWN	0.389	0.350	0.329	0.267	0.252	0.221
MTL	0.016	0.077	0.089	0.071	0.088	0.065
MLWN	-0.357	-0.196	-0.150	-0.124	-0.075	-0.092
MLW	-0.485	-0.280	-0.221	-0.175	-0.116	-0.128
MLWS	-0.614	-0.364	-0.292	-0.227	-0.157	-0.163
ISLW	-0.852	-0.562	-0.482	-0.398	-0.318	-0.317

* Note: Data from Site 14 was only available for a shorter period of time due to instrument malfunction

Table 2.4: Comparison of Tidal Planes – Cockle Channel

HHW (SS)	Higher Water (Spring Solstices)	MLWN	Mean Low Water Neaps
MHWS	Mean High Water Springs	MLW	Mean Low Water
MHW	Mean High Water	MLWS	Mean Low Water Springs
MHWN	Mean High Water Neaps	ISLW	Indian Spring Low Water
MTL	Mean Tide Level		

Note:- These tidal planes should not be used for mean high water boundary definition

Tidal Ranges	Ocean Site 0 (m AHD)	Brisbane Water				Woy Woy Inlet
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 16 (m AHD)
HHW(SS)	1.832	1.358	1.218	1.008	1.026	1.023
Mean Spring	1.260	0.883	0.763	0.596	0.616	0.615
Mean	1.003	0.715	0.621	0.493	0.510	0.509
Mean Neap	0.746	0.546	0.479	0.390	0.404	0.402

Table 2.5: Comparison of Tidal Ranges – Woy Woy Inlet

Tidal Range	Ocean Site 0 (m AHD)	Brisbane Water				Narara Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 20 (m AHD)	Site 22 (m AHD)
HHW(SS)	1.832	1.358	1.218	1.008	1.026	0.996	1.196
Mean Spring	1.260	0.883	0.763	0.596	0.616	0.593	0.570
Mean	1.003	0.715	0.621	0.493	0.510	0.488	0.495
Mean Neap	0.746	0.546	0.479	0.390	0.404	0.382	0.421

Table 2.6: Comparison of Tidal Ranges – Narara Creek

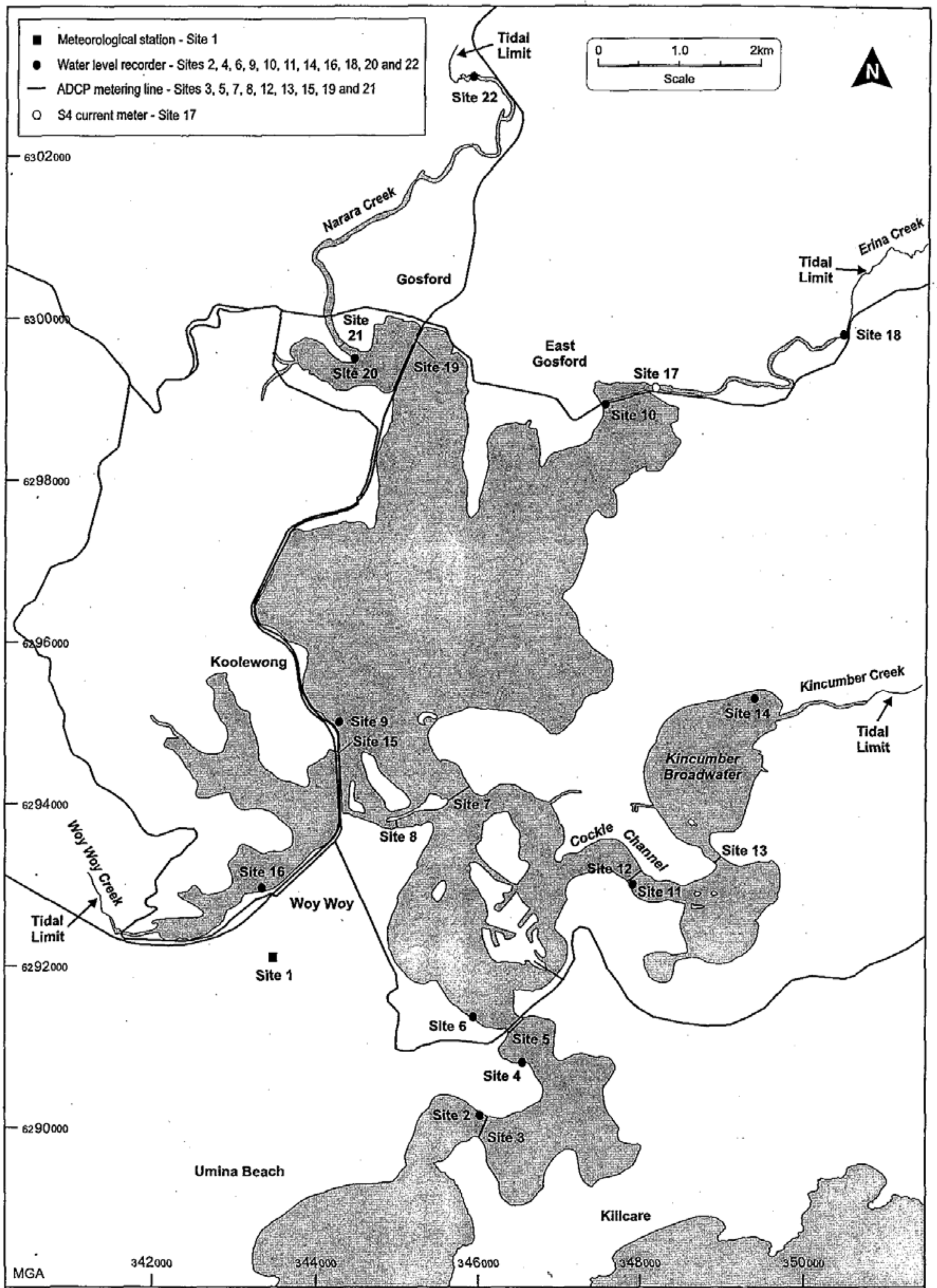
Tidal Range	Ocean Site 0 (m AHD)	Brisbane Water				Erina Creek	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 9 (m AHD)	Site 10 (m AHD)	Site 18 (m AHD)
HHW(SS)	1.832	1.358	1.218	1.008	1.026	1.027	1.054
Mean Spring	1.260	0.883	0.763	0.596	0.616	0.620	0.634
Mean	1.003	0.715	0.621	0.493	0.510	0.514	0.523
Mean Neap	0.746	0.546	0.479	0.390	0.404	0.407	0.413

Table 2.7: Comparison of Tidal Ranges – Erina Creek

Tidal Ranges	Ocean Site 0 (m AHD)	Brisbane Water			Kincumber Broadwater	
		Site 2 (m AHD)	Site 4 (m AHD)	Site 6 (m AHD)	Site 11 (m AHD)	Site 14 (m AHD)
HHW(SS)	1.832	1.358	1.218	1.008	0.875	0.826
Mean Spring	1.260	0.883	0.763	0.596	0.491	0.456
Mean	1.003	0.715	0.621	0.493	0.409	0.385
Mean Neap	0.746	0.546	0.479	0.390	0.327	0.313

* Note: Data from Site 14 was only available for a shorter period of time due to instrument malfunction.

Table 2.8: Comparison of Tidal Ranges – Cockle Channel



NSW Department of Commerce

MANLY HYDRAULICS LABORATORY

DETAILED LOCATION MAP OF STUDY AREA

MHL Report 1319

Figure 1.2

DRAWING 1319-1-02.CDR

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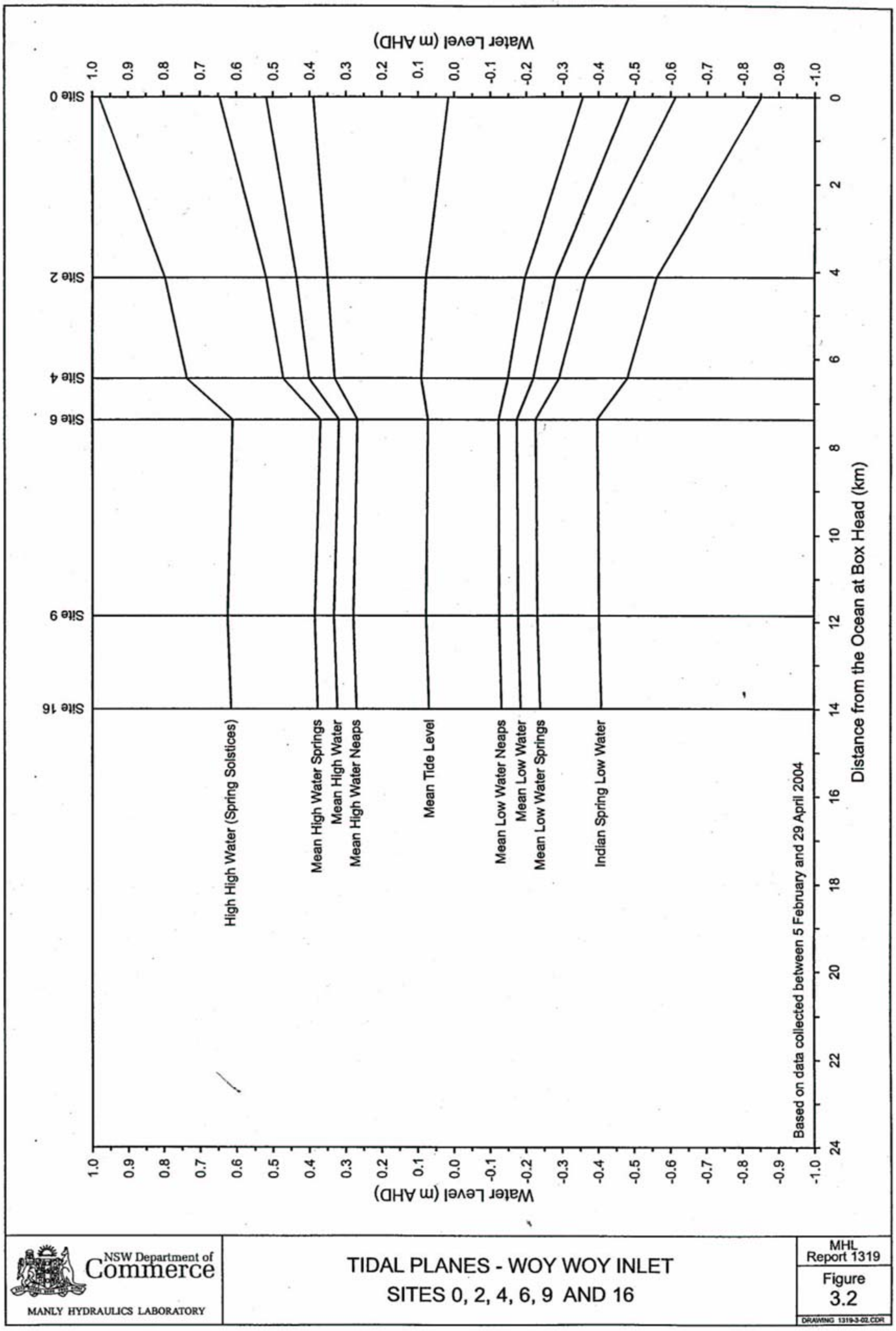
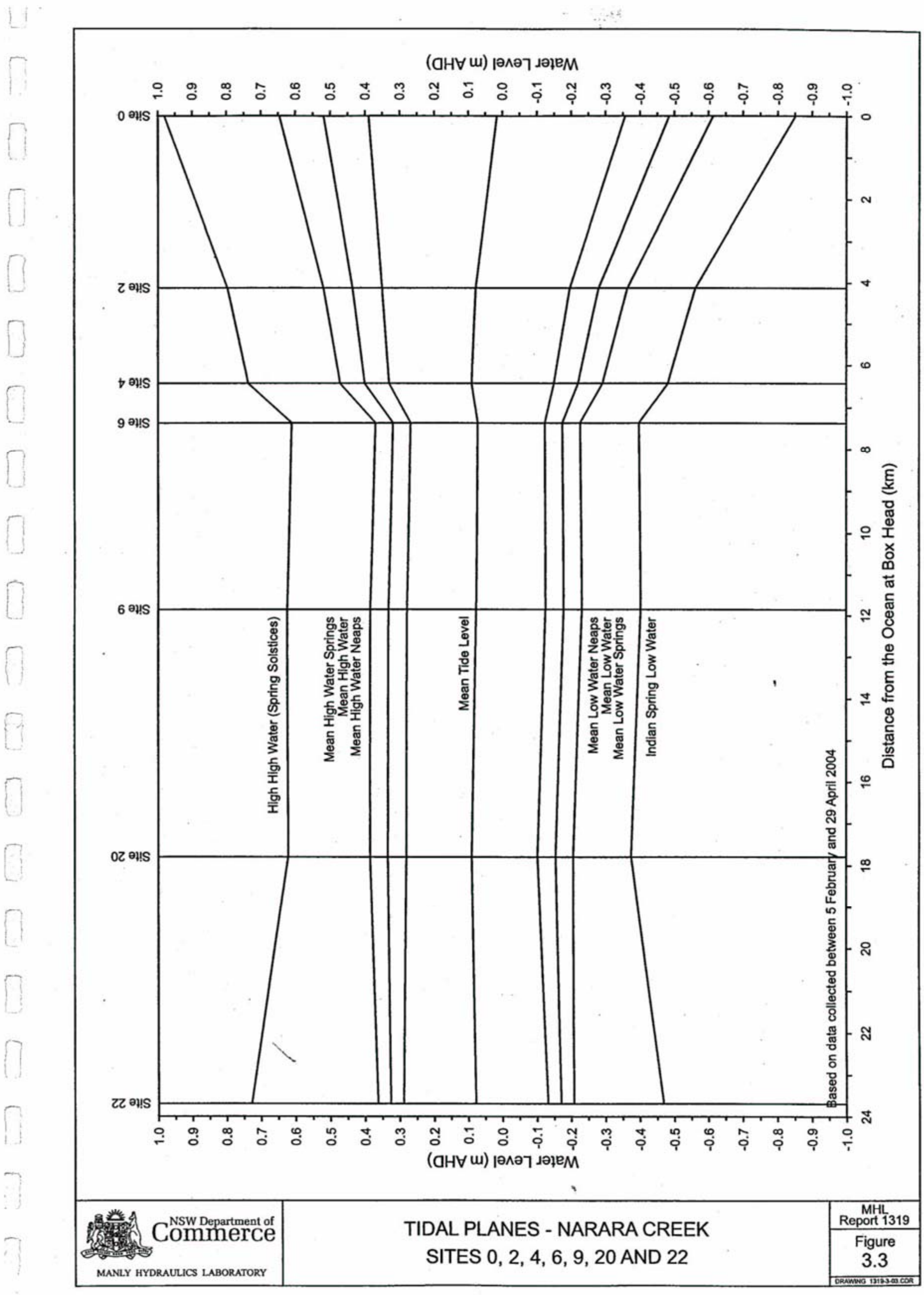
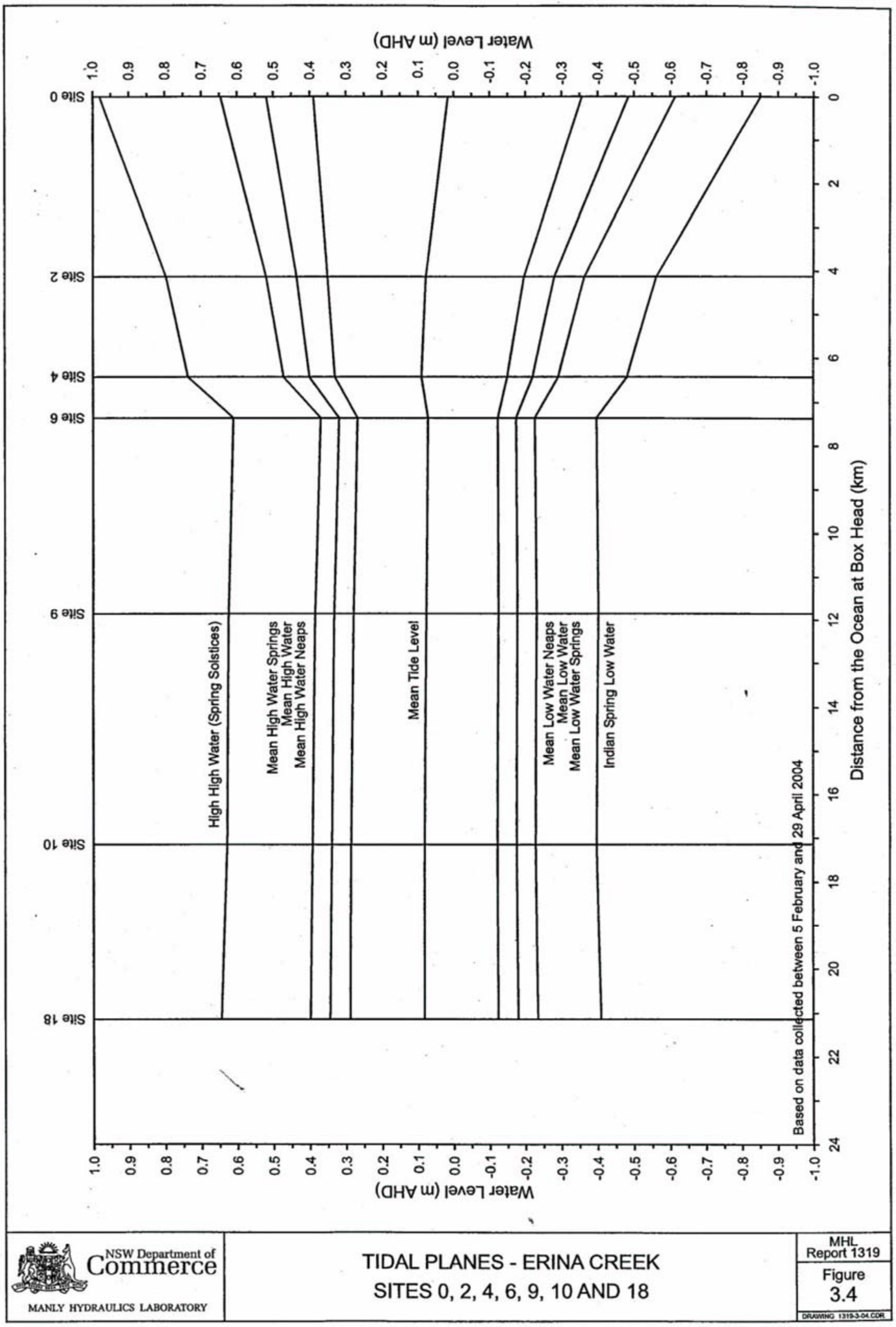



