Coastal Processes Report

Hydrodynamic and Sediment Transport Assessment of Wallis Lake Dredging

301020-02712

FINAL REPORT (v2)

21 October 2011

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PROJECT 301020-02712 - COASTAL PROCESSES REPORT

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
A	Issued for internal review	E Watterson	H Nelson		Feb 2011	N/A	
B	Issued for client review	E Watterson	G Tuckerman		March 2011		
C	Final issued to client	K Newton		P Moses	21 Oct 2011		
D	Final 2 issued to client	K Newton	D Powell	D Powell	20 May 2013	G Tuckerman	

EXECUTIVE SUMMARY

In support of investigations into the feasibility of dredging works within the Wallis Lake estuary, a coastal processes assessment has been undertaken with the aim of facilitating a better understanding of the impacts and effectiveness of proposed dredging in the estuary and options for the disposal of dredged material. The coastal processes assessment includes the development and application of numerical hydrodynamic and sediment transport models. These models are then used as tools along with other data to make a qualitative assessment of proposed dredging works.

Establishment of a Hydrodynamic and Sediment Transport Model of Wallis Lake estuary

The tidal hydraulics of Wallis Lake was modelled using a MIKE 21 (two-dimensional (2D)) hydrodynamic model. The hydrodynamic model was developed primarily to describe the tidal water levels, tidal prism and estuarine flow patterns in the Wallis Lake estuary.

The model calibration and verification shows that the model is able to accurately predict tidal water levels and the main flow features and behaviours occurring in the lower Wallis Lake estuary. Modelled and measured water levels and discharges show very good agreement for both calibration and verification periods. As such, the hydrodynamic model is considered to be calibrated and fit for further application. The calibrated 2010 model forms the basis for all further simulations.

Sediment transport modelling has been conducted for lower Wallis Lake estuary using the MIKE 21 ST module that uses flow information from the MIKE 21 HD (hydrodynamic) model to calculate sediment transport rates. The MIKE 21 ST sediment transport rates for the lower Wallis Lake and estuary have been verified against measurements of bed sand transport in a similar estuarine environment for a study recently undertaken by WorleyParsons.

A key outcome of this study is the establishment of a coastal modelling system that is capable of accurately simulating the tidal and sediment transport behaviour of the Wallis Lake estuary. The established models would be capable of assisting in future estuary process and flood studies and assessing impacts and changes to the estuary resulting from sea level rise (SLR), catchment flooding, storm surge and other coastal processes.

Assessment of Dredging

Using the calibrated hydrodynamic and sediment transport model a number of potential dredging areas within the Wallis Lake estuary were assessed. Dredging of a navigation channel at ‘The Step’ is considered to be a feasible option to improve navigation to the main body of Wallis Lake. However, dredging of a sediment trap at ‘The Step’ is not considered to be effective due to changes to the local flow and sediment transport patterns. Direct removal of sediments from the lakeward slope of the drop-over is likely to provide a better option to reduce progradation of this shoal onto seagrass beds. Dredging of a navigation channel at ‘The Western Step’ is considered a feasible option to improve navigation to the Coolongolook River area and the western side of Wallis Lake. However, some impacts are expected on tidal flows with a significant increase in the tidal prism upstream as a result of the channel deepening. This would require a more detailed assessment to be undertaken before dredging of this area was to proceed. Dredging of a navigation channel at Wang Wauk (Boomers) Channel appears to be an ineffective option for improving navigation along the Wang Wauk (Boomers) Channel.

Disposal Options Assessment

A coastal processes assessment of two potential disposal options for material dredged from the lower Wallis Lake estuary was completed. The feasibility of the following options was investigated:

- beach nourishment of the southern end of Nine Mile Beach (commonly referred to as Tuncurry Beach);
- dumping of material within relatively calm zones identified in the lower estuary.

Nourishment of Tuncurry Beach is considered a feasible and long-term solution for the disposal of material dredged from the lower Wallis Lake estuary. If dredge spoil is placed in the identified area (refer to **Figure 8.14**) minimum sediment loss from the overall estuarine and coastal compartment is expected. The impacts of additional sediment movements associated with beach nourishment on coastal processes, estuarine function and navigation are expected to be minimal.

Beach nourishment, in isolation, is not currently required from a property protection or beach amenity perspective. However, changes to key coastal processes and potential development may necessitate on-going nourishment works in the future.

Depositing dredge spoil material within the lower Wallis Lake estuary was found to be a more cost effective disposal option. An area located on the southern side of Mather Island (refer to **Figure 8.15**) was investigated in the coastal processes assessment as a potential location for dumping spoil. A sand spit at the eastern end of Mather Island was created some years ago to improve the water quality for ‘The Paddock’ oyster lease area by reducing turbulent flood flows from the upper estuary entering the area. Filling of this area would have the added benefit of providing further protection against a flood breaking through the sand spit.

An hydrodynamic and sediment transport model has been used to assess the stability of dredge material dumped at this site. Based on model outputs dredge spoil would be expected be stable under typical tidal conditions if placed in this area.

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1 INTRODUCTION

WorleyParsons has been engaged by Great Lakes Council to undertake a feasibility study for nourishment of Tuncurry Beach and the preparation of a Review of Environmental Factors (REF) for the proposed dredging of 'The Step' in the Wallis Lake estuary.

In support of these studies, a coastal processes assessment has been undertaken with the aim of facilitating a better understanding of the impacts and effectiveness of proposed dredging in the estuary and options for the disposal of dredged material. The coastal processes assessment includes the development and application of numerical hydrodynamic and sediment transport models. These models are then used as tools, along with other data, to make a qualitative assessment of proposed dredging works.

This *Coastal Processes Report* supplements the main report; *'Wallis Lake – Dredging and Disposal Options Assessment Report*'.

1.1 Study Objectives

The principal intention of this study is to provide an assessment of the key coastal processes operating within the lower Wallis Lake estuary and the impacts of potential dredging in the estuary. The main study tasks were to:

- compile and review existing data and information pertaining to coastal processes affecting Wallis Lake estuary;
- establish a calibrated hydrodynamic and sediment transport model of the estuary;
- assess potential dredge scenarios; and
- assess dredge disposal options, particularly within the active beach system.

A key outcome of the study is the establishment of a coastal modelling system that is capable of accurately simulating the tidal and sediment transport behaviour of the Wallis Lake estuary. The established models would be capable of assisting in future estuary process and flood studies and assessing impacts and changes to the estuary resulting from sea level rise (SLR), catchment flooding, storm surge and other coastal processes, as well as dredging and other works.

1.2 Study Area

The study area comprises the Wallis Lake estuary (to the approximate location of the tidal limits) and the nearshore area in the direct vicinity of the entrance channel, to approximately the 20 m depth contour. Wallis Lake estuary is one of the largest coastal lakes in Eastern Australia.

It is a complex system comprising a main lake, large rivers and entrance area with interconnecting channels that separate the coastal towns of Tuncurry and Forster. The estuary covers an area of 98.7 km^2 including areas mapped as open water, mangrove and saltmarsh areas (DECCW 2010). The estuary is connected to the ocean by a narrow trained entrance channel. A location map of the Wallis Lake estuary is provided in **Figure 1.1**.

For the purposes of this study, the study area has been divided into five geographic regions (refer to **Figure 1.1**):

- lower estuary – this area is characterised by a highly dynamic system of interconnected channels and islands with bed sediments primarily composed of marine sand (WMA, 1999). This area is the primary focus of this study as this is where dredging is proposed.
- the main Wallis Lake area;
- Wallamba River;
- Coolongolook River system; and
- the coastal compartment adjacent to the estuary, this includes the entrance bar and adjacent beaches.

1.3 Study Approach

Study objectives were achieved through the development and application of a range of numerical modelling systems that were largely based on the 2D/3D capabilities of the MIKE coastal modelling system. Generally, the investigations proceeded as follows:

- review of previous studies and collection of available data (refer to **Sections 3 and 4**);
- establishment and calibration of the MIKE 21 hydrodynamic model system of Wallis Lake (refer to **Section 5**);
- establishment and verification of the sediment transport model for Wallis Lake (refer to **Sections 6**);
- assessment of potential dredging scenarios identified as part of this study (refer to **Section 7**); and
- assessment of potential disposal options identified as part of this study (refer to **Section 8**).

A brief description of the MIKE coastal modelling systems used in this study is provided in **Appendix A**.

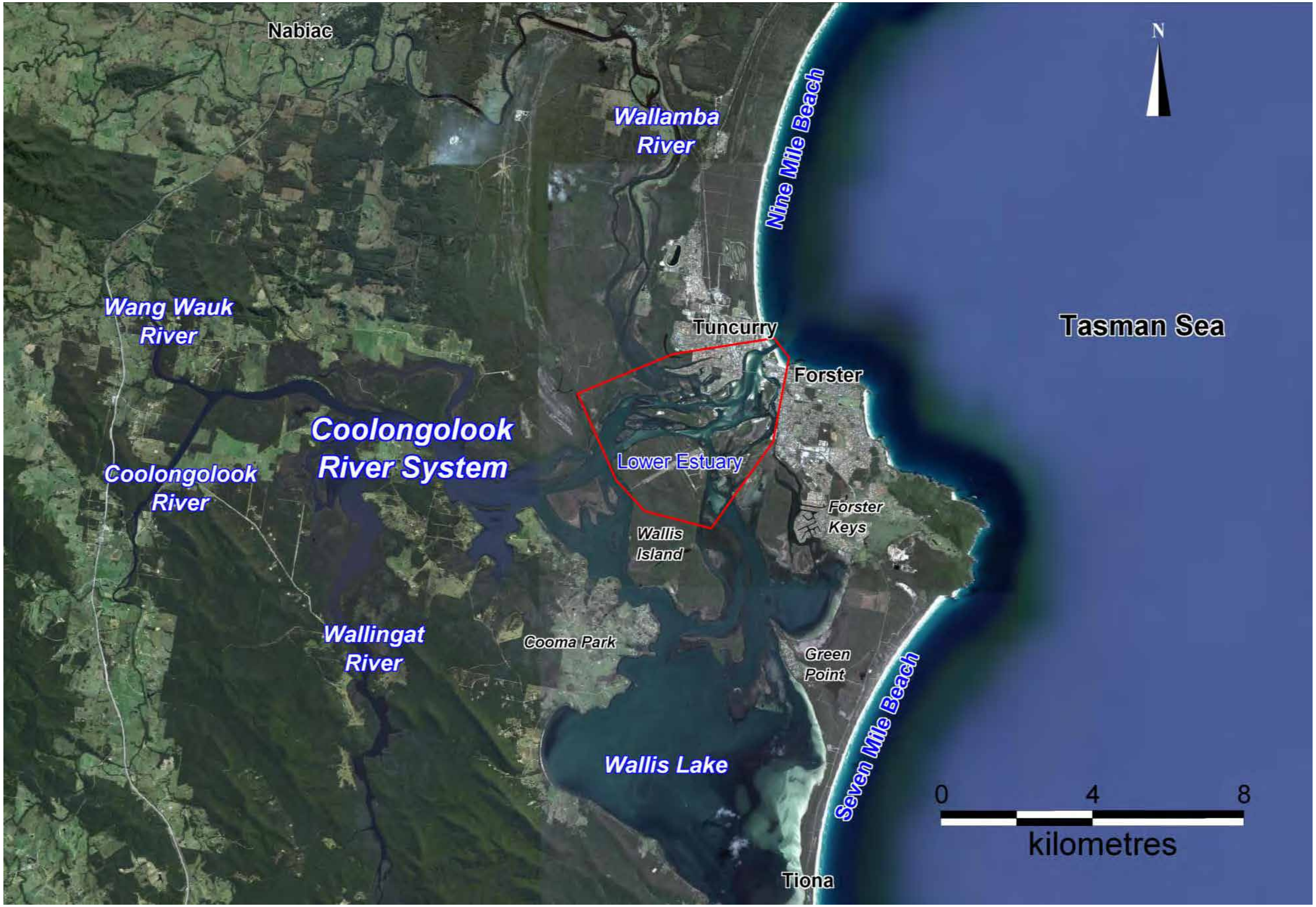


Figure 1.1 Wallis Lake Location map

2 PHYSICAL PROCESSES

The purpose of this section is to give a general description of some of the important coastal and estuarine processes operating within the study area. These processes include:

- inlet hydrodynamics;
- ocean water levels;
- lake water levels;
- waves;
- sediment transport processes;
- sea level rise; and
- other climate change impacts.

2.1 Inlet Hydrodynamics

Hydrodynamic conditions at tidal inlets can range from relatively simple ebb-and-flood tidal systems to complex environments in which tide, wind stress, freshwater influx, and waves influence the system (US Army Corp, 2002). Tidal inlets typically have a complex shoal pattern, further complicated by structures such as entrance breakwaters that influence wave refraction patterns.

The morphology, or shape of the landforms such as the channel and shoals, within a tidal inlet is influenced by tidal, wave and fluvial forces, as well as the sediment properties such as grain size, and boundary conditions such as bedrock and structures. The morphology of a tidal inlet is not static, and the existing shoals and channel tend to vary within a range of dynamic equilibrium states if in a stable condition. The tidal regime of such estuaries tends to develop so that there is a balance between the tidal prism and the cross-sectional area of the entrance and a balance between the width and the depth of the entrance channel. On the other hand, a tidal inlet may be in an unstable condition, and may evolve towards a new equilibrium morphology following a disturbance such as construction of structures (e.g. entrance training breakwaters), dredging and sea level rise. An unstable tidal inlet may experience shoaling and become cut-off from the sea, or may experience scouring, where the channel erodes and becomes deeper and more hydraulically efficient, and the tidal range and the tidal current velocities within the inlet increase. The stability of the Wallis Lake estuary’s ocean inlet is further discussed in **Section 4.3**.

2.2 Ocean Water Levels

The main factor that contributes to still water level variation (offshore of the wave breaking zone) is the astronomical tide. The astronomical tide is the periodic rise and fall of the Earth’s ocean surface caused by the gravitational forces of the Moon and the Sun acting on the oceans. While the vertical tidal fluctuations are generated as a result of these forces, the distribution of land masses, bathymetrical variation and Coriolis force determine the local tidal characteristics.

Tides along the NSW coastline are semi-diurnal, with high and low water approximately equally spaced in time and occurring twice daily (that is, on average, there are two high tides and two low tides in any 24 hour period). There is also a significant diurnal inequality in NSW coast tides, which is a difference in the height of the two high waters or two low waters of each tidal day. The astronomical tide ranges between about –0.9 m AHD (Lowest Astronomical Tide) and 1.2 m AHD (Highest Astronomical Tide) along the NSW coast, with 0 m AHD close to mean sea level.

Actual sea level fluctuations are not solely caused by astronomical tides, but may be affected by barometric pressure, wind and other oceanographic effects. Barometric pressure changes cause a localised vertical rise or fall in the still water level due to a reduction or increase, respectively, in atmospheric pressure. The variation in water level is approximately 0.1 m for each 10 hectopascal difference from the normal barometric pressure of 1013 hPa (MHL, 1992). Note that hectopascals are approximately equivalent to millibars.

Storm surge events, associated with severe coastal storms, can give rise to short periods of elevated ocean water levels. The components that give rise to wind setup and storm surge comprise inverse barometric setup. Elevated ocean water levels associated with storm surge may persist for several hours to days. Wind setup results from strong onshore winds pushing surface waters against the coastline. Wind stress occurs parallel to the ocean surface as energy and momentum is transferred to the water, and is proportional the square of wind speed. Storm surge height can be amplified by channelling through local bathymetry. Storm surges in NSW can be generated by both tropical and extra tropical cyclones, including both east coast cyclones and mid-latitude lows. The highest storm surge reported in Sydney measured 0.59 metres and was associated with the May 1974 storm event.

Wave setup is caused by breaking waves and is experienced landward of the breaking zone. It is additional to storm surge. On the open coast beaches of NSW wave setup of up to 1.5 m is expected (typically about 10-15% of the deepwater significant wave height). Wave setup has been shown to be much less than this for shallow trained ocean entrances such as Wallis Lake (Dunn et al, 1999).

2.3 Lake Water Levels

Water level data gathered between March and June 1998 was analysed to determine tidal planes and ranges from the ocean, along the entrance/island area, and into the main lake and up the tributary rivers (MHL, 1998). The analysis removed the anomalies due to meteorologic and hydrologic affects so as to show clearly the influence of the local bathymetry. A summary of the results is presented in **Table 2.1. Table 2.2** presents the tidal ranges for spring and neap tides, as well as the mean phase lag for all tides.

Table 2.1 Tidal Planes (m AHD)

Gauge Location	**Ocean**	**Entrance**	**Islands**	**Main Lake**	**Wallamba River**	**Coolon. River**	**Wang Wauk River**	**Wallingat River**
Gauge No. (MHL, 1998)	**0**	**1**	**7**	**17**	**32**	**25**	**26**	**23**
High High Water Solstice Springs	1.059	0.798	0.323	0.271	0.45	0.249	0.246	0.269
Mean High Water Springs	0.671	0.488	0.216	0.184	0.32	0.172	0.17	0.188
Mean High Water	0.536	0.384	0.193	0.171	0.294	0.162	0.16	0.178
Mean High Water Neaps	0.401	0.281	0.17	0.158	0.268	0.152	0.149	0.167
Mean Sea Level	0.011	-0.046	0.095	0.11	0.16	0.1	0.098	0.111
Mean Low Water Neaps	-0.378	-0.373	0.02	0.062	0.051	0.047	0.046	0.054
Mean Low Water	-0.513	-0.477	0	0.049	0.025	0.037	0.035	0.043
Mean Low Water Springs	-0.649	-0.58	-0.03	0.036	-0.001	0.027	0.025	0.033
Indian Spring Low Water	-0.926	-0.802	-0.103	-0.03	-0.094	-0.028	-0.029	-0.025

Table 2.2 Tidal Ranges and Mean Phase Lag

Gauge Location	**Ocean**	**Entrance**	**Islands**	**Main Lake**	**Wallamba River**	**Coolon. River**	**Wang Wauk River**	**Wallingat River**
Gauge No. (MHL, 1998)	**0**	**1**	**7**	**17**	**32**	**25**	**26**	**23**
Mean Spring Range (m)	1.32	1.068	0.241	0.147	0.321	0.145	0.145	0.156
Mean Range (m)	1.049	0.861	0.196	0.122	0.269	0.125	0.124	0.134
Mean Neap Range (m)	0.779	0.654	0.15	0.097	0.217	0.105	0.103	0.113
Mean Phase Lag (m)	0	4	74	214	191	209	209	230

The tables shows a large drop in tidal range between the entrance and the rest of the estuary system. The main lake and the upper estuary reaches of the Coolongolook, Wang Wauk and Wallingat Rivers have a tidal range approximately 10 to 15% of the ocean tide, while the Wallamba River has a range approximately 25% of the ocean.

The drop in the tidal range is also associated with a large increase in the time the estuary tide lags behind the ocean tide (usually measured at high and low tides). This lag exceeds 3 hours, or approximately a quarter of a tidal period, in the main lake as well as in the tributary upper reaches.

The drop in tidal range and increase in lag across the entrance and into the main water body is typical of estuary lake systems such as Wallis Lake, and is associated with friction losses and shallow water effects within the estuary entrance. These effects restrict flows and limit the capacity of the tide to fill the lake during a tidal cycle. As a result, the lake acts as a large reservoir which drains or fills through the narrow entrance channel depending on the relative level of the ocean. Because of its size the lake level remains fairly constant, in a small band just above mean ocean level, with the ‘reservoir’ only partially filling when the ocean tide is high and partially emptying when the ocean tide is low.

This ‘reservoir’ filling feature means that the lake only finishes filling, that is reaches its maximum level, after the ocean tide drops below the lake level (at a bit above mean tide level). This occurs some three hours or a quarter of a tidal phase after the peak ocean tide. Similarly, the lake only finishes emptying (reaches its minimum level) when the ocean tide again rises above lake level some three hours or a quarter of a tidal phase after the minimum ocean tide.

The ‘reservoir’ filling and emptying effect means that outflowing (ebb) tides occur during low ocean tides and inflowing (flood) tides occur during high ocean tides. Peak flows occur when the water level differences between the lake and the ocean are at the greatest (at peak high water and bottom low water).

This is a typical feature of lake estuaries and differs from open bay and river estuaries (eg Sydney Harbour and the Manning River) where the tide enters and then progressively travels up the waterway, with the outflowing tide commencing immediately after the slack water at the high tide peak, and finishing with the slack water at the low tide trough, and vice versa for the inflowing tide.

2.4 Wave Processes

Waves on the surface of the ocean with periods of 3 to 25 seconds are primarily generated by winds and are fundamental features of the coastal region. Other wave motions include tides, internal waves and edge waves. As wind-generated waves are of primary concern in this study, unless otherwise indicated, the term ‘wave’ applies only to surface gravity waves in the wind wave range (i.e. 3 to 25 seconds).

Ocean wind-waves that propagate into the study area may have energy in two distinct frequency bands. These are ocean swell (7 to 20 seconds) and local seas (7 seconds or less) and are principally determined by generation and propagation mechanisms. When the wind is blowing and the waves are growing in response, the sea surface tends to be confused: a wide range of heights and periods is observed and the length of individual crests may only be a wave length or two in extent (short-crested). Long-period waves that have travelled far from their region of origin tend to be more uniform in height, period and direction and have long individual crests, often many wave lengths in extent (i.e. long-crested). These waves are termed swell. A sea state may consist of just sea or just swell or may be a combination of both.

Ocean waves are irregular in height and period, so it is necessary to describe wave conditions using statistical terms. In this study we have adopted the most commonly used parameters:

- H_s significant wave height based on $4\sqrt{M_o}$ where M_o is the zeroth moment of the wave energy spectrum (rather than the time dominated mean of the highest one-third of wave heights $H_{1/3}$ parameter).
- H_{max} the largest 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.

As waves approach the shore from deep water into shallow water, they may be transformed by the processes of refraction, shoaling, diffraction, attenuation, additional growth due to wind, wave–current interactions and wave-wave interactions and breaking (US Army Corps, 2002).

Wave refraction is caused by the differential speeds of waves that interact with the sea bottom. For shallow water or transitional waves propagating incident to a sloping bed, changes in wave speed will change the direction of wave travel such that wave crests align with the bottom contours. Wave shoaling occurs when waves propagate shoreward and reduce in speed as they enter shallow water. In order to maintain a constant energy flux (ignoring other dissipation processes) their height must increase.

For the purpose of this investigation, wave diffraction is best described as the apparent bending of waves around small (relatively speaking) obstacles such as the entrance breakwaters. When ocean waves propagate past these objects some of the wave energy is blocked by the object. This creates a wave 'shadow' in the lee of the object. Wave diffraction acts to bend wave energy around the ends of the object to redistribute the wave energy from the nearby wave crest into this wave shadow.

The deepwater wave climate offshore from the study area is described in **Section 3.3.4**.

2.5 Sediment Transport

Sediment transport in marine environments is caused by the water particle motions of waves and currents that lead to shear stress on seabed sediments. Generally, sediment motion commences when the seabed shear exceeds a threshold value, which is dependent on particle size and density. Sediments may be transported as bed load or suspended load. Bed load transport occurs 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 upwards from the seabed.

In a tidal environment such as the Wallis Lake entrance area, the tidal currents in addition to wave stress are responsible for the mobilisation and entrainment of sediments. The relative strength of the flood and ebb current velocities, wave action and sediment properties determine the overall sediment transport regime, and the net direction of sediment transport. Fluvial transportation of sediment in runoff events can also be important in estuarine environments.

2.6 Sea level Rise

The principal impact of climate change on Wallis Lake will be associated with the predicted rise in mean sea level. The latest research on the evidence of sea level rise indicates that we are currently tracking at the upper end of IPCC's predictions (Church, et. al., 2008). Ocean thermal expansion and melting of non-polar glaciers and ice caps are the largest contributors to recent sea level rise.

Sea level projections are reported in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) of 2007 for a range of future emissions scenarios. The range of AR4 model projections (with a 90% confidence range) are for a mean sea level rise of 18-59 cm in the 2090 to 2100 decade (IPCC, 2007). The AR4 predicted range of sea level rise does not include potential dynamic response of ice-sheets, however, qualifying statements in AR4 make an allowance of 10-20 cm to account for this possibility. Although this addition is never made explicitly in the AR4, the total projected range would be 18-79 cm, once the allowance for dynamic ice sheet contribution is included. The AR4 specifically states: *"Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood to provide a best estimate or an upper bound for sea level rise"*. It is noted that sea level projections for the 21st century from AR4 of 2007 are similar to the IPCC Third Assessment report (TAR) of 2001 when the qualifying statements in the AR4 are considered.

Increases in sea level will not occur uniformly across ocean basins with some regions experiencing higher levels of sea level rise and others lower. Variations in the mean sea level anomaly are the result of spatial variations in the thermal expansion of the ocean due to large scale atmospheric and oceanographic circulation patterns. A study by McInnes et al (2007) found the future sea level rise along the NSW coast will be slightly higher than the global averages, with an upper estimate of 12 cm by 2070.

The NSW Department of Environment, Climate Change and Water (DECCW) released the *Sea Level Rise Policy Statement* in 2009. The NSW government guideline document adopts a sea level rise planning benchmark for the NSW coastline based on the upper limits of the most credible national and international projections. The NSW sea level rise planning benchmark is an increase above 1990 mean sea levels of 0.40 m by 2050 and 0.90 m by 2100. The planning benchmark of 0.9 m increase by 2100 is similar to the high-range sea level rise estimate of 0.91 m previously adopted (DECCW, 2007). The benchmark's primary purpose is to provide guidance to support consistent consideration of sea level rise impacts, within applicable decision-making frameworks.

2.7 Other Climate Change Impacts

Another potential outcome of climate change is a possible change in the frequency and intensity of storm events. This would include both coastal storms with damaging winds and waves and rainfall events.

Modest to moderate increases in average and maximum cyclone intensities are expected in the Australian region in a warmer world. However, cyclone frequency and intensity are strongly associated with the El Niño/Southern Oscillation (ENSO) phenomenon. How this phenomenon will vary in a warmer world is currently unknown (CSIRO, 2001; CSIRO Marine Research, 2001).

Mid-latitude storms have been predicted to increase in intensity but decrease in frequency with global warming (CSIRO, 2002), due to a reduction in equator to pole temperature gradients. However as with tropical cyclones, climate modelling at present lacks the resolution to accurately predict changes associated with global warming.

3 DATA ACQUISITION AND ANAYLSIS

A range of available data sets were acquired and used in various capacities (individually and/or combined) throughout the study for model setup, model calibration and verification, wave modelling and wave climate evaluation, and morphological modelling. In addition, some data sets were used to qualify historical changes in the estuary system, e.g. through tidal analysis of estuary water levels. A minor data collection exercise was also carried out for the purposes of this study to fill gaps identified in this available data.

A summary of the available data used in this study is provided in this section, a brief summary of the collection exercise is also included.

3.1 Historical Aerials

Aerial photography is available for the Wallis Lake estuary dating back to 1951. To assist in gaining an understanding of the coastal processes a review of the aerial photographs was undertaken, see **Section 8.1.3**. The photographs can be found in **Appendix B**.

A detailed review of these aerial photographs was also undertaken to document observed morphological changes in the estuary at key areas of interest, such as ‘The Step’. The outcome of this detailed review is presented in **Section 4.5**.

3.2 Bathymetric Data

Various survey data sets were acquired and utilised for this study. Survey data was used for the definition of land boundaries, bathymetry, and in morphological assessments. **Table 3.1** outlines the survey data sets used in this study and their main purposes.

Table 3.1: Available bathymetric data sets

Data Parameter	Location/ Description	Source	Date	Purpose
1998 Hydrographic Survey	Wallis Lake estuary including Wallis Lake, Wallamba, Coolongolook and Wang Wauk Rivers and entrance bar. The data collected is shown in **Figure 3.1**.	Department Public Works and Services (DPWS)	March 1998	Used to establish the hydrodynamic model bathymetry and for morphological change assessment.
2010 DECCW Hydrographic Survey	Lower Wallis Lake estuary area. The data collected is shown in **Figure 3.2**.	Department of Environment, Climate Change and Water	March 2010	Used for updating and refinement of the model domain to current conditions and for morphological change assessment.
2010 WorleyParsons Hydrographic Survey	Forster entrance bar **Figure 3.2**.	WorleyParsons	November 2010	Used for updating and refinement of the model domain to current conditions and for morphological change assessment.
Offshore Bathymetry	Navigation Charts – Aus 810 and Aus 219. Data extracted from charts is shown in **Figure 3.1**.	Royal Australian Navy	Unknown	Used to define model bathymetry in inner shelf regions (between 15 m and 100 m depth contours).

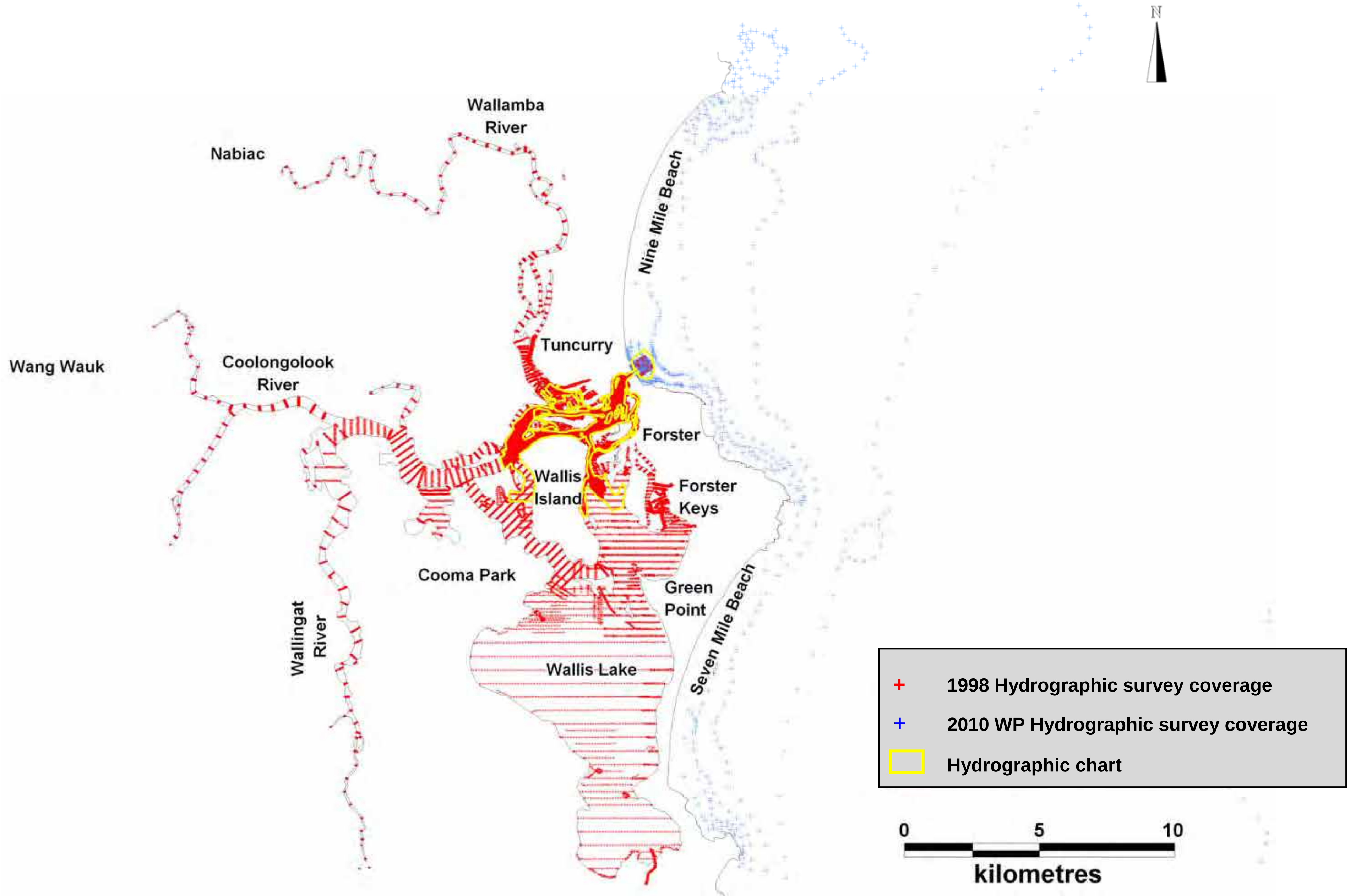


Figure 3.1 1998 DLWC hydrographic survey and navigational chart bathymetry data

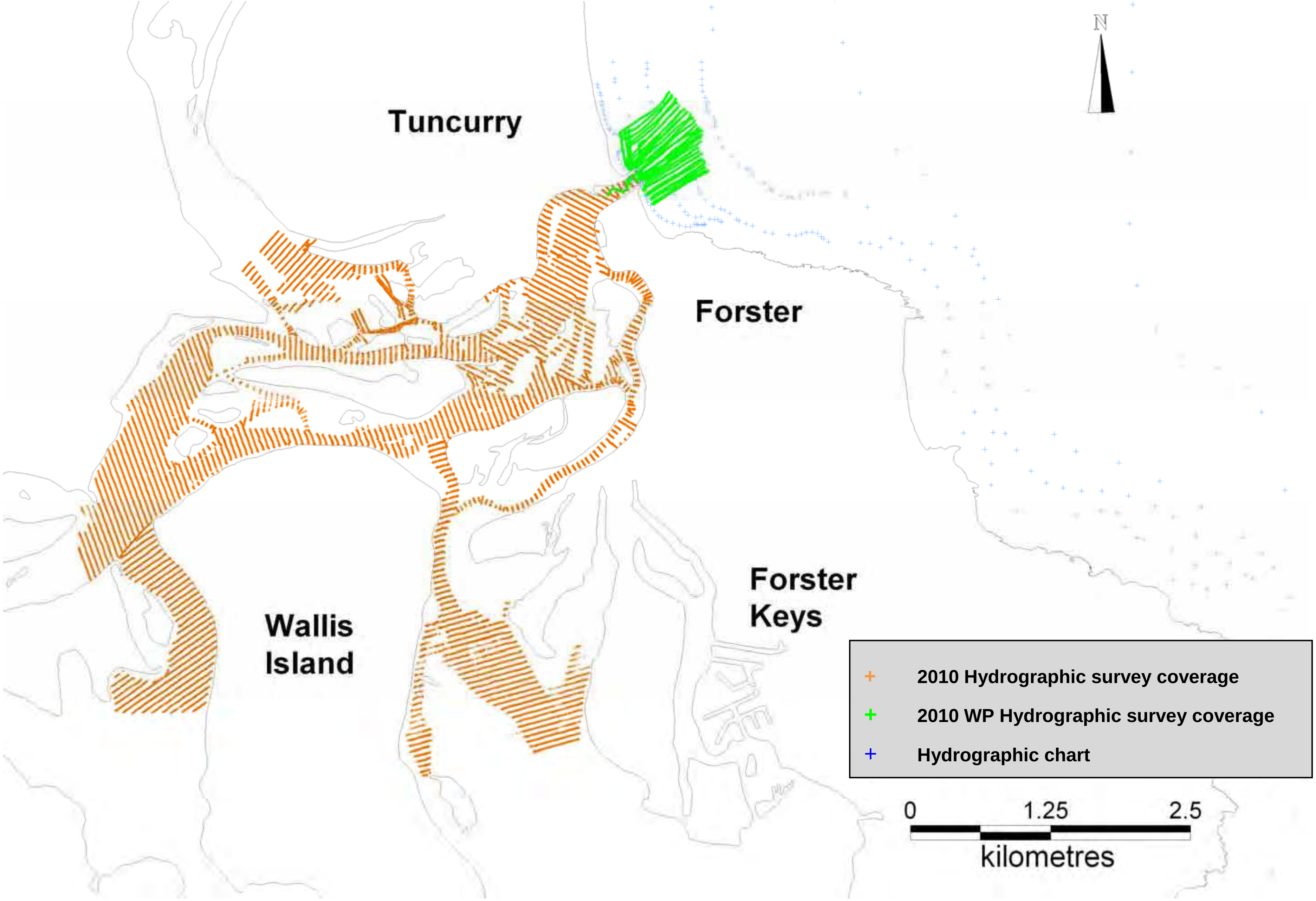


Figure 3.2 2010 hydrographic survey data including DECCW survey and WorleyParsons survey

3.3 Metocean Data

Existing metocean data for Wallis Lake estuary and the adjacent coastal area was sourced from various organisations and used for the assessment of coastal processes and establishment of numerical models. Existing metocean data was supplemented with data collection undertaken by WorleyParsons as part of this study (refer to **Section 3.3.2**).

3.3.1 MHL 1998 Data Collection

Between March and June in 1998 a comprehensive data collection exercise was undertaken by the NSW Government in the Wallis Lake estuary. Data collected during the 1998 exercise included a detailed hydrographic survey of the entire estuary (refer to **Section 3.2** above) as well as water level, flow and water quality data from around the estuary. Prior to this there was a lack of hydrographic and hydrodynamic data for Wallis Lake (Willing and Partners, 1996). This survey and tidal data forms the most comprehensive set of data available for the estuary and provides a baseline for the estuary.

Manly Hydraulics Laboratory (MHL) completed the 1998 tidal data collection with the results presented in *Wallis Lake Estuary Tidal Data Collection March-June 1998* (MHL, 1998). Data resulting from this exercise that has been utilised in this study included:

- *Water levels* data at twenty locations collected for at least a two to three month period in an area covering the ocean, main river tributaries and the main body of the lake; and
- *Tidal flow* data collected at 14 locations for a 24 hour period on the 28 March in the entrance/island area and midway along the Wallamba and Coolongolook Rivers.

MHL measurement locations and associated site identifiers (ID’s) are provided in **Figure 3.3**.