Water Level (m AHD)
Distance from the Ocean at Box Head (km)
Site 0
Site 2
Site 4
Site 6
Site 9
Site 20
Site 22
High High Water (Spring Solstices)
Mean High Water Springs
Mean High Water
Mean High Water Neaps
Mean Tide Level
Mean Low Water Neaps
Mean Low Water
Mean Low Water Springs
Indian Spring Low Water
Based on data collected between 5 February and 29 April 2004
NSW Department of Commerce
MANLY HYDRAULICS LABORATORY
TIDAL PLANES - NARARA CREEK
SITES 0, 2, 4, 6, 9, 20 AND 22
MHL Report 1319
Figure 3.3


Water Level (m AHD)
Distance from the Ocean at Box Head (km)
Site 0
Site 2
Site 4
Site 6
Site 9
Site 10
Site 18
High High Water (Spring Solstices)
Mean High Water Springs
Mean High Water
Mean High Water Neaps
Mean Tide Level
Mean Low Water Neaps
Mean Low Water
Mean Low Water Springs
Indian Spring Low Water
Based on data collected between 5 February and 29 April 2004
NSW Department of Commerce
MANLY HYDRAULICS LABORATORY
TIDAL PLANES - ERINA CREEK
SITES 0, 2, 4, 6, 9, 10 AND 18
MHL Report 1319
Figure 3.4

APPENDIX 2

Joint Wind Speed and Direction Occurrence at Sydney Airport

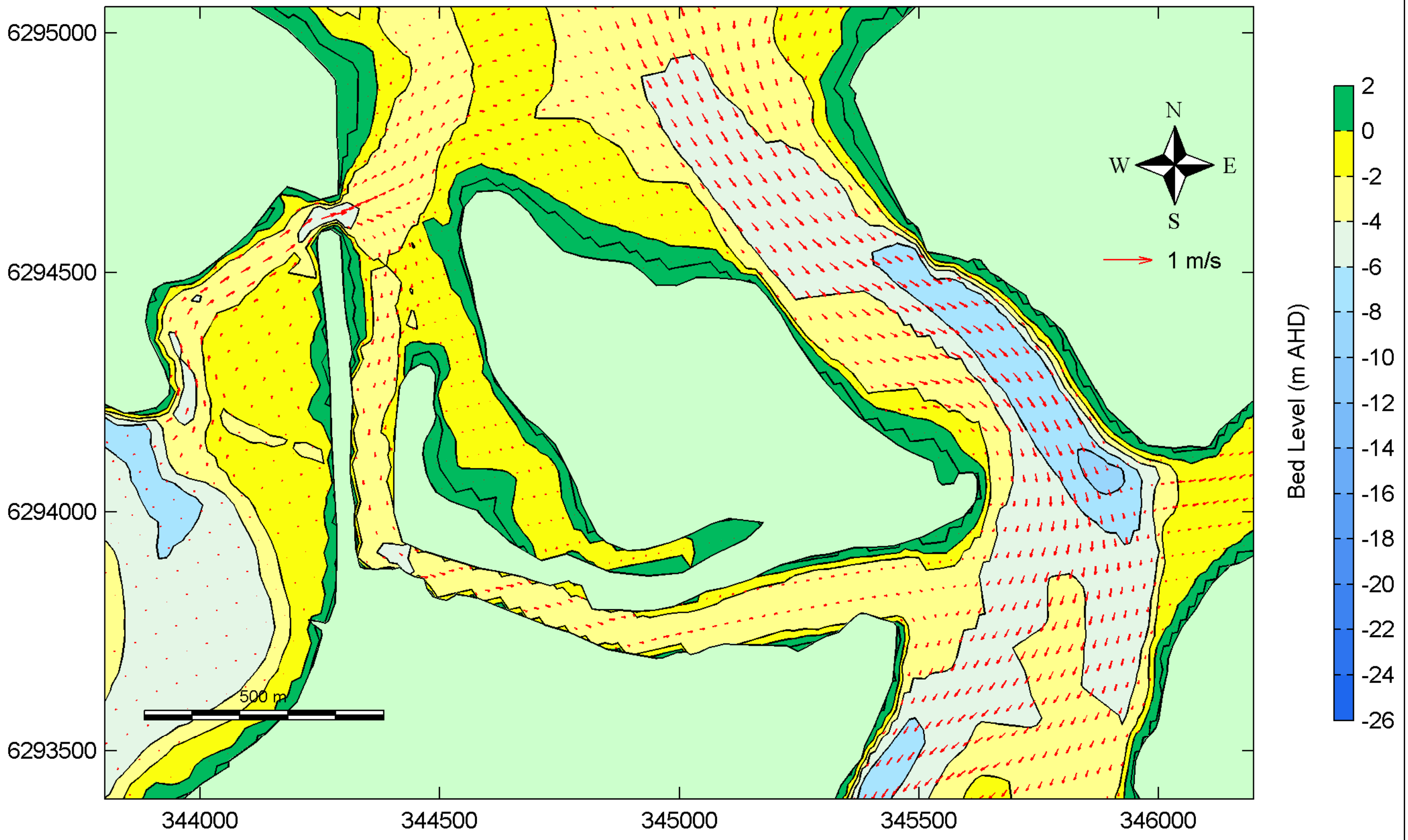
Table 2.1: Joint Occurrence of Wind Speed and Direction at Mascot
Percentage Calms - 17.4

	Wind Speed (m/s)										
Dirn	0.0-2.5	2.5-5.0	5.0-7.5	7.5-10.0	10.0-12.5	12.5-15.0	15.0-17.5	17.5-20.0	20.0-22.5	22.5-25.0	**TOTAL**
N	0.48	1.73	0.98	0.33	0.07	0.01	0.00	0.00	0.00	0.00	3.60
NNE	0.25	1.36	1.39	0.88	0.37	0.08	0.01	0.00	0.00	0.00	4.34
NE	0.34	1.94	2.51	1.72	0.74	0.15	0.01	0.00	0.00	0.00	7.41
ENE	0.22	1.10	1.18	0.48	0.08	0.01	0.00	0.00	0.00	0.00	3.07
E	0.33	1.66	1.32	0.28	0.03	0.01	0.00	0.00	0.00	0.00	3.63
ESE	0.21	1.09	0.82	0.21	0.04	0.01	0.00	0.00	0.00	0.00	2.38
SE	0.31	1.82	1.95	0.79	0.19	0.05	0.02	0.00	0.00	0.00	5.13
SSE	0.19	1.61	2.28	1.31	0.56	0.18	0.05	0.01	0.00	0.00	6.19
S	0.31	1.84	3.13	2.86	1.62	0.67	0.18	0.03	0.01	0.00	10.66
SSW	0.16	0.84	1.05	1.01	0.54	0.23	0.06	0.02	0.00	0.00	3.92
SW	0.37	1.25	0.98	0.55	0.18	0.06	0.02	0.01	0.00	0.00	3.41
WSW	0.29	1.32	1.13	0.64	0.24	0.07	0.02	0.00	0.00	0.00	3.71
W	0.86	3.03	2.00	1.03	0.52	0.20	0.06	0.01	0.00	0.00	7.70
WNW	1.08	2.87	0.98	0.45	0.26	0.12	0.04	0.00	0.00	0.00	5.79
NW	1.78	4.34	1.19	0.44	0.22	0.07	0.02	0.00	0.00	0.00	8.07
NNW	0.59	1.90	0.69	0.26	0.10	0.02	0.01	0.00	0.00	0.00	3.56
TOTAL (%)	7.78	29.71	23.56	13.23	5.77	1.92	0.49	0.08	0.02	0.01	82.58
P of E (%)	82.58	74.79	45.08	21.52	8.29	2.52	0.60	0.11	0.03	0.01	