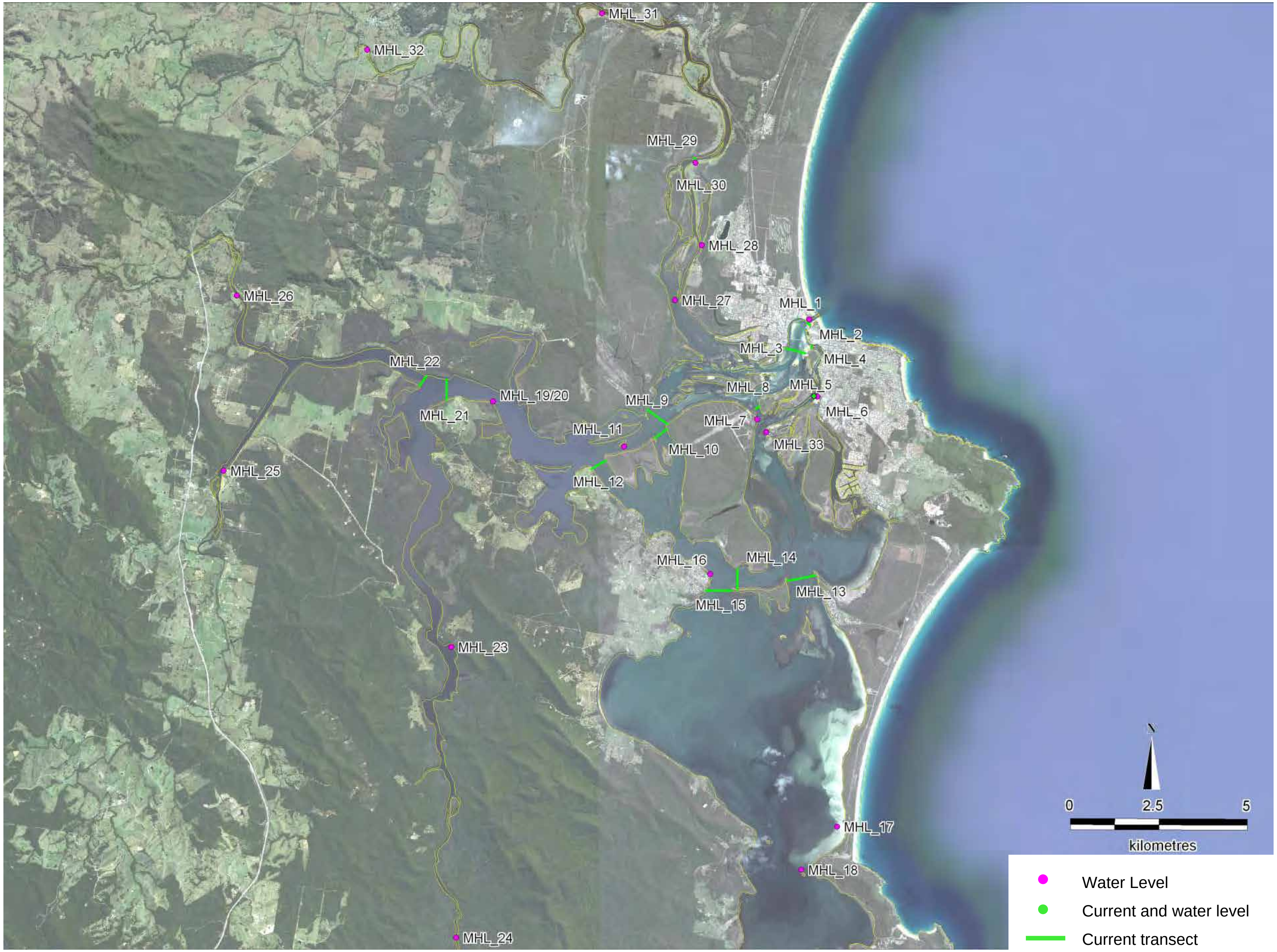


Figure 3.3 1998 MHL tidal data collection measurement locations

3.3.2 WorleyParsons 2010 Data Collection Exercise

In October 2010, members of the WorleyParsons study team conducted a short intensive data collection exercise in Wallis Lake. The main objective of the WorleyParsons 2010 data collection exercise was to establish a 2010 hydrographic and hydrodynamic baseline for the Wallis Lake estuary.

Both tidal flow data and a hydrographic survey of the entrance bar were identified as 'gaps' in the available data. When supplemented with DECCW 2010 hydrographic survey (refer to **Section 3.2**) and data from MHL's permanent tidal gauge network (refer to **Section 3.3.3**) a reasonably comprehensive 2010 baseline condition could be established. This completed 2010 baseline could then be used for:

- model verification purposes to ensure that the model systems established for the Wallis Lake estuary were current (refer to **Section 5.3**); and
- examination of the 2010 tidal regime and bathymetry of the estuary and to capture potential changes to this dynamic estuary since 1998 (refer to **Section 4**).

The measurements were made using a Sontek RiverSurveyor M9 Acoustic Doppler Profiler, (ADP) with an integrated DGPS system mounted on a hydroboard (refer to **Figure 3.4**). A suitable work boat was chartered from a local diving company; Action Divers (refer to **Figure 3.4**).

Figure 3.4 Instrument (left) and vessel (right) used for WorleyParsons data collection exercise.

Figure 3.5 presents the measurement locations for the 2010 WorleyParsons data collection exercise. The permanent in-situ water level gauges in the study area, managed by MHL, are also included on this figure.

The measurements made were:

- Current velocity profiles and channel discharge measurements on 12 October 2010. Repeated 3D current profiler transects for a full tidal cycle capturing both flood and ebb tide velocity structure and discharge hydrograph at WP_01, WP_02, WP_03, WP_06, WP_07 and WP_08 (refer to **Figure 3.5**).
- Bathymetric survey of the entrance bar carried out on the 18 October 2010.

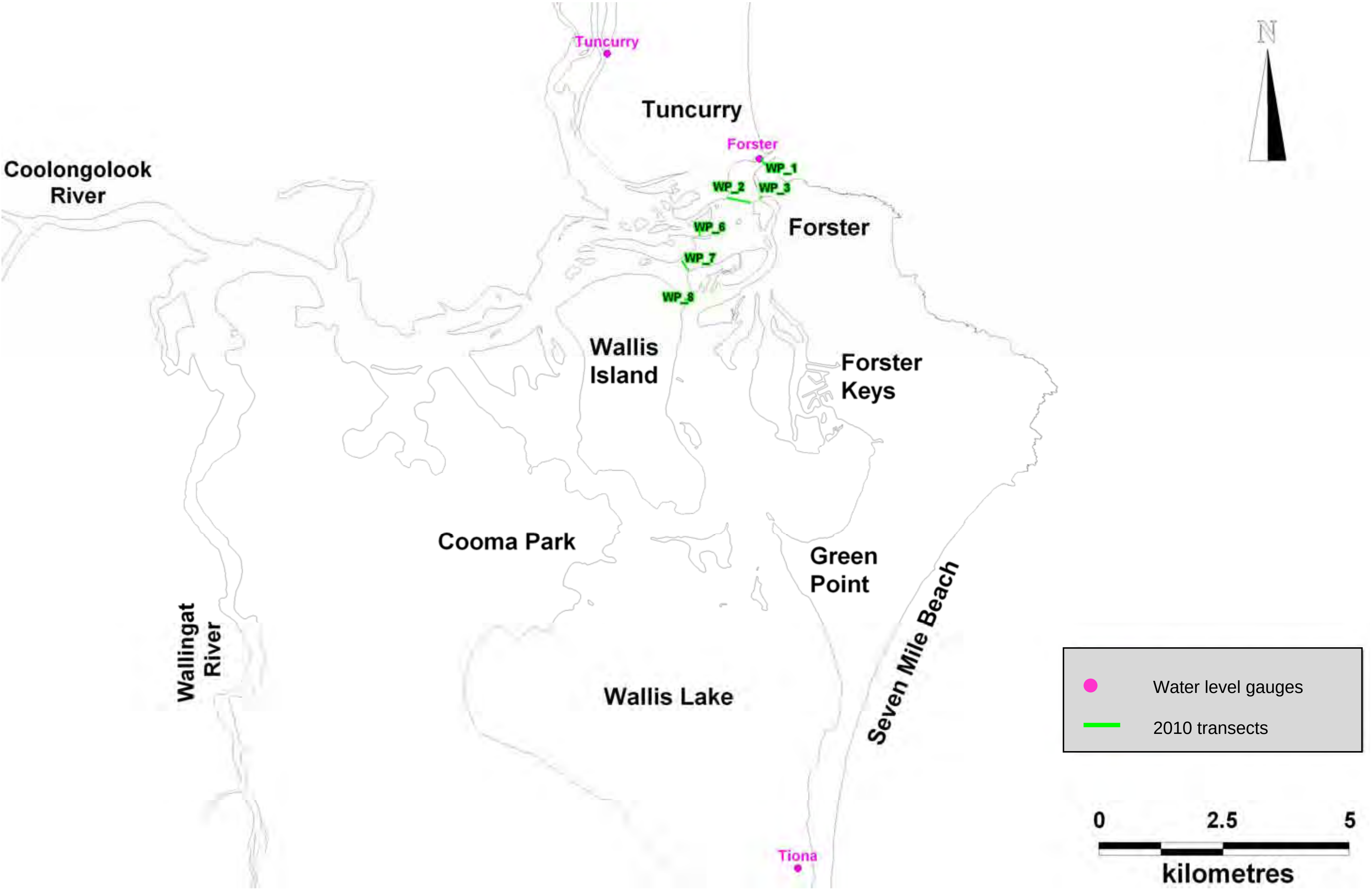


Figure 3.5 2010 WorleyParsons measurement locations and MHL permanent water level gauges in Wallis Lake

3.3.3 Permanent Water Level Gauges

In NSW, MHL collects water level data at about 200 continuously recording sites. Within Wallis Lake and nearby coastal areas, water level data are recorded at the following measurement locations (refer to **Figure 3.5** for locations in the Wallis Lake system):

- Crowdy Head;
- Tunucurry;
- Forster; and
- Tiona.

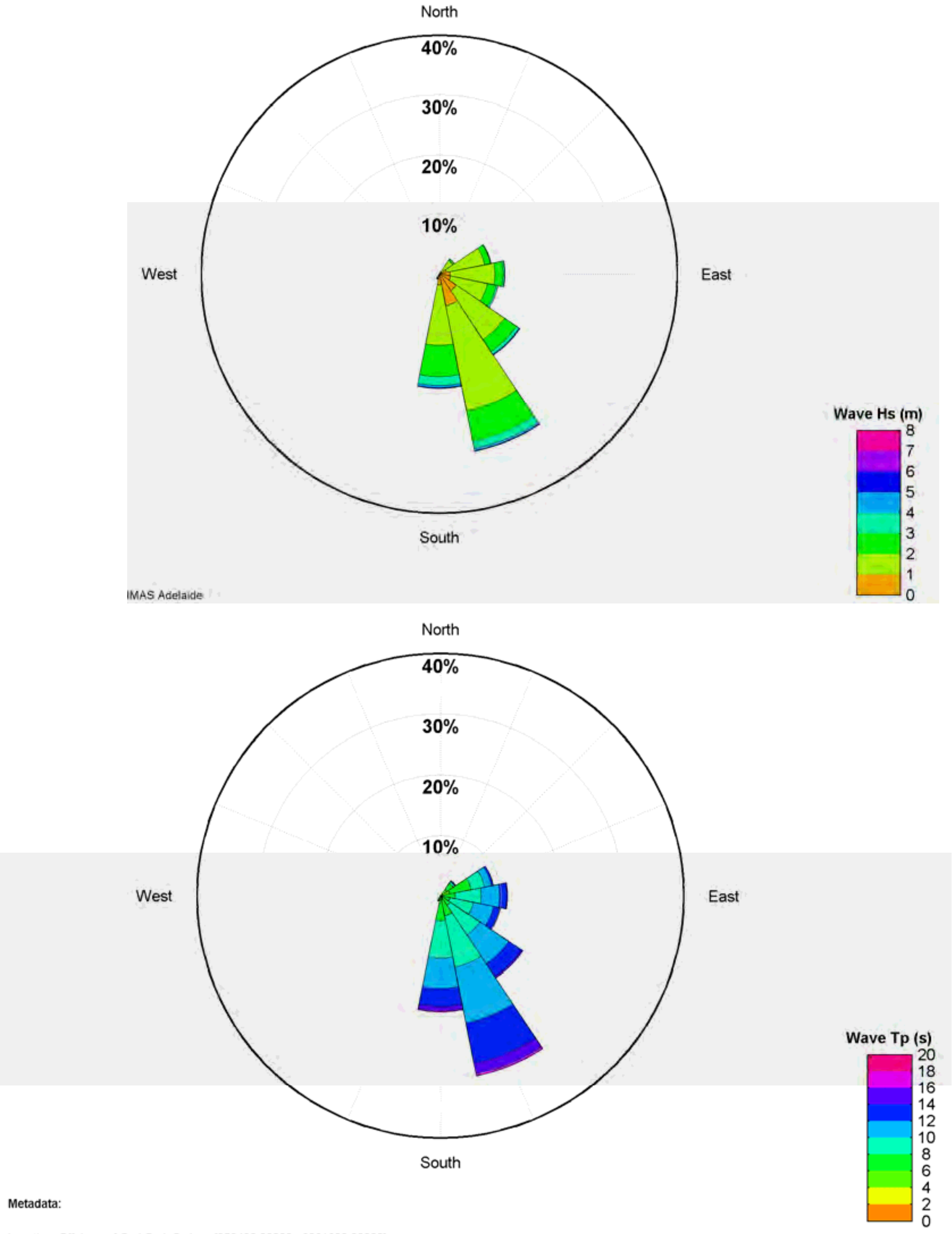
3.3.4 Offshore Wave Data and Wave Climate

The study site is located on the shore of the south-west Pacific Ocean at 32.2°S and receives waves generated in the southern Coral and Tasman Seas and the Southern Ocean. The annual wave climate is both energetic and highly variable with a distinct seasonality present. Based on a recent analysis of long-term records, March and June-July experience the largest average monthly wave heights (Harley et al, 2009). Although moderate waves dominate the climate, large waves (H_s>4 m) and/or low swell may occur in any month (Short and Trenaman, 1992). Extreme events (H_s>6m) occur predominantly in autumn and winter. Waves in the region are generated by five typical meteorological systems: east-coast lows, tropical cyclones, mid-latitude cyclones, zonal anticyclonic highs and local summer sea breezes (Short and Trenaman, 1992).

For the purpose of this investigation, the derivation of the regional wave climate has been based primarily on directional data obtained from the Sydney Waverider Buoy (SWB). Wave measurements were supplied by Manly Hydraulics Laboratory (MHL). Reference has also been made to a number of previous studies on the wave climate in the study region.

Figure 3.6 shows the wave height and wave period roses for the entire dataset. Wave roses show that the majority (approximately 65 %) of offshore wave energy propagates from the SSE sector (i.e. S, SSE and SE cardinal directions). SSE waves originate from storms and swells generated in the Tasman Sea and Southern Ocean, and can occur during any season. Easterly waves (i.e. ESE, E and ENE cardinal directions) make up approximately 30 % of the total offshore wave energy. N-NE waves make up approximately 3 % of the offshore wave energy and are generated by summer sea breeze systems and tropical cyclones in the Coral Sea. The largest period waves typical arrive from the S-SE sector in the winter months.

The influence of a range of climate oscillations, such as the El Niño/ Southern Oscillation, may help to explain the high variability observed in the offshore wave climate in the Sydney region (Harley *et. al*., 2009). Climate change may influence future trends in the offshore wave climate (McInnes *et. al*., 2007).



Metadata:

Location: Offshore of Curl Curl, Sydney [353490.00000 , 6261620.00000]
Data period: 03-Mar-1992 09:00:00 to 31-Aug-2008 23:00:00
Data source: Sydney Directional Waverider Buoy
Data summary: All Records
Number of Records: 116808

Figure 3.6 Sydney Offshore wave roses, wave height (top) and wave period (bottom)

3.4 Sediments

WMA (1999) identified three broad types of bed sediments in the Wallis Lake estuary:

- fluvial muds, sands and gravels;
- reworked coastal sands; and
- beach and nearshore sands.

A map of the distribution of sediments throughout the estuary is shown in **Figure 3.7** (sourced from WMA, 1999 Figure 14). Fluvial sediments are distributed along the tributary rivers and creeks and over the bed of the lake. Larger sand and gravel particles are located in the upper reaches of the tributaries. Sand-sized particles are widely distributed along the tributaries. Both Seven Mile Beach, the barrier between the lake and the ocean and Nine Mile Beach (to the north of the entrance) comprise marine sands, as does the marine tidal delta within the entrance. The marine delta which is the main focus of this study, extends from the ocean to drop-overs located at the 'The Step' and the 'Western Step' (approximately 5 km upstream of the entrance).

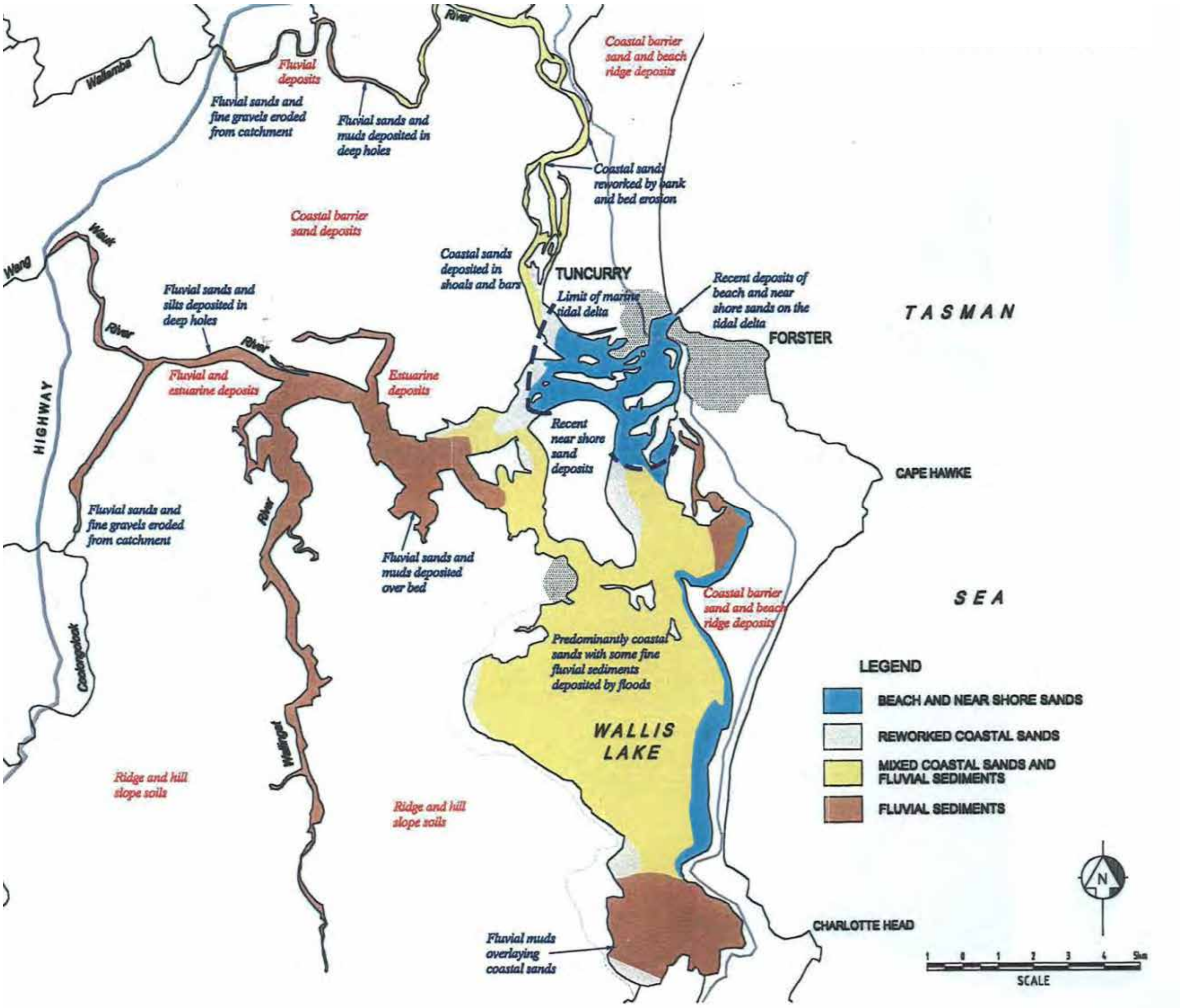


Figure 3.7 Bed sediment distribution (source: WMA, 1999)

3.4.1 WorleyParsons Sediment Sampling and Analysis

WorleyParsons undertook sediment sampling in Wallis Lake estuary and Nine Mile Beach in July 2010. Samples were taken in three general locations:

- Tuncurry Beach;
- the entrance area; and
- The Step

The sediments in the beach area were 100 % sand, with a d_{50} (median grain size) of approximately 0.30 mm. The sediments in the entrance area were 97 % sand, with a d_{50} of approximately 0.35 mm. The sediments at The Step were 94 – 98 % sand, with a d_{50} of approximately 0.30 to 0.35 mm.

More details on this sediment sampling exercise is provided in **Appendix D**, REF for dredging The Step.

3.4.2 Geology

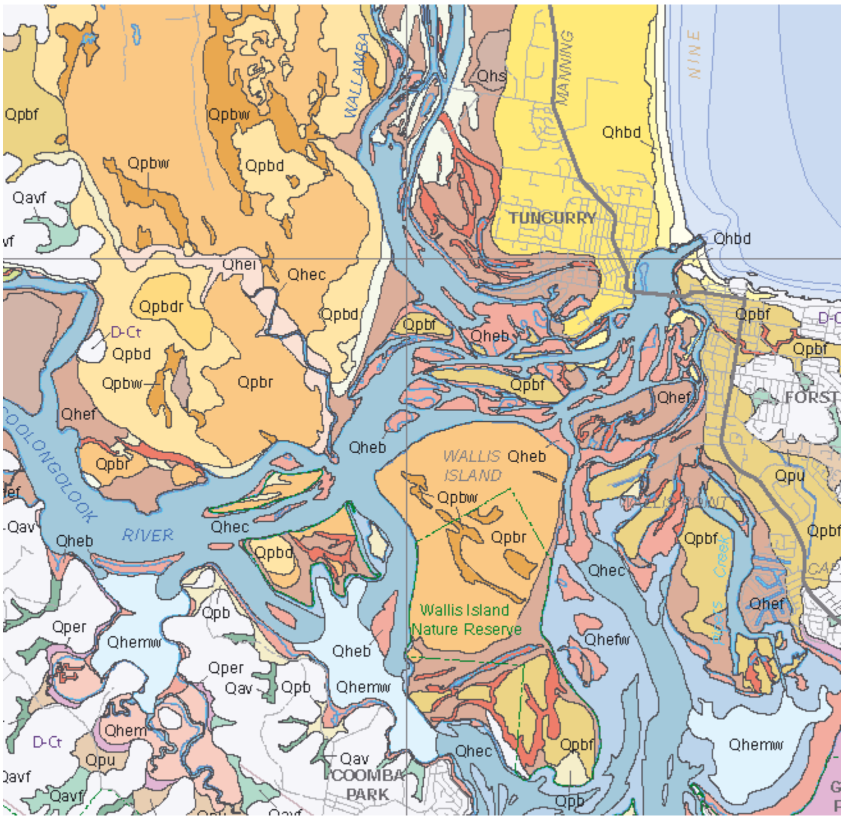
Geology of the main Wallis Lake area consists of ancient (Palezoic) sedimentary rock hills and ridges forming the western foreshore and a more recent (Quaternary) dune system which forms the coastal plain and eastern foreshore barrier between the lake and the ocean.

Figure 3.8 provides a map of the coastal quaternary geology of the Wallis Lake area.

The fluvial sediments are of Holocene origin (last 6000 years), originating from soils and rocks of the upper catchment, and contain a mixture of size fractions from clay and silt to gravels and sands, and consist of lithic particles.

The reworked coastal sands originate from remnant beach deposits from the previous periods of high sea level. These sands tend to be well sorted, well rounded and mainly consist of quartz. They contain grains with organic coating.

The beach and nearshore sands are similar to the reworked sands, but are of more recent origin, having been pushed up the continental shelf by the Holocene episode of sea level rise. These generally have high shell content and an absence of organic coating.



Key

Qhap - Holocene floodplain;

Qhbb - Holocene sandy beach;

Qhbd - Holocene dune, marine sand;

Qhbf - Holocene backbarrier flat;

Qhbr - Holocene beach ridge;

Qhef - Holocene tidal-delta flat;

Qpbd - Pleistocene dune, marine sandy indurated sand;

Qpbf - Back barrier flat;

Qpbr - Pleistocene beach ridge;

Qpbdr - Bedrock mantling dune.

D-Ct - Devonian to Carboniferous sedimentary rocks (Tamworth Belt);

Figure 3.8 Wallis Lake geology

(source: NSW Coastal Quaternary Geology, DPI 2005)

3.5 Photogrammetric Data

As part of a recently completed coastal processes study (WorleyParsons, 2010) a detailed photogrammetric analysis of historical vertical aerial photography (photogrammetry) was undertaken by DECCW. This enabled long term recession rates and storm erosion demand to be assessed for the southern part of Nine Mile Beach (Tuncurry Beach). The photogrammetric data consisted of 142 cross-shore profiles in 6 blocks covering approximately 4.6 km of the coastline, from the northern Wallis Lake entrance training wall (refer to **Figure 3.9**). The data covered a period of 45 years and included eight different years, from 1963 to 2008. WorleyParsons (2010) provides further information regarding the photogrammetry including:

- details of the dates of photography and the locations of photogrammetric profiles;
- a description of the methodology used in the analysis of the photogrammetric data; and
- tables and plots of analysis results.

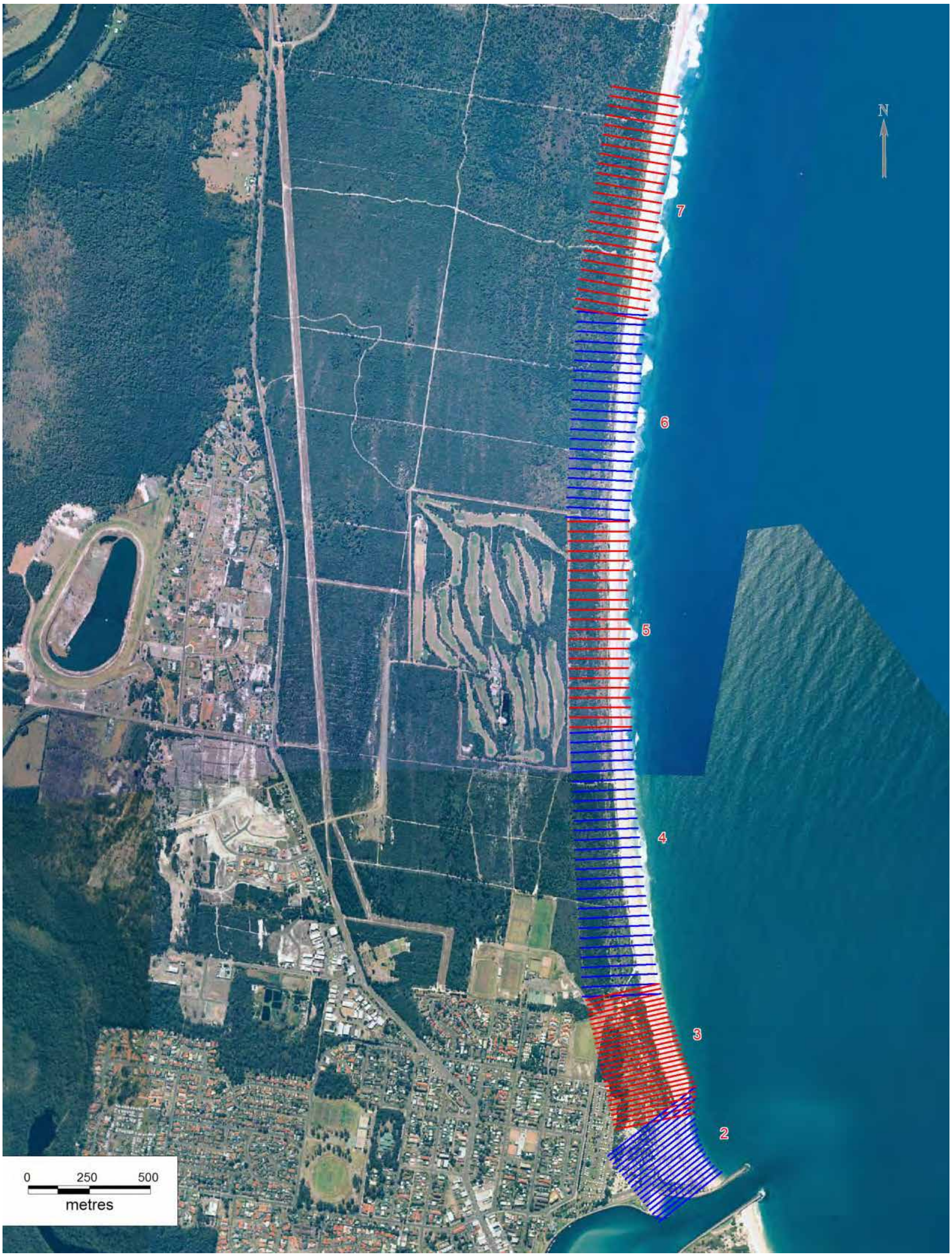


Figure 3.9 Photogrammetry profile locations

4 OBSERVED HYDRODYNAMICS AND MORPHOLOGY OF WALLIS LAKE

The aim of this section was to use observational data to assess the historical, current and on-going hydrodynamics and morphology of Wallis Lake. Using these observations an assessment is made of the overall stability of the estuary.

Although not specifically addressed in this study, the historical and on-going morphological evolution of the channel may have important ramifications on future navigational dredging requirements, stability of protection works and natural foreshores and intertidal habitats within Wallis Lake.

4.1 Wallis Lake Estuary

As noted in **Section 1.2**, the Wallis Lake estuary is a complex system with interconnecting channels. The ocean inlet to the estuary is trained by rock training walls and breakwaters on both the northern (Tuncurry) and southern (Forster) sides of the channel.

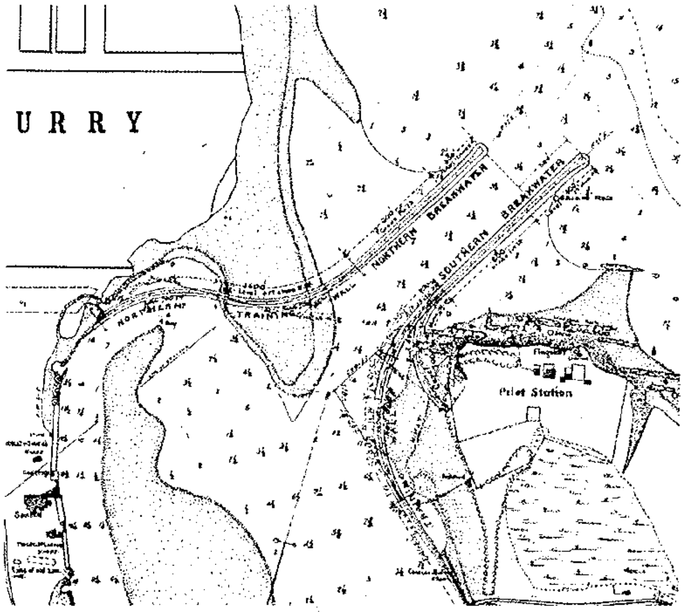


Figure 4.1. Wallis Lake inlet prior to training wall and breakwater construction (source: Nielsen and Gordon, 2008).

Prior to breakwater construction, the inlet to Wallis Lake was choked with sand transported by littoral drift, (refer to **Figure 4.1**). The southern (Forster) breakwater was constructed in 1898. While improving the tidal conveyance somewhat, entrance navigability was often compromised and, in 1966, the southern breakwater was extended some 90 m and the 460 m northern (Tuncurry) breakwater was constructed.

Training of the entrance increased the hydraulic efficiency of the estuary to tidal flows. It is likely that this in turn resulted in significant increase in the scour of the lower estuary. Evidence of this comes from a lakeward progradation of the marine delta drop-overs (refer to **Section 4.5.6** for information on progradation of 'The Step'). It is also likely that marine sand deposits in the lower estuary were transported out of the estuary via the ocean inlet. Littoral drift is likely to have moved sediments, supplied to the coastal compartment by the estuary, north onto Nine Mile Beach.

The hydrodynamic characteristics of Wallis Lake are quite complex. The lower estuary is dominated by tidal flows with average spring tides producing flows of a similar magnitude to the biennial flood event (having an Average Recurrence Interval (ARI) of 2 years). In the upper reaches of the tributary river (Wallamba and Coolongolook River Systems) flows are dominated by catchment runoff, with peak biennial flood flows over one hundred times the peak tidal flows (WMA, 1999).

In the lower estuary, the focus of this study, there is a decrease in the tidal range, with the range of 1.98 m recorded in the ocean (Crowdy Head) deceasing to a range of around 0.30 m in the lake proper (MHL, 1998). Tidal lag also varies along the estuary. These characteristics drive strong tidal currents, for example, on large spring ebb tides peak velocities through the entrance channel approach or exceed 2 m/s. As such the lower estuary is highly dynamic.

4.2 Estuarine Morphology

Estuarine morphology is to a large extent determined by the residual (or net) sediment transport pattern. Residual sediment transport depends on differences in magnitude and duration between ebb and flood currents. Such differences ('tidal asymmetry') are produced by distortion of the tidal wave propagation on the coastal shelf and entering estuary inlets. As such, estuaries experience a feedback relationship between their morphology and the current velocities generated within. It can be useful to characterise the nature of this feedback so that the implications of a change in the estuary, e.g. dredging, can be deduced in a broad overall sense.

The evolution of an estuary depends essentially on two processes (Donkers, 1986):

- the long-term average sediment supply from inland or coastal origins and the direction and magnitude of the long-term averaged sediment transport; and
- abrupt changes in the estuarine morphology caused by storm surge or by engineering works.

The sediment supply and sediment transport patterns in an estuary depend on several factors (Donkers, 1986), such as:

> *Sediment characteristics* – in broad terms sediments can be characterised as either 'fine' or 'coarse' depending on the grain size and fall velocity. The sediment within the lower Wallis Lake estuary is described as medium grained marine sand (refer to **Section 3.4**), and can be considered as coarse sediment. The transport of coarse sediment is strongly influenced by current speed. For coarse sediments, mobilisation does not occur until a critical velocity is reached, after which the transport load increases strongly with increasing current velocity (Van Rijn, 2007). Therefore, a tidal asymmetry in the maximum current velocity may affect the dominant direction of sediment transport. Fine sediments are not considered in this study as they do not represent a significant percentage of the material found within the lower Wallis Lake estuary.
>
> *Sediment Supply* – the supply of sand sized sediments to the lower estuary from fluvial sources is likely to be minor (WMA, 1999).

4.3 Estuary Stability

Estuaries are typically in a constant state of flux responding to changes such as the spring/neap tidal cycle, episodic flood discharges, coastal storms and anthropogenic perturbations. The sensitivity of the estuarine response to such perturbations depends primarily on the size of the estuary (Nielsen & Gordon, 2008). A stable estuary is defined as having a tidal discharge and channel cross-sectional area that vary about stable average values. The apparent stability of Wallis Lake is due to its large hydrodynamic mass. Unlike ICOLLs (Intermittently Closed and Open Lakes and Lagoons), Wallis Lake responds slowly to perturbations and changes may go unnoticed.

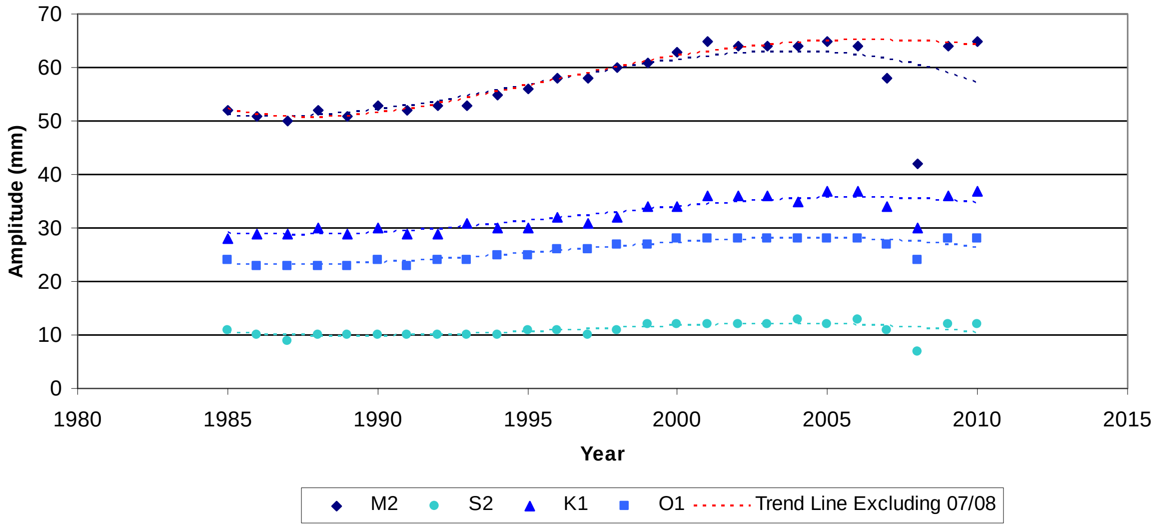
Wallis Lake estuary inlet is not in a stable equilibrium state. Evidence indicates that Wallis Lake has been in an unstable scouring mode since the construction of training walls at the entrance, which commenced over 110 years ago. However, the impact of the change on estuary stability was noticed first only accidently in the late 1970s with the imminent failure of Forster/Tuncurry Bridge (Nielsen and Gordon, 2008). A commuter on the bridge had noticed that the structure was swaying following the passage of trucks (pers. comm. Ron Cox to Evan Watterson, 2002).

Nielsen and Gordon (2008) recently used the time history of amplitude and phase of tidal constituents within large estuaries, along with classic estuary stability theory, to predict that the tidal range in Wallis Lake could eventually reach around 84 % of the ocean tidal range. Currently the lake's tidal range is around 12% of that in the ocean. Based on the current rate of change, it could take some 375 years. However, other methods presented by the same authors (Nielsen and Gordon, 1980) indicate that Wallis Lake could take some 50 years to stabilise (1967 to 2017). These estimated time scales indicate that morphological evolution of the inlet channel to Wallis Lake is likely to be a slow process.

4.4 Observed Tidal Regime Change

Long-term water level records are valuable in determining subtle changes in the tidal regime of an estuary. The tidal regime of an estuary can be well described by the tidal range, as calculated from the amplitude of the major tidal constituents measured within the estuary. For example, increasing amplitudes of the major constituents within an estuary (and subsequently tidal range) would indicate that the tidal prism is increasing. Tidal analysis was conducted on the long-term measured water level data available for a NSW open ocean site and a site within Wallis Lake estuary.

The analysis of the tidal regime within the Wallis Lake estuary indicates that the trained entrance compartment is reaching an equilibrium state, as per the findings of Nielsen and Gordon (2008). **Figure 4.2** shows four tidal constituents for the Tiona water level gauge (Tiona is located to the south of Forster-Tuncurry). A trend line, excluding the anomalous values from 2007 and 2008, has been provided. Based on this data it is estimated that equilibrium of the entrance system may be reached soon. When this occurs the net supply of sediment to Nine Mile Beach would only be that which bypasses the entrance, or is scoured out of the entrance during extreme flood events. At Nine Mile Beach, the severity of the future response to a potentially reduced sediment supply from Wallis Lake entrance is unknown. However it is anticipated that there would be a return to a zeta shaped embayment, with progressive recession from south to north. This is discussed in more detail in **Section 8.1.3**.



M_2 = main lunar semidiurnal constituent, S_2 = main solar constituent, K_1 = soli-lunar constituent, O_1 = main lunar diurnal constituent

Figure 4.2 Tidal Constituents for Tiona Water Level (after Nielsen, 2006)

4.5 Observed Morphological Change in Wallis Lake estuary

Two complete hydrographic surveys of the lower Wallis Lake estuary were available for this study:

- *April 1998 - DLWC Hydrographic survey.* Undertaken as part of the base line data collection program for the Wallis Lake estuary. The survey covers the entire estuary, extending from the ocean side of the entrance bar approximately to the 10 m contour line, to upstream areas of Wallamba River and Coolongolook River. The resolution of the survey was variable but was generally approximately 20 m^2. **Figure 4.3** presents the 1998 bathymetry as a coloured DTM (refer to **Figure 3.1** for a plot of survey transects).

- *2010 - DECCW and WorleyParsons Hydrographic Survey.* In August 2010 DECCW undertook a hydrographic survey of the lower estuary. This extended from the entrance inlet channel to beyond the drop-overs of the marine delta (i.e. beyond 'The Step' and 'The Western Step'). The DECCW survey was conducted using cross sections at 50 m spacing. Combined with WorleyParsons' October survey of the entrance bar (refer to **Section 3.3.2**) this provided a complete survey of the 2010 bathymetry. **Figure 4.4** presents the 2010 bathymetry as a coloured DTM (refer to **Figure 3.2** for plot of survey transects).

A check of these two surveys in areas where negligible bed level change is expected (e.g., the lake proper) indicates that the surveys are sufficiently accurate to allow comparison.

A snap-shot of the morphological change (both natural and anthropogenic) over the 12.4 year period between surveys is provided by taking the 1998 bed levels from the 2010 bed levels (refer to **Figure 4.5**).

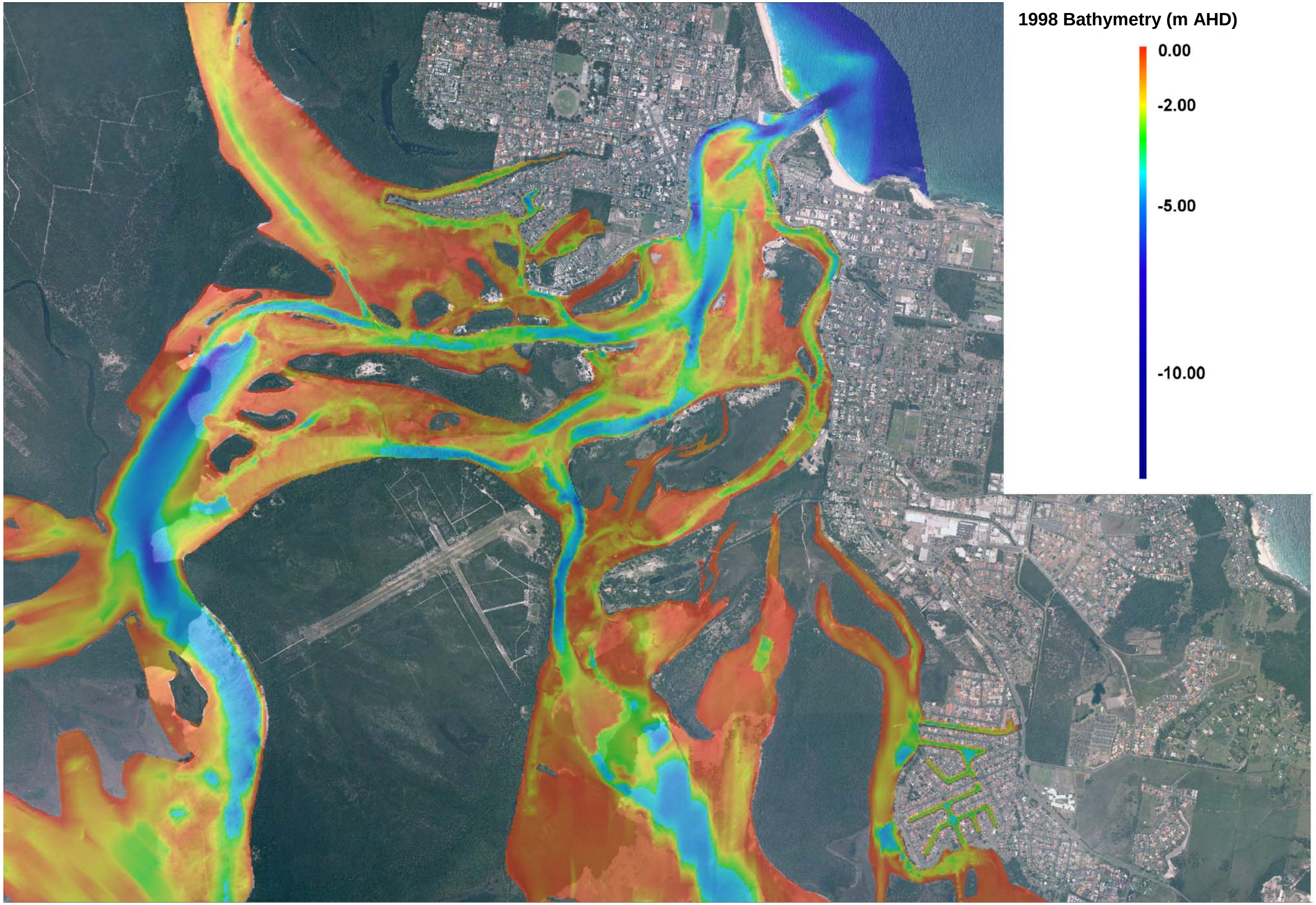


Figure 4.3 1998 Hydrographic Survey

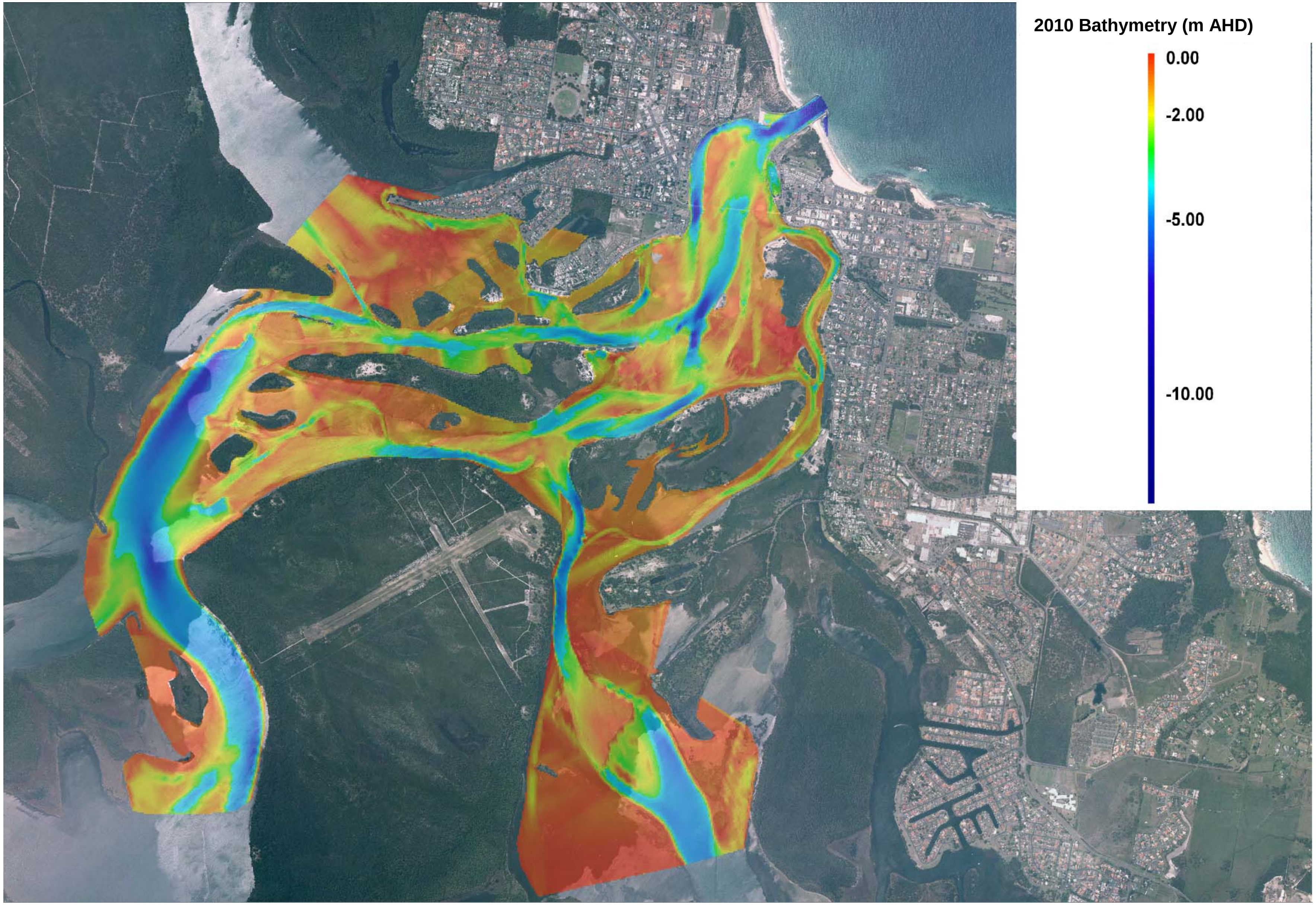


Figure 4.4 DECCW 2010 Hydrographic Survey

Figure 4.5 Depth Differences between 1998 and 2010 Hydrographic Survey

4.5.1 General

The most noticeable changes appear to be the significant sediment accumulation in the entrance area of the estuary and the scouring of the navigation channel in the entrance area. It is also observed that the middle ground and the Point Road Channel shoals have grown considerably over the 12 year period.

Other notable changes include the scouring and deepening of the estuary inlet between the training walls, and evidence of infilling in the navigation channel along the Tuncurry foreshores. Deposition of sediment on the lee slope (ocean side) of the entrance bar can also be observed.

Further upstream of the entrance, significant sediment accumulation at ‘The Step’ was observed.

4.5.2 Entrance Bar

Deposition of sediment has occurred on the lee slope of the entrance bar. This deposition is displayed in **Figure 4.6**. It can also be seen from this figure that the entrance bar has scoured and the overall extent of the entrance bar has moved in a seaward direction.

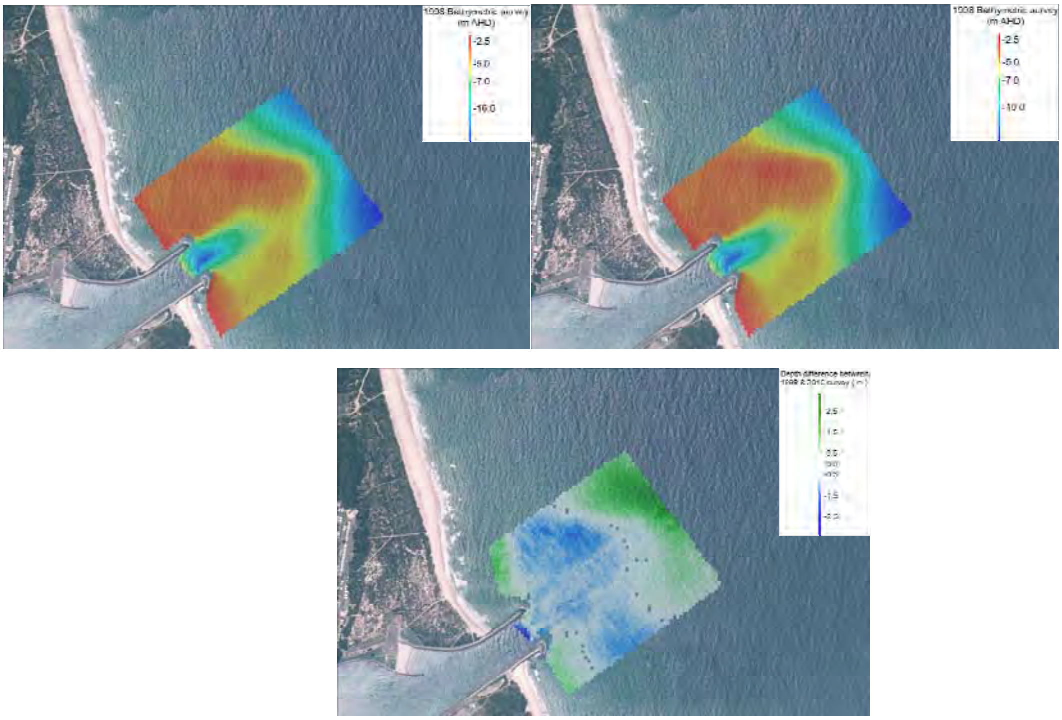


Figure 4.6 Entrance bar in 1998 (top right), 2010 (top left) and the difference (bottom).

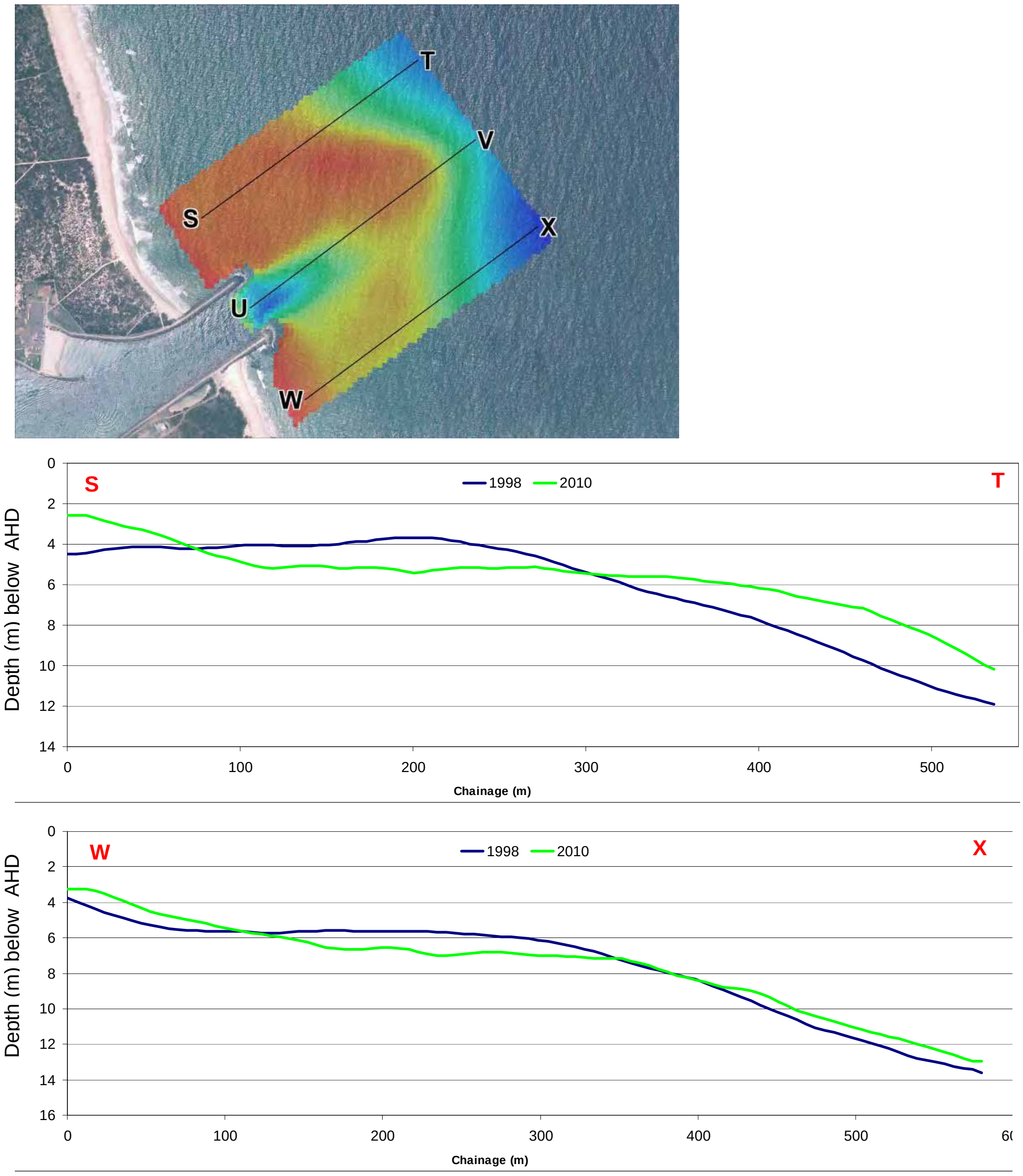
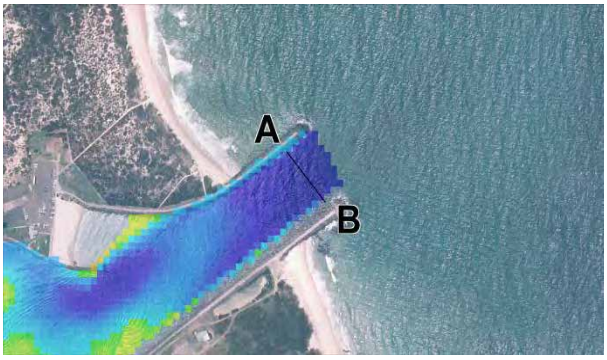


Figure 4.7 Entrance bar cross-sections

It should be noted that the 1998 coverage of the hydrographic survey limits the comparison of the entrance bar and beach system. However, it can be observed that morphological changes are more significant in the area north of the northern training wall, in particular the deposition on the lee slope, as seen in the section ST. Section WX indicates that the general shape of the bar was maintained.

4.5.3 Ocean Inlet



The Wallis Lake estuary is connected to the ocean via a trained inlet approximately 120 m wide and 400 m long. Based on the cross section AB, it is evident that the inlet has scoured and deepened over the 12 year period, up to around 4 m (refer to **Figure 4.8**).

This morphological change suggests that the cross-sectional flow area at the estuary inlet has been increasing and becoming more hydraulically efficient.

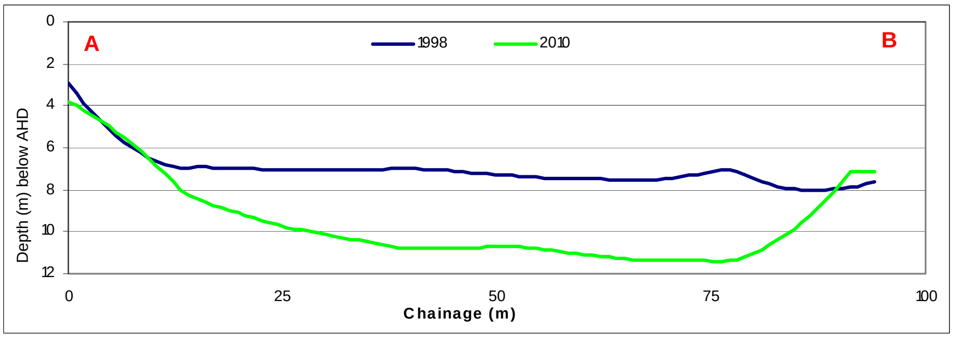
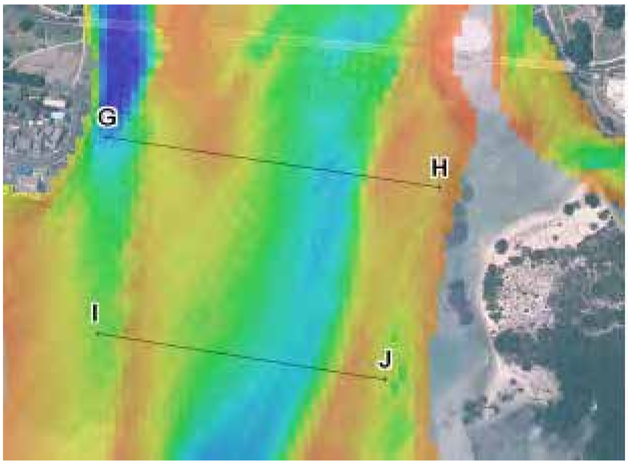


Figure 4.8 Comparison of 1998 and 2010 Survey, Estuary Inlet

4.5.4 Entrance Area



The most notable morphological change over the 12 year analysis period in the entrance area is the significant accretion of sediment in the estuary entrance. Comparison of the cross sections GH and IJ (refer to **Figure 4.9**) indicates that shoaling has occurred in the entrance channel and that the channel has shifted towards the east.

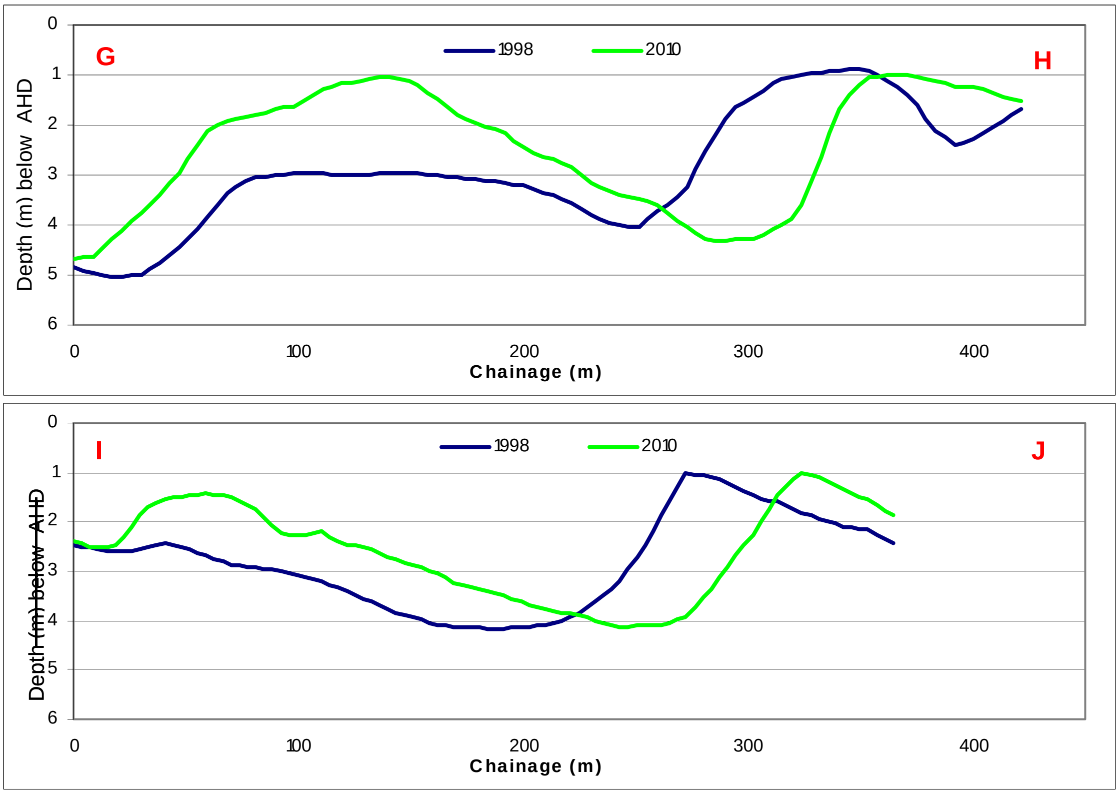
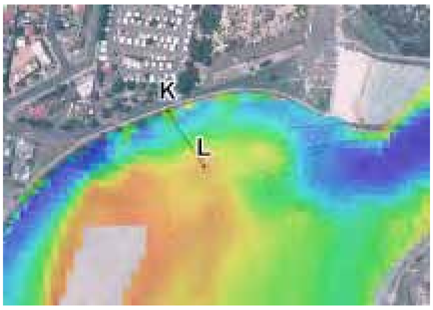


Figure 4.9 Comparison of 1998 and 2010 Survey, Entrance Area

4.5.5 Navigation channel



A channel hugging the Tuncurry foreshores has been dredged on several occasions for navigation purposes since the construction of the Forster – Tuncurry bridge in 1966. Comparison of 1998 and 2010 bathymetry indicates the infilling of this navigation channel has occurred over the 12 years. It can be seen from cross section KL that infilling of up to 3m is evident (refer to **Figure 4.10**).

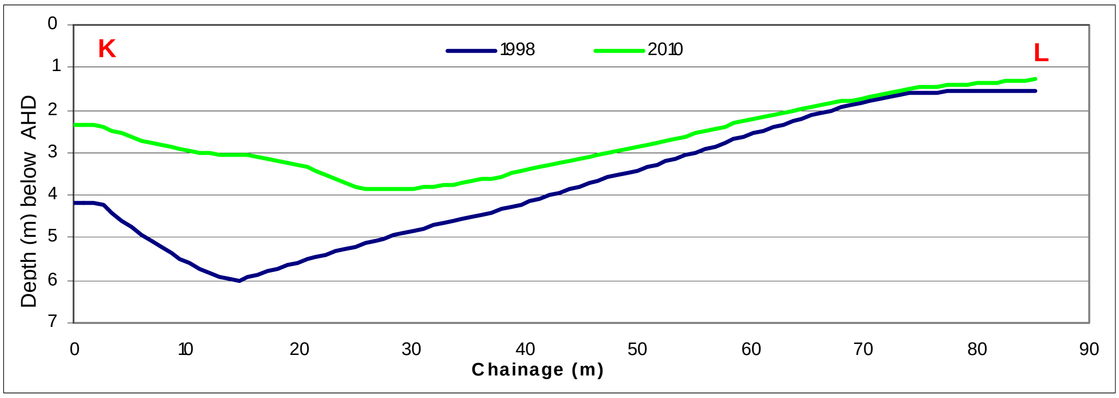
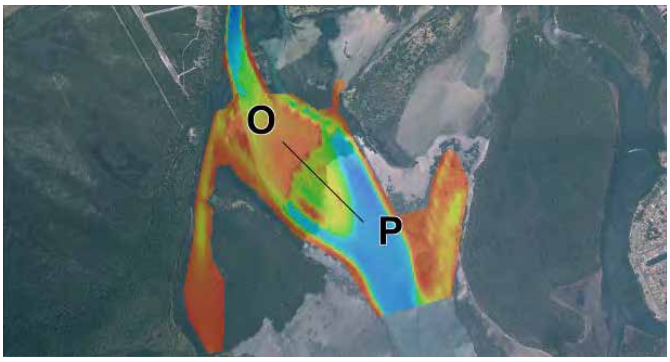


Figure 4.10 Comparison of 1998 and 2010 Survey, Navigation Channel

4.5.6 The Step



There is evidence of 'The Step' migration since the earliest available photograph in 1952. It appears that migration of the bed into the lake proper occurs in 2 stages; the first step in the bed form located at around 1.5 – 2 m below AHD and the lower second step which drops into Wallis Lake. It can be seen from section OP that the most noticeable change in this area is the growth of the first step, approximately 100 – 150 m migration towards the main body of the lake over 12 years (refer to **Figure 4.11**).

The bed form into the lake proper (i.e., the second step) appears to remain unchanged over the period of analysis.

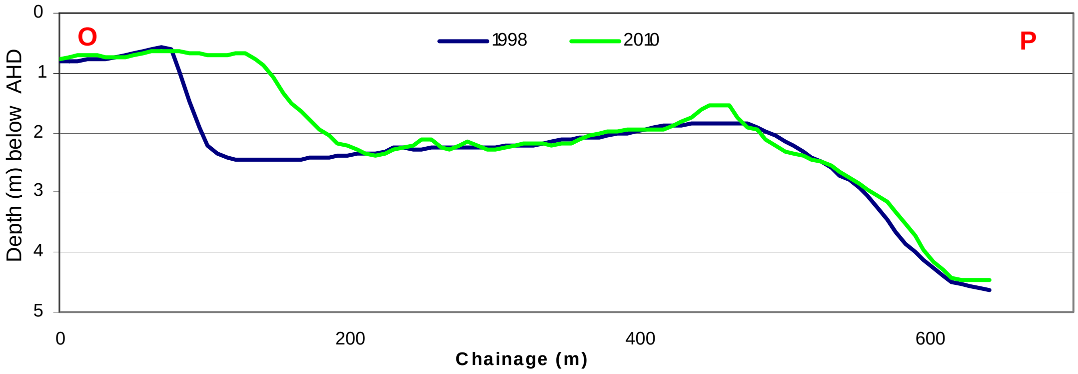


Figure 4.11 Comparison of 1998 and 2010 Survey, ‘The Step’

5 HYDRODYNAMIC MODEL

The tidal hydraulics of Wallis Lake was modelled using a MIKE 21 (two-dimensional (2D)) hydrodynamic model. The hydrodynamic model was developed primarily to describe the tidal water levels, tidal prism and estuarine flow patterns in the Wallis Lake estuary.

The numerical model is based on the finite element version of MIKE 21, which utilises an unstructured computational mesh to provide the optimal degree of flexibility in describing ambient flow conditions. The model is capable of simulating most of the important physical processes observed in the lake and channel flows. The tidal hydrodynamics for the existing lake and channel conditions were simulated using appropriate model forcing. The ‘existing conditions’ hydrodynamic model was calibrated and verified against available water level and current data.

5.1 Model Establishment

The model domain encompasses the entire intertidal area of Wallis Lake estuary and the nearshore region, extending offshore to approximately 100 m depth contour. Various model resolutions (i.e. size of mesh elements) were applied throughout the model domain. The finest resolution was provided at the critical areas of the model, e.g. the estuary inlet area and areas of interest, e.g. ‘The Step’. The computational mesh, including a representation of the interpolated bathymetry, used in the model is shown in **Figure 5.1**.

Various sources of hydrographic and topographic survey information have been used to describe the models bathymetry and land boundaries; these data sets are described in **Section 3.2**.

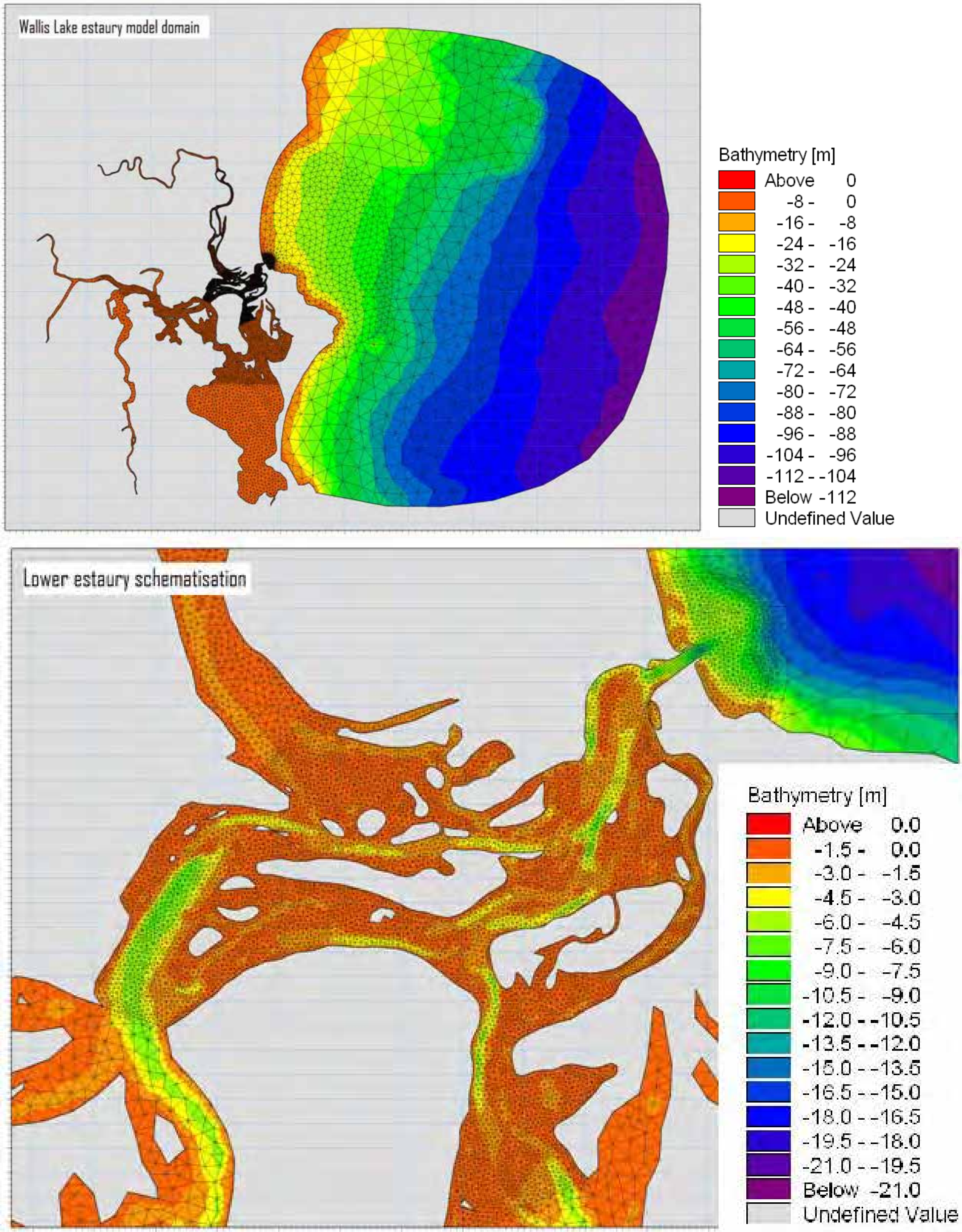


Figure 5.1: Computational mesh used in the MIKE 21 Flow Model (top) including a zoom of the lower estuary (bottom).

5.1.1 Model Forcing

Tidal forcing of the hydrodynamic model was applied to the ocean boundary by way of a time varying water level. The model's ocean boundary was forced using a measured ocean water level time series from data collected at MHL's Crowdy Head water level recorder (refer to **Section 3.3.3**).

5.2 Model Calibration

Model calibration is the process of setting physically realistic values for model parameters so that the model reproduces observed values to the desired level of accuracy. The process provides confidence in the hydrodynamic model results and is essential for the accurate representation of the estuary hydraulics and for subsequent sediment transport calculations.

The 2D hydrodynamic model has been calibrated against the most comprehensive set of tidal water level and discharge data collected in the Wallis Lake estuary and upstream rivers. From 25 March to 10 June 1998, a tidal data collection exercise was undertaken in the estuary by MHL with the aim of providing baseline data to facilitate an understanding of the hydraulic processes operating in the estuary (MHL, 1998) (refer to **Section 3.3.1**). A short-term intensive data collection program was also carried out, collecting tidal velocities and discharge measurements at 14 sites throughout the estuary over a spring flood-ebb semidiurnal tidal cycle. The locations and parameters collected at each site are presented in **Figure 3.4**. For model calibration, the bathymetry of the Wallis Lake estuary was described using the hydrographic survey information collected in 1998 (refer to **Section 3.2**).

Selecting a 29-day period of available water level data that also included the short-term intensive flow data, the calibration period for the model has been defined as spanning from 26 March 1998 to 23 April 1998, a period of 29 days. This period contains both spring and neap tidal conditions and provides a good representation of typical tidal conditions in the estuary. Model calibration focused on achieving good agreement between the modelled and measured data at the measurement sites considered relevant for this study for the following parameters (refer to **Figure 3.4):**

- 3 Water level sites:
    - MHL_1, MHL_7, MHL_11, MHL_16, MHL_17, MHL_18, MHL_19, MHL_23, MHL_24, MHL_25, MHL_26, MHL_27, MHL_28, MHL_31 and MHL_32.
- Measured spring discharges (28 March 1998):
    - MHL_2, MHL_3, MHL_4, MHL_8, MHL_9, MHL_10, MHL_12, MHL_13, MHL_14, MHL_15, MHL_21, MHL_22 and MHL_29.

The calibration process involved a series of minor modifications to the schematisation and resolution of the computational meshes and to the model's bed roughness, until a good agreement with the measured data was achieved. Comparative water level and discharge plots for all water level sites, displaying modelled versus measured data, are presented in **Appendix C**. Examination of these plots indicates that the model produces good overall agreement with the measured data.

In order to quantify the model data against measurements, tidal analysis[1] was conducted on the water level measurement sites. The calculated amplitudes and phases of the four primary tidal constituents (refer to **Section 3.3.2**) (M2, S2, K1 and O1) for the modelled and measured water levels at three example sites are presented in **Table 5.1**. The error (%) in the modelled tidal amplitude and phases difference (°) compared to those acquired from the measured data are provided. The modelled and measured amplitudes and phases of the four primary tidal constituents for each MHL site are included in **Appendix C**.

The error in the amplitude for the M2, S2 and K2 was generally less than 10 %. The error in phase was generally less than 10 °. Based on this result the calibration to measured water levels was considered acceptable for the purpose of this investigation.

Table 5.1: Comparison of the amplitude and phase of the four primary tidal constituents during the 1998 calibration period (refer to Figure 3.3 for locations)

Constituent	Amplitude			Phase		
	Measured (m)	Modelled (m)	Error (%)	Measured (°)	Modelled (°)	Error (°)
Site : MHL_1 (entrance channel)						
M2	0.428	0.412	-4%	237	237	0.7 °
S2	0.130	0.122	-6%	257	257	0.0 °
K1	0.108	0.103	-5%	110	115	5.5 °
O1	0.080	0.078	-3%	73	80	6.9 °
Site : MHL_7 (Hells Gate)						
M2	0.100	0.102	2%	263	262	-1.3 °
S2	0.027	0.029	6%	280	280	-0.8 °
K1	0.035	0.035	0%	154	154	-0.1 °
O1	0.031	0.033	6%	124	125	0.4 °
Site : MHL_17 (Tiona)						
M2	0.061	0.056	-8%	337	339	2.2
S2	0.015	0.014	-7%	352	1	8.4
K1	0.027	0.025	-7%	198	206	8.2
O1	0.025	0.025	0%	178	179	1.5

---

[1] Classic tidal harmonic analysis was completed in MATLAB (Mathworks, 2009) using T_Tide (Pawlowicz, et. al., 2002). The general principals of tidal analysis are discussed in Section 4.3.1.

Plots showing the modelled and measured discharges within the Wallis Lake estuary are provided in **Appendix C**. As observed, the model predictions closely follow the field measurements. It is noted that there is evidence of disparity between the modelled and measured discharge data at sites MHL_12 and MHL_14 (located in the connecting channels, rather than the main flow channels). Due to smaller flows through these locations, e.g. maximum flow approximately 50 m^3s^{-1}, the deviation in the modelled discharge data at sites MHL_12 and MHL_14 is unlikely to have significant effect on the overall hydrodynamics of the model.

In order to quantify the models agreement with measured data, total flood and ebb volumes were derived by numerical integration of the discharge curve between zero-crossings, assuming that the point of zero-crossing represents the full reversal of the tide. These tidal prism volumes at sites MHL_3, MHL_7, MHL_10 and MHL_12 are presented in **Table 5.2**. In general tidal prisms calculated by the model are within 10% of measured values. Based on this result the calibration to measured tidal discharges was considered acceptable for the purpose of this investigation.

Table 5.2: Modelled and measured tidal prism volumes

Date (Tidal condition)	**Site**	**Measured**		**Modelled**		**% Error**	
		Flood (1x10^{6}m^{3})	**Ebb (1x10^{6}m^{3})**	**Flood (1x10^{6}m^{3})**	**Ebb (1x10^{6}m^{3})**		
28 March 1998 (Springs)	MHL_2	16.9	-13.8	15.8	-14.5	-5%	5%
	MHL_3	16.2	-12.4	14.9	-13.4	-8%	8%
	MHL_8	4.7	N/A	4.4	-3.8	-6%	N/A
	MHL_9	8.6	-7.4	7.7	-7.2	-10%	-3%
	MHL_10	6.0	-5.4	5.4	-4.9	-10%	-9%

5.3 Model Verification

Model verification is used to confirm that the calibrated model continues to perform consistently in periods other than the calibration period.

For model verification and all further existing case modelling, the model was converted to a 2010 baseline by applying bathymetry points from the DECCW and WorleyParsons hydrographic survey undertaken on Wallis Lake estuary in 2010 (refer to **Section 4.2**). Verification of the 2010 model was undertaken for a 29 day period from the 3 October 2010 to 1 November 2010. The verification period was selected to include a good range of tidal conditions with representative spring and neap ranges.

Data used for the 2010 model verification included:

- MHL's permanent water level gauges (refer to **Section 3.3.3**) at Forster, Tuncurry and Tiona; and
- WorleyParsons tidal flow data collected at six sites (refer to **Section 3.3.2**).

Refer to **Figure 3.5** for locations where data was available during the model verification period.

Comparative plots for water level and discharge curves for the available data location (refer to **Figure 3.5**), showing modelled versus measured data, are presented in **Appendix D**.