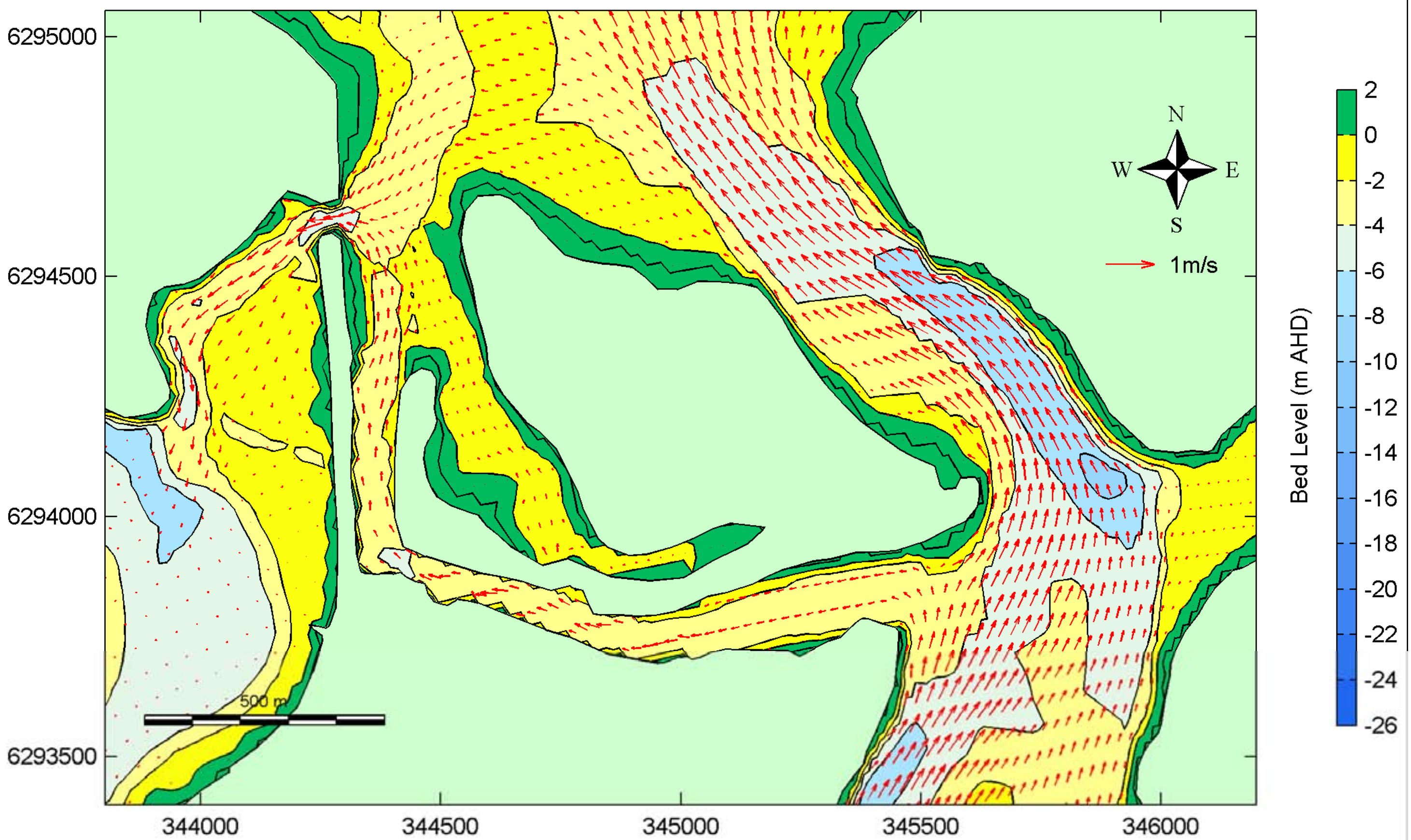
APPENDIX 3

Current Vectors - Brisbane Water Delft3D Model

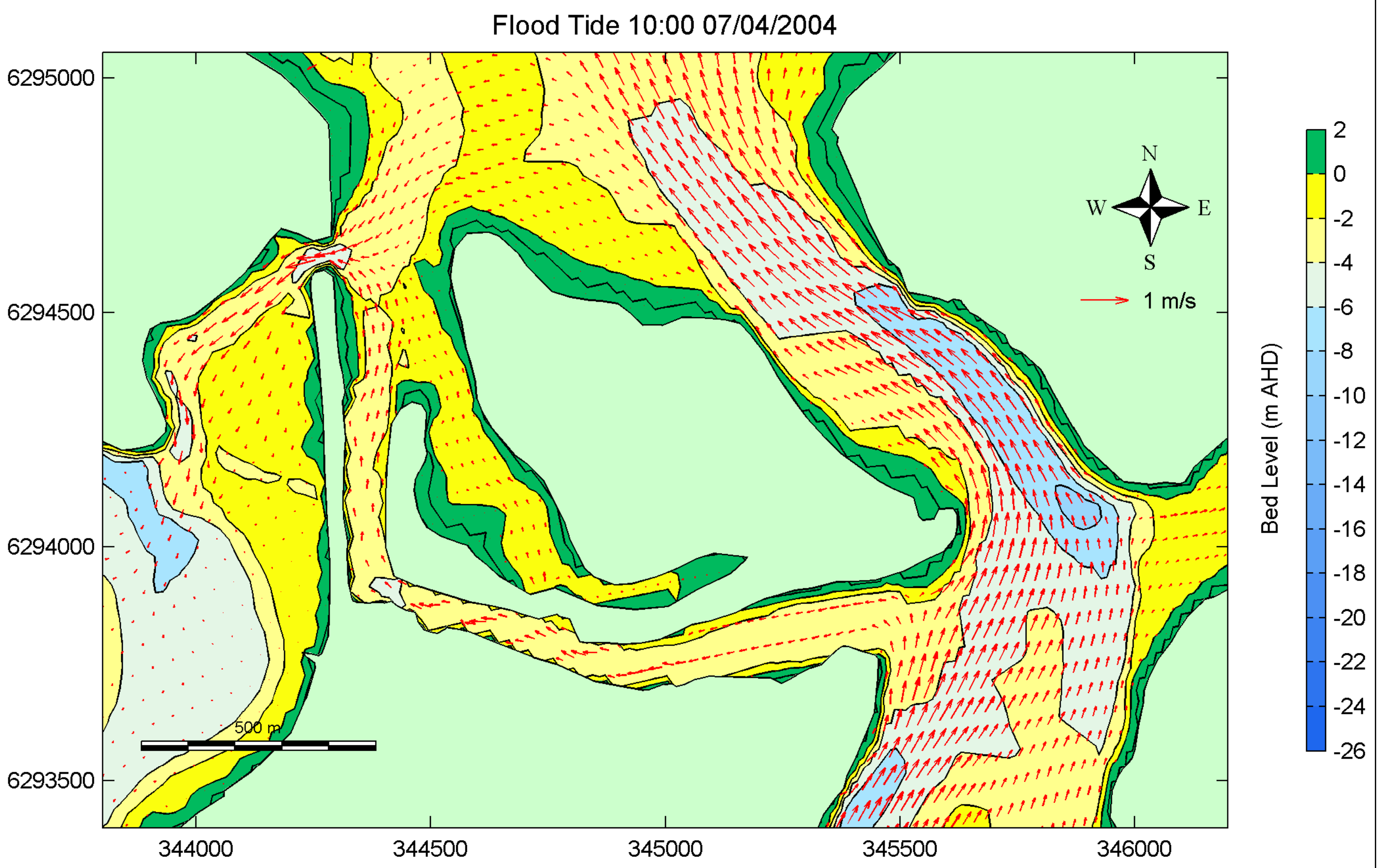
Slack Water 06:00 07/04/2004

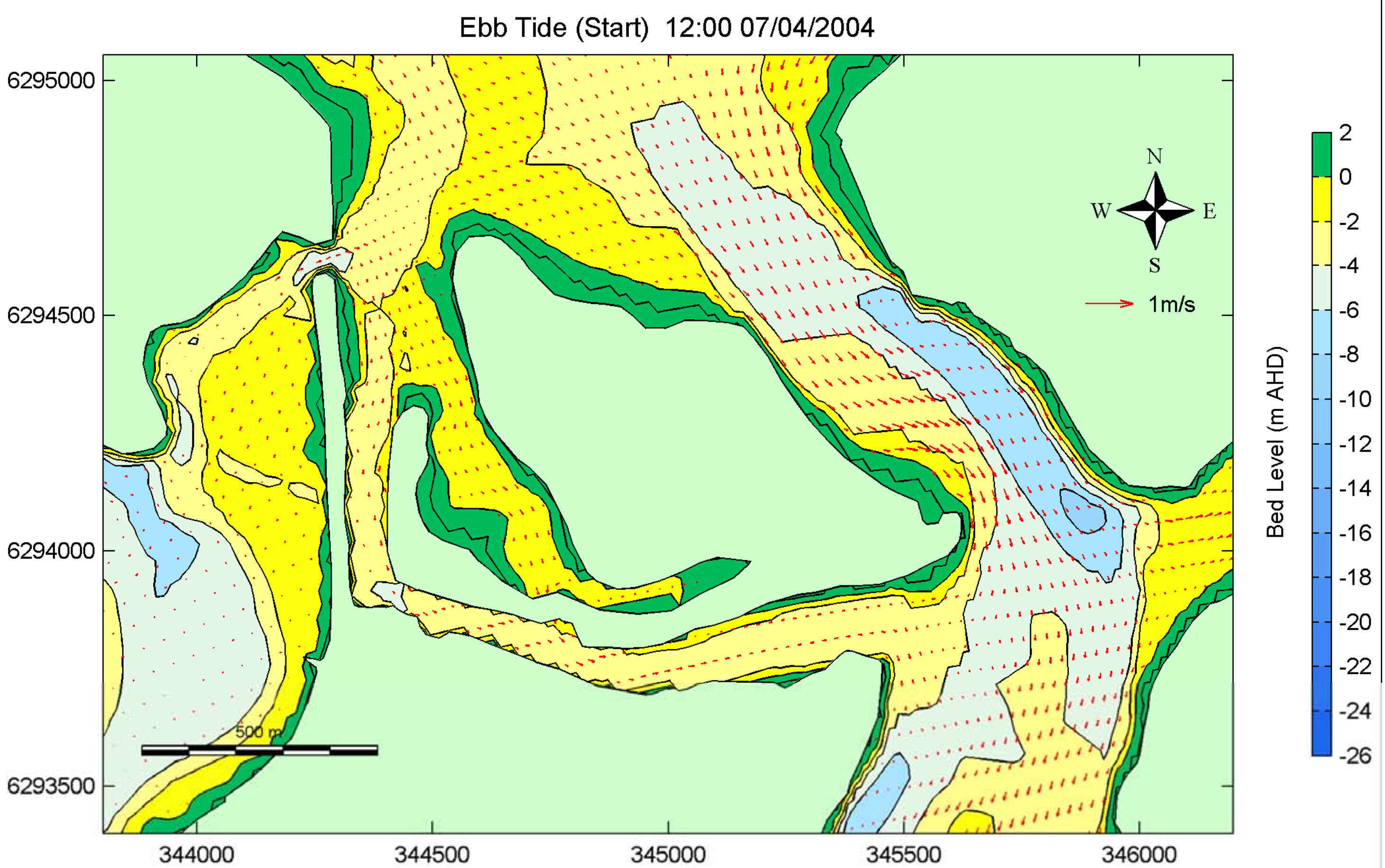


Flood Tide 08:00 07/04/2004

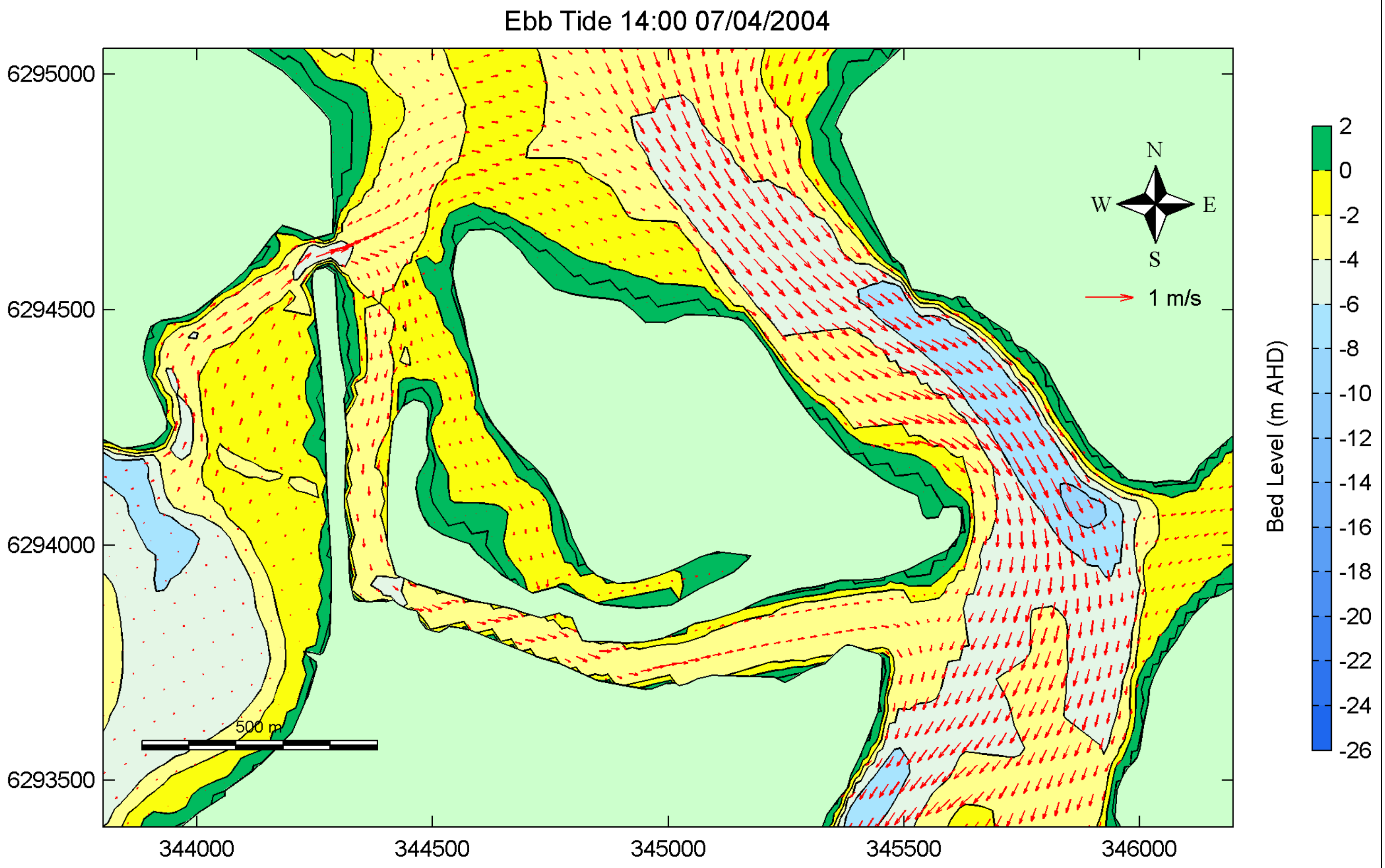


Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - WOY WOY
DEPTH-AVERAGED
Figure A3-1