A similar assessment of tidal constituents was undertaken for the verification period. Recorded water levels from the three permanent sites were the only data available during the verification period. Very good agreement was reached between modelled and measured values during the model verification period, with errors in amplitude and phase generally less than 5%.

Based on the good agreement between modelled and measured data, in both calibration and verification, the hydrodynamic model of Wallis Lake can be considered calibrated.

5.4 Model results (Existing Conditions)

5.4.1 Tidal current patterns

Figures 5.2 and **5.3** present peak flood and ebb spring current speed and direction plots simulated for the study area flood and ebb conditions, respectively. In these plots current speed is illustrated using a colour scale with vectors (shown as black arrows) used to show flow direction. The flow conditions within the lower Wallis Lake estuary are reasonably complex due to the high velocities, the number of interconnected channels and the breakwaters.

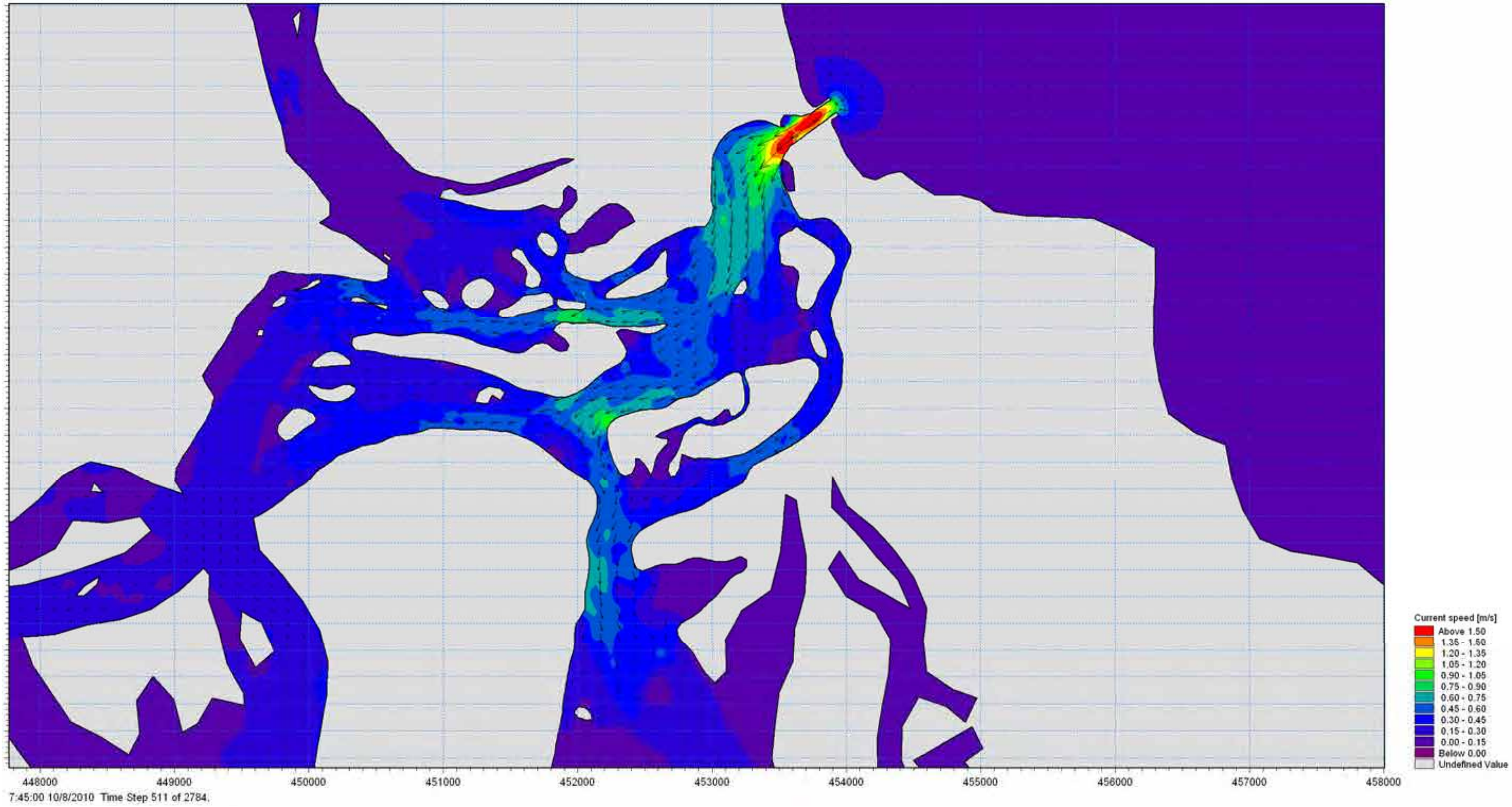


Figure 5.2 Peak flood tide currents in lower estuary.

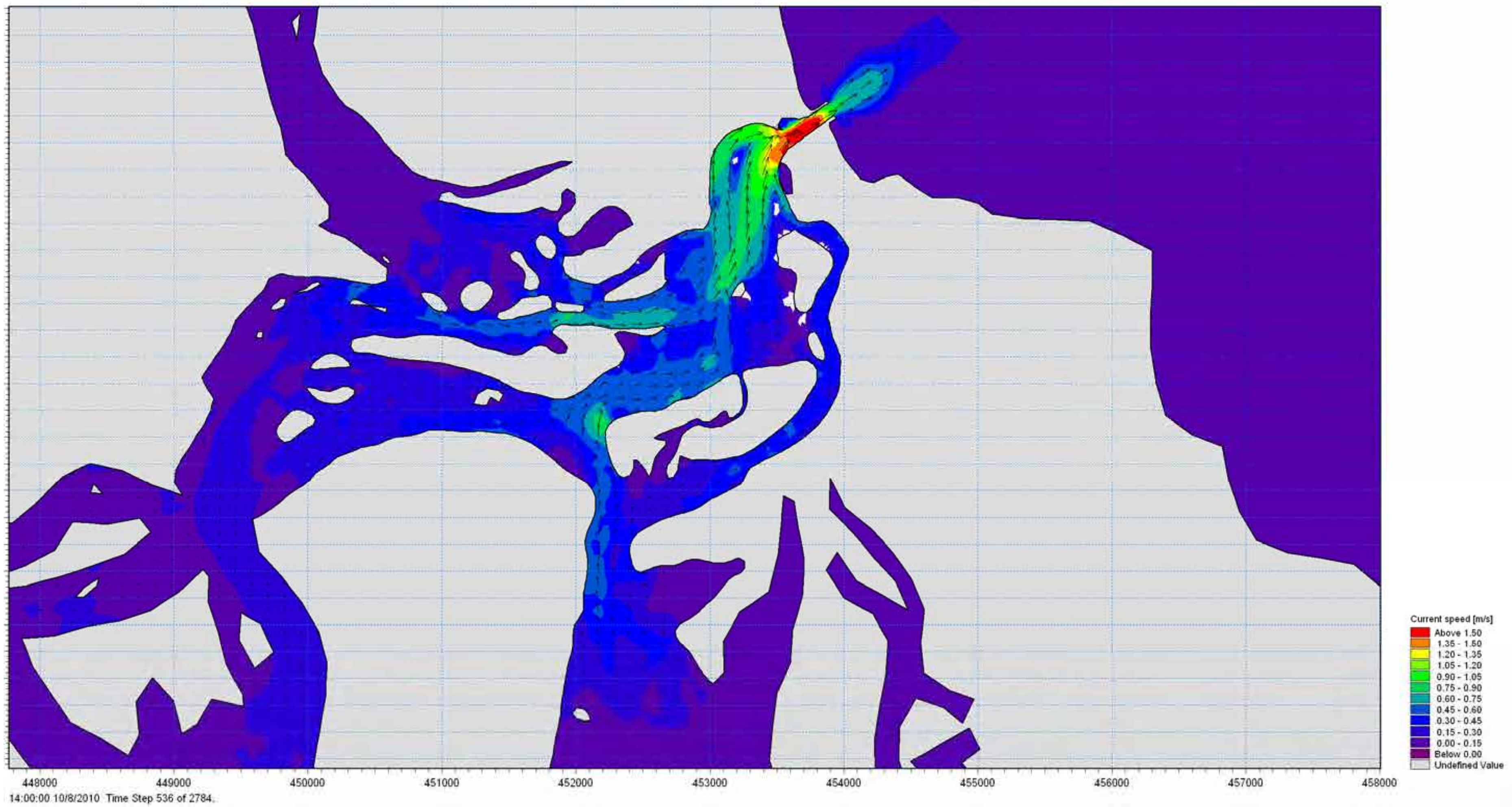


Figure 5.3 Peak ebb tide currents in lower estuary.

5.5 Conclusions

The model calibration and verification shows that the model is able to accurately predict tidal water levels and the main flow features and behaviours occurring in the lower Wallis Lake estuary. Modelled and measured water levels and discharges show very good agreement for both calibration and verification periods. As such, the hydrodynamic model is considered to be calibrated and fit for further application. The calibrated 2010 model forms the basis for all further simulations.

5.6 Assumptions and Limitations

Catchment runoff that provides freshwater inflows to the estuary and precipitation over the waterway area have not been included in this investigation. The increase in lake water levels due to rainfall, and the joint probability of local rainfall intensities / volumes should be looked at in conjunction with future flood assessments.

Density stratification has not been included in this investigation, modelling assumes a vertically mixed profile. For Wallis Lake this is not an unreasonable assumption, as stratification is only observed following significant rainfall (MHL, 1998). Due to the shallow lake depths, wind and wave action quickly breaks down any stratification following rainfall.

6 SEDIMENT TRANSPORT

The morphology of the lower Wallis Lake estuary is highly dynamic, whereby channels, sand shoals and islands are often subject to change due to tidal currents, wave action and flood events driving an active sediment transport system.

Sediment transport modelling has been conducted for the lower Wallis Lake estuary using the MIKE 21 ST module that uses flow information from the MIKE 21 HD (hydrodynamic) model (refer to **Section 5**) to calculate sediment transport rate.

6.1 Modelling Objectives

Ongoing dredging works are proposed within the lower Wallis Lake estuary. The objective of sediment transport modelling for this study were to:

- provide estimates for the sediment transport rates in the study area;
- provide provisional estimations for infilling rates for a number of potential dredging areas to determine maintenance dredging requirements; and
- determine the relative impact of the proposed dredging on the overall morphology of the estuary.

6.2 Verification of Sediment Transport Rates

Typically, a sediment transport model is calibrated or verified using in-situ measurements of sediment transport rates or by using repeat hydrographic surveys following some anthropogenic perturbation (for example a set of pre- and post-dredging surveys). As neither of these data sources currently exist for Wallis Lake, the sediment transport model has been verified using sediment transport measurements in other similar environments.

Several formulations for calculating sand transport in pure currents are implemented in the model. For this study, a Van-Rijn derivation of bed and suspended sediment loads has been adopted (DHI, 2009). Using this formulation the primary ST model parameter that affects calculated transport rates is the sediment particle size (d_{50}). A d_{50} of 0.35 mm has been used in sediment transport modelling in line with the sediment particle size data available for the study area (refer to **Section 3.4**). Current speed and other flow related parameters that are used in the calculation of sediment transport rates are derived directly from the hydrodynamic model.

WorleyParsons recently completed in-situ sediment transport measurements in a similar estuarine environment using acoustic techniques, after Williams (2008). The measured bed load sediment transport rates are presented below in **Figure 6.1**.

Figure 6.1 presents a comparison of the bed load transport rate ($m^3/s/m$) as calculated from:

- measurements from similar environments - downward looking ADCP (Acoustic Doppler Current Profiler) moving bed measurements; and
- modelled – based on output from the MIKE 21 ST model for Wallis Lake

This represents the volumetric sediment transport rate per metre of channel section.

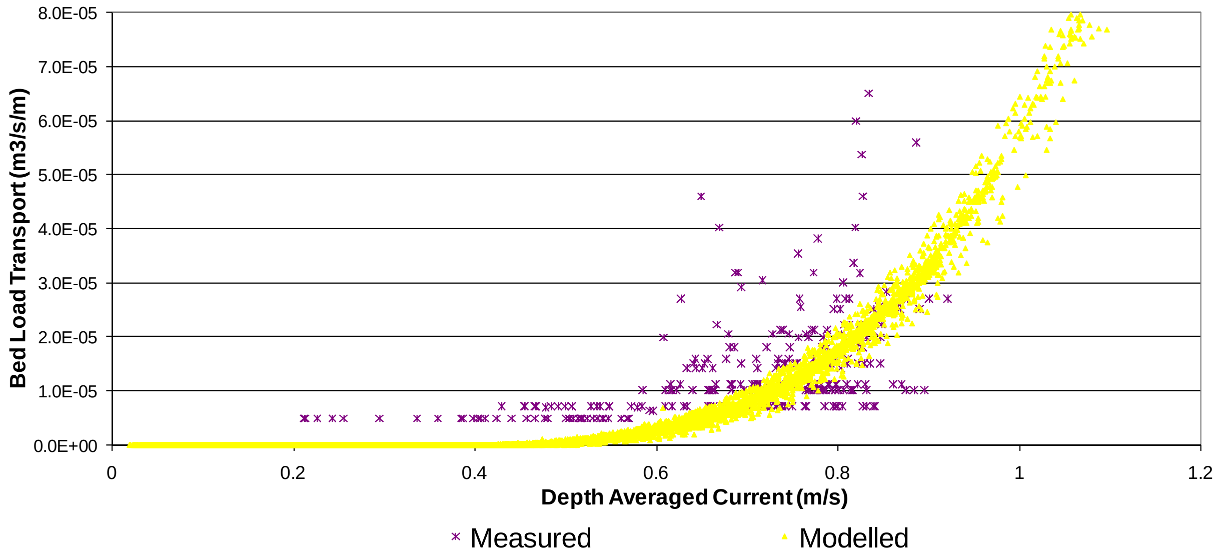


Figure 6.1 Comparison of modelled bed load sediment transport rate at Wallis Lake with measurements for similar environments

Figure 6.1 demonstrates that a reasonable agreement has been reached between the bed load sediment transport rate as inferred from measured data and the MIKE 21 model. Typically for sediment transport modelling, agreements within an order of magnitude are considered calibrated.

6.3 Sediment Transport Simulations

Simulations of typical tidal flows and sediment transport conditions in the lower estuary have been conducted for the 29-day 2010 verification period (see **Section 5.3**). These simulations included existing and dredged condition scenarios, the results are further discussed in **Section 7**.

6.4 Conclusions

The MIKE 21 ST sediment transport model of the lower Wallis Lake estuary has been established and modelled sediment transport rates verified against measurements of bed sand transport recently undertaken by WorleyParsons in a similar estuarine environment.

6.5 Assumptions and Limitations

Any sediment transport or morphological model calculation of this nature is subject to a significant amount of uncertainty. The underlying physical processes are complicated and not fully understood at present. As a result, sediment transport models are typically based upon empirical relationships which vary in their applicability to various studies. Regardless of this the model is a useful tool when analysing trends or comparing relative changes as is the case in the present study.

Verification of the model was based on in-situ sediment transport measurements undertaken in a similar estuarine environment to Wallis Lake. To improve the sediment transport verification, sediment transport measurements should be conducted in the lower Wallis Lake estuary.

7 DREDGING ASSESSMENT

The purpose of this section is to provide an assessment of potential dredging works.

7.1 Areas Identified for Potential Dredging

For the purposes of this assessment four potential dredging areas have been identified for a variety of reasons and are discussed in the main report. Dredging areas identified are shown in **Figure 7.1** and **Table 7.1**. It is assumed that all areas are dredged to a width of 30 m.

Table 7.1 Summary of potential dredging areas

Proposed dredge area	Proposed dredge level (m AHD)	Length (m)	Dredge area (m^2)	Dredge volume (m^3)
'The Step'	-2.5	700	20,900	15,000
Sediment Trap at 'The Step'		400	11,700	19,000
'Western Step'	-2.5	1,270	38,000	30,000
Wang Wauk (Boomers) Channel	-2.5	600	17,600	7,000

Figure 7.1 Potential dredging areas identified in this study

7.1.1 Dredging scenarios used for assessment

Dredging within Wallis Lake is likely to proceed on an ‘as needed’ basis when funds for required works become available. For the purposes of this assessment the following dredging scenarios have been considered:

> *Scenario A* – Dredging of a navigation channel at ‘The Step’ in isolation.
>
> *Scenario B* – Dredging of a navigation channel at ‘The Step’ along with dredging a sediment trap designed to reduce progradation of the drop over onto seagrass beds.
>
> *Scenario C* - Dredging of a navigation channel at ‘The Western Step’ in isolation.
>
> *Scenario D* - Dredging of a navigation channel along the Wang Wauk Channel (Boomers Channel) in isolation.
>
> *Scenario E* – Ultimate scenario which includes dredging of all four of the dredging areas shown on **Figure 7.1**.

The existing conditions scenario (based on the 2010 condition) is also included for comparative purposes.

7.2 Assessment Methodology

The calibrated hydrodynamic and sediment transport model was used as a tool to assess the various dredging scenarios (refer to **Sections 5** and **6**). The model system was used to simulate 29-days of typical tidal flow conditions, based on the 2010 conditions for each dredging scenario. Sediment transport was included, as well as a morphological update of lake bed levels based on the net sediment transport calculated by the model.

Each of the options was compared against the baseline scenario and against each other by assessing:

- hydrodynamic and sediment transport conditions within the dredge area;
- tidal regime change; and
- channel infilling (or sedimentation of the dredged channel).

7.3 Hydrodynamic and Sediment transport conditions

The local hydrodynamic and sediment transport conditions at each of the four potential dredge areas was examined. Plots showing the modelled water level, current speed and rate of sediment transport for each of the potential dredge areas under both existing and design conditions (i.e. post dredging) are shown in **Appendix E**.

7.3.1 ‘The Step’

Currently the ruling depth across the channel used for navigation to pass ‘The Step’ is around 1.5 m below AHD (based on the 2010 DECCW survey). Tidal water level variations are relatively small with a mean spring tidal range of approximately 0.14 m.

Based on the hydrodynamic model, current speeds within this area are flood velocity dominated (i.e. peak flood current speeds are greater than peak ebb currents speeds). At the model output location within 'The Step' potential dredging area, as shown on **Figure 7.1**, the peak flood currents under existing conditions are approximately 0.40 m/s in magnitude, while peak ebb currents are 0.25 m/s (refer to **Appendix E**). As sediment transport is proportional to current speed, the dominance of peak flood currents means that net sediment transport is in the flood direction.

Scenario A modelling estimates an increase in the peak flood velocity within the dredged channel to approximately 0.45 m/s. This is associated with an increase in net sediment transport towards the lake in the dredged channel.

This change to the local hydrodynamics and sediment transport patterns is likely to result in an increased rate of progradation of the drop-over at the lakeward end of the dredged channel. The model indicates that it is possible that increased flow and sediment transport through the dredged channel would reduce the rate of progradation along the remaining sections (i.e. east of the potential dredged channel) of the 'The Step' drop-over.

7.3.2 Sediment Trap

Current depths in the area proposed for the sediment trap (refer to **Figure 7.1**) are approximately 0.8 m below AHD (based on the 2010 DECCW survey). Tidal water level variations are relatively small with a mean spring tidal range of approximately 0.14 m.

Modelling shows that in this area flood velocities dominate. Under existing conditions the peak flood currents are approximately 0.42 m/s in magnitude while peak ebb currents are approximately 0.26 m/s (refer to **Appendix E**) at the model output location within the potential sediment trap dredging area, as shown on **Figure 7.1**. A net flood sediment transport is predicted by the model.

Scenario A modelling estimates a reduction in the peak flood velocity to approximately 0.38 m/s at this location. This is likely due to the increase in flow through the dredged channel. *Scenario B* modelling, which includes dredging of a 1.2 m deep sediment trench at this location (increasing the depth to approximately 2.0 m from 0.8 m), shows a reduction in the current speed to 0.18 m/s. Sediment transport in the dredged trench is estimated by the model to be negligible under tidal conditions.

While the sediment trap appears to be effective at trapping sediment its effect on the progradation of the drop-over at 'The Step' is unclear in the model. Eventually, over time, the progradation would be expected to reduce due to the finite sediment supply/source available between the trap and the drop-over. The model indicates that sediments on the lakeward side of the trench may still be transported towards and accumulate on the lakeward slope of the drop-overs. In addition, the trench is indicated by the model to change the local flow structure.

It is likely that the best dredging option for reducing the progradation of the drop-over at 'The Step' would be to remove sediment off the lakeward slope of the drop-over. This would not change the pattern of the local flow structure, rather it would translate the existing flow structure upstream slightly. Maintenance of the drop-over would require around 6,000 m^3/year to be removed. This could be removed at 5-10 year intervals.

Dredging of the navigation channel (i.e. *Scenario A*) may also assist in reducing progradation along much of 'The Step', however, a local increase is likely at the end of this dredged channel.

The effectiveness of the sediment trap should not be altered considerably if it was positioned closer to the edge of the drop off, however, trapping sediments earlier (i.e. away from the drop off) may aid in reducing smothering of the immediately adjacent seagrass beds. The main issue influencing the effectiveness of the sediment trap would likley be its size (i.e. depth and width).

7.3.3 'The Western Step'

Currently the minimum depth across 'The Western Step' is approximately 1.0 m below AHD. Tidal water level variations are relative small, with a spring tidal range of approximately 0.08 m.

Based on the hydrodynamic model, current speeds within this area are flood velocity dominated. At the output location shown for 'The Western Step' on **Figure 7.1**, the peak flood currents are approximately 0.34 m/s in magnitude while peak ebb currents are approximately 0.28 m/s. A net upstream (towards the Coolongolook River) sediment transport is estimated by the model.

A significant increase in the peak flood and ebb tidal current speed is calculated by the model due to dredging (*Scenario C*) (refer to **Appendix E**). At this location peak flood velocity within the dredged channel increases to approximately 0.40 m/s and ebb velocities increase to approximately 3.1 m/s. This is believed to be due to both a change to local flow patterns due to the dredged channel being in the direction of the flow and a greater overall flow in this channel as a result of dredging. The changed flow patterns are associated with a slight increase in net upstream sediment transport in the dredged channel.

7.3.4 Wang Wauk (Boomers) Channel

Currently the minimum depth across the potential dredge area identified in the Wang Wauk (Boomers) Channel is approximately 1.0 m below AHD. Tidal water level variations are relatively small with a mean spring tidal range of approximately 0.25 m.

Based on the hydrodynamic model current speeds within this area are flood velocity dominated. At the output location shown for the Wang Wauk (Boomers) Channel on **Figure 7.1**, the peak flood currents are approximately 0.50 m/s in magnitude while peak ebb currents are 0.42 m/s. As current speeds are generally higher in this area (relative to other dredging areas) the tidal sediment transport regime is more active. A net upstream (towards the Coolongolook River) sediment transport is estimated by the model.

Only a very slight increase in the peak flood and ebb tidal current speeds is calculated by the model due to dredging (*Scenario D*) (refer to **Appendix E**).

7.4 Tidal regime

The impact on the Wallis Lake estuary hydrodynamics was examined for the various options by comparing the tidal planes, tidal ranges and tidal prism for each dredging scenario with existing conditions.

Table 7.2 presents the calculated spring tidal planes and ranges based on the results of model simulations. It is noted that there are only minor changes to the existing tidal water levels simulated in the modelling. Where there was found to be a difference (these are shown in bold red text).

Generally, changes to tidal water levels, as a result of the proposed dredging, are considered to be minor.

Table 7.2: Modelled spring tidal planes and tidal ranges for existing and dredge scenario conditions

Tidal plane or range	Existing Conditions	Dredging Scenarios				
		A	B	C	D	E
Site: Wallis Lake						
MHWS (m AHD)	0.084	0.084	0.084	0.084	0.084	**0.083**
MLWS (m AHD)	-0.056	-0.056	-0.056	-0.056	-0.056	**-0.057**
Mean spring range (m)	0.140	0.140	0.140	0.140	0.140	0.140
Site: Entrance Wallamba River						
MHWS (m AHD)	0.161	0.161	0.161	0.161	0.161	0.161
MLWS (m AHD)	-0.135	-0.135	-0.135	-0.135	-0.135	-0.135
Mean spring range (m)	0.296	0.296	0.296	0.296	0.296	0.296
Site: Entrance Coolonglook River						
MHWS (m AHD)	0.083	0.083	0.083	0.083	0.082	0.083
MLWS (m AHD)	-0.051	-0.051	-0.051	**-0.053**	-0.052	**-0.053**
Mean Spring Range (m)	0.134	0.134	0.134	**0.136**	0.134	**0.136**

Table 7.3 presents the calculated mean tidal prisms based on the results of model simulations for the locations of model outputs referred to **Figure 7.1**. In general, only minor changes (<5% difference) are expected in the mean tidal prisms in the lower estuary as a result of the potential dredging works. However, dredging of 'The Western Step' (as included in *Scenario C* and *Scenario E*) appears to significantly increase the flow occurring through the 'Western Step' cross-section.

Table 7.3 Modelled tidal prisms for existing and dredge scenario conditions

Tidal Prism	**Existing Conditions**	**Dredging Scenarios**				
		A	**B**	**C**	**D**	**E**
Site : 'The Step' Cross Section						
Flood	4.55	4.63	4.66	4.51	4.53	4.58
(% difference to existing)		(+2%)	(+2%)	(-1%)	(-1%)	(+1%)
Ebb	4.46	4.54	4.57	4.40	4.45	4.49
(% difference to existing)		(+2%)	(+3%)	(-1%)	(0%)	(+1%)
Site : 'The Western Step' Cross Section						
Flood	1.64	1.63	1.62	**1.93**	1.67	**1.95**
(% difference to existing)		(-1%)	(-1%)	**(+18%)**	(+2%)	**(+19%)**
Ebb	1.58	1.57	1.56	**1.86**	1.61	**1.88**
(% difference to existing)		(-1%)	(-1%)	**(+18%)**	(+2%)	**(+19%)**
Site : Wang Wauk Channel Cross Section						
Flood	2.87	2.84	2.83	2.98	2.93	**3.03**
(% difference to existing)		(-1%)	(-1%)	(+4%)	(+2%)	**(+6%)**
Ebb	2.63	2.61	2.59	2.77	2.69	**2.81**
(% difference to existing)		(-1%)	(-2%)	(+5%)	(+2%)	**(+6%)**

7.5 Channel Infilling Estimates

The rate of channel infilling (or siltation) following dredging was estimated based on results of the hydrodynamic and sediment transport models. The annual siltation depths and volumes derived are presented in **Table 7.4**.

Table 7.4: Annual siltation summary

Tidal Plane or Range	Dredging Scenarios				
	A	B	C	D	E
Dredge Area: 'The Step'					
Average depth of siltation (m)	0.15	0.18	-	-	0.12
Volume of siltation (m^3)	3,100	3,700	-	-	2,600
Estimated time to infill to existing (years)	5	4	-	-	6
Dredge Area: 'The Step' sediment trap					
Average depth of siltation (m)	-	0.24	-	-	0.45
Volume of siltation (m^3)	-	2,900	-	-	5,500
Estimated time to infill to existing (years)	-	7	-	-	4
Dredge Area: 'The Western Step'					
Average depth of siltation (m)	-	-	0.04		0.05
Volume of siltation (m^3)	-	-	1,500		1,800
Estimated time to infill to existing (years)	-	-	20		16
Dredge Area: Wang Wauk Channel					
Average depth of siltation (m)				0.50	0.56
Volume of siltation (m^3)				8,700	9,800
Estimated time to infill to existing (years)				1	1

It is noted that sediment infilling due to catchment inflows have not been considered in this assessment, however, it is expected that these would generally be low in the Wallis Lake estuary.

7.6 Conclusion

Dredging of a navigation channel at 'The Step' is considered to be a feasible option for improving navigation to Wallis Lake. The local sediment transport regime is moderately active, however, the alignment of the dredged channel in the direction of the flow will act to reduce siltation. Estimates of channel infilling indicate that maintenance dredging would be required at around 5 year intervals if this channel is to be maintained. Minimal impacts are expected on the tidal regime from dredging works at 'The Step'.

Dredging of a sediment trap at 'The Step' is not considered to be effective due to changes to the local flow and sediment transport patterns. Direct removal of sediments from the lakeward slope of the drop-over is likely to provide a better option to avoid progradation of this sediment shoal onto seagrass beds. Maintenance of the drop-over would require around 6,000 m^3/year to be removed. This could be removed at 5 to10 year intervals. In addition, dredging of the navigation channel at 'The Step' may also assist in reducing progradation along much of 'The Step', however, local increases in sedimentation are likely at the end of this dredged channel.

Dredging of a navigational channel at 'The Western Step' is considered a feasible option to improve navigation to Coolongolook River area and to the western side of Wallis Island. The local sediment transport regime is relatively inactive and estimated infilling rates are low. Some impacts are expected on tidal flows with a significant increase in the tidal prism upstream as a result of the channel deepening. It is recommended that a more detailed assessment is undertaken before any dredging of this area proceeds.

Dredging of a navigation channel at Wang Wauk (Boomers) Channel appears to be an ineffective option for improving navigation along this Channel. This area is characterised by a relatively active sediment transport regime with channel infilling estimated to occur rapidly following dredging.

8 DISPOSAL OPTIONS ASSESSMENT

This section presents a coastal processes assessment of disposal options for material dredged from the lower Wallis Lake estuary. Dredge disposal options are identified in **Section 4.2** of the main report (*Wallis Lake - Dredging and Disposal Options Assessment*). The coastal processes assessment covers the following disposal options:

- beach nourishment of the southern end of Nine Mile Beach (commonly referred to as Tuncurry Beach);
- dumping of material within relatively calm zones identified in the lower estuary.

The coastal processes assessment provided in this study is aimed at determining if these options are feasible. If a particular disposal option is proposed, it is recommended further detailed investigation would be required.

The potential impacts of land-based disposal (i.e. disposal of dredge material outside the active sediment zone) are not considered. For example, the impact of dredged sand used as fill material on nearby floodplain development sites or disposed of in back beach areas, were not considered as part of the coastal processes assessment.

8.1 Nourishment of Tuncurry Beach

One of the current impediments to dredging in the lower Wallis Lake estuary is identifying suitable disposal sites. To facilitate ongoing dredging works (for both navigational and oyster lease maintenance) in the lower Wallis Lake estuary, Great Lakes Council is seeking to investigate the use of a permanent pipeline as a means of dredge disposal and reuse of dredge spoil for nourishment of Tuncurry Beach. The permanent pipeline is proposed to have an intake on the northern shoreline of the estuary and outlet discharging the sand slurry to the foredune at Tuncurry Beach. More details on the proposed pipeline are provided in **Section 5.5** of the main report.

This section examines the likely impacts of placing sand dredged from the estuary within the active beach profile (i.e. beach nourishment) at the southern end of Nine Mile Beach. Recommendations are made as to the feasibility (form a coastal processes perspective) of this disposal option.

8.1.1 Need for Nourishment

Typically, the main objectives for a beach nourishment projects are:

- to provide protection for beachfront developments at risk from coastal hazards; and
- to maintain and enhance recreational amenity of the beach.

In this instance, an additional objective of beach nourishment is to provide a suitable site for the on-going disposal of material dredged from the estuary.

Tuncurry Beach has not been subject to artificial beach nourished in the past.

Coastal Hazard Risk at Tuncurry Beach

The principal coastal hazards addressed by beach nourishment are;

- beach erosion as a result of severe or extreme storm events; and
- shoreline recession as a result of a net sediment loss from the beach system or sea level rise.

WorleyParsons recently completed a coastal hazards assessment for the southern area of Nine Mile Beach as part of a development assessment in North Tuncurry (*North Tuncurry – Coastal Processes, Hazards and Planning Study,* WorleyParsons 2010 report for Landcom). Based on the current knowledge of the coastal processes that operate within the area, this assessment examined the coastal hazards that impact the coastline, assessing these hazards to determine the immediate, 2060 and 2100 hazard lines.

Figure 8.1 presents the resulting hazard lines for the southern end of Nine Mile Beach. The first hazard line is used to identify at risk areas due to severe coastal storms (immediate hazard). By including long-term trends in shoreline position that also incorporate predicted sea level rise, hazard lines are generated for future planning horizons (2060 and 2100 hazard lines).

For Tuncurry Beach (southern end of Nine Mile Beach) no significant public or private developments were identified at immediate risk from coastal hazards (WorleyParsons, 2010). This is largely due to the lack of development with this area. A review of aerial photography suggests that the closest significant built features are:

- Rockpool Beach car park is located approximately 150 m landward of the beach foredune; and
- Tuncurry Beach Caravan Park is approximately 240 m landward of the foredune (the most seaward caravans).

However, some minor infrastructure, associated with beach access, dune protection and beach lookout towers, are located within the coastal hazard zones.

Local Beach Amenity

Tuncurry Beach is a popular beach servicing the local community and tourist population. The principal coastal hazard potentially affecting beach amenity would be coastal erosion from severe storm events. It is expected that beach amenity would be temporarily impacted following a severe coastal storm with damage to some of the minor infrastructure associated with beach access ways.

Figure 8.2 shows a recent photo of a slightly eroded foredune at Tuncurry Beach.

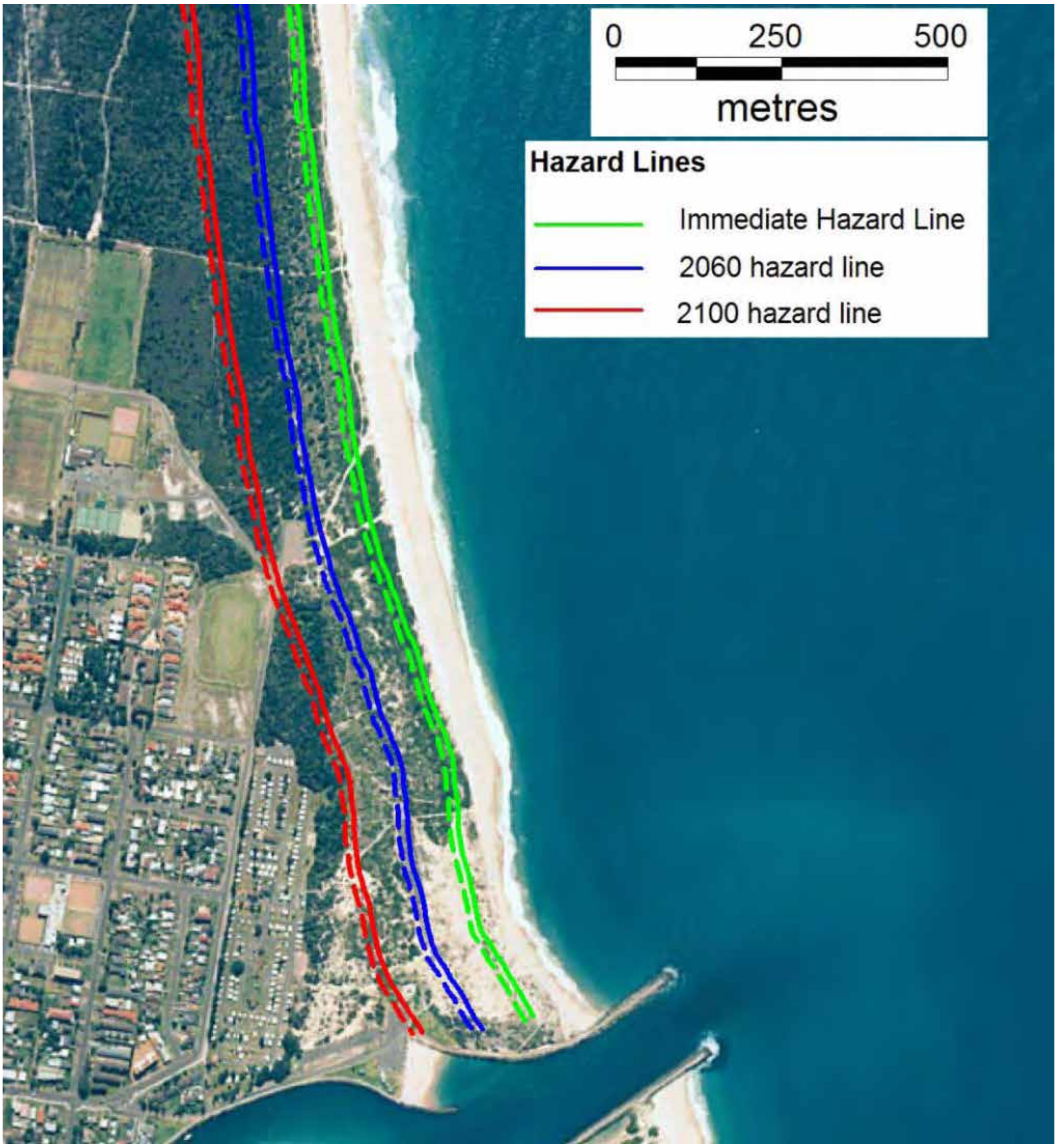


Figure 8.1 Hazard lines identifying areas at risk to coastal hazards (source: WorleyParsons, 2010)

Figure 8.2 Evidence of eroded foredune at Tuncurry Beach

8.1.2 Regional Coastal Processes

The coastline from Cape Hawke in the south to Black Head in the north (refer to **Figure 8.3**) represents a coastal processes compartment containing the area of interest. This regional compartment is complicated by the presence of the dynamic Wallis Lake estuary entrance and the anthropogenic influence of training works undertaken to stabilise the entrance for navigational purposes.

Sediment transport in this coastal compartment is characterised by a net northerly littoral drift of relatively small magnitude. Others have quantified the regional sediment transport rate as being in the order of 20,000 to 30,000 m^3/yr (Nielsen and Gordon, 2008 and WMA, 1999). In the absence of the required data to further quantify sediment transport rates this estimate has been adopted for the purposes of this study.

A conceptual model of the regional processes occurring between Cape Hawke and Black Head is presented in **Figure 8.4**. Potential relative sediment transport rates are indicated by the relative magnitude of arrow lengths. Further explanation of these processes is provided below (from south to north).

It is important to note that the conceptual model attempts to summarise the long term average condition. Event based conditions may occur which would appear to contradict this model, especially where complex local coastal features exist, e.g. Wallis Lake estuary entrance. Additionally, climate change impacts have not been considered in the conceptual model.

The planform of a sandy coastline is shaped by the *actual* alongshore sediment transport processes. The magnitude of the *potential* alongshore transport at any place depends on the incident wave conditions, the offshore topography, and the coastal alignment. However, the *actual* rate of transport depends on the volume of sand available to be transported by this *potential*. Where the supply of sand exceeds the amount the waves can potentially transport, sand is deposited and the foreshore progrades. Conversely, where the supply is less than the amount waves can potentially transport, sand is eroded from the beach and the foreshore recedes.

The *North Tuncurry Coastal Processes, Hazard and Planning Study* (WorleyParsons, 2010) suggested that the entrance construction is likely to have caused a significant perturbation in the supply of sediment to the adjacent downdrift foreshore (Nine Mile Beach) and that the current coastal planform has been driven by this supply mechanism, as outlined below:

- significant volumes of sand once held in the entrance compartment, in equilibrium with the coastal and estuarine processes (periodic flooding), have been mobilised by the increased hydraulic efficiency of the trained entrance.
- initially sand deposited on the offshore entrance bar was moved onto the downdrift foreshore by wave processes, at a much greater rate than could be moved further north by littoral drift.
- this reducing rate of transport in the northerly direction resulted in a prograding shoreline (refer to **Section 8.1.3** below) in contradiction to the classic zeta from embayment evolution.

It is likely that other factors have affected the progradation of Nine Mile Beach. For example, there would have been a reduction is the size of the shoals at the bar as a consequence of entrance training leading to a net onshore movement of sand to the beach immediately to the north of the entrance and thereby the beach prograding. This is a common feature of other areas where training walls have been constructed (for example, Port Macquarie and other Clarence River). Progradation at the southern end of the beach may then have resulted in the forward translation of the beach profile observed along much of Nine Mile Beach as the system sort to re-establish a new seaward equilibrium position.

Cape Hawke to the south of the study area is a significant coastal feature marking the northern extremity of the next significant beach compartment to the south. Sand by-passing of this feature by littoral drift is considered to be limited. To the north of Cape Hawke, the foreshore is predominantly rocky with a few intermittent pocket beach compartments until the Wallis Lake Entrance area/ Forster Main Beach and Nine Mile Beach. Sand by-passing of this rocky foreshore area by littoral drift is also considered to be limited. As such the net supply of sediment to the Nine Mile Beach compartment (including Forster Beach and the entrance area) from the south is considered to be limited.

Figure 8.3 Regional conceptual coastal processes model

8.1.3 Local Coastal Processes Overview

Local coastal processes at Tuncurry Beach are complex. The interactions between the dynamic Wallis Lake estuary and the adjacent coastal compartment are further complicated by the breakwater structures.

Observed historical beach behaviour

The construction of the Forster/Tuncurry breakwaters significantly altered Nine Mile Beach, particularly the southernmost corner. The most dramatic changes to Tuncurry Beach occurred as a result of the construction of the 460 m northern breakwater, which was completed in 1966.

Examination of historical aerials (refer to **Appendix B**) shows the dramatic change in the beach form as a result of the breakwater structures.

Prior to breakwater construction (refer to photographs of 1952 and 1963) a shallower and more extensive entrance bar system appears on the northern side of the entrance area. This ebb shoal system typically appears attached to the beach on the down-drift side (northern or Tuncurry side), to the north of North Street. This attachment point would generally be where flow and thus sediment transport diverge. This location is commonly referred to as a 'nodal point'. South of the 'nodal point' wave processes would have driven a net sand southward movement of sand into the entrance area. North of the 'nodal point' the northerly littoral drift is continued.

Post breakwater construction (refer to photos from 1971 onwards) the ebb shoal (or entrance bar) system appears less extensive. Nine Mile Beach appears to be wider and the southern end is more stable. The 'nodal point' appears to have moved south to be roughly in-line with North Street

To provide a quantitative assessment of the observed changes, photogrammetry data, as described in **Section 3.5**, has been reviewed. Plots of beach profile data from photogrammetry *Blocks 2 (A702)* and *3 (A703)* (these blocks are located along Tuncurry Beach, refer to **Figure 3.9**) are provided in **Appendix F**. Examination of these profile plots shows that significant accretion (i.e. seaward movement of the beach system) has occurred along this section of beach since the construction of the northern breakwater. For example, the southernmost profile (i.e. closest to the breakwater) has accreted by approximately 300 m. Shoreline accretion reduces north along Nine Mile Beach at the northern end of *Block 3* the accretion is approximately 120 m. Furthermore this accretion appears to have predominately occurred between the 1963 and 1980 beach profile dates. This would suggesting that this section of beach had become somewhat stabilised by the 1980's.

Beach volumes were calculated on a profile by profile basis for each year of available aerial photography. To summarise this information, beach volumes were averaged across photogrammetry blocks. **Figure 8.3** provides a plot of the resulting block averaged beach volume time series for Blocks 2 and 3. This plot confirms the description of historical beach behaviour based on examination of beach profile data (i.e. a significant increase in beach width/volume that appeared to stabilise around the 1980's).

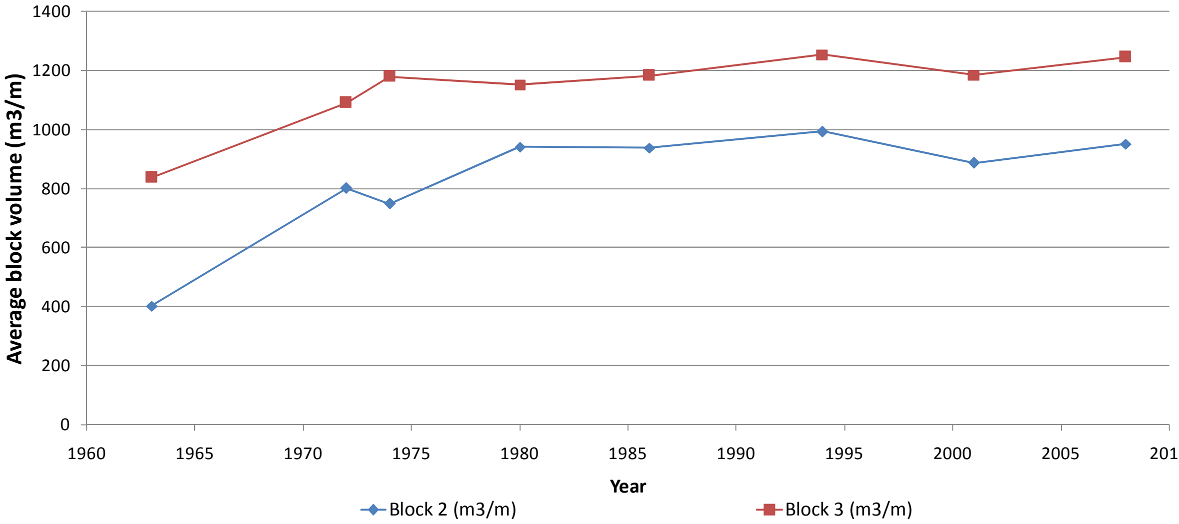


Figure 8.4 Average block volumes plotted for Blocks 2 and 3

The accretion along the southern Nine Mile Beach has resulted in a wide and relatively stable area of beach barrier system on the eastern side of the Tuncurry Beach Caravan Park. Examination of historical aerials (**Appendix B**) shows that this area has become vegetated over time. Stabilisation of this area was initiated by landscaping works undertaken by Council (refer to main report). Vegetation of the area has been greatly assisted by the work of the local dune care group.

Conceptual Model of Existing Coastal Processes

Based on typical existing conditions, a conceptual model of the local complexities in coastal processes occurring in the immediate vicinity of the harbour entrance is presented in **Figure 8.5**. This conceptual model seeks to identify the pathways of sand movements between the estuary inlet, beach and nearshore systems.

A description of the sediment pathways is:

- net northerly drift is interrupted by the tidal currents through the inlet. Some bypassing of sand via the entrance bar is expected;
- tidal flows through the estuary inlet interchanging sand between the ebb and flood shoals, the net direction of sediment movements is unknown but likely dependent on metocean and catchment conditions. The ebb tide jet and catchment runoff are suspected to currently contribute to a net supply of sediment to the entrance bar system; and
- southerly return of sand in the lee of the entrance bar forms a semi-closed loop between Tuncurry Beach and the entrance bar system with some losses to the inlet and to the northerly littoral drift.

A significant planform feature of Nine Mile Beach is the occurrence of a sediment transport ‘nodal point’ evident approximately 500 m north of the northern entrance breakwater where sediment is moving onshore from the offshore entrance bar under the influence of local breaking wave processes. Southward movement occurs south of the ‘nodal point’ due to lateral expansion currents (caused by a differential in wave heights as a result of the diffraction/ refraction wave shadow in the lee of the entrance bar) and northward sediment movements north of the node point due to the net weighted average wave direction being at an angle to the beach alignment.

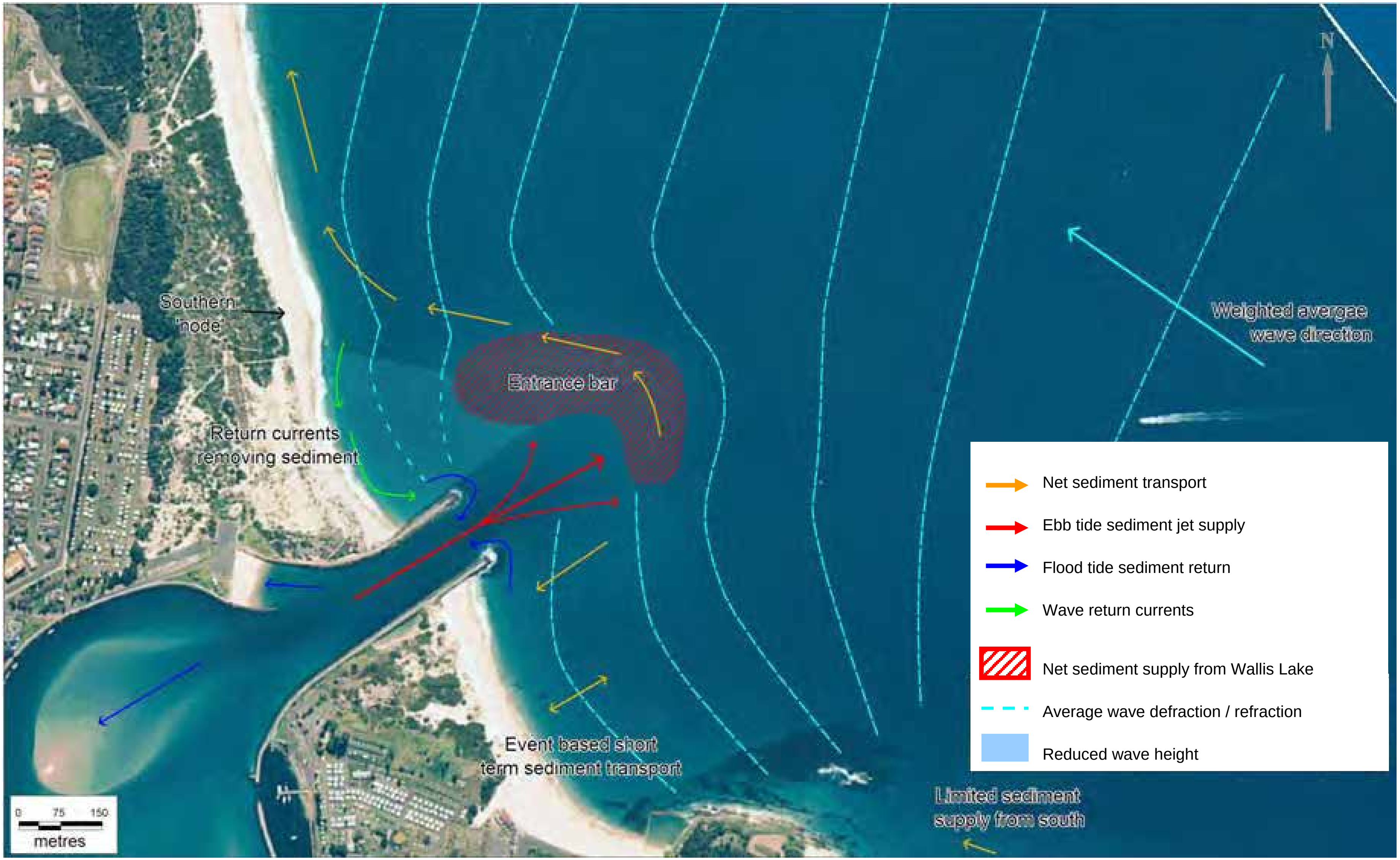


Figure 8.5 Local conceptual coastal processes model

8.1.4 Numerical Modelling of Local Coastal Processes

A coupled modelling approach was used to investigate sediment transport patterns in the entrance area under a limited number of typical conditions. The purpose was to confirm the conceptual processes model and examine the possible behaviour of beach fill material.

Method

The coupled modelling approach utilised the calibrated MIKE 21 hydrodynamic model (refer to **Section 5**) and the established sediment transport model (refer to **Section 6**).

A MIKE 21 SW (Spectral Wave) model was used to transfer waves from the model's ocean boundary. MIKE 21 SW module simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. It includes wave processes important to this study; refraction, diffraction, shoaling and wave-current interactions. Coupling of the wave model means that wave driven flows are incorporated into the hydrodynamics.

The MIKE 21 ST (Sand Transport) module is then used to calculate rates of sediment transport due to combined current and waves. A fully dynamic coupling of wave and currents is achieved by using a coupled approach. More information on MIKE 21 SW and ST is provided in **Appendix A**.

Two example storm event conditions were examined by including wave forcing of the offshore boundary using the typical tidal condition, based on the 2010 verification period (refer to **Section 5**). The offshore wave conditions were:

- South easterly event: H_s = 7.0 m, T_p = 13 seconds, Mean Wave Direction (MWD)= 135°N; and
- North easterly event: H_s = 2.8 m, T_p = 10 seconds, Mean Wave Direction (MWD)= 45°N;

Modelled wave directions have focused on the most dominate wave direction (SE) as this represents the sector from which the majority (approximately 65%) of the wave energy arrives (refer to **Section 3.3.4**). The north easterly event was also considered to examine the influence of a northerly wave condition.

Results

The results are presented as a series of plots showing 2-dimensional model results:

- **Figure 8.6** local 2010 bathymetry used in the modelling;
- **Figure 8.7** modelled wave heights (colour scale) and wave direction (vectors) for south easterly event;
- **Figure 8.8** modelled flow patterns (flood tide) with surface elevation (colour scale) and current speed and direction indicated by the vectors for south easterly event; and
- **Figure 8.9** modelled sediment transport patterns (flood tide), colour scale indicates the magnitude of sediment movement and the vectors indicate the direction of sediment movement for south easterly event.

Figures 8.10 to **8.12** presents a similar series of results (i.e. wave, flow and sediment transport) for the north easterly event.

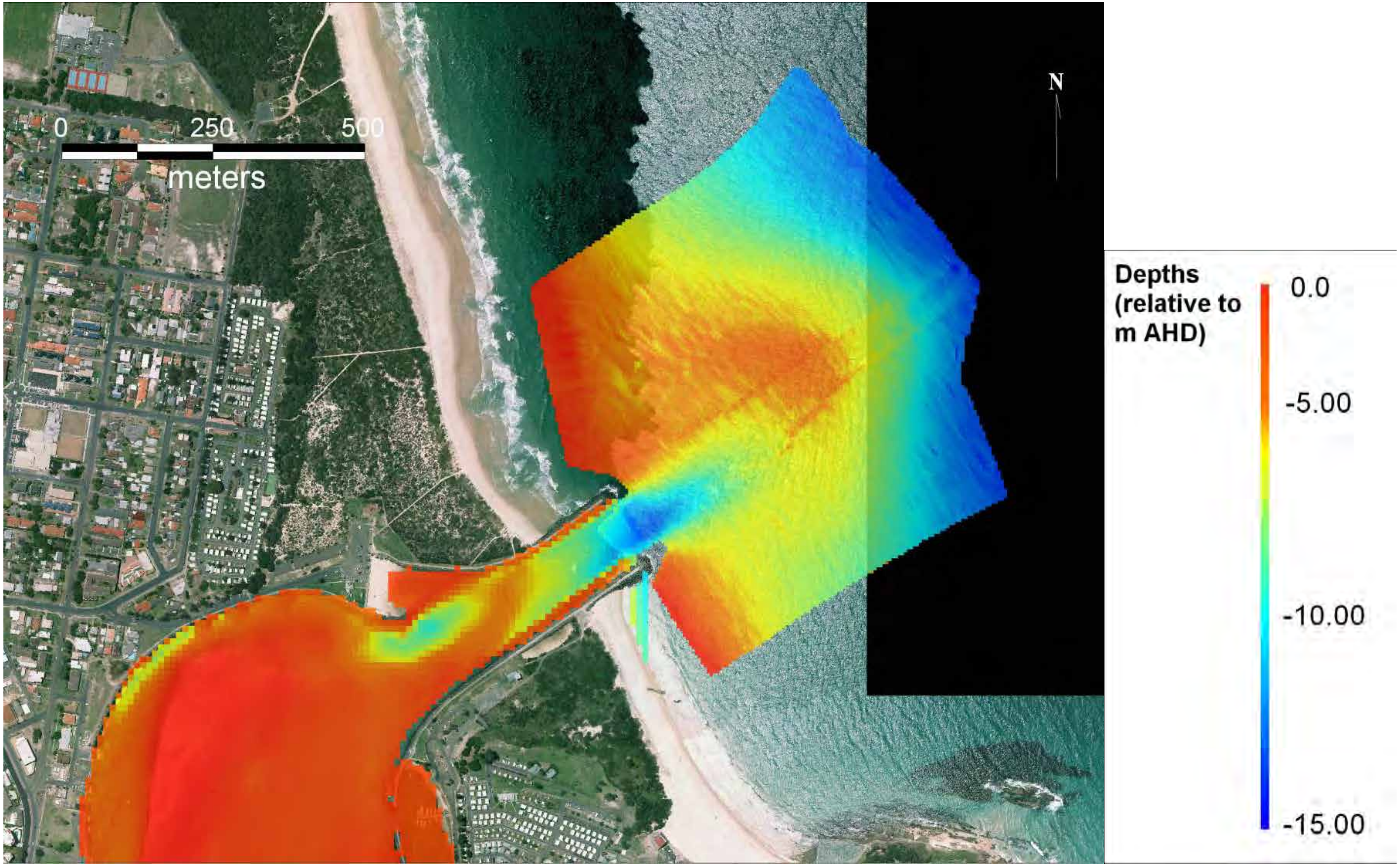


Figure 8.6 Local bathymetry based on 2010 surveys

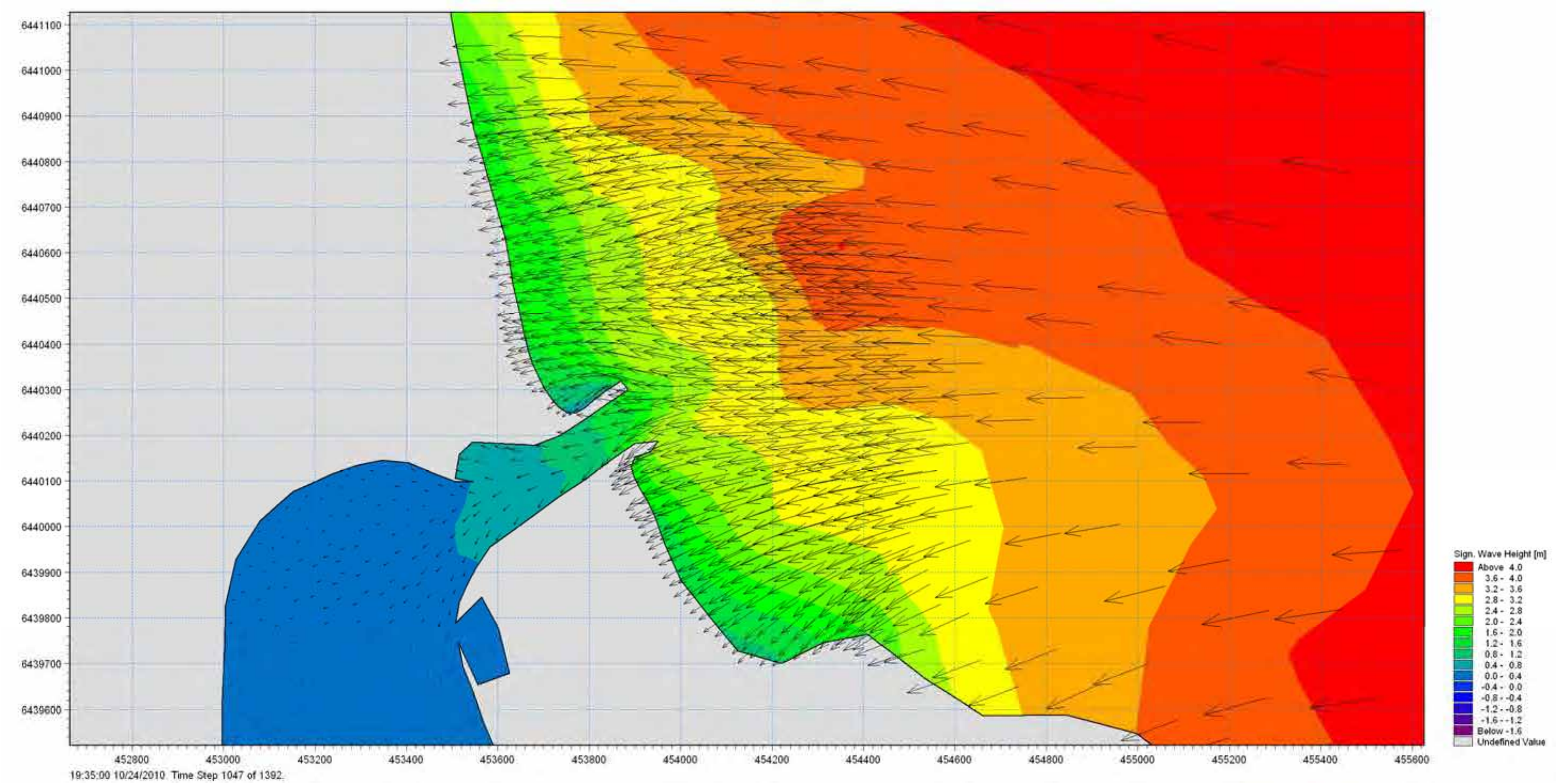


Figure 8.7 Modelled wave height and directions for south easterly event.

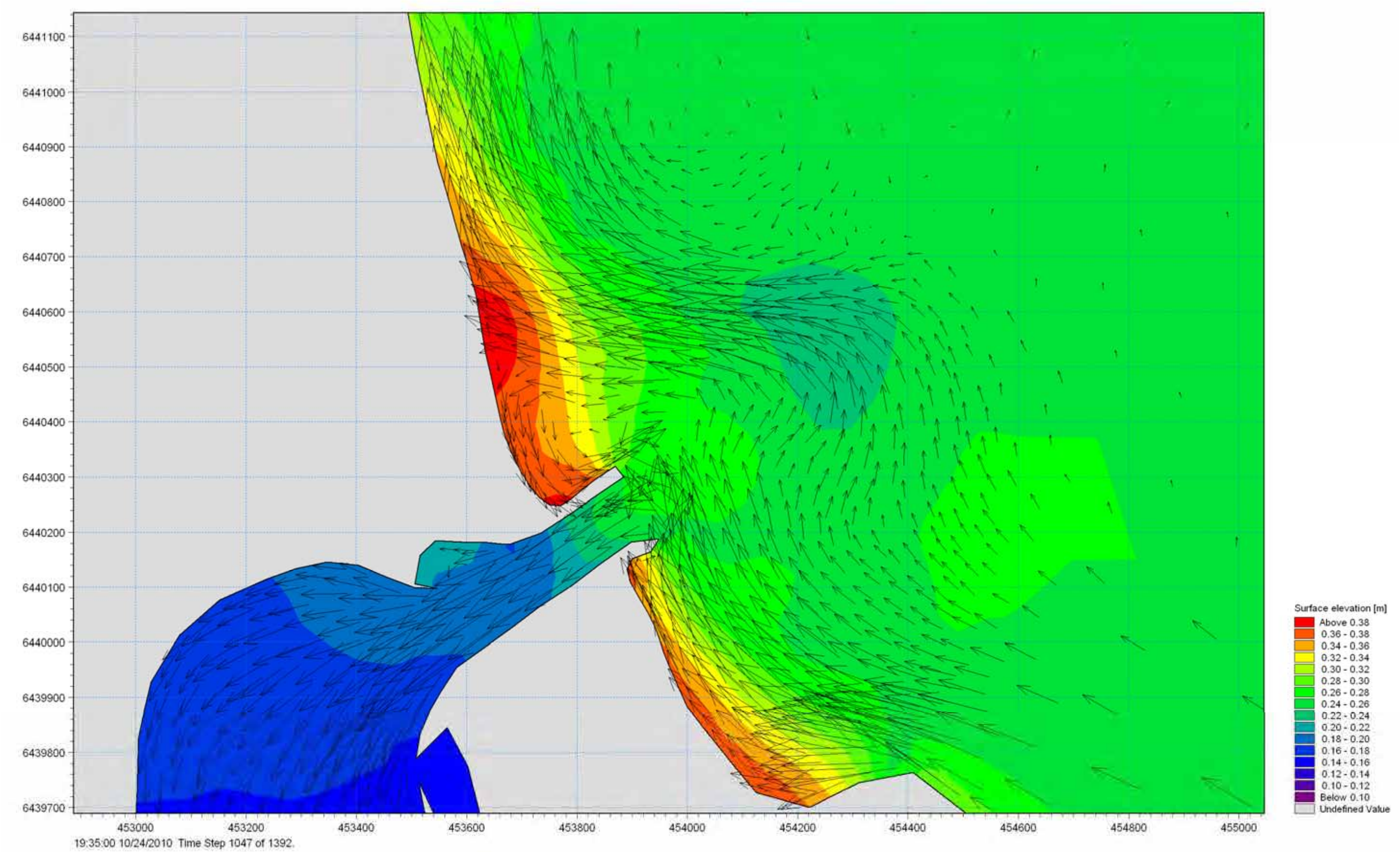


Figure 8.8 Modelled flows and surface elevations for south easterly event.

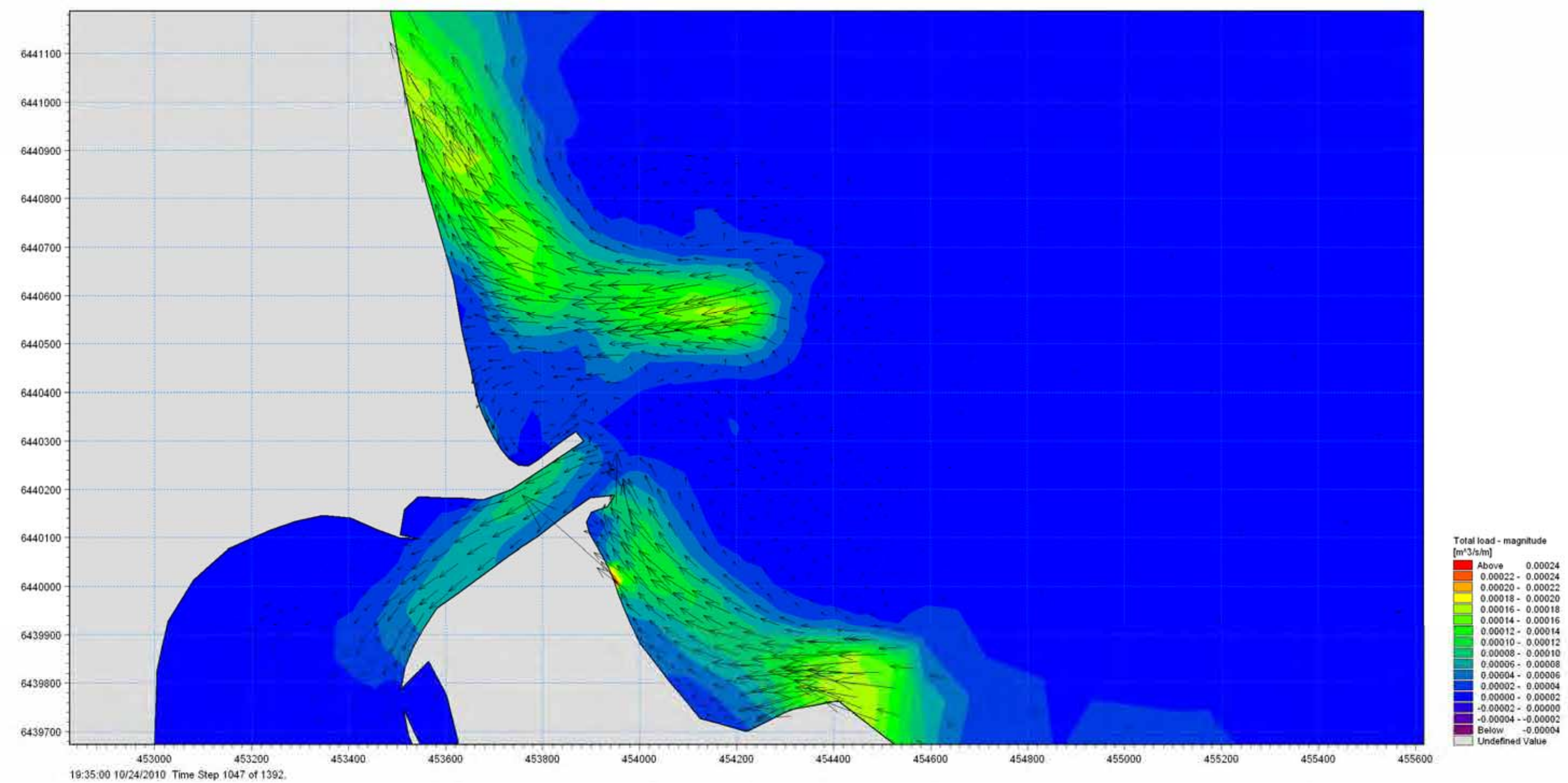


Figure 8.9 Modelled sediment transport for south easterly event.

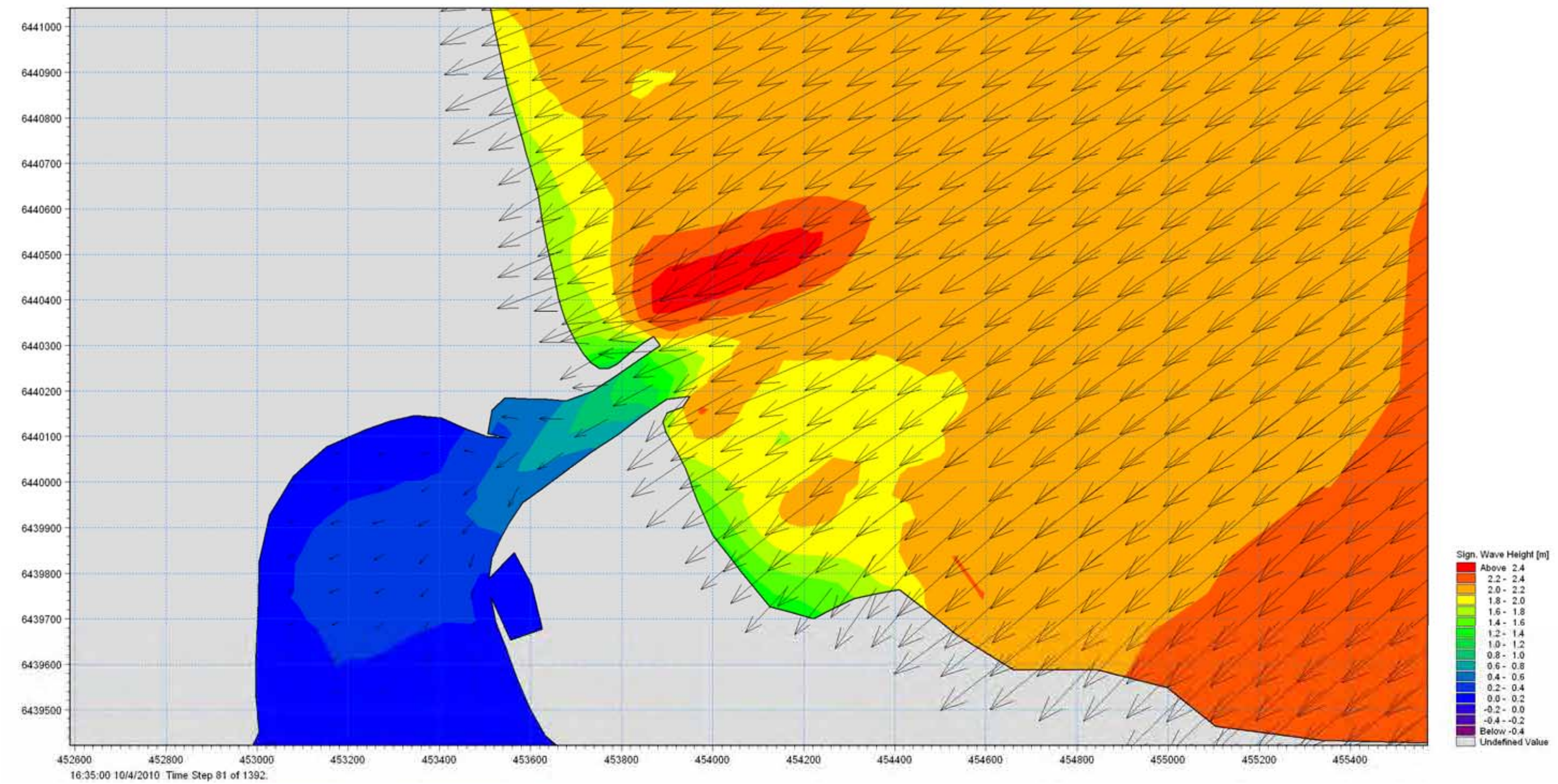


Figure 8.10 Modelled wave height and directions for north easterly event.

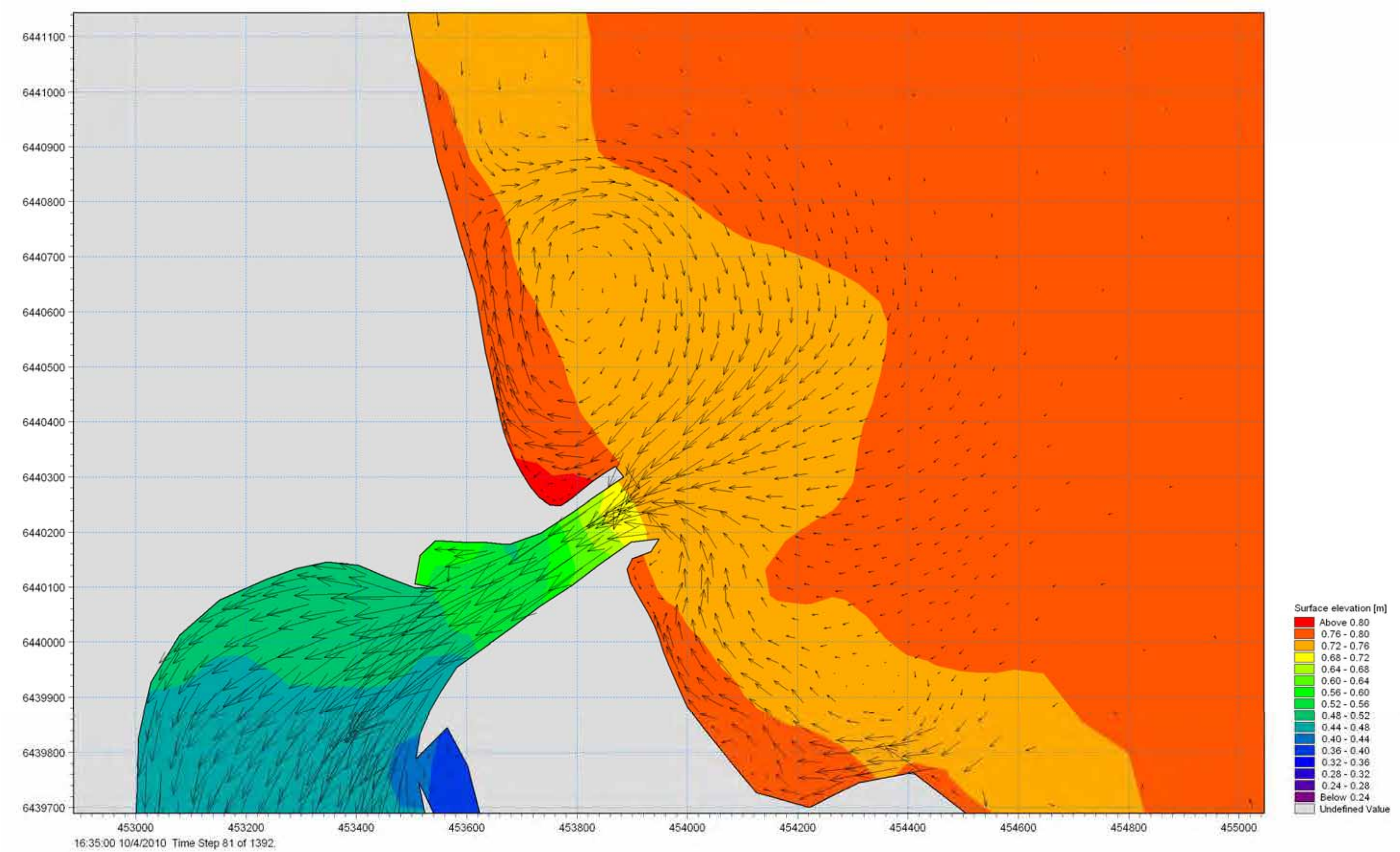


Figure 8.11 Modelled flows and surface elevations for north easterly event.

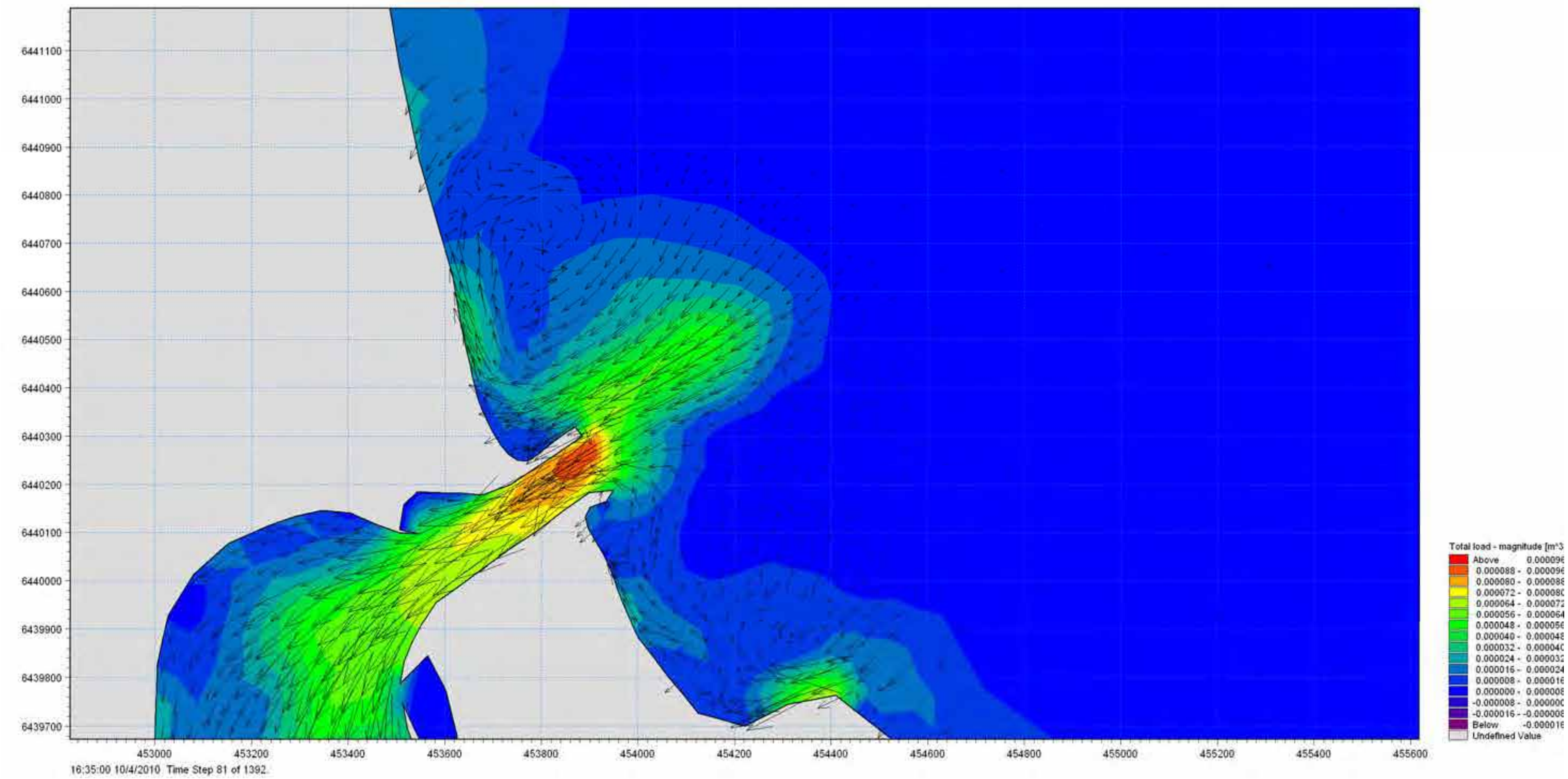


Figure 8.12 Modelled sediment transport for north easterly event.