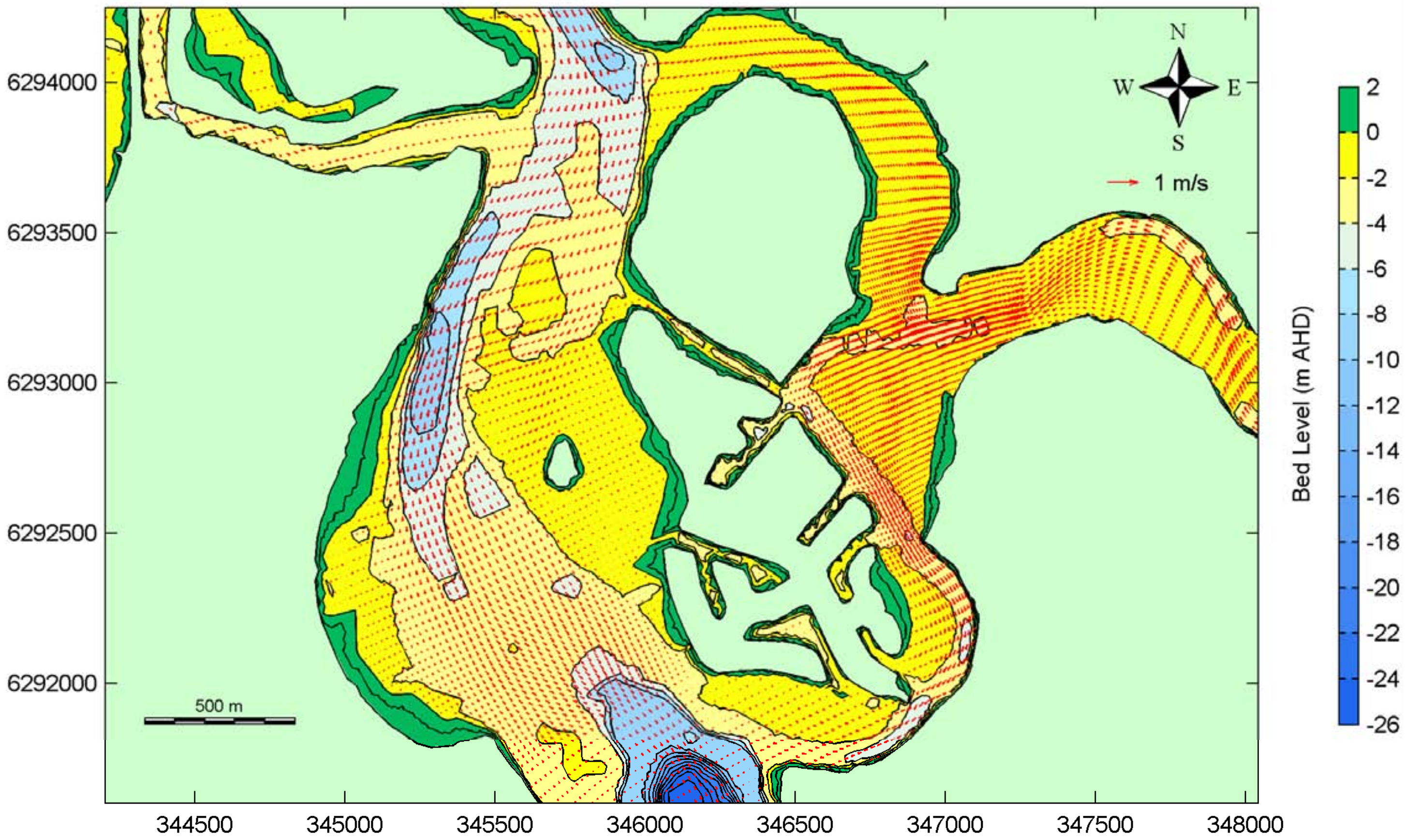


Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - WOY WOY
DEPTH-AVERAGED
Figure A3-2

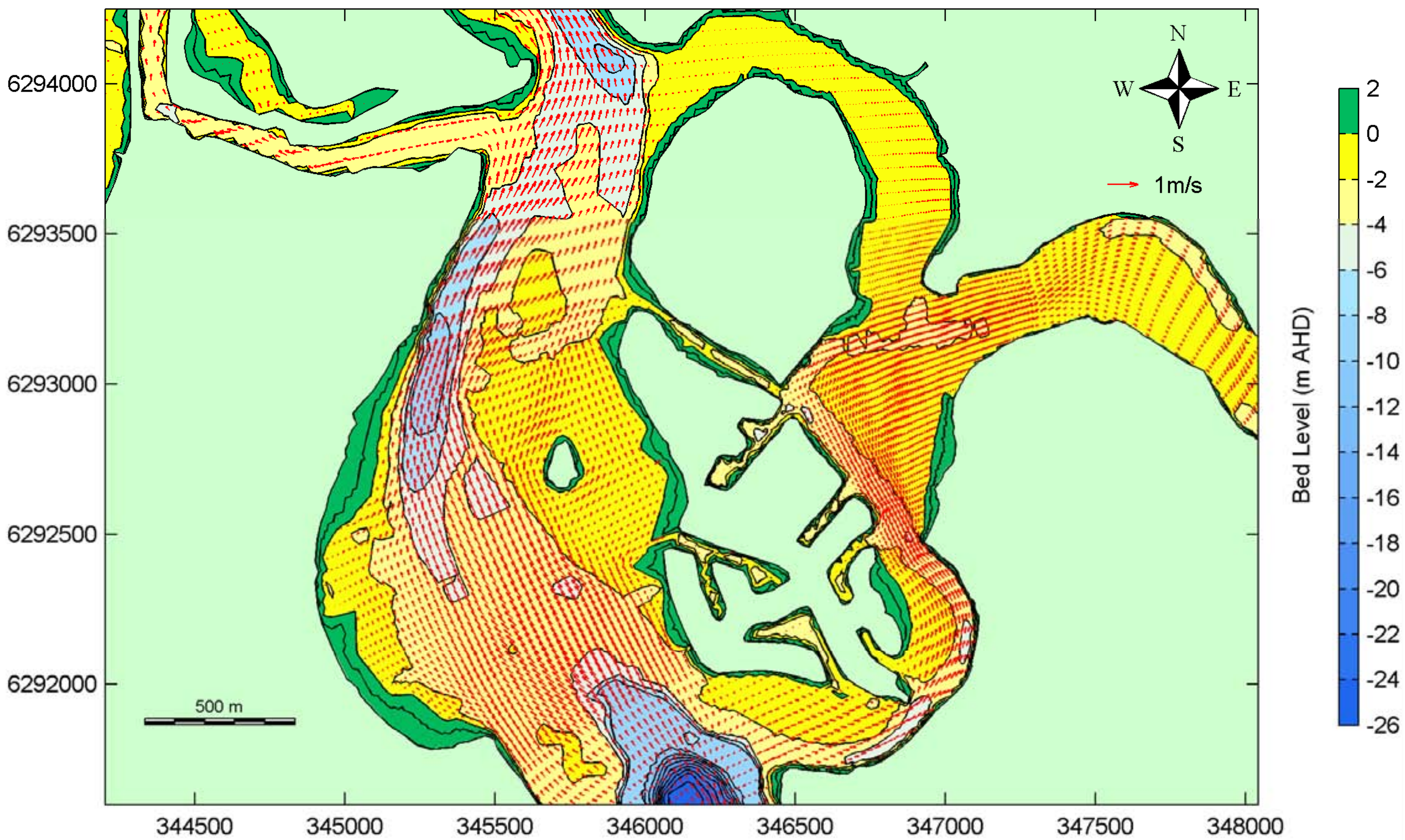


Ebb Tide 14:00 07/04/2004
6295000
6294500
6294000
6293500
344000
344500
345000
345500
346000
N
W
E
S
1 m/s
500 m
Bed Level (m AHD)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26

Slack Water 06:00 07/04/2004



Flood Tide 08:00 07/04/2004



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J/CM/J2255bw/Figures/R2312/FigureA3-4.png

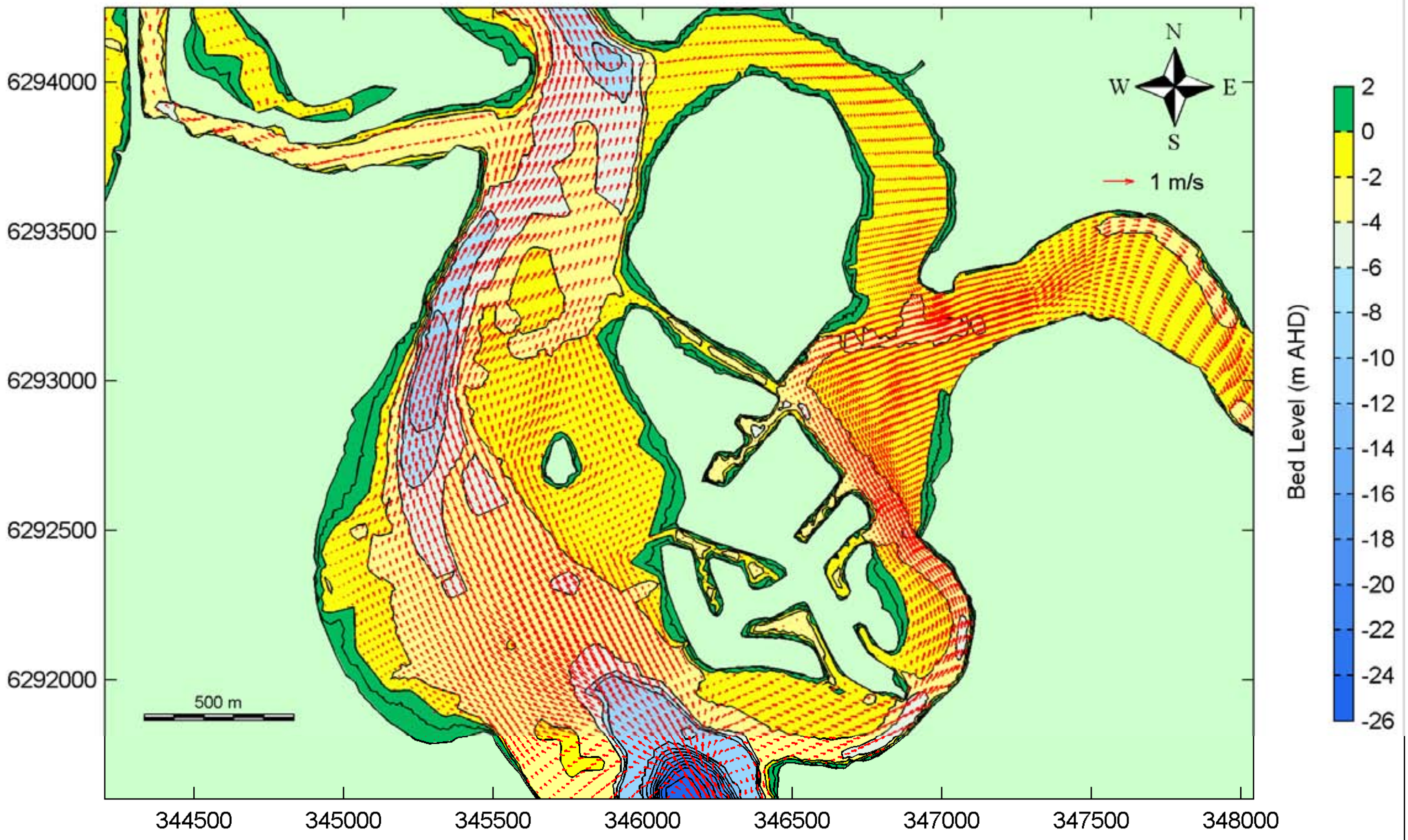
Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL CURRENTS - ST HUBERTS

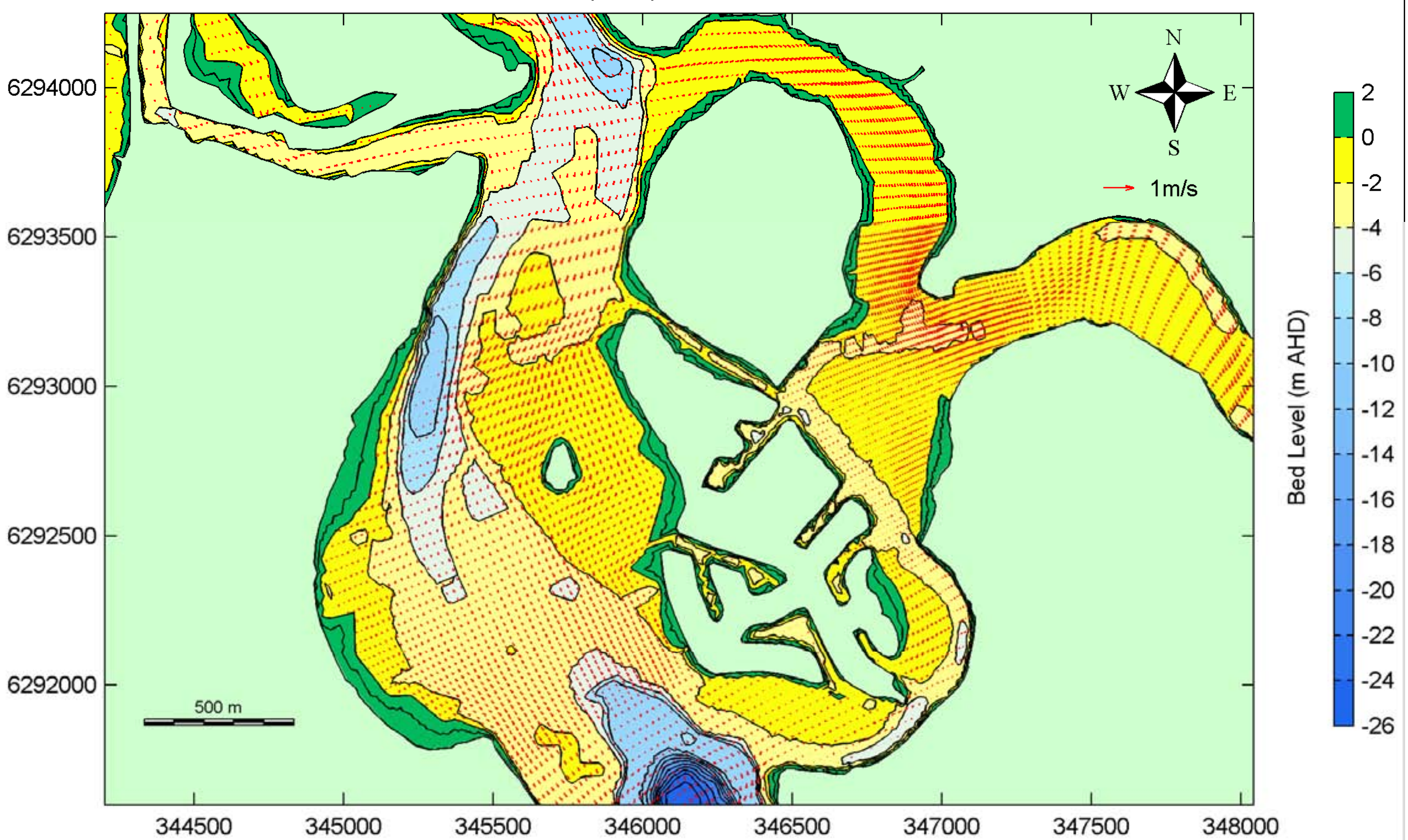
DEPTH-AVERAGED

Figure A3-4

Flood Tide 10:00 07/04/2004

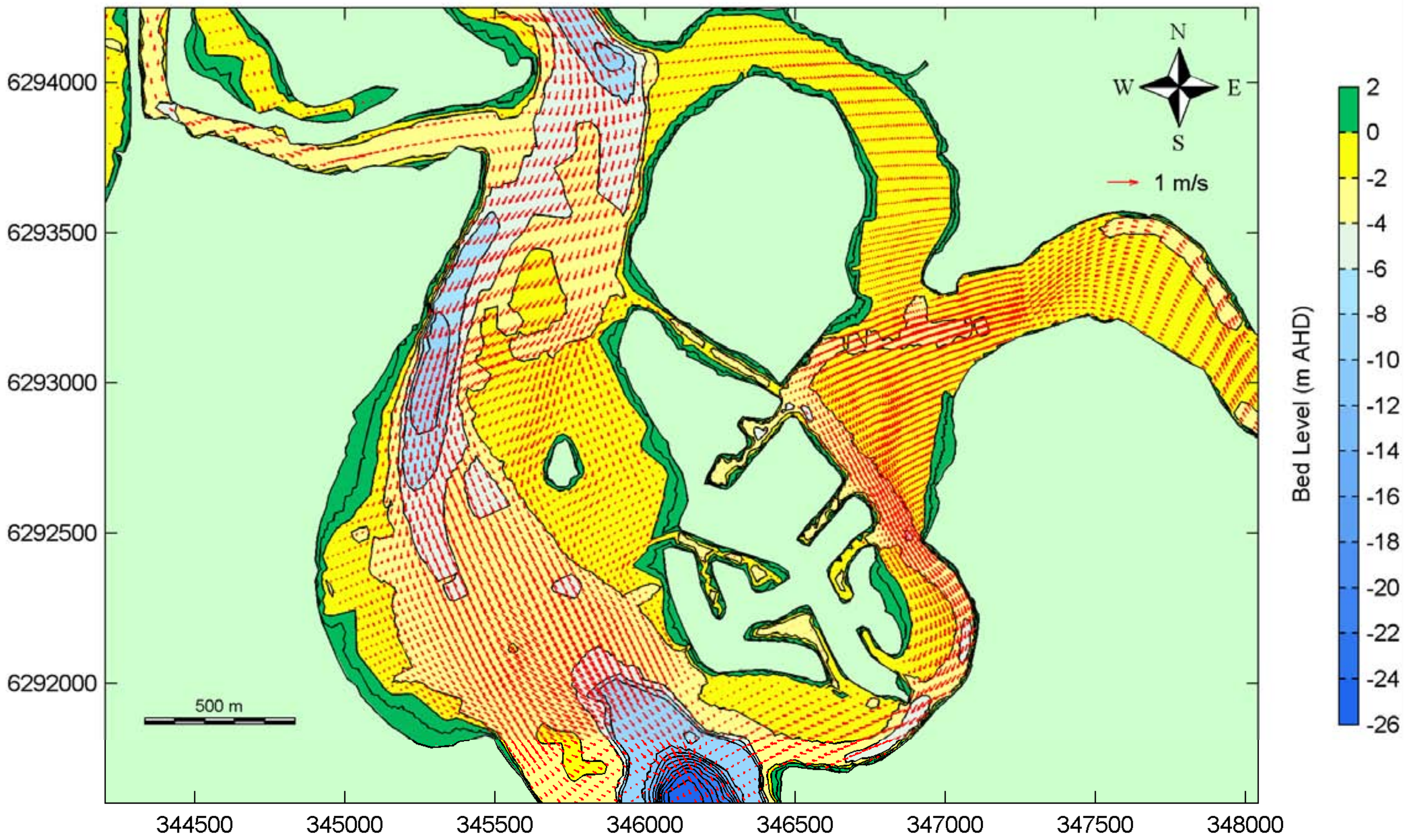


Ebb Tide (Start) 12:00 07/04/2004

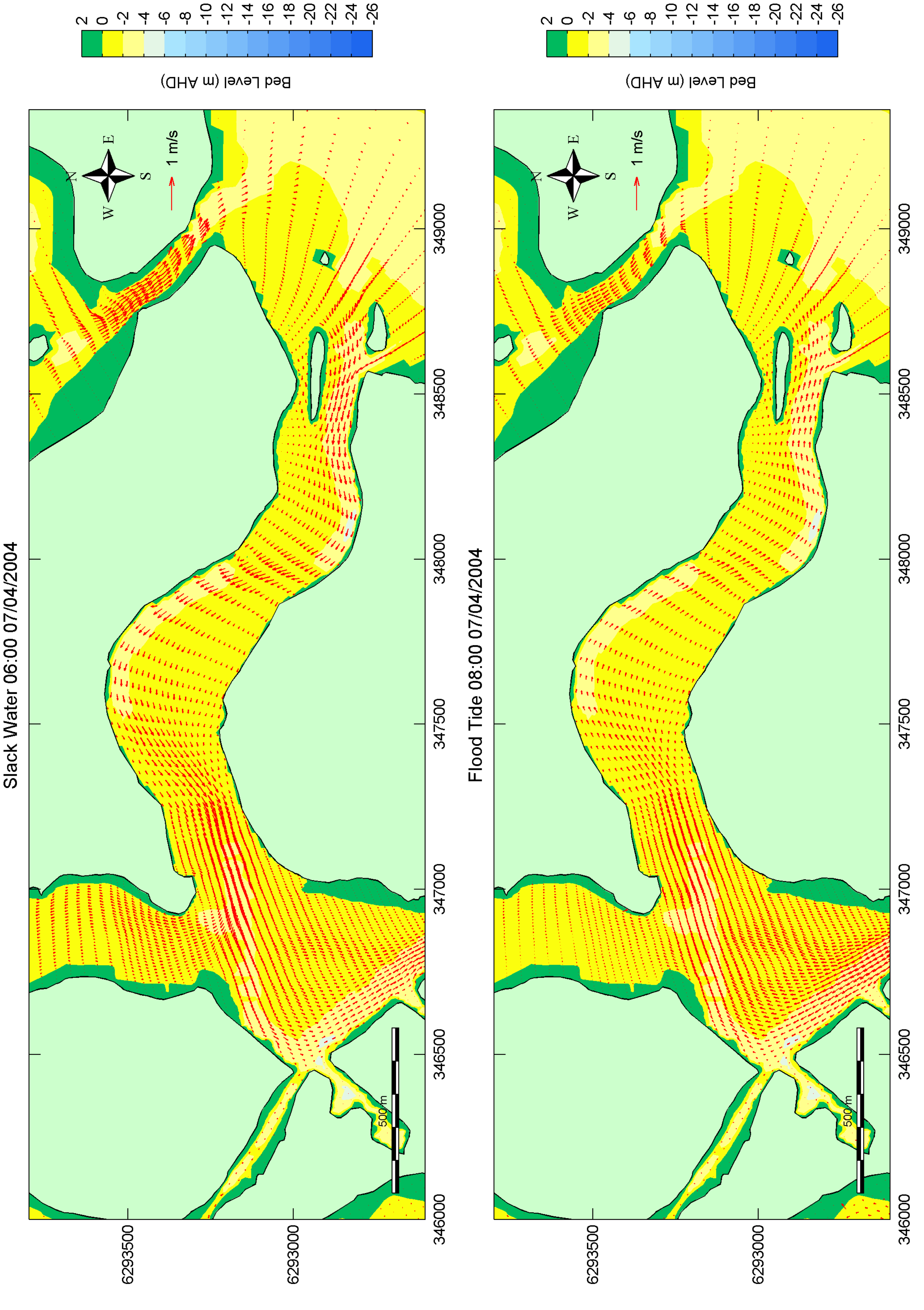


Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - ST HUBERTS
DEPTH-AVERAGED
Figure A3-5

Ebb Tide 14:00 07/04/2004



Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - ST HUBERTS
DEPTH-AVERAGED
Figure A3-6



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Lawson Treloar

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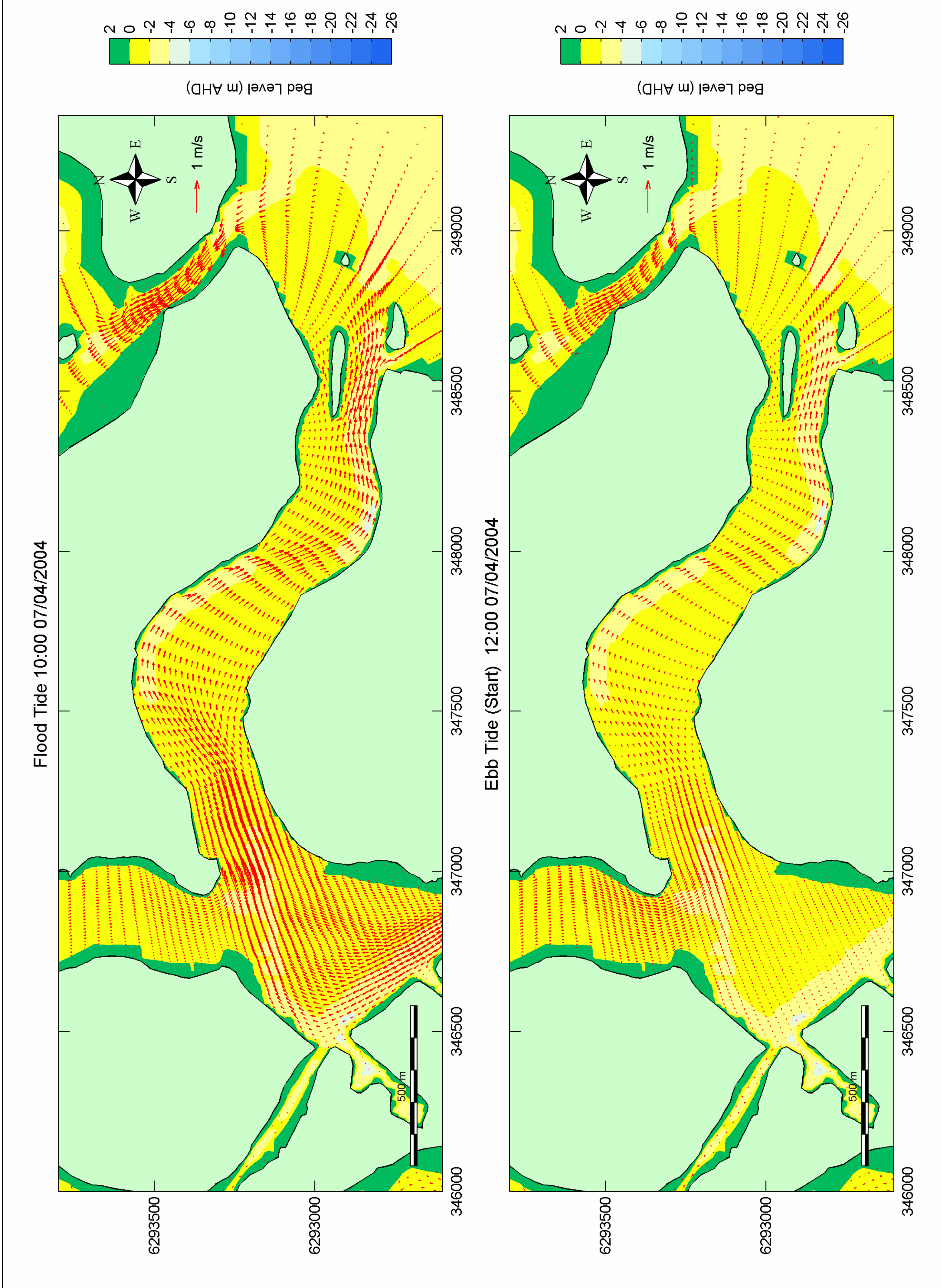
J/CM/J2255bw/Figures/R2312/FigureA3-7.png

Brisbane Water Estuary Processes Study - Hydraulic Processes
TIDAL CURRENTS - COCKLE CHANNEL
DEPTH-AVERAGED
Figure A3-7