Discussion

Coupled modelling of south easterly wave conditions appears to support the conceptual model, and is summarised as follows:

- The angle of wave approach to the coastline drives a northerly flow and sediment drift;
- Littoral drift (or potential littoral drift) is interrupted by tidal flows through the entrance inlet (refer to **Figure 8.8**);
- The nodal point modelled is in a similar location to that evident in aerial photography (refer to **Figure 8.6**), as indicated by the area where the northern flow of sediment attaches to the shoreline north of the entrance bar (refer to **Figure 8.9**);
- Local wave refraction/diffraction patterns and wave breaking occurring around the entrance bar causes differential wave heights and wave set-ups that drive a southward return current and eddy of flow and sediment movement between the beach, the northern breakwater and the entrance bar.

These results would indicate that sediment placed on Tuncurry Beach south of the nodal point has a greater chance of being retained in this area than if it is placed to the north of the nodal point.

Coupled modelling of the north easterly wave conditions also appears to be favorable to placement of nourishment sand to the south of the nodal point. In this case the modeling indicated that there is a northerly flow until sediment is deflected by the attached entrance bar and circulated back to the south.

Coupled flow, wave and sediment transport modelling appears to support the placement of sediment to the south of the nodal point. The modelling shows a greater probability of the nourishment sand being retained in the local sediment system between Tuncurry Beach, the surf zone and the entrance bar if placed in this area. Some losses of sediment to the northern littoral system and into the estuary inlet would be expected but are difficult to quantify from this limited assessment.

Limitations

The wave and coupled wave-flow-sediment transport model has not been calibrated. As such, this modelling is used to assess the relative change in entrance currents and sediment transport observed in the model under different wave conditions. Absolute values are not considered to be reliable given the lack of model calibration.

8.1.5 Future Considerations

Based on the low current coastal hazard risk to beachfront development and beach amenity, nourishment of Tuncurry Beach is not, in isolation, likely to be a priority project. However, potential future changes to the dominant coastal processes within the study area may increase the need for beach nourishment in the future. Principally these changes may be expected to be:

- adjustments in the sediment budget as a result of Wallis Lake estuary coming to an equilibrium condition; and
- climate change and sea level rise resulting in shoreline response;

These changes are discussed further below. In addition, potential future development of the area landward of Tuncurry Beach would increase the consequences of coastal hazards.

Changes to sediment supply

As discussed in **Section 4**, there is evidence to suggest that the Wallis Lake estuary is reaching a stable equilibrium following a period in which the inlet has experience scour following entrance training works. The scour of the inlet has potentially supplied Tuncurry Beach with a source of sediment (via the entrance bar system).

It follows that without the excess sediment supply, the planform of the coastline may readjust until a new equilibrium is reached. The supply of sediment from the entrance compartment may continue to reduce until the actual sediment supply is less than the amount which could potentially be moved further north by the littoral drift system. The resulting imbalance in the supply rate and the potential northerly transport rate may cause a return to the evolution of a zeta form embayment (recession progressively from south to north) until the shoreline of Nine Mile Beach is in equilibrium with the sediment supply and wave climate.

Tuncurry Beach and the greater Nine Mile Beach system may be subject to shoreline recession in the future if these changes to the sediment balance occur.

Climate change and sea level rise

A progressive rise in sea level will result in shoreline recession through two mechanisms: first, by drowning low-lying coastal land, and second, by shoreline readjustment to the new coastal water levels. The second mechanism is probably the more important: deeper offshore waters expose the coast to attack by larger waves; the nearshore refraction and diffraction behaviour of waves will change; a significant volume of sediment will move offshore as the beach adjusts to a new equilibrium profile.

Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise, the so-called Bruun Rule. The Bruun Rule is based on the concept that sea level rise will lead to erosion of the upper shoreface and deposition of this sediment offshore, followed by re-establishment of the original equilibrium profile. The beach profile is re-established by a shift landward and upward.

The Bruun Rule was applied to Tuncurry Beach and is incorporated into the 2060 and 2100 hazard line as discussed below.

2060 and 2100 Hazard Lines

Considerable uncertainty is associated with the processes discussed above. As such, the 2060 and 2100 hazard lines presented in **Figure 8.1** took a conservative approach in accounting for both long-term recessions due to sediment imbalance and sea level rise.

It is noted that Council are currently undertaking a *Coastal Processes and Hazard* assessment of Great Lakes Local Government Area. This study may result in a revision of the current understanding of coastal process and hazard risk at Nine Mile Beach.

Future Development

The area behind Tuncurry Beach has already been earmarked for potential future development. The *draft Forster-Tuncurry Crown Harbour Project* places a harbour, marina and associated commercial and residential developments within the area identified at risk over the 2060 and 2100 planning horizons (refer to **Figure 8.13**). More discussion on the *Crown Harbour Project* is provided in the main report (WorleyParsons, 2011).

Figure 8.13 Proposed Tuncurry Marina associated with the Crown Harbour Project (source: Land Property Management Authority)

8.1.6 Preliminary Sediment Assessment

A key aspect of the performance of beach nourishment is the quality of the sand to be used for nourishment. Good quality sand, in this instance, would generally be sand with properties that closely match sand on Tuncurry Beach ('native' sand). A preliminary assessment of the compatibility of sand dredged from the lower Wallis Lake estuary (i.e. the 'borrow' sand) to the native sand is presented here. If it is proposed that beach nourishment would precede then a more detailed assessment is recommended.

The basic context behind a comparison of sediment textural properties is that those of the native sand (mean grain size and sorting) are a direct response of sand sorting by natural processes and that these same processes will redistribute borrow material to a similar textural pattern as the native material. Thus some sediments sizes which are within the borrow material and not the native material, for example, fine sands, may not be suitable in a beach environment.

This preliminary assessment is based on sediment sampling undertaken by WorleyParsons in the Wallis Lake estuary and Nine Mile Beach in July 2010 (refer to **Section 3.4.1**). Samples were taken in three general locations:

- Tuncurry Beach;
- the entrance area; and

- The Step

Particle size analysis was also undertaken.

More detail on the sediment sampling exercise and analysis is provided in the REF report (refer to **Appendix B** of the main report).

Table 8.1 presents the particle size distributions for each of the analysed samples. Generally the sediment properties in the three areas are described as:

> *Tuncurry Beach (native sand):* composed mostly of fine to medium grain sand with coarser sand typically less than 20%. Sediment is reasonably well sorted.
>
> *Entrance Sand (borrow sand):* composed of fine, medium and coarse grained sand with between 5 – 15% coarser material. The coarser nature of this sand is likely to be due to the preferential sorting of the high velocity tidal flows in the entrance area. Sediment is reasonably well sorted.
>
> *The Step (borrow sand):* composed of mainly fine to medium grained sands, however, contains both fines (generally less than 10%) and coarser material (generally less than 15%). One outliner sample (Site 1) contains much more estuarine (or fluvial) mud (36% fines). Sediment is not well sorted.

This preliminary sediment assessment indicates that sampled areas of the lower Wallis Lake estuary show good compatibility to native sand. Borrow sand generally contains mean grain sizes larger than the native sand. The Step sediments appear to show slightly less sorting while the entrance area sand has a similar level of sorting to the native sand. A greater mean grain size and more grading (i.e. less sorted) are generally considerable favorable attributes in beach nourishment projects.

Although not completed here, a detailed assessment of native and borrow sand would typically be undertaken based on the following characteristics:

- Mean grain size including shell content
- Range of mean grain size
- Sorting including shell content
- Range of sorting
- Shell content
- Percentage of fine material

Based on these physical characteristics, two ratios are then calculated to determine the suitability of sand for nourishment purposes relative to the native sand. The two ratios, an overfill ratio R_A, and a re-nourishment ration R_J, where:

R_A	the estimated number of cubic meters of fill (nourishment) material required to produce 1 cubic meter of beach material when the beach is in a condition compatible with the native material. This is used to estimate the initial quantities of nourishment required;
R_J	the ratio of the rate at which borrow material will erode to the rate at which the native material is eroding. It is used to estimate how often re-nourishment is required.

Table 8.1 Particle size distribution for sample locations

Sediment Size	Sample Location Number								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tuncurry Beach									
Fines (<75µm)	0	0	1	1	0	0	0	-	-
Very fine sand (75µm - 150µm)	0	0	0	0	0	0	0	-	-
Fine sand (150µm - 300µm)	45	37	53	30	37	81	32	-	-
Medium sand (300µm - 425µm)	48	47	37	40	44	17	44	-	-
Coarse sand (425µm - 600µm)	7	15	9	21	11	2	19	-	-
Very coarse sand (600µm - 1180µm)	0	1	0	6	5	0	5	-	-
Gravel (>2 mm)	0	0	0	2	3	0	0	-	-
Entrance Area									
Fines (<75µm)	0	0	1	1	1	1	3	-	-
Very fine sand (75µm - 150µm)	0	0	0	0	0	0	1	-	-
Fine sand (150µm - 300µm)	12	15	9	30	48	38	68	-	-
Medium sand (300µm - 425µm)	42	44	40	51	37	50	25	-	-
Coarse sand (425µm - 600µm)	31	25	31	16	5	9	3	-	-
Very coarse sand (600µm - 1180µm)	10	11	12	2	4	2	0	-	-
Gravel (>2 mm)	1	4	5					-	-
‘The Step’									
Fines (<75µm)	36	5	2	2	2	1	2	6	6
Very fine sand (75µm - 150µm)	1	0	0	0	0	0	0	8	8
Fine sand (150µm - 300µm)	28	24	35	53	55	48	42	57	41
Medium sand (300µm - 425µm)	25	52	48	34	32	39	51	19	34
Coarse sand (425µm - 600µm)	7	15	11	8	7	9	3	8	10
Very coarse sand (600µm - 1180µm)	1	3	4	3	3	3	2	2	1
Gravel (>2 mm)	2	1	0	0	1	0	0	0	0

8.1.7 Recommendation on Nourishment

Nourishment of Tuncurry Beach is a feasible and long-term solution for the disposal of material dredged from the lower Wallis Lake estuary. If dredge spoil is placed in the area identified in **Figure 8.14**, minimum sediment loss from the overall estuarine and coastal compartment is expected. The impacts of additional sediment movements associated with beach nourishment on coastal processes, estuarine function and navigation, are expected to be minimal. The greatest impact would be associated with the construction phase of the project. This is discussed in the main report but is expected to be minimised by the timing of the works.

Beach nourishment, in isolation, is not currently required from a property protection or beach amenity perspective, however, changes to the governing coastal processes and potential development may necessitate on-going nourishment works in the future.

Figure 8.14 Potential beach nourishment area at southern end of Nine Mile Beach

Limitation

An accurate understanding of the sediment budget is an important part of the planning of a beach nourishment project. Accurately quantifying the magnitude of sediment movement (along the pathways defined in the conceptual coastal processes model) is a difficult task that typically requires extensive historical data and comprehensive numerical modelling.

This has not been attempted as part of this study. However, if nourishment was to proceed it is recommended.

8.2 Disposal within Estuary

At a relatively cheap disposal cost, dredge spoil could potentially be disposed of by dumping (or side casting) the material within the lower Wallis Lake estuary. To investigate this option a relatively calm area of the estuary has been identified. The area is on the eastern side of the small cove located on the southern side of Mather Island (refer to **Figure 8.15**). The area has been identified as it has a low energy. Filling of this area would also act to protect against a flood breaking through the sand spit designed to improve the water quality for ‘The Paddock’ oyster lease area. Other constraints such as existing infrastructure and seagrass beds at this location are discussed in the main report.

Hydrodynamic and sediment transport conditions have been assessed using the calibrated hydrodynamic model (refer to **Sections 5 and 6**). Based on model outputs at the location shown in **Figure 8.16** dredge spoil would be expected be stable if placed in this area. The hydrodynamic modelling determined mean and maximum current speeds of 0.02 and 0.04 m/s respectively in this location. Due to very low current speeds experienced at this proposed site, it is likely that disposed material would generally be stable.

This is consistent with the sediment transport modelling result, which predicted negligible sediment transport rates and bed level change over the period of 29 days of simulation.

Further, hydrographic survey for 1998 and 2010 (survey data described in **Section 3.2**) was compared (where depth soundings were comparable). It was evident that there was minimum change in bathymetry over the 12 year period.

Figure 8.15 Potential lower Wallis Lake estuary disposal area

Figure 8.16 Location of model result output

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Appendix A Model Systems

Numerical modelling for this study was undertaken utilizing the MIKE range of coastal modelling software. MIKE is produced by the Danish Hydraulic Institute (DHI), it is widely considered to be industry leading software in this specialist field. The modelling systems is designed in an integrated modular framework with the main MIKE 21/3 hydrodynamic modules simulating the free surface flows in 2D or 3D modes. Additional modules are used in this study for the simulation of waves, sediment transport, morphological change and fate and transport of pollutants. The following sections provide brief descriptions of the relevant MIKE modules.

MIKE 21/3

MIKE 21/3 hydrodynamic module is used to simulate free surface flows in coastal and marine environments. In 3D mode (MIKE 3) the hydrodynamic module is based on the numerical solution of the three-dimensional incompressible Reynolds averaged Navier-Stokes equation invoking the assumptions of Boussinsq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulent closure scheme. The free surface is taken into account using a sigma-coordinate transformation approach. In 2D mode (MIKE 21) the hydrodynamic module is based on the shallow water equations – the depth-integrated incompressible Reynolds averaged Navier-Stokes equations. In the horizontal domain both Cartesian and spherical coordinates can be used.

The hydrodynamic module would be utilised to investigate tidal and wave and wind generated flows in the study area. The flexibility inherited in the unstructured meshes used in MIKE 21/3 would be utilized to accommodate the variety of scales needed to be simulated in this investigation.

The MIKE hydrodynamic module simulates water level variations and flows in response to a variety of forcing mechanisms. The effects and facilities relevant to this project include:

- flooding and drying;
- momentum dispersion;
- bottom shear stress;
- wind shear stress;
- barometric pressure gradients;
- tidal potential;
- precipitation/evaporation;
- wave radiation stresses; and
- sources and sinks (intakes and discharges).

MIKE 21 Spectral Wave (SW)

The MIKE 21 Spectral Wave module (SW) was used to transform offshore wave conditions to the nearshore and for the investigation of wave penetration and wave setup within the estuary. MIKE 21 SW a state-of-the-art third generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. The following physical phenomena are taken into account:

- wave growth by action of wind;
- non-linear wave-wave interaction;
- dissipation due to white-capping;
- dissipation due to bottom friction;
- dissipation due to depth-induced wave breaking;
- refraction and shoaling dues to depth variations;
- wave-current interaction;
- approximation to wave diffraction; and
- effect of time-varying water depth and flooding and drying

MIKE 21 SW includes two different formulations:

- directional decoupled parametric formulation; and
- fully spectral formulation.

The directional decoupled parametric formulation is based on a parameterization of the wave action conservation equation. The parameterization is made in the frequency domain by introducing the zeroth and first moment of the wave action spectrum as dependent variables following Holthuijsen (1989). A similar approximation is used in MIKE 21 NSW Nearshore Spectral Wind-Wave Module. The fully spectral formulation is based on the wave action conservation equation where the directional-frequency wave action spectrum is the dependent variable.

Sand Transport / Morphological (ST)

The Sediment Transport (ST) module is an advanced sand transport model with several formulations for current and current/wave generated transport of non-cohesive sediment. It is mainly used to determine the sediment transport pattern (or changes in this pattern) and the initial rates of sedimentation/erosion due to the impact of engineering works. Simulations can be done for pure currents and combined currents and waves. Several formulations calculating sand transport in pure currents are implemented in the model. The STP (detailed sand transport model, Van Rijh and Bijker´s method are available for calculating sand transport rates in combined currents and waves.

It is an advanced sand transport model both for pure current or current and wave conditions, which includes influence of breaking and non-breaking waves, currents due to various driving forces, coastal structures, complex bathymetry, sediment gradation, etc. Some of the processes described in STP include: waves propagating at an arbitrary angle with respect to the current, breaking/unbroken waves, effect of ripples, sediment grading, bed slope, wave asymmetry, undertow, etc.

Typical application areas for MIKE 21 ST are:

- Morphological optimisation of port layouts, taking into consideration sedimentation at port entrance, sand bypassing and downdrift impact, etc

- Detailed coastal area investigation of the impact of shore protection structures on adjacent shoreline. Sand losses from bays due to rip currents, etc
- Stability of tidal inlets - assessment of the ability of the tidal flows to maintain the entrance after sudden sedimentation due to littoral drift

Appendix B Historical Aerials


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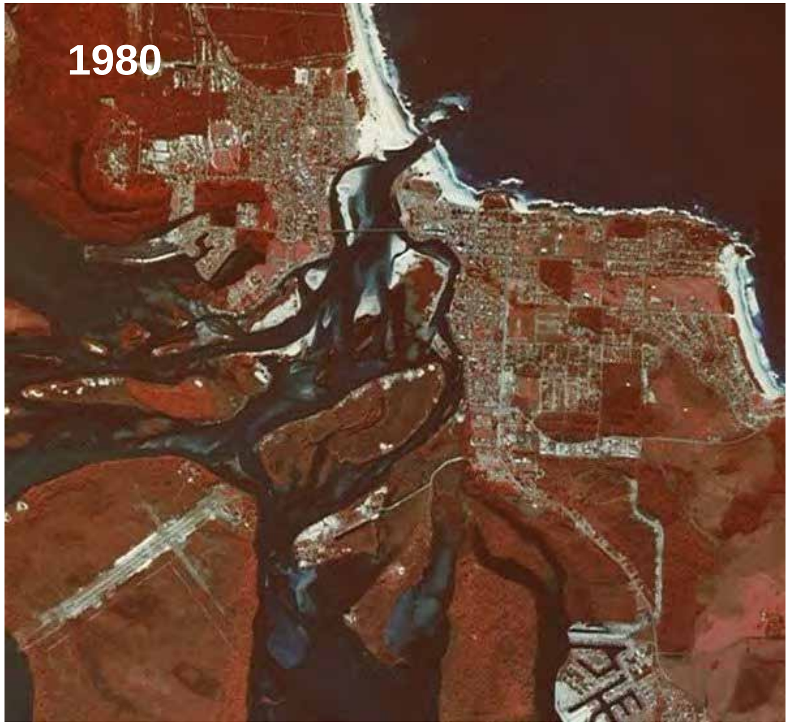
1963


1971


1977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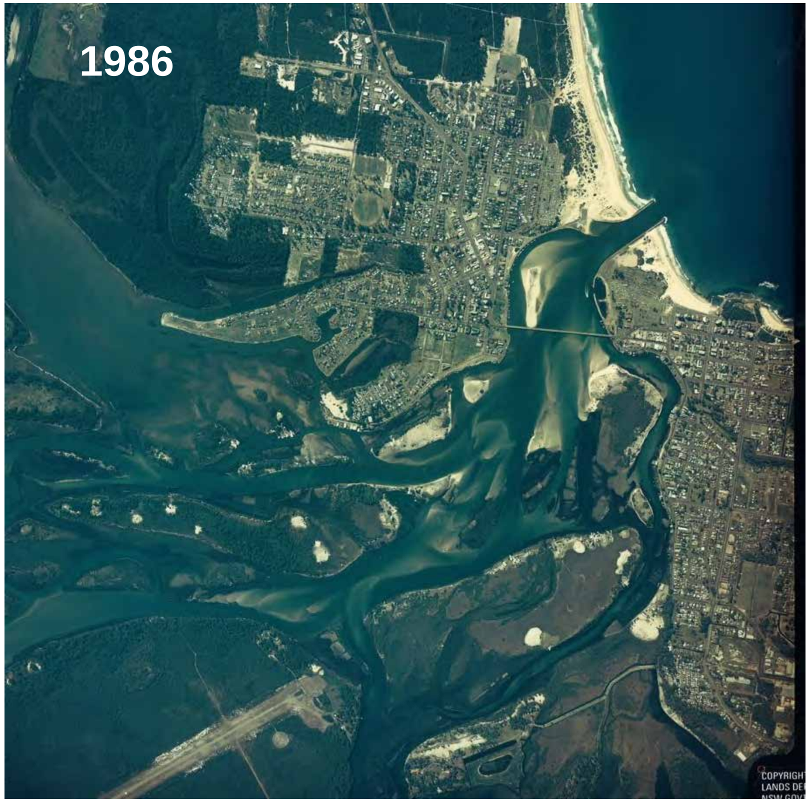
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Appendix C Calibration Results

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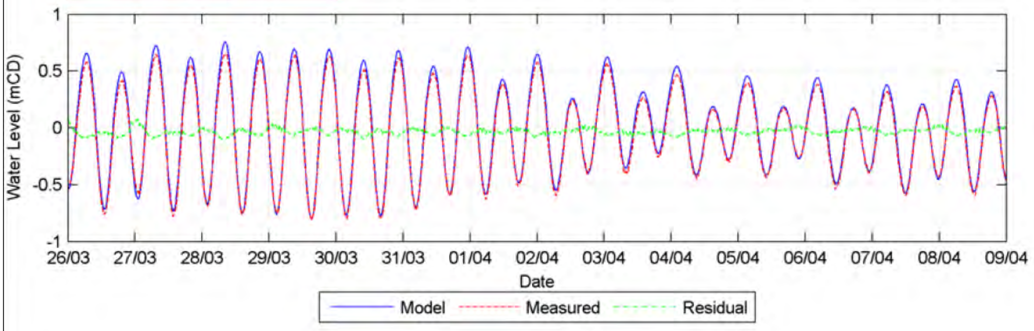

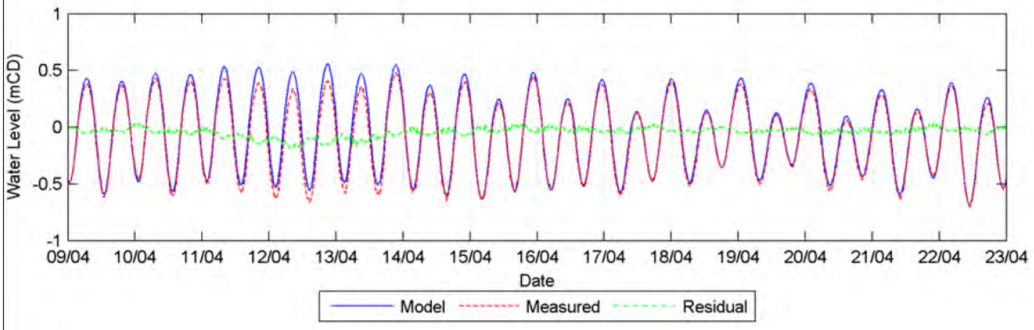

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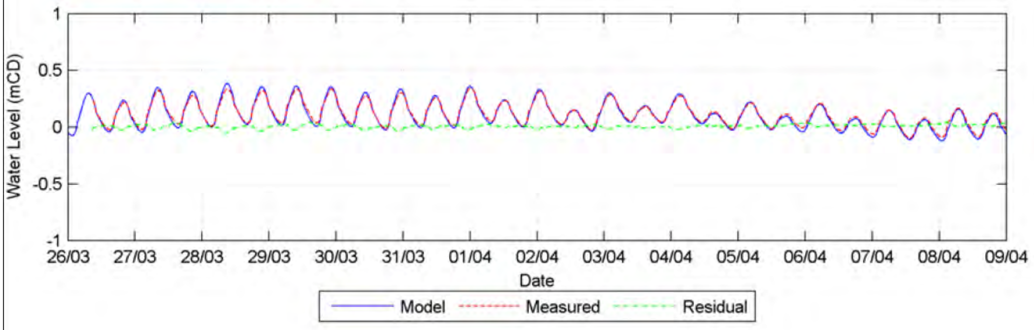

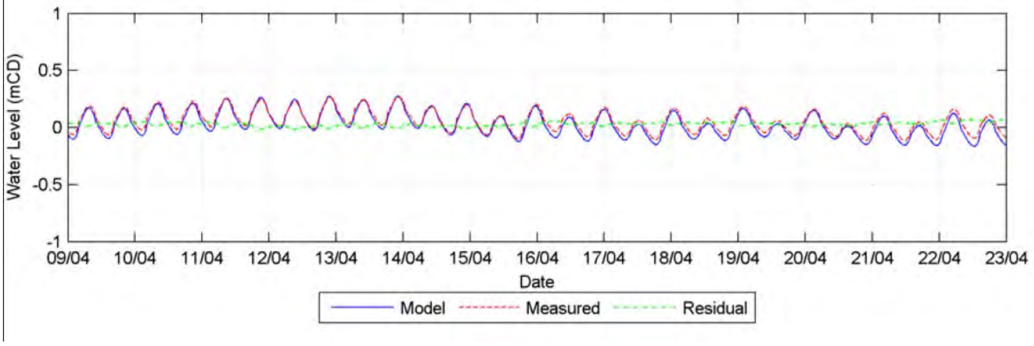

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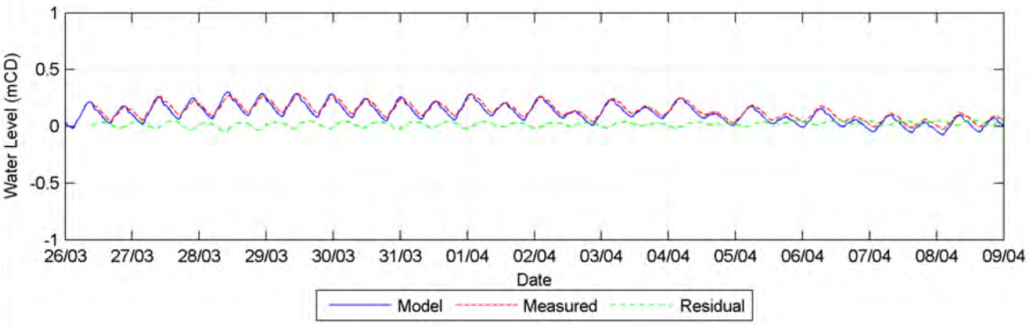

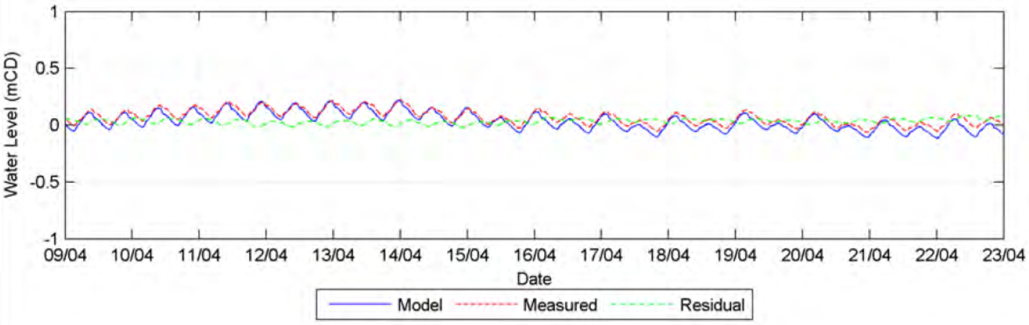

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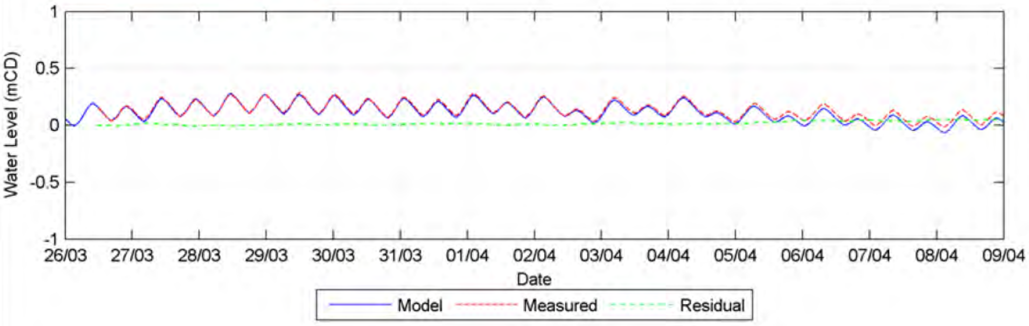

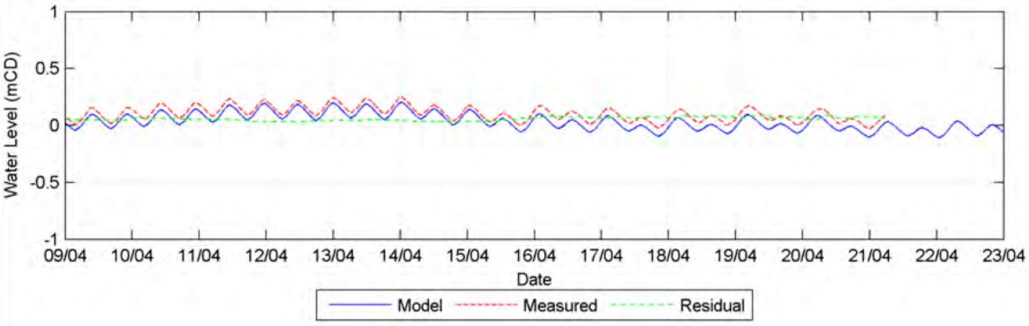

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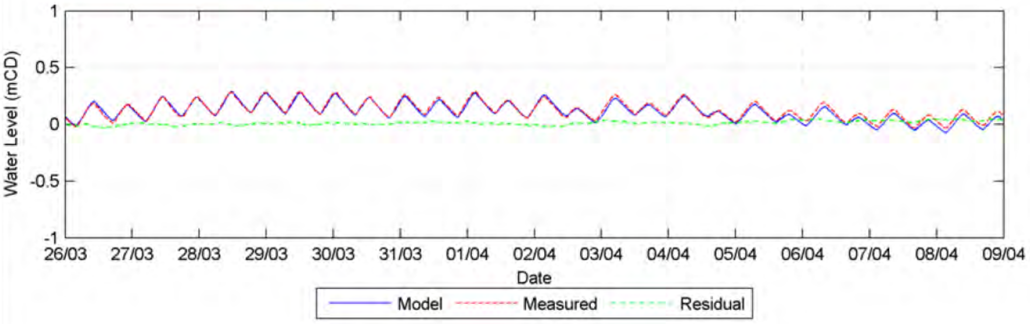

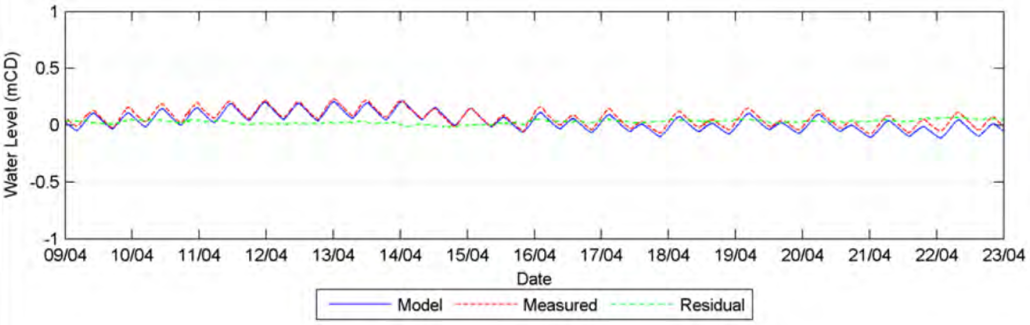

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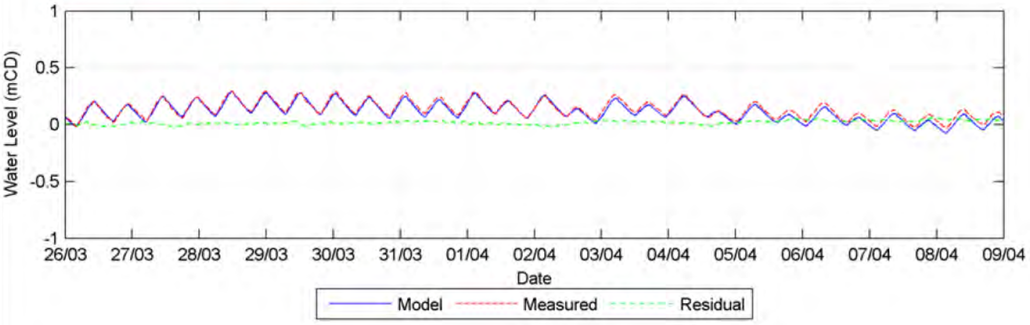

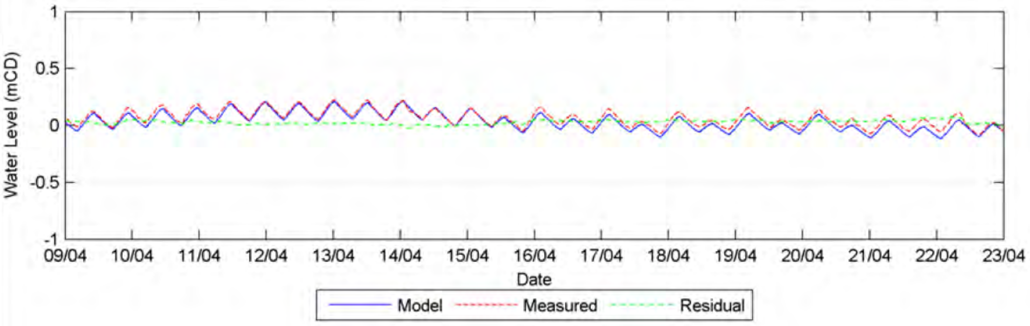

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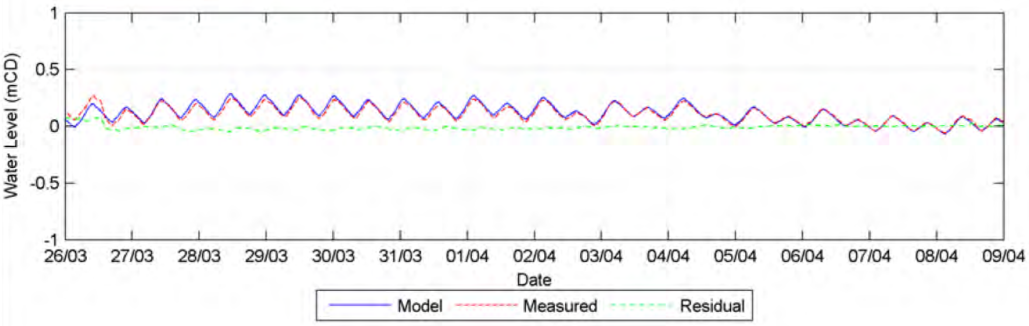

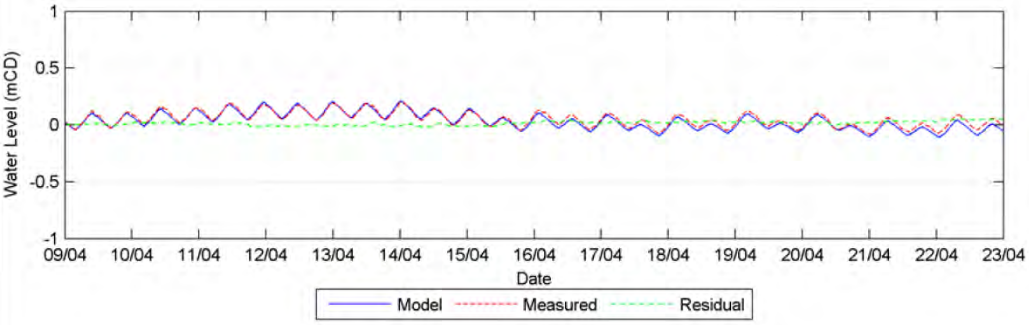

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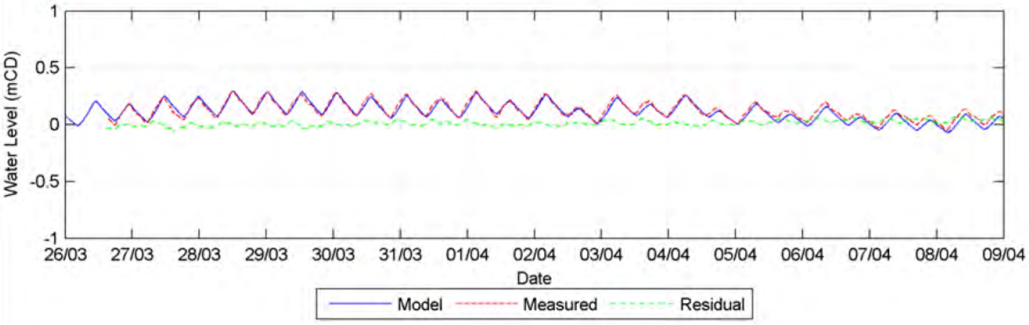

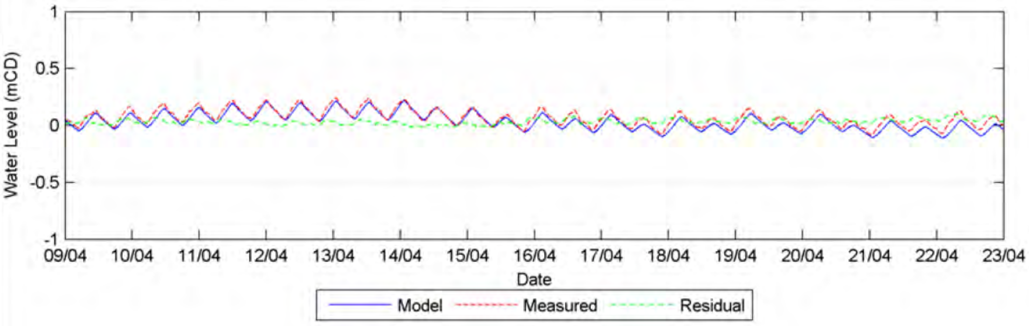

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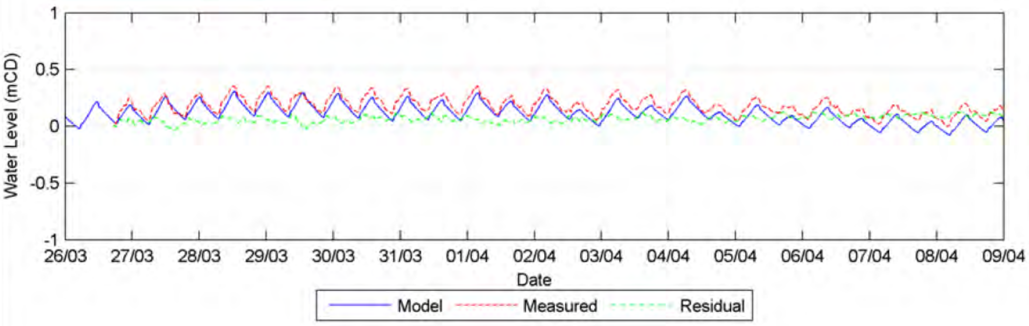

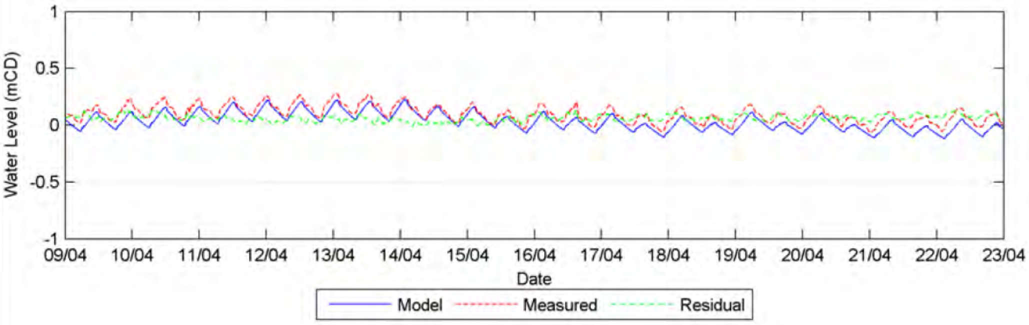

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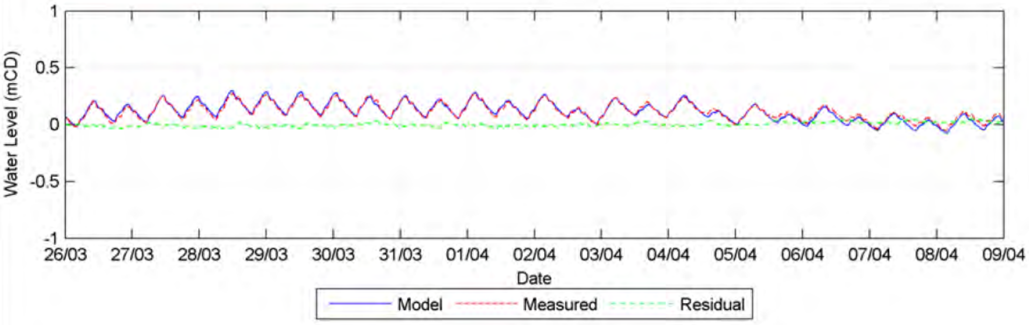

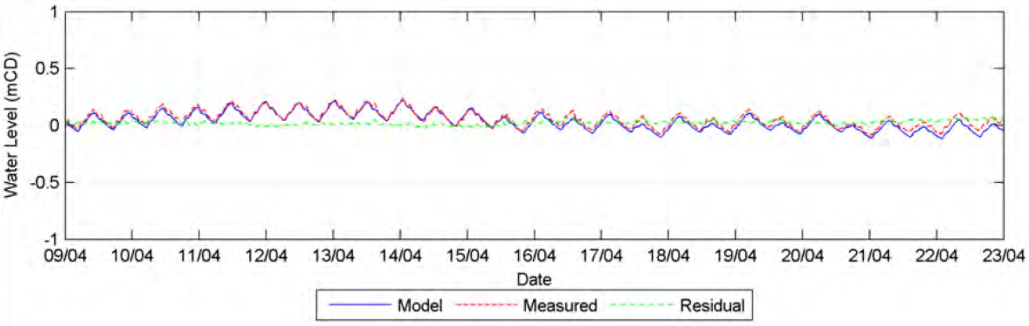

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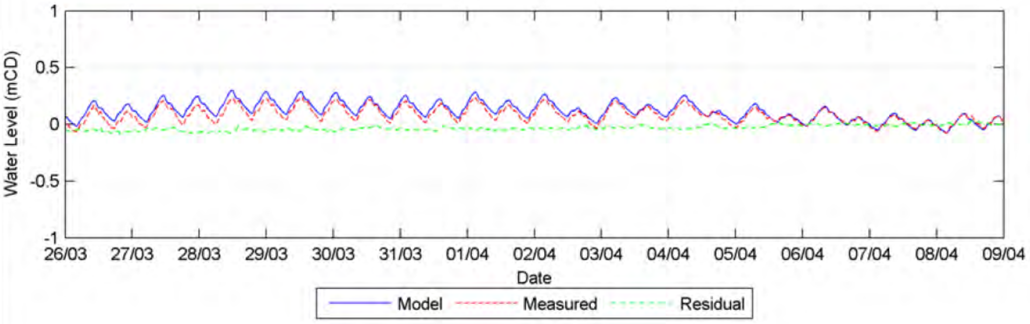

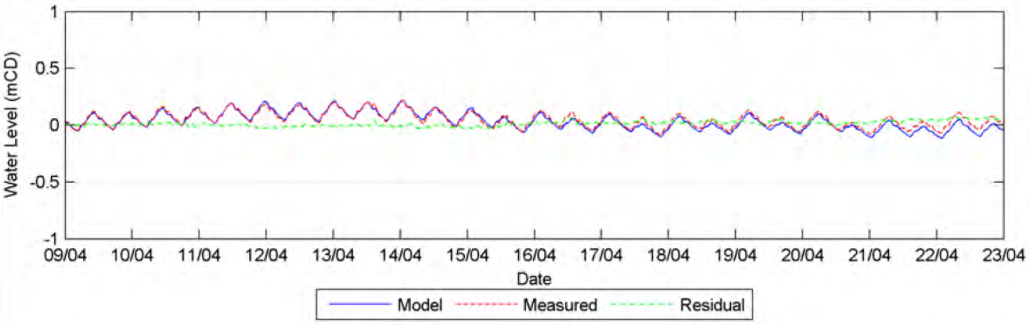

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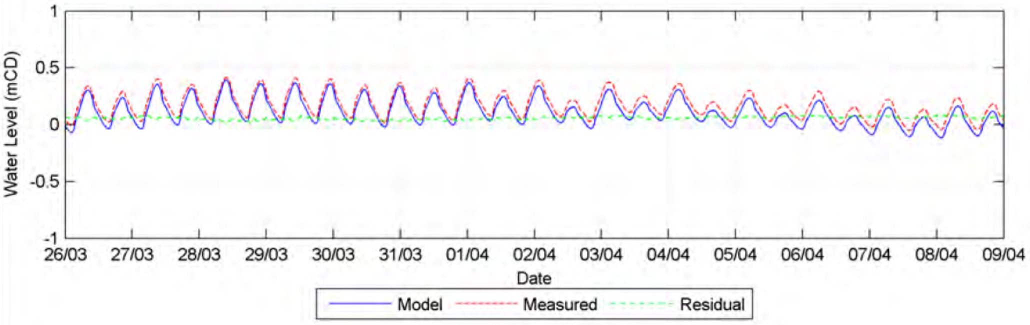

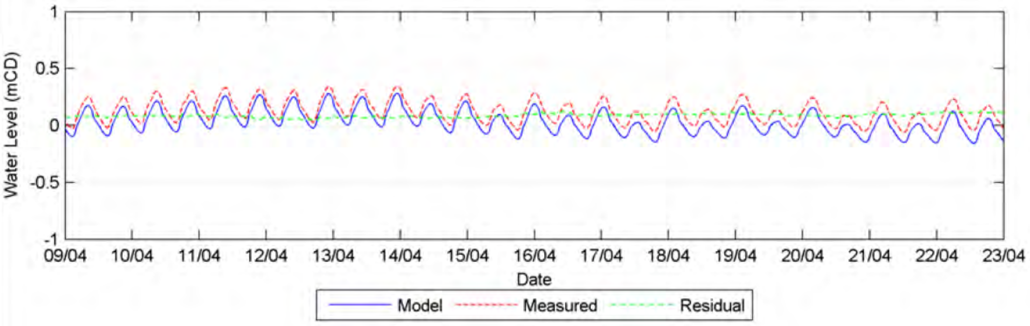

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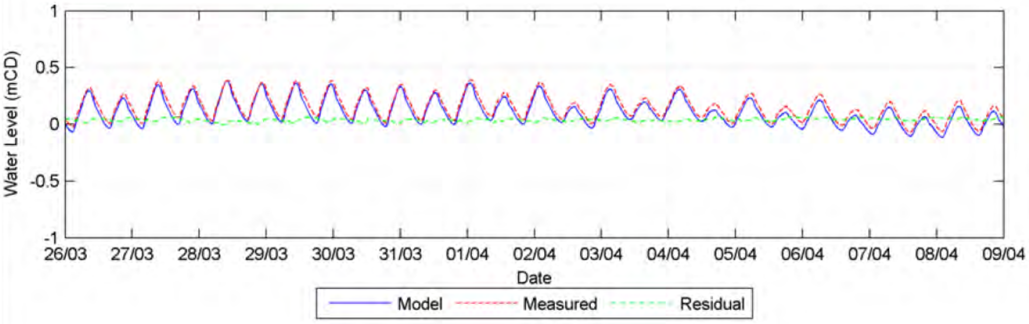

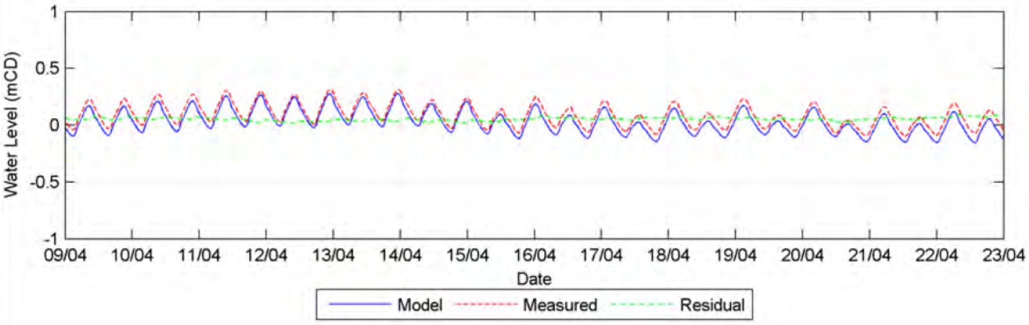

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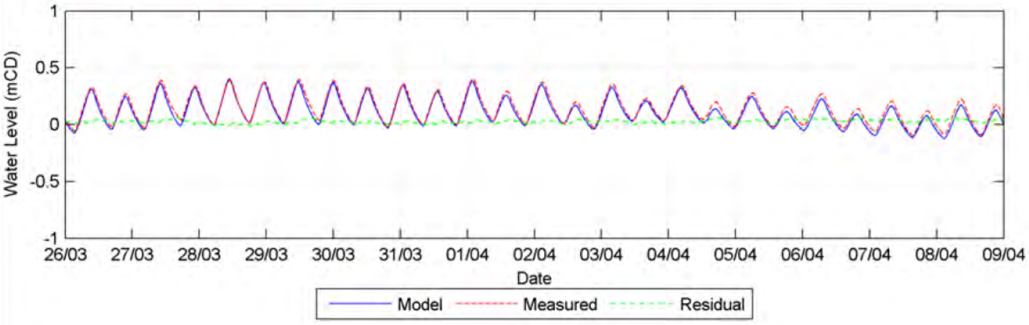

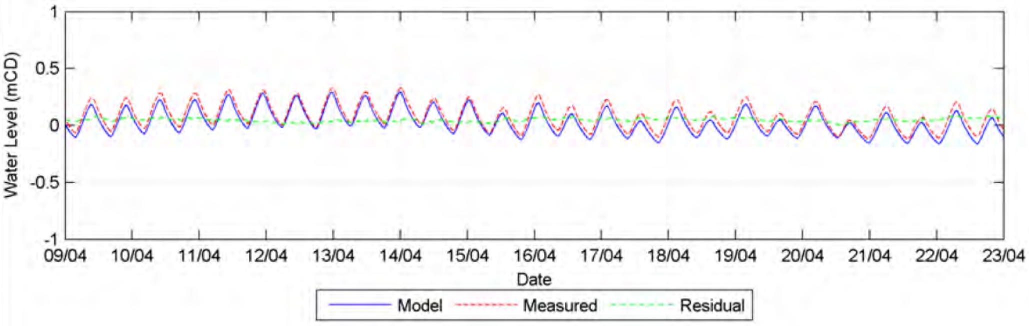

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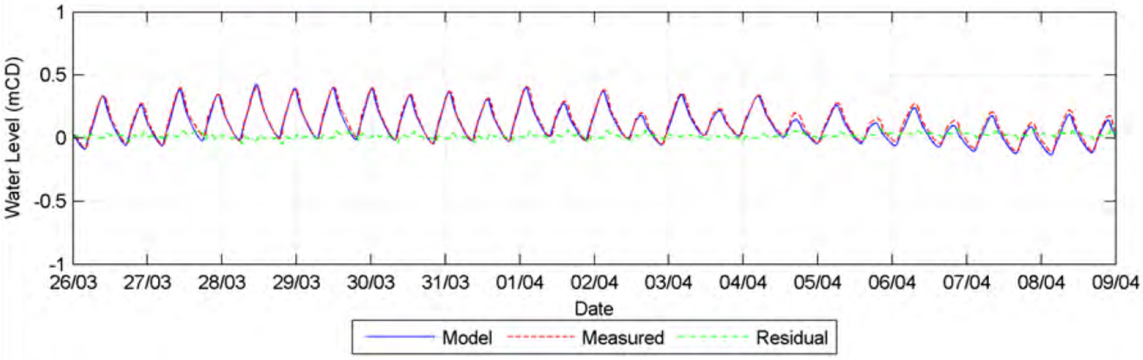
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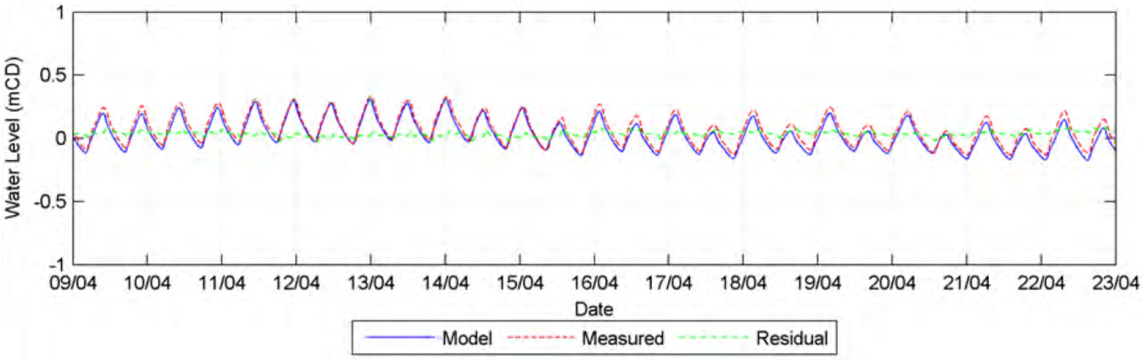
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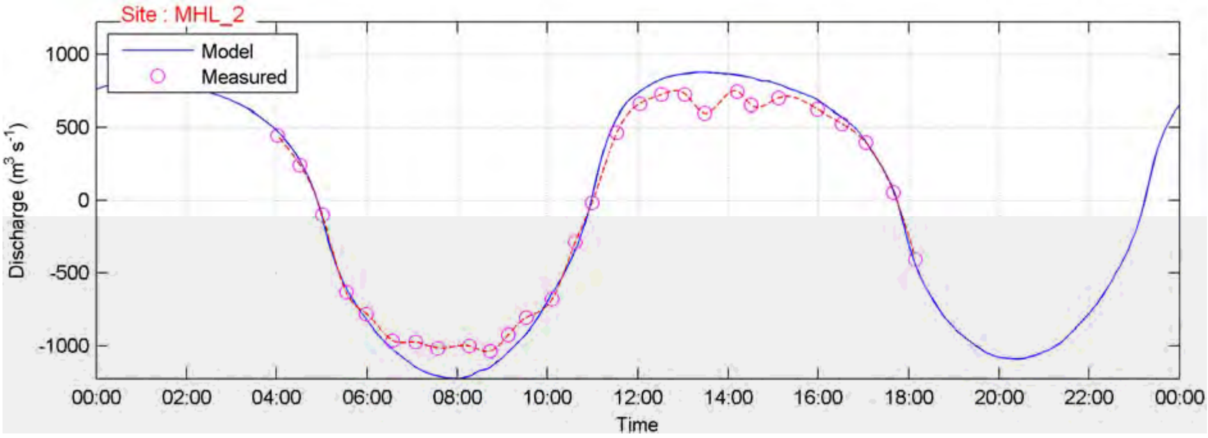
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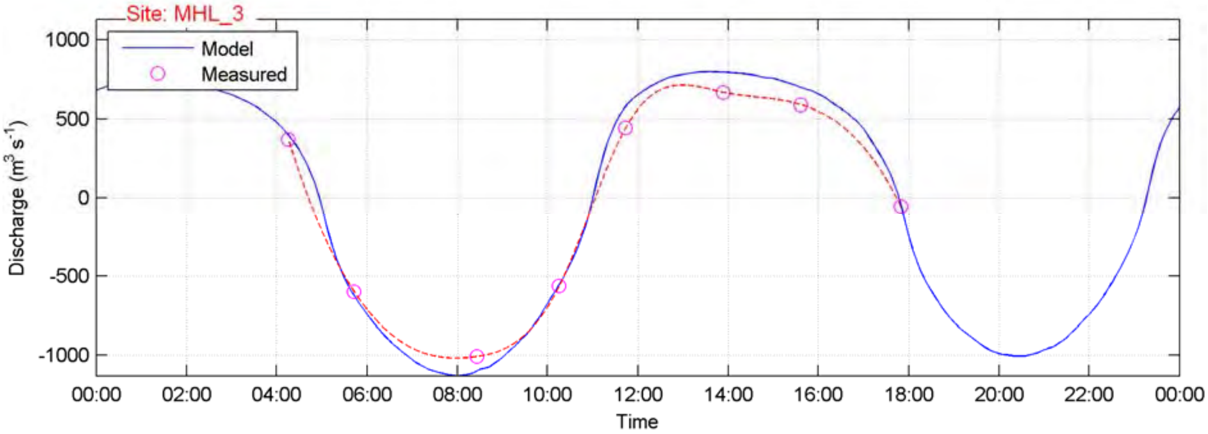
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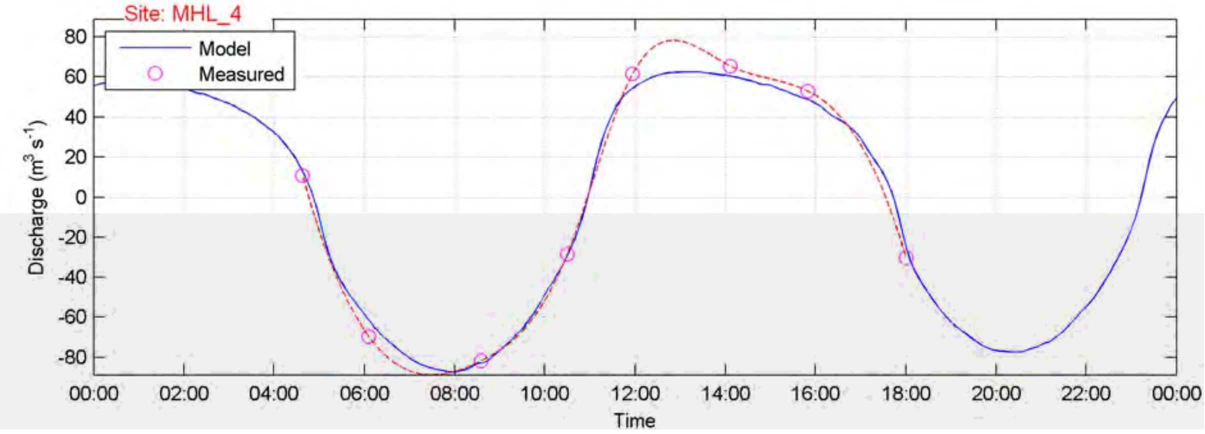
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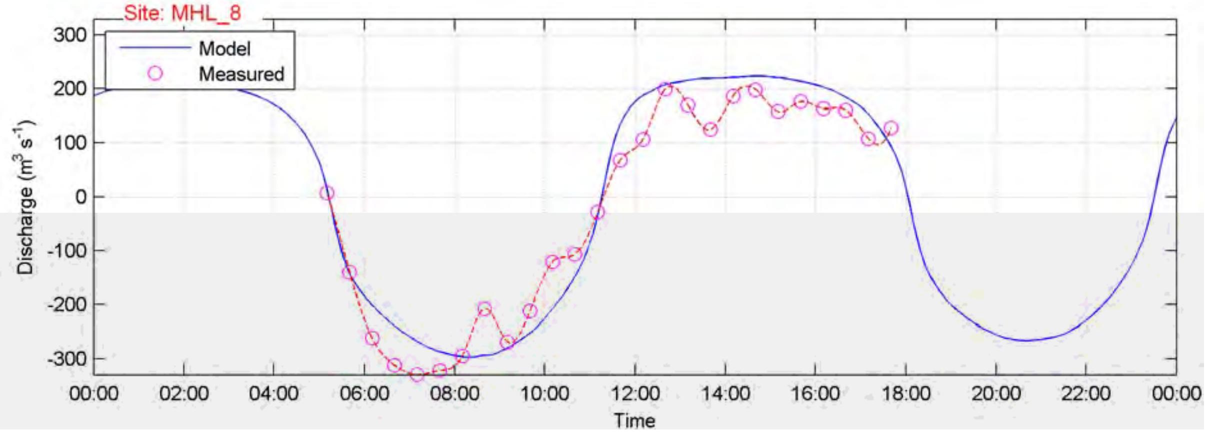
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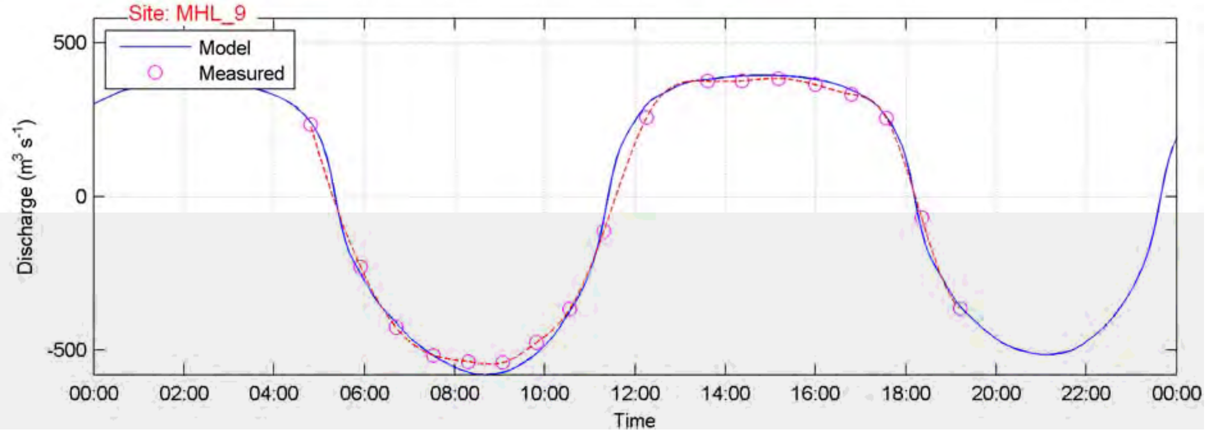
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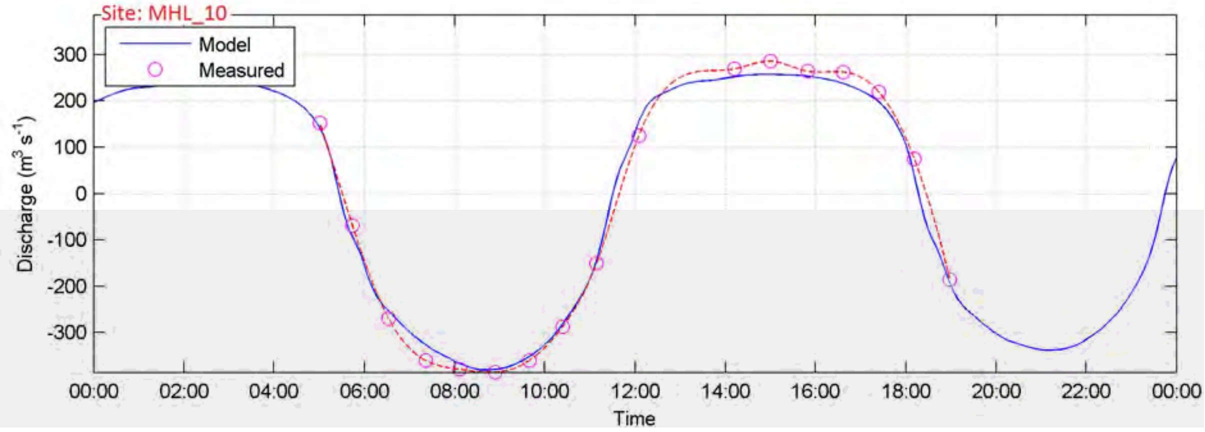
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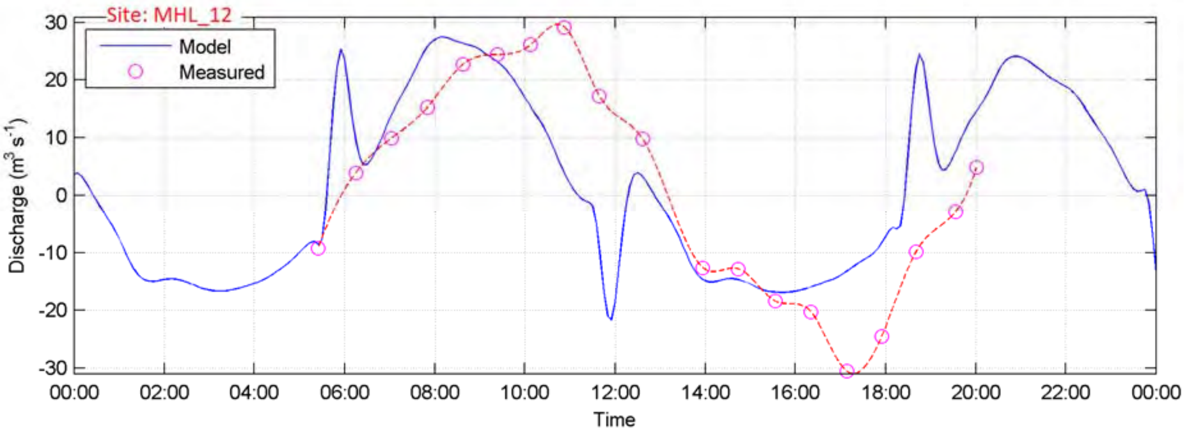
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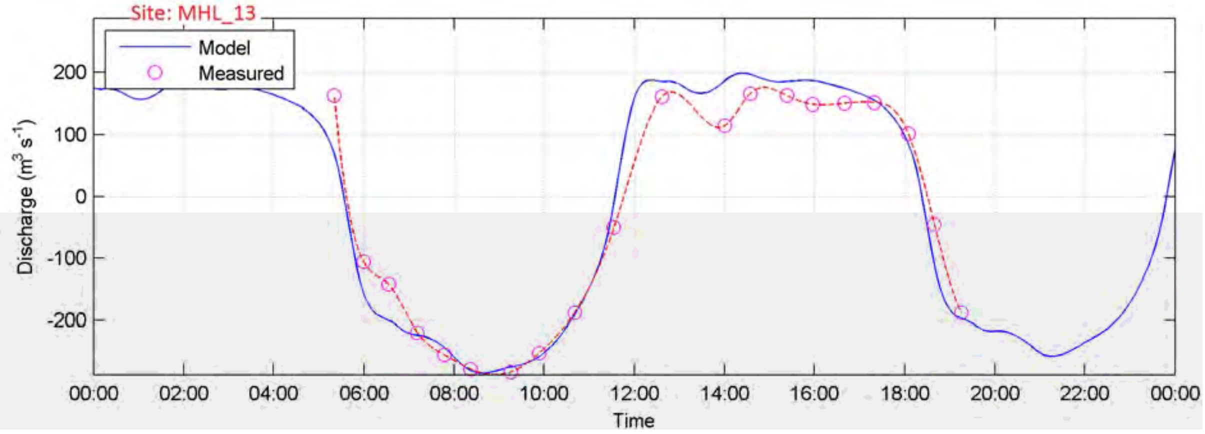
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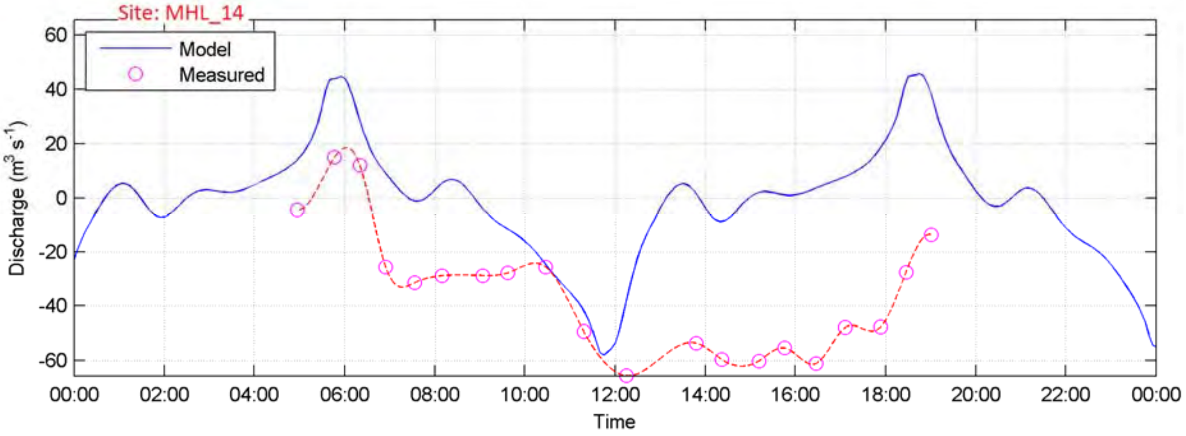
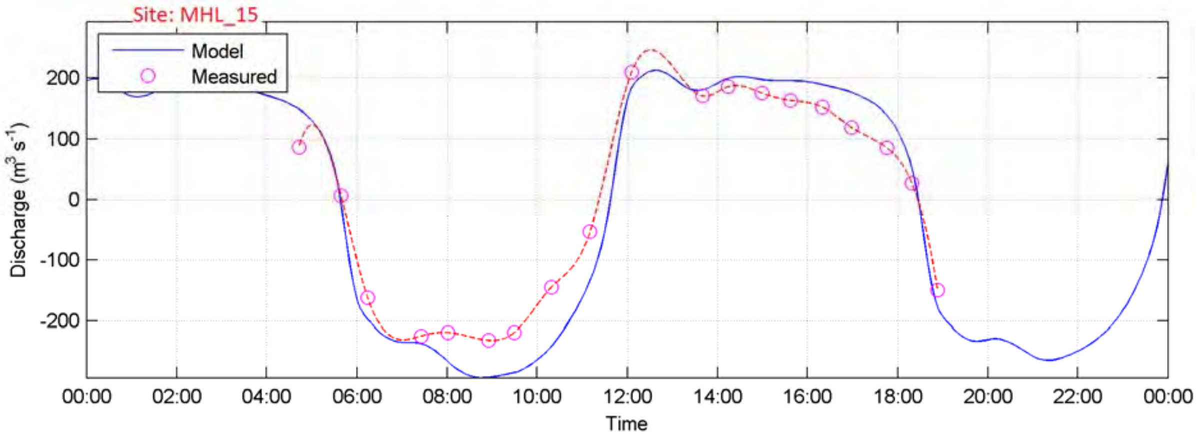
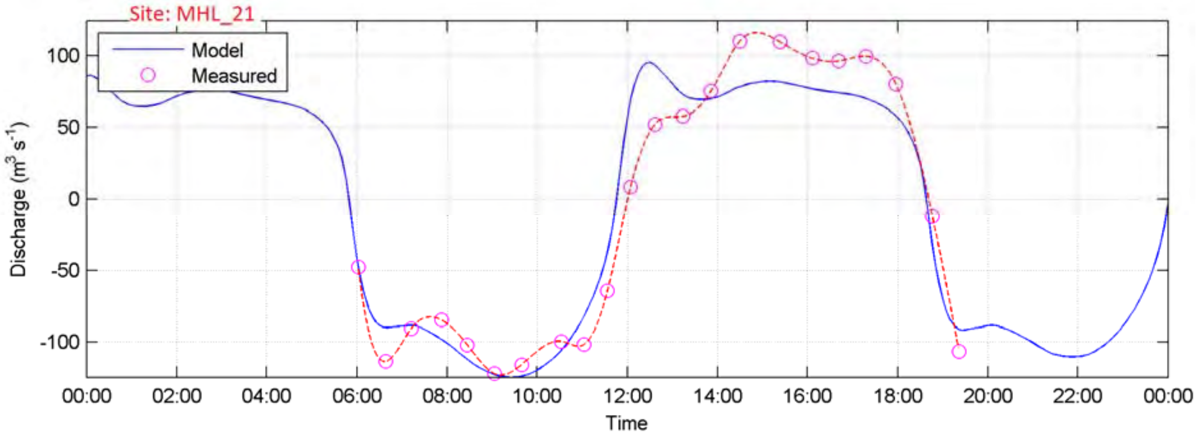
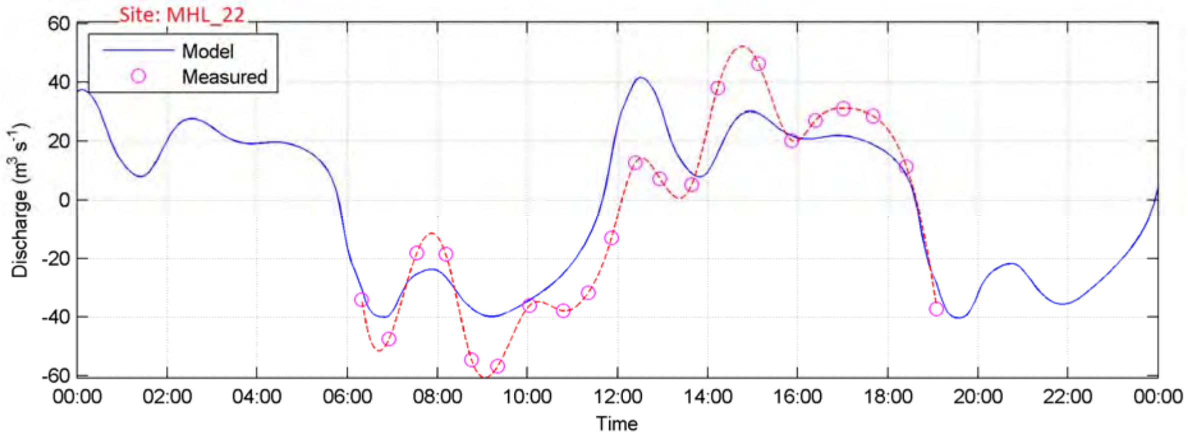
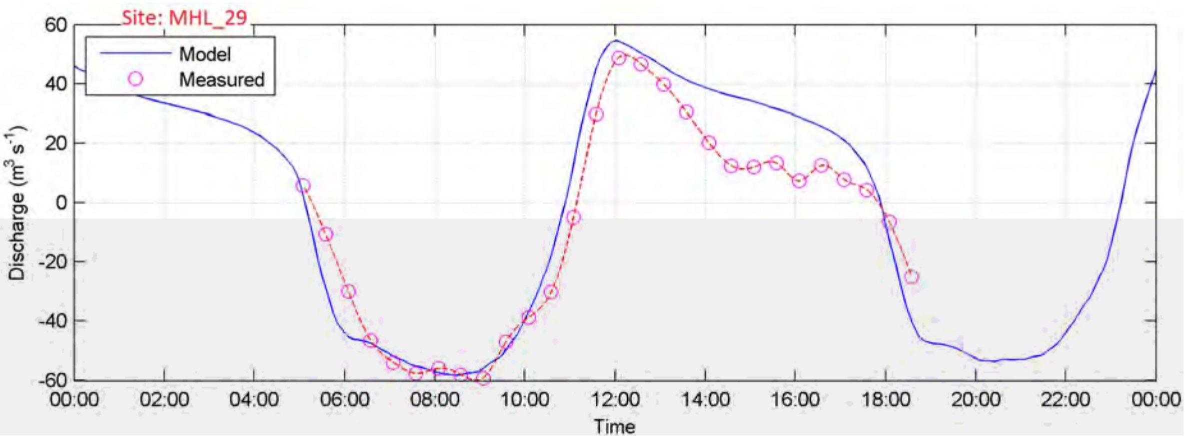
Model
Measured
Discharge (m^3 s^{-1})
200
100
0
-100
-200
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time


Site: MHL_14
Model
Measured
Discharge (m^3 s^{-1})
60
40
20
0
-20
-40
-60
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time


Site: MHL_15
Model
Measured
Discharge (m^3 s^{-1})
200
100
0
-100
-200
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time


Site: MHL_21
Model
Measured
Discharge (m^3 s^{-1})
100
50
0
-50
-100
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time


Site: MHL_22
Model
Measured
Discharge (m^3 s^{-1})
60
40
20
0
-20
-40
-60
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time


Site: MHL_29
Model
Measured
Discharge ($m^3 s^{-1}$)
60
40
20
0
-20
-40
-60
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time

Modelled and Measured amplitude and phase of four primary constituents for MHL 15 water level sites (refer to Figure 3.3 for locations)

Consitiuent	MHL_1		MHL_7		MHL_11		MHL_16		MHL_17		MHL_18		MHL_19		MHL_23	
	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.
Amplitude																
M2	0.412	0.428	0.102	0.100	0.051	0.049	0.051	0.054	0.056	0.061	0.055	0.060	0.051	0.055	0.057	0.063
S2	0.122	0.130	0.029	0.027	0.013	0.012	0.015	0.015	0.014	0.015	0.014	0.015	0.013	0.014	0.015	0.016
K1	0.103	0.108	0.035	0.035	0.025	0.025	0.024	0.026	0.025	0.027	0.024	0.027	0.024	0.026	0.023	0.023
O1	0.078	0.080	0.033	0.031	0.025	0.024	0.025	0.024	0.025	0.025	0.025	0.023	0.024	0.024	0.024	0.024
Phase																
M2	237	237	262	263	313	317	331	334	339	337	340	337	332	337	0	351
S2	257	257	280	280	330	338	351	344	1	352	2	353	353	6	23	21
K1	115	110	154	154	187	195	209	203	206	198	211	200	207	215	222	219
O1	80	73	125	124	157	163	175	172	179	178	180	179	176	172	191	183