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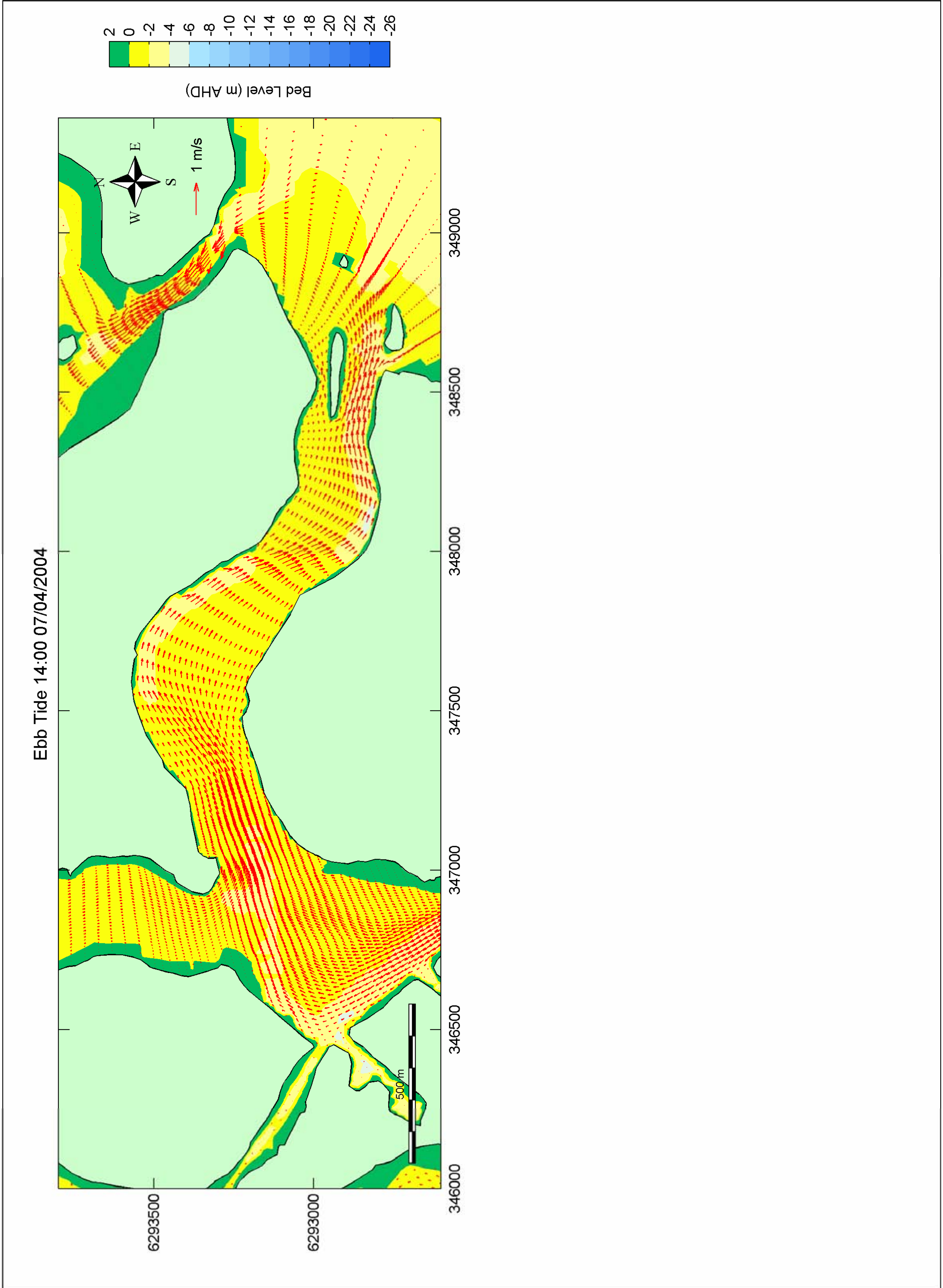
J/CM/J2255bw/Figures/R2312/FigureA3-8.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL CURRENTS - COCKLE CHANNEL

DEPTH-AVERAGED

Figure A3-8



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J/CM/J2255bw/Figures/R2312/FigureA3-9.png

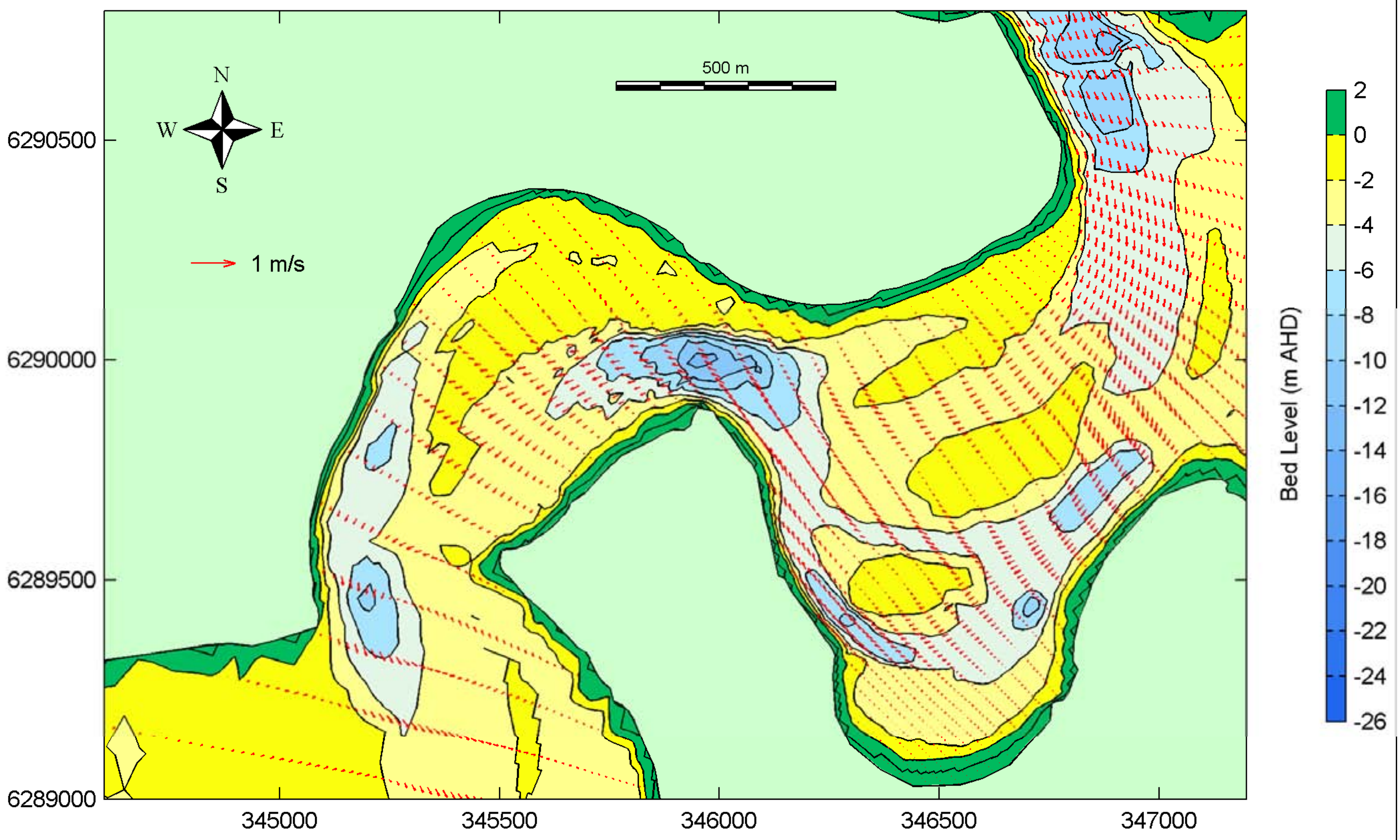
Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL CURRENTS - COCKLE CHANNEL

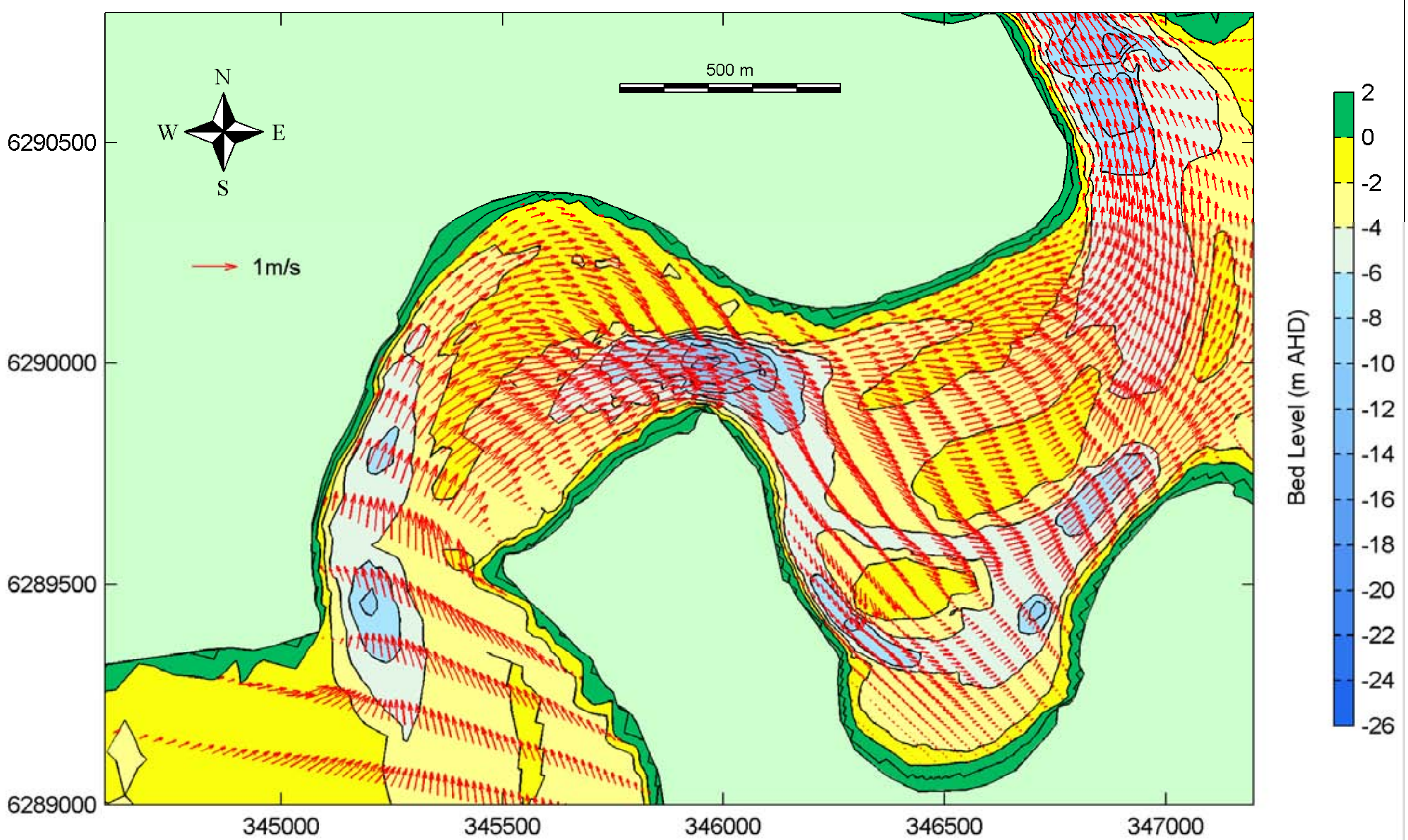
DEPTH-AVERAGED

Figure A3-9

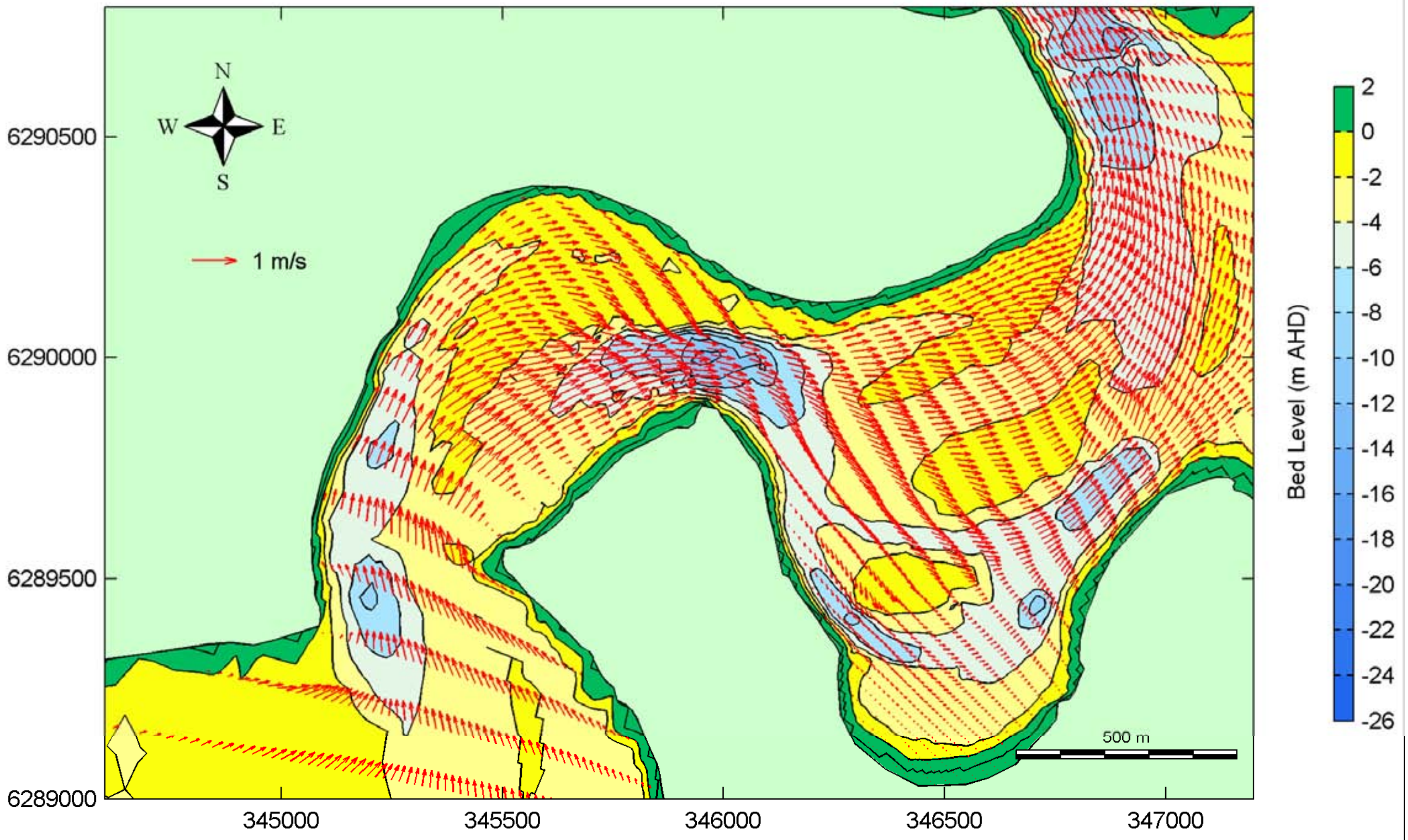
Slack Water 06:00 07/04/2004



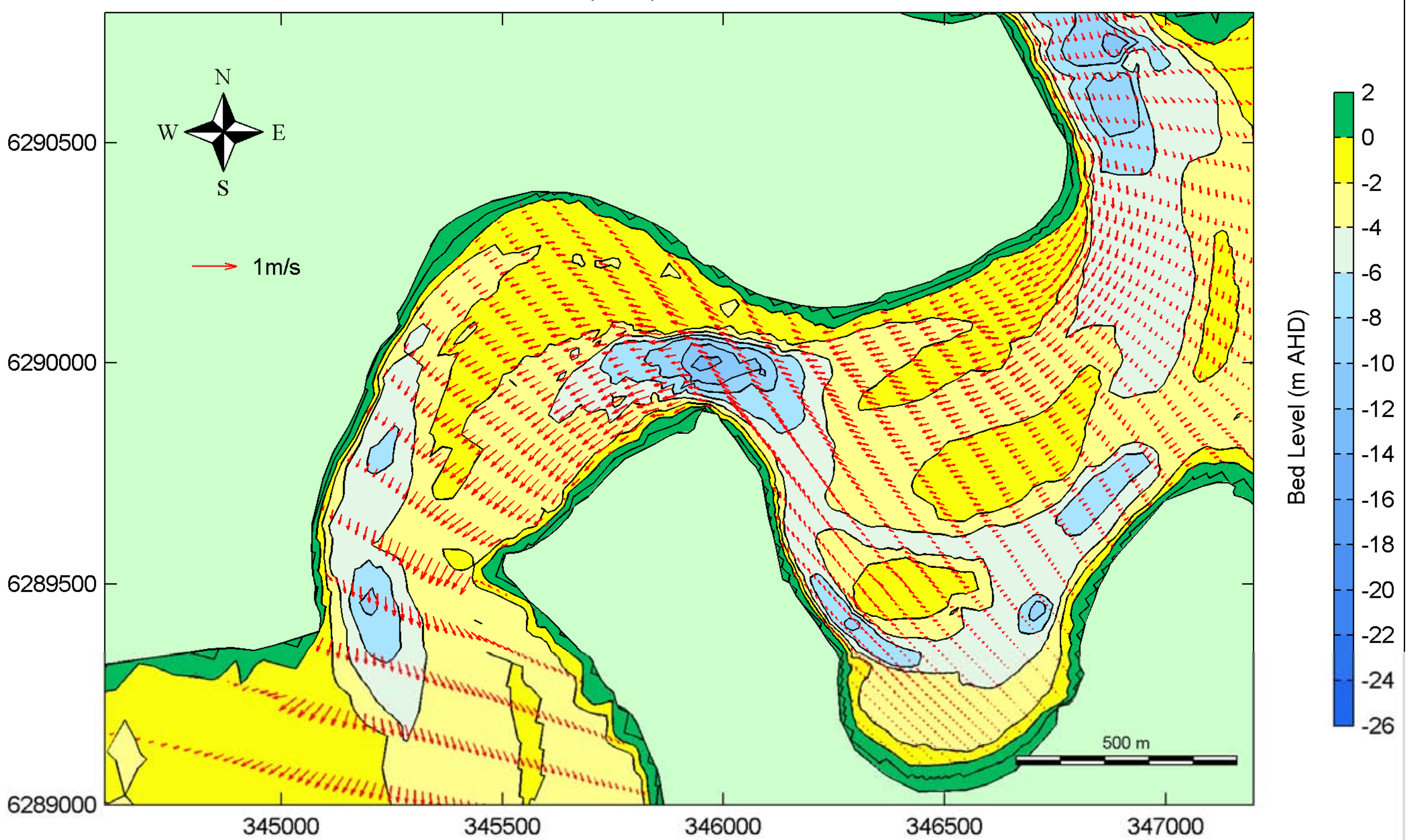
Flood Tide 08:00 07/04/2004



Flood Tide 10:00 07/04/2004



Ebb Tide (Start) 12:00 07/04/2004



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J/CM/J2255bw/Figures/R2312/FigureA3-11.png

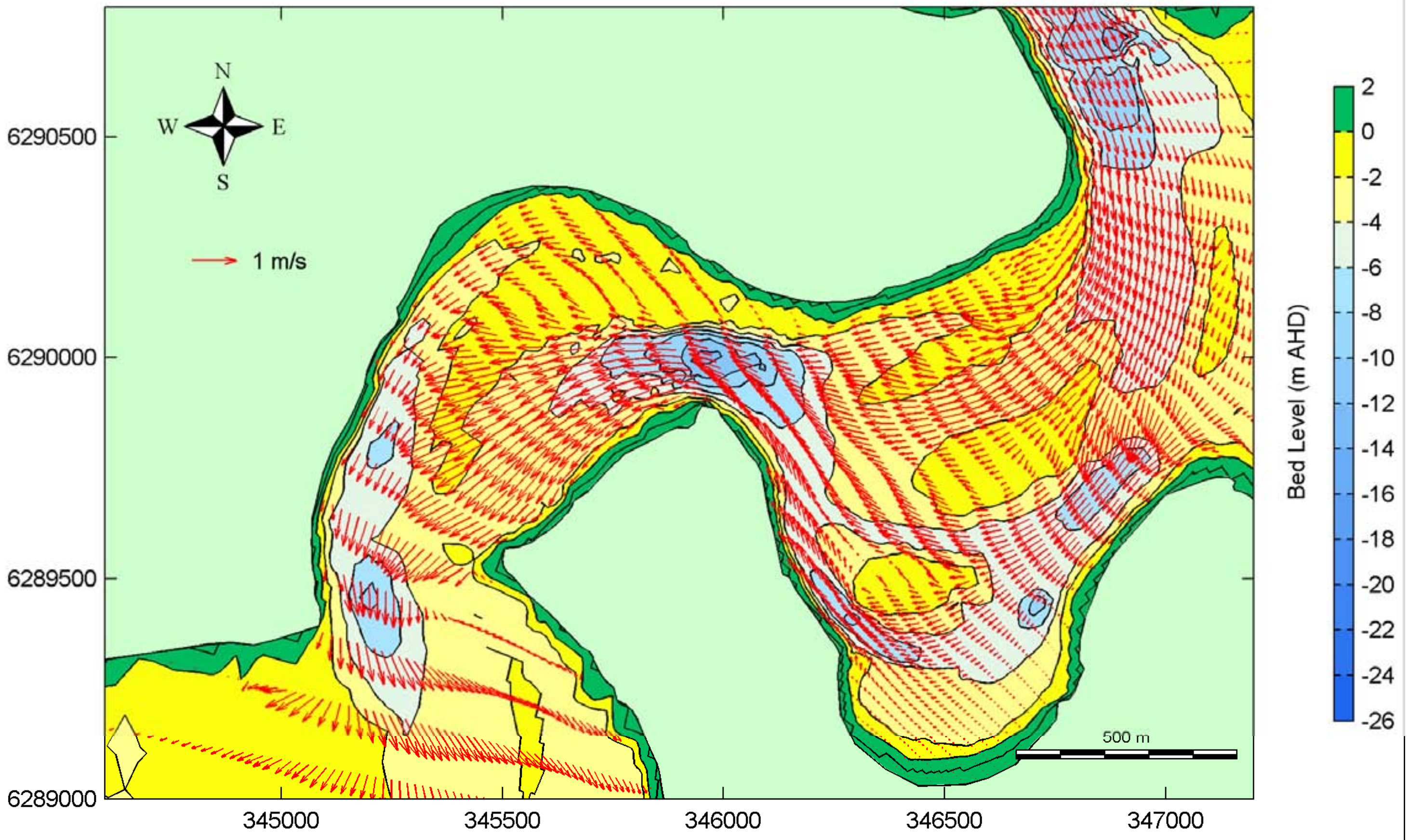
Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL CURRENTS - ETTALONG

DEPTH-AVERAGED

Figure A3-11

Flood Tide 10:00 07/04/2004

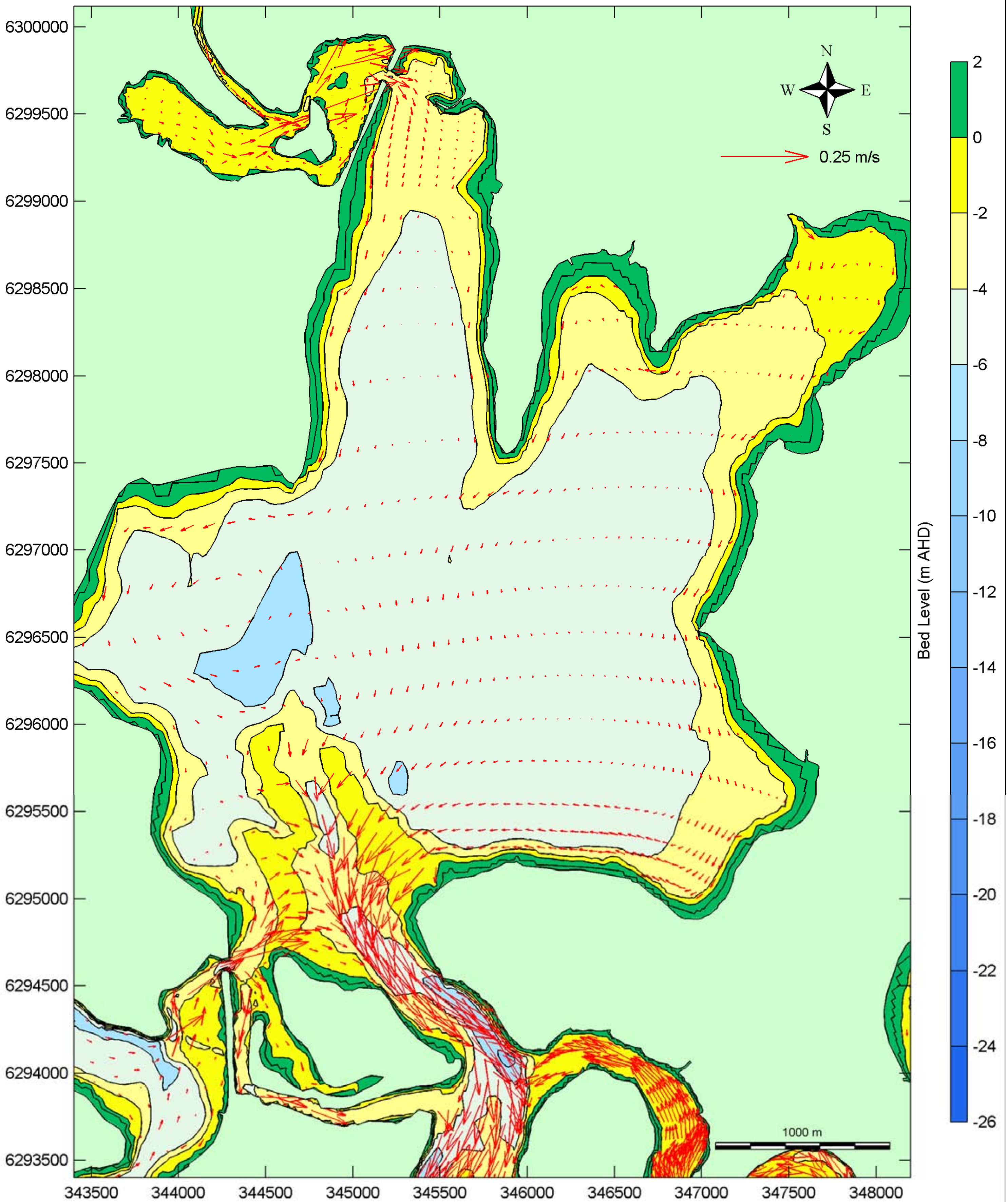


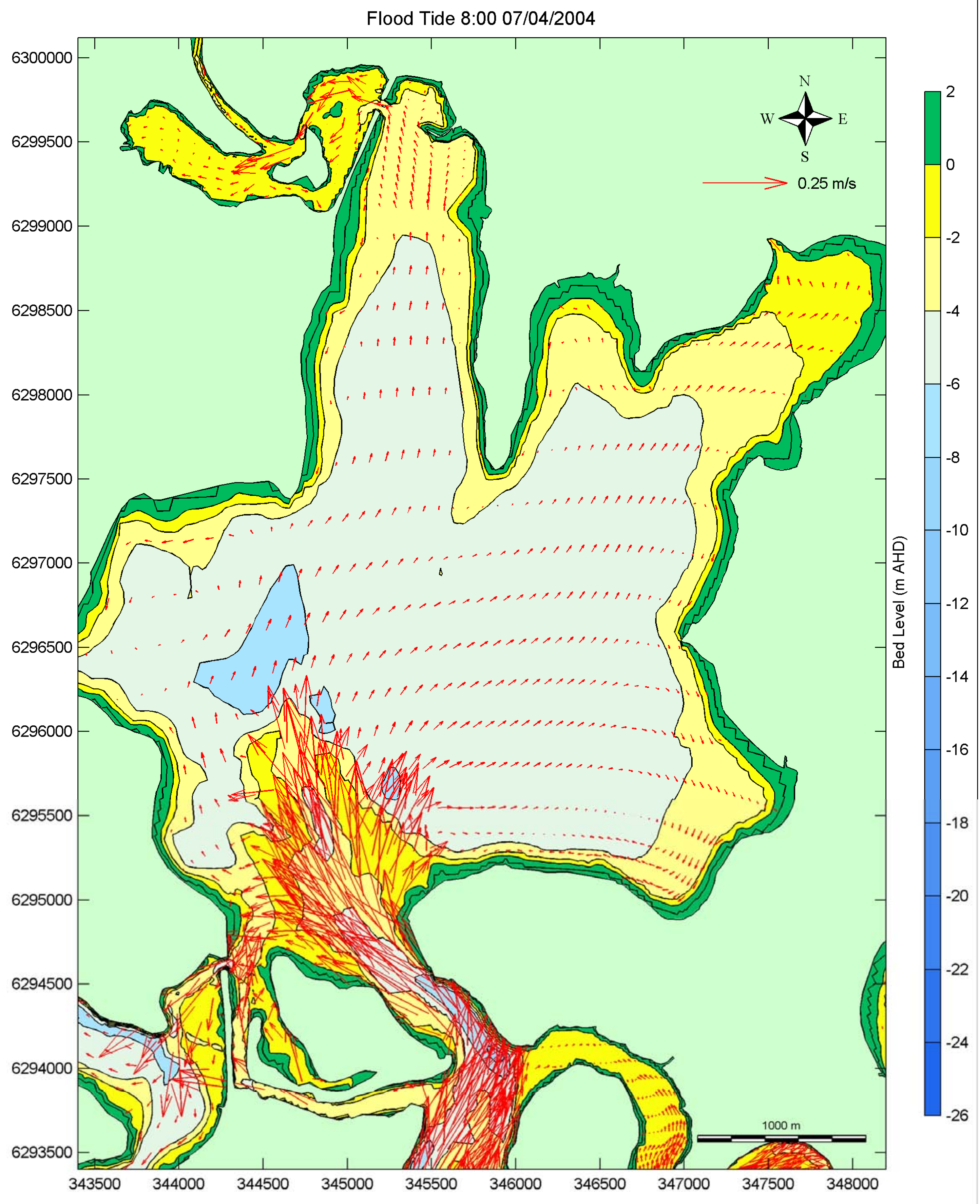
TIDAL CURRENTS - ETTALONG

DEPTH-AVERAGED

Figure A3-12

Slack Water 6:00 07/04/2004





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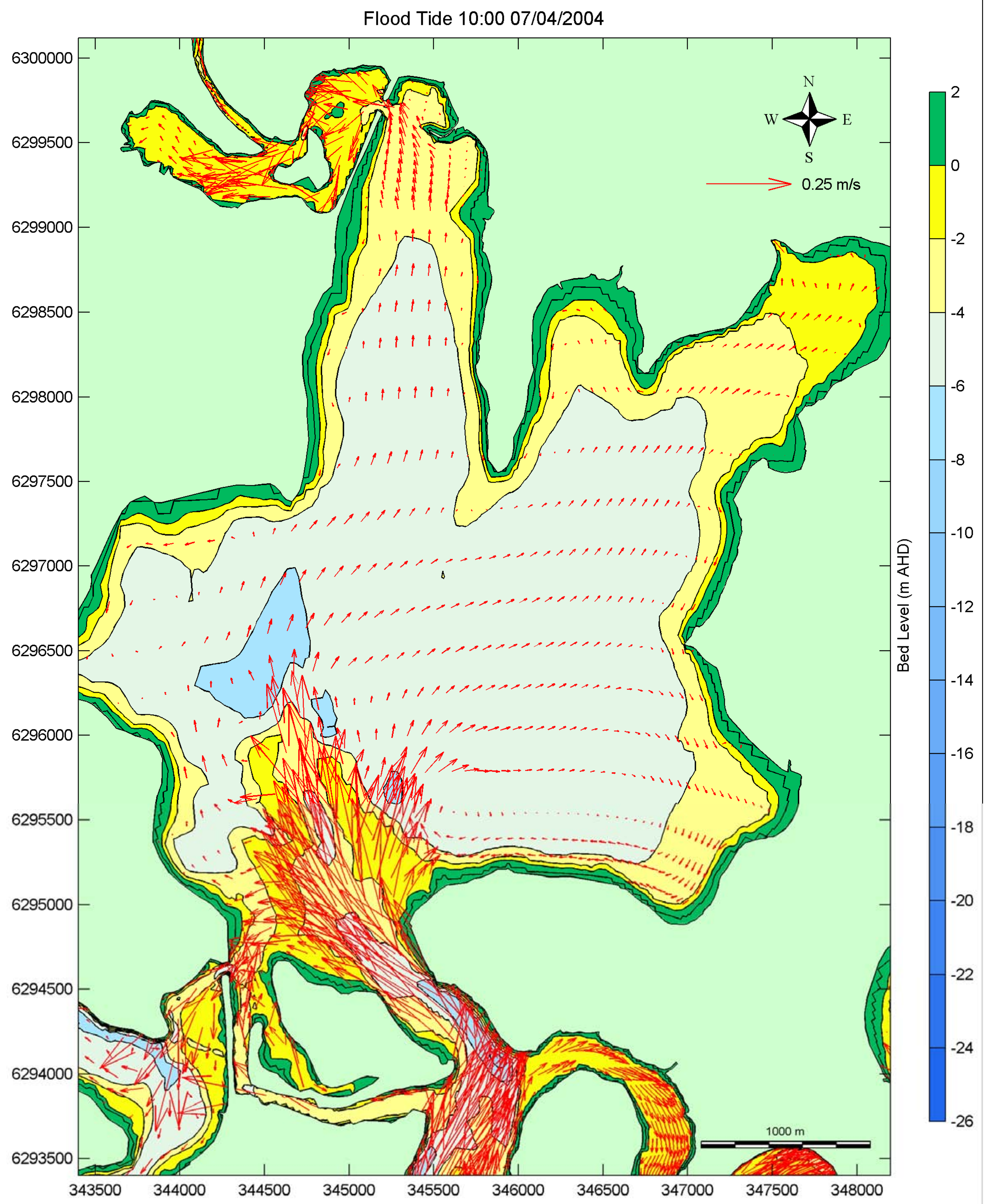
J/CM/J2255bw/Figures/R2312/FigureA3-14.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL AND SUMMER WIND GENERATED CURRENTS - BROADWATER

DEPTH-AVERAGED

Figure A3-14



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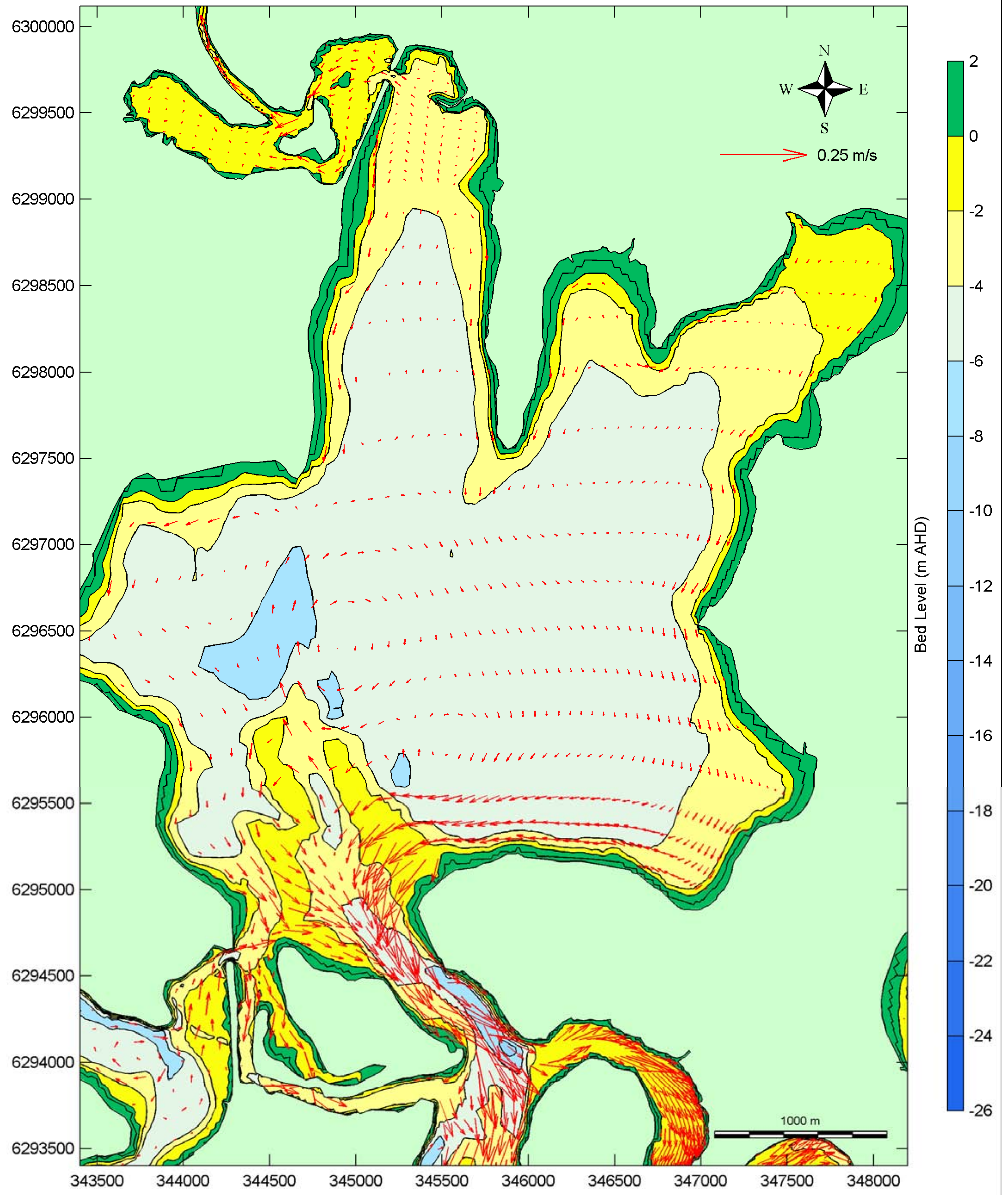
J/CM/J2255bw/Figures/R2312/FigureA3-15.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL AND SUMMER WIND GENERATED CURRENTS - BROADWATER DEPTH-AVERAGED

Figure A3-15

Ebb Tide (Start) 12:00 07/04/2004



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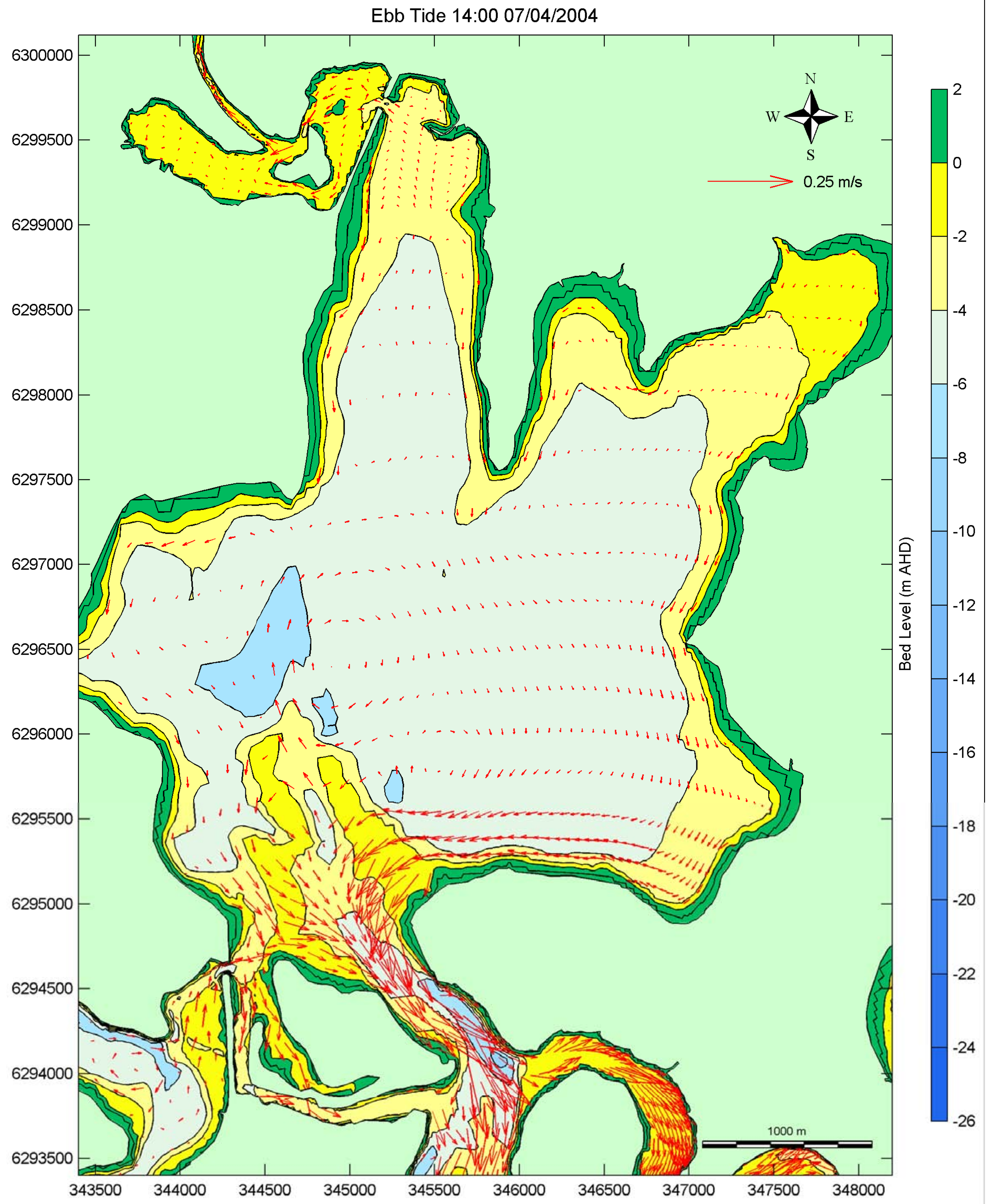
J/CM/J2255bw/Figures/R2312/FigureA3-16.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL AND SUMMER WIND GENERATED CURRENTS - BROADWATER

DEPTH-AVERAGED

Figure A3-16



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J/CM/J2255bw/Figures/R2312/FigureA3-17.png

Brisbane Water Estuary Processes Study - Hydraulic Processes

TIDAL AND SUMMER WIND GENERATED CURRENTS - BROADWATER DEPTH-AVERAGED

Figure A3-17