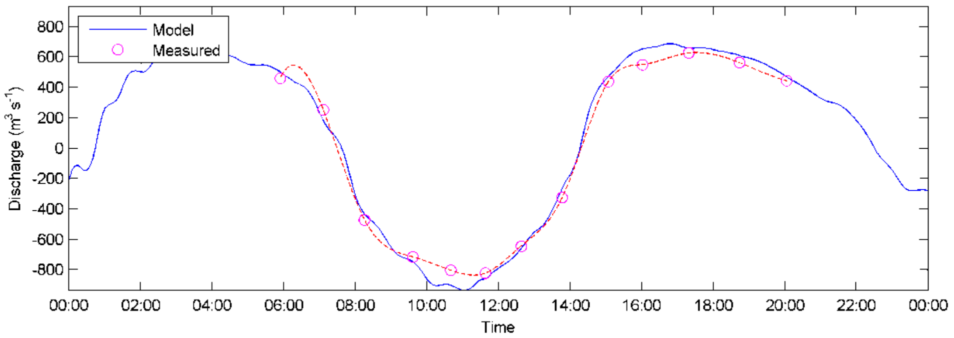
Consitiuent	MHL_24		MHL_25		MHL_26		MHL_27		MHL_28		MHL_31		MHL_32	
	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.	Model	Meas.
Amplitude														
M2	0.060	0.066	0.055	0.059	0.055	0.059	0.104	0.110	0.100	0.106	0.109	0.121	0.121	0.130
S2	0.015	0.016	0.015	0.016	0.014	0.017	0.028	0.030	0.027	0.027	0.028	0.030	0.031	0.033
K1	0.023	0.024	0.023	0.023	0.023	0.024	0.036	0.039	0.034	0.036	0.035	0.038	0.035	0.037
O1	0.024	0.025	0.025	0.025	0.025	0.025	0.034	0.035	0.034	0.036	0.035	0.039	0.035	0.039
Phase														
M2	4	352	341	340	341	340	278	279	288	295	317	316	326	322
S2	27	23	9	19	9	19	297	297	309	313	343	343	353	350
K1	225	218	218	223	218	225	164	163	170	168	186	183	191	188
O1	193	187	181	176	181	175	135	133	140	139	154	147	158	151

Error in amplitude and difference in phase of four primary constituents for MHL 15 water level sites (refer to Figure 3.3 for locations)

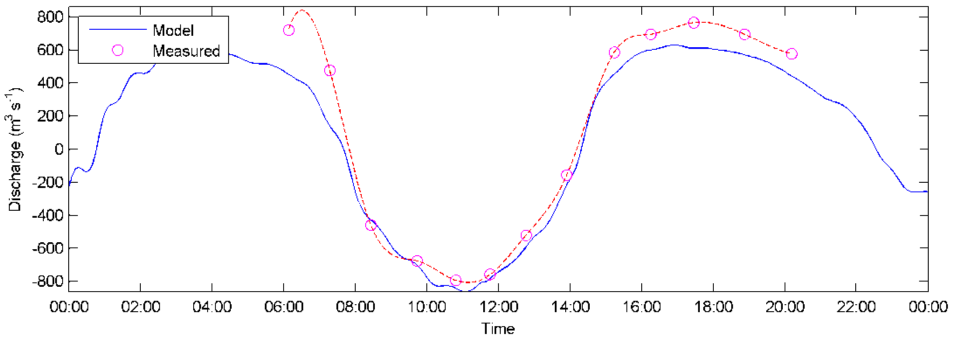
Consitiuent	MHL_1	MHL_7	MHL_11	MHL_16	MHL_17	MHL_18	MHL_19	MHL_23	MHL_24	MHL_25	MHL_26	MHL_27	MHL_28	MHL_31	MHL_32
Amplitude															
M2	-4%	2%	4%	-6%	-8%	-8%	-7%	-10%	-9%	-7%	-7%	-5%	-6%	-10%	-7%
S2	-6%	7%	8%	0%	-7%	-7%	-7%	-6%	-6%	-6%	-18%	-7%	0%	-7%	-6%
K1	-5%	0%	0%	-8%	-7%	-11%	-8%	0%	-4%	0%	-4%	-8%	-6%	-8%	-5%
O1	-3%	6%	4%	4%	0%	9%	0%	0%	-4%	0%	0%	-3%	-6%	-10%	-10%
Phase															
M2	0.7	-1.3	-4.7	-2.8	2.2	2.9	-4.9	9.1	11.7	1.2	1.0	-1.0	-6.3	0.9	4.1
S2	0.0	-0.8	-8.3	6.8	8.4	8.9	1.8	2.1	4.9	-10.5	-9.7	0.3	-4.5	-0.2	3.2
K1	5.5	-0.1	-8.0	5.7	8.2	10.5	-7.9	3.9	6.9	-5.4	-6.5	1.0	2.1	3.3	3.2
O1	6.9	0.4	-5.4	3.1	1.5	0.9	4.1	7.4	6.0	4.3	6.2	1.6	0.7	6.8	7.4

Appendix D Verification Results

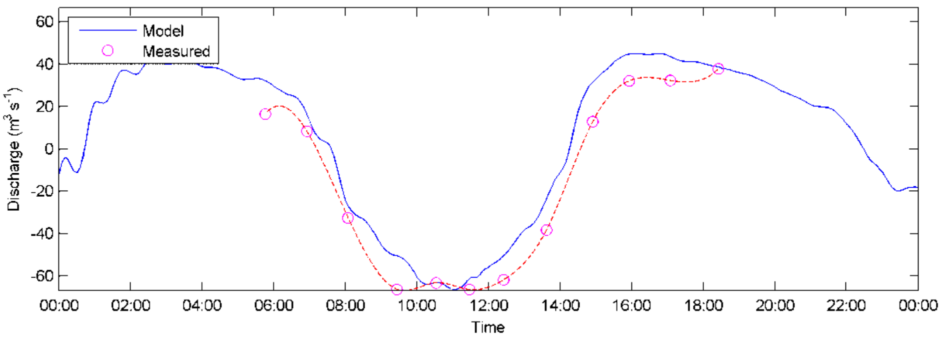
Site: WP_1



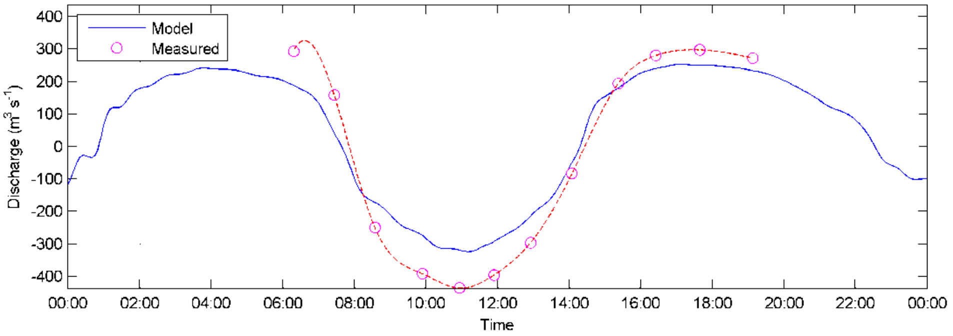
Site: WP_2



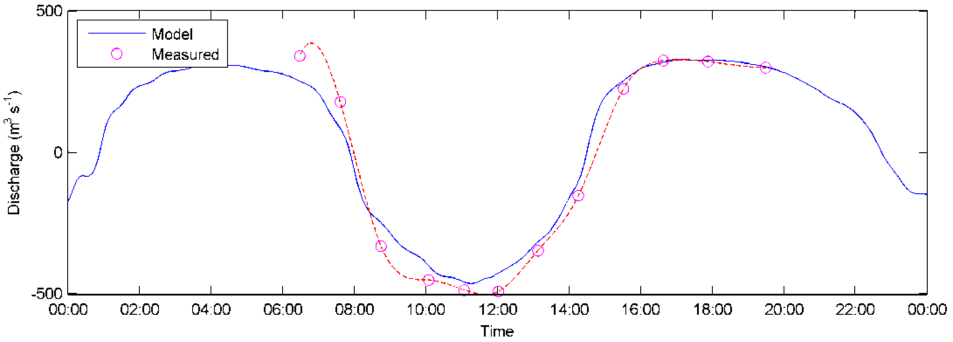
Site: WP_3



Site: WP_6

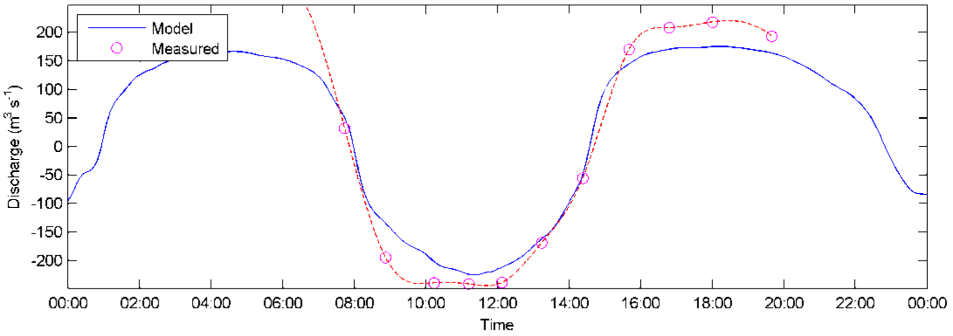


Site: WP_7

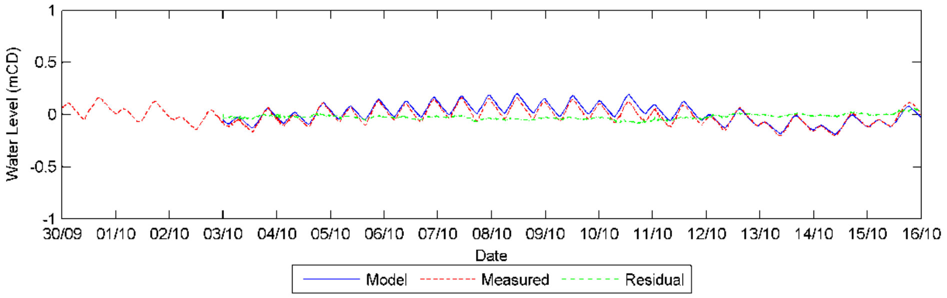


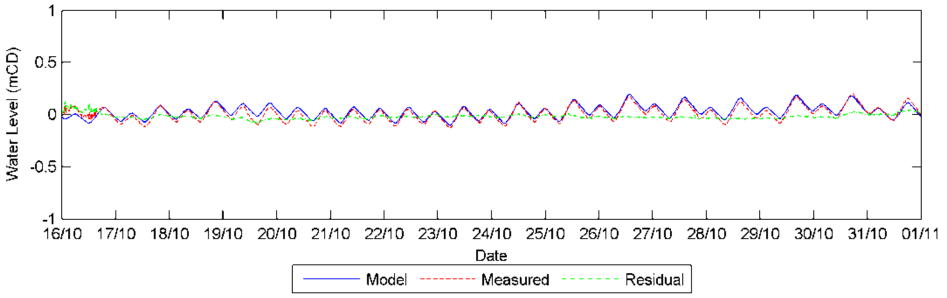
Site:

Site: WP_8

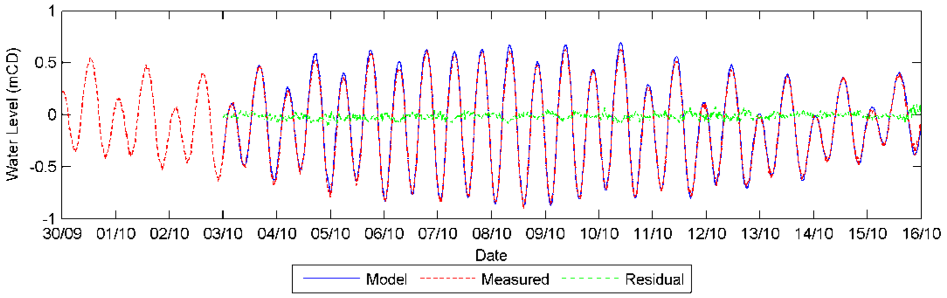


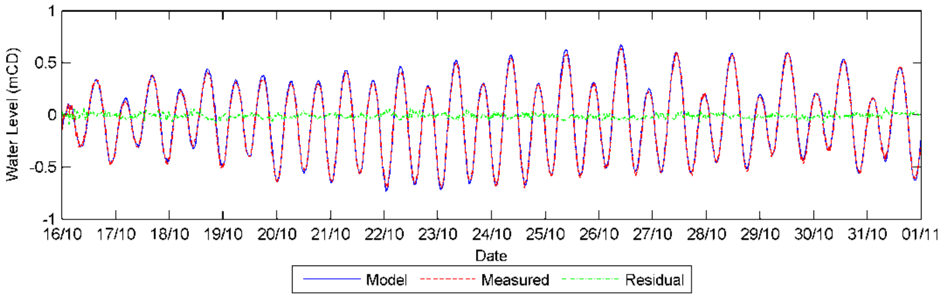
Water Level: Tiona



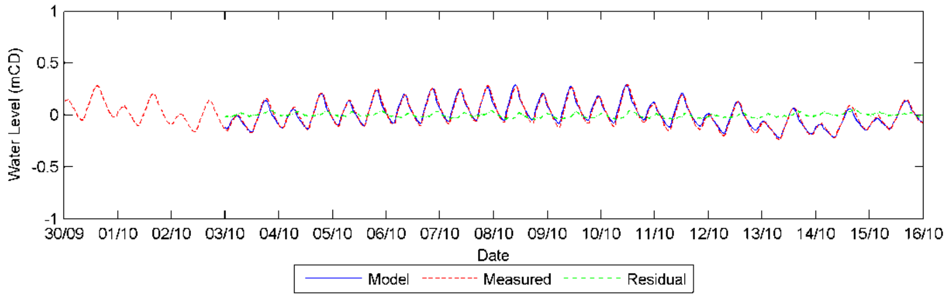


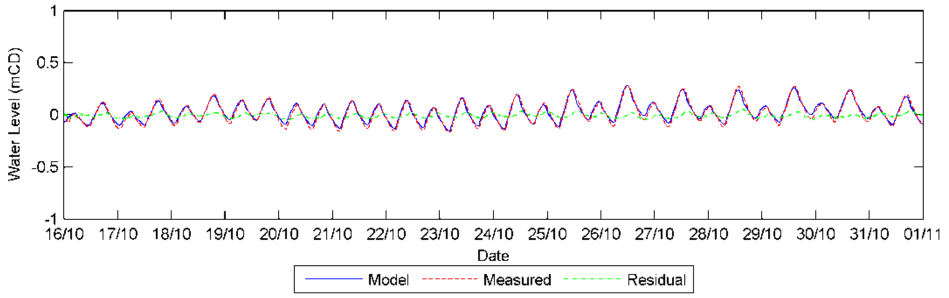
Foster



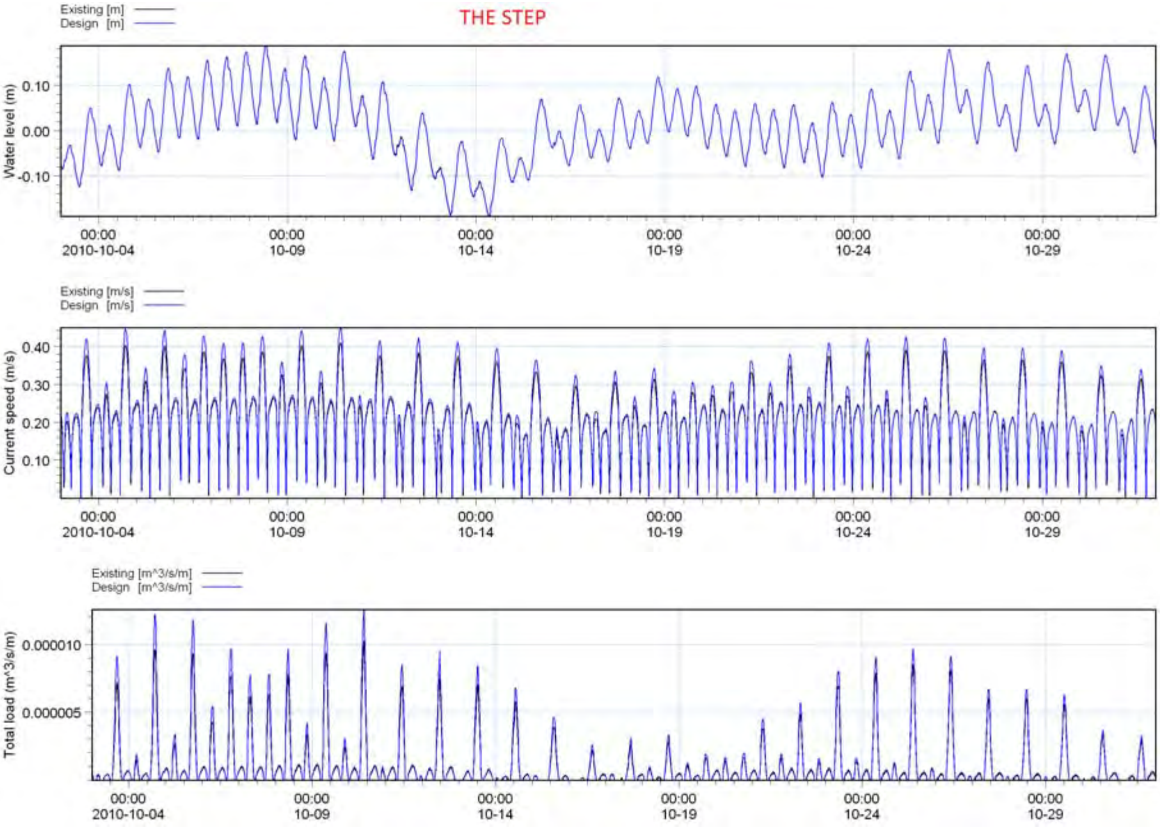


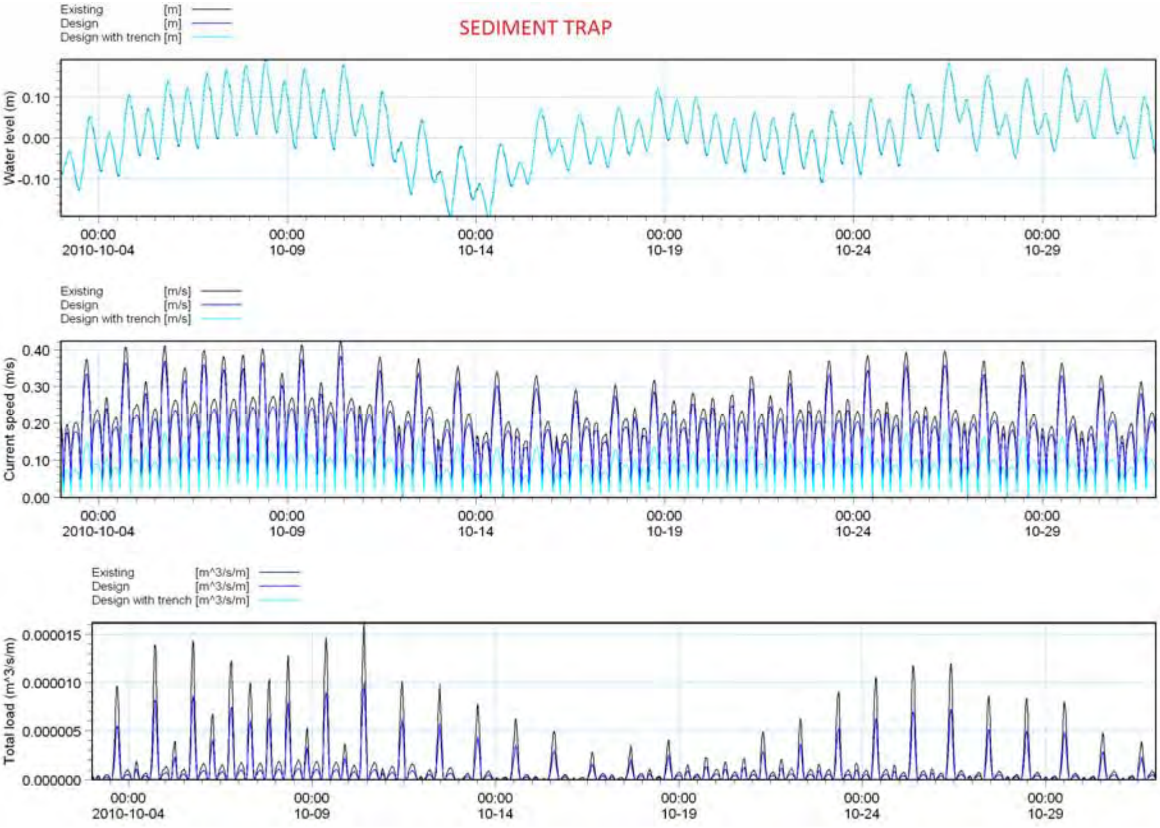
Tuncurry

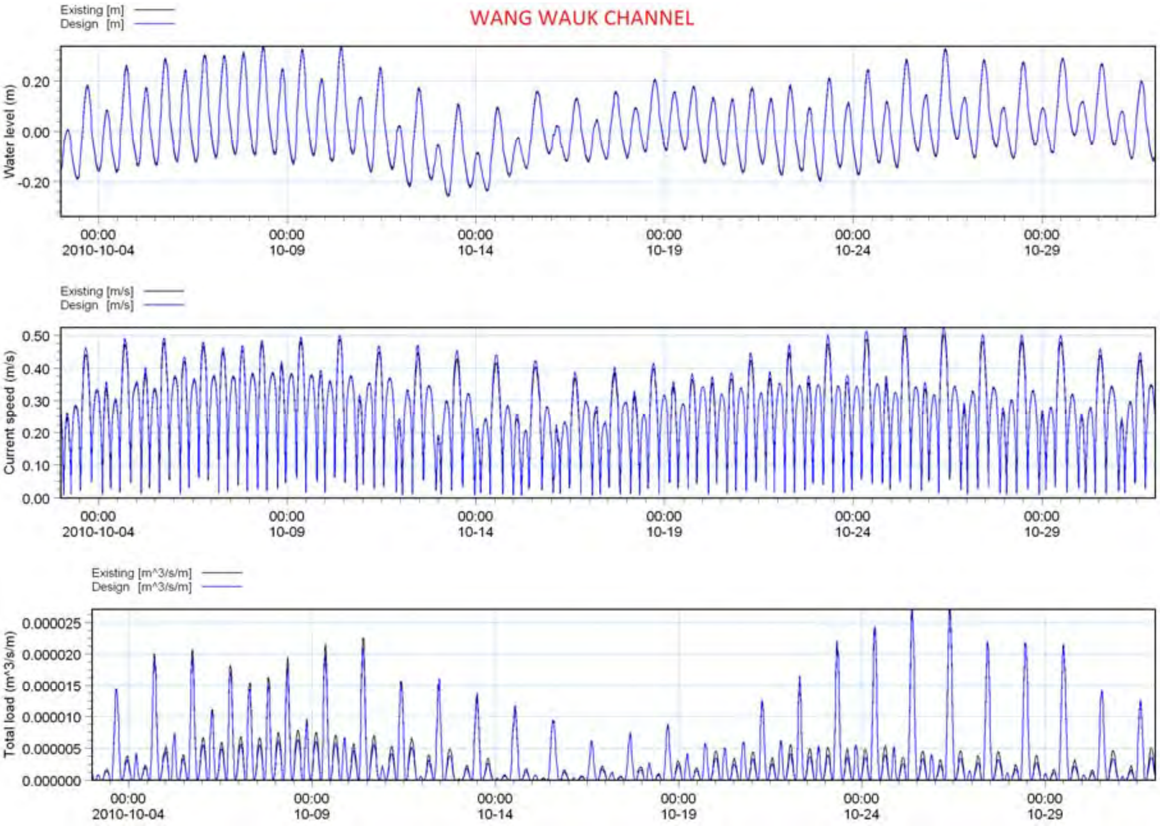

Water Level (mCD)
1
0.5
0
-0.5
-1
30/09
01/10
02/10
03/10
04/10
05/10
06/10
07/10
08/10
09/10
10/10
11/10
12/10
13/10
14/10
15/10
16/10
Date
Model
Measured
Residual

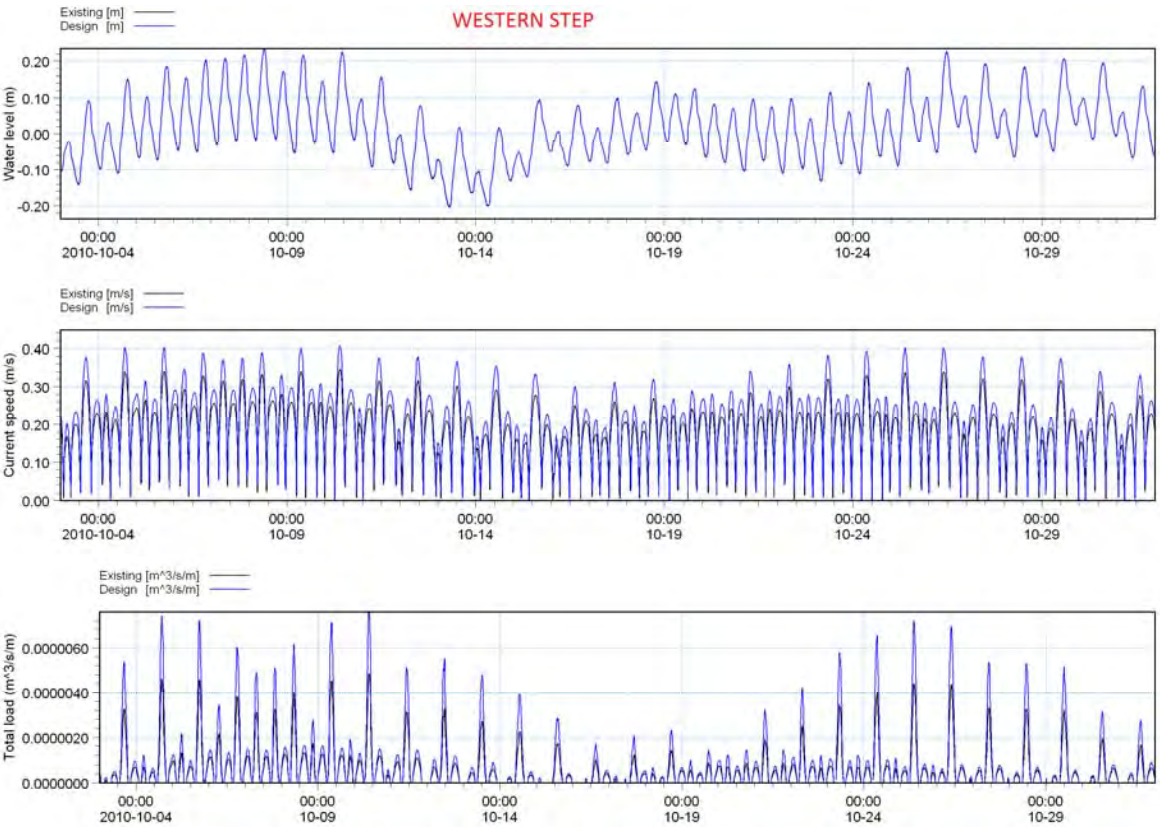

Water Level (mCD)
1
0.5
0
-0.5
-1
16/10
17/10
18/10
19/10
20/10
21/10
22/10
23/10
24/10
25/10
26/10
27/10
28/10
29/10
30/10
31/10
01/11
Date
Model
Measured
Residual

Appendix E Proposed Dredge Area Results

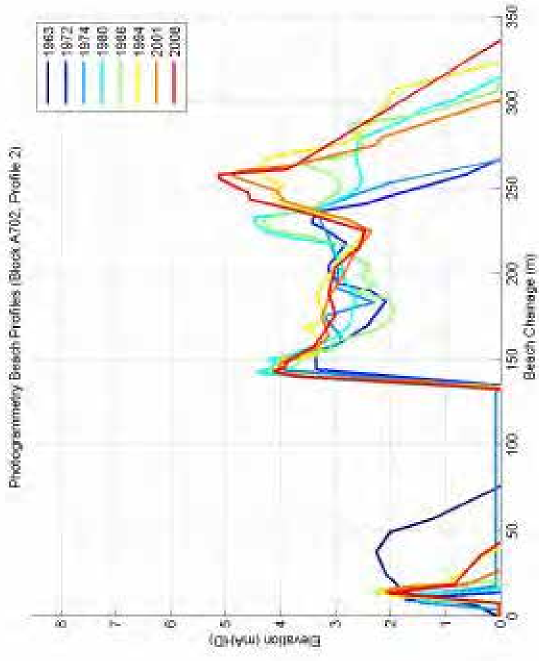

THE STEP
Existing [m]
Design [m]
Water level (m)
0.10
0.00
-0.10
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m/s]
Design [m/s]
Current speed (m/s)
0.40
0.30
0.20
0.10
Existing [m^3/s/m]
Design [m^3/s/m]
Total load (m^3/s/m)
0.000010
0.000005


SEDIMENT TRAP
Existing [m]
Design [m]
Design with trench [m]
Water level (m)
0.10
0.00
-0.10
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m/s]
Design [m/s]
Design with trench [m/s]
Current speed (m/s)
0.40
0.30
0.20
0.10
0.00
Existing [m^3/s/m]
Design [m^3/s/m]
Design with trench [m^3/s/m]
Total load (m^3/s/m)
0.000015
0.000010
0.000005
0.000000

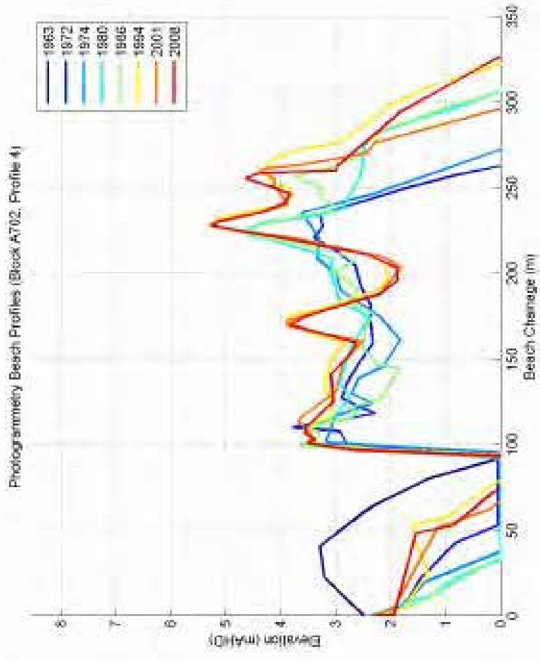

WANG WAUK CHANNEL
Existing [m]
Design [m]
Water level (m)
0.20
0.00
-0.20
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m/s]
Design [m/s]
Current speed (m/s)
0.50
0.40
0.30
0.20
0.10
0.00
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m^3/s/m]
Design [m^3/s/m]
Total load (m^3/s/m)
0.000025
0.000020
0.000015
0.000010
0.000005
0.000000
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29


WESTERN STEP
Existing [m]
Design [m]
Water level (m)
0.20
0.10
0.00
-0.10
-0.20
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m/s]
Design [m/s]
Current speed (m/s)
0.40
0.30
0.20
0.10
0.00
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29
Existing [m^3/s/m]
Design [m^3/s/m]
Total load (m^3/s/m)
0.0000060
0.0000040
0.0000020
0.0000000
00:00
2010-10-04
00:00
10-09
00:00
10-14
00:00
10-19
00:00
10-24
00:00
10-29

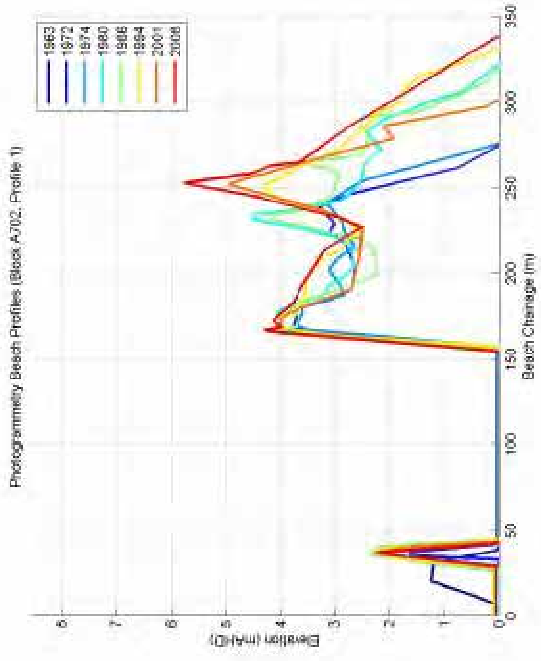
Appendix F Photogrammetry Beach Profiles



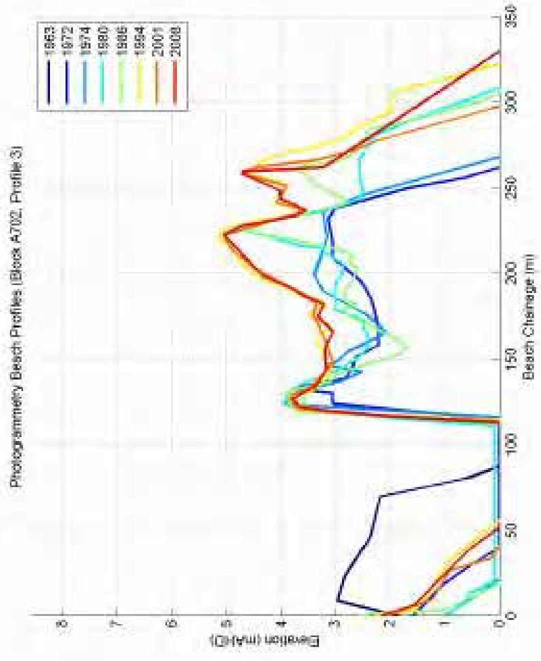
Photogrammetry Beach Profiles (Block A702, Profile 2)



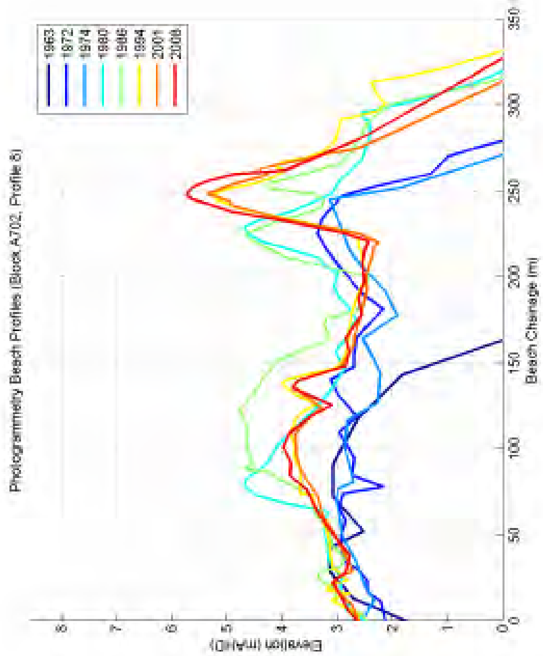
Photogrammetry Beach Profiles (Block A702, Profile 4)

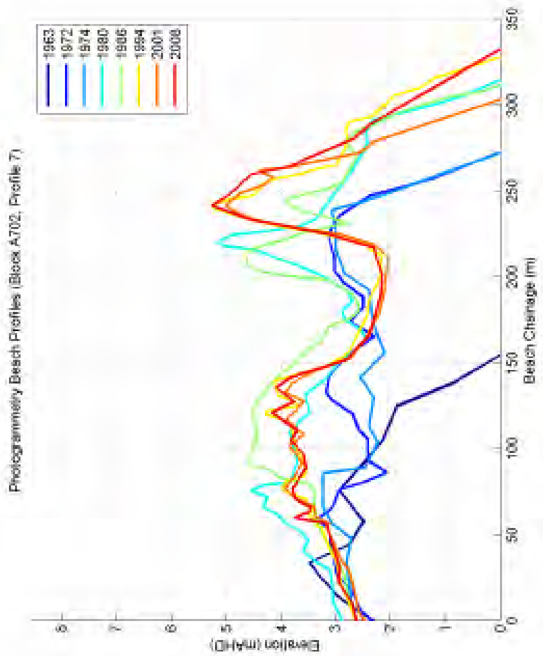


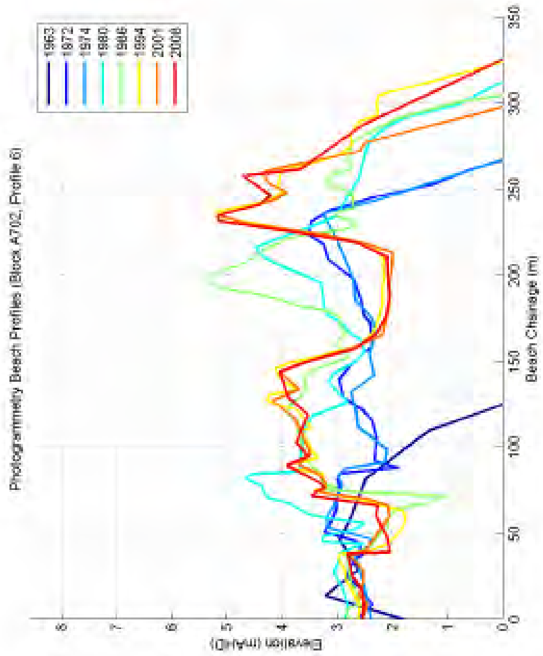
Photogrammetry Beach Profiles (Block A702, Profile 1)

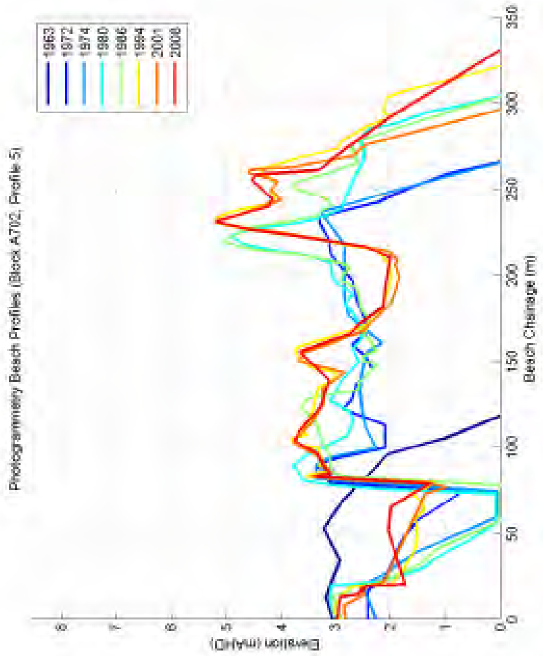


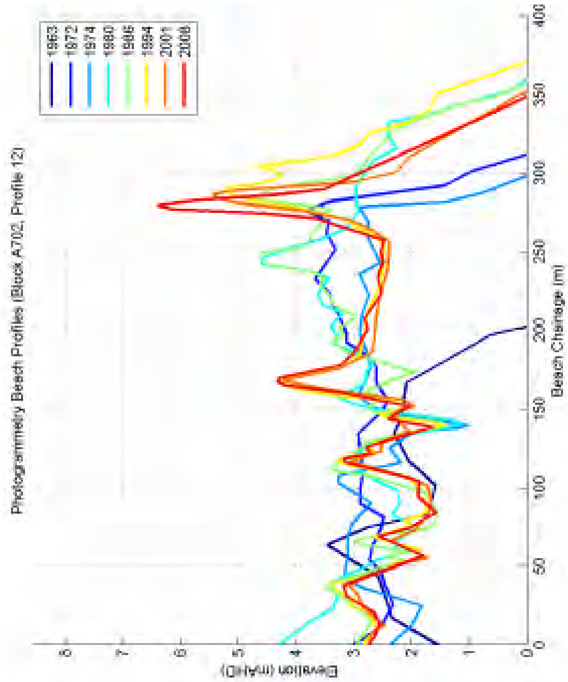
Photogrammetry Beach Profiles (Block A702, Profile 3)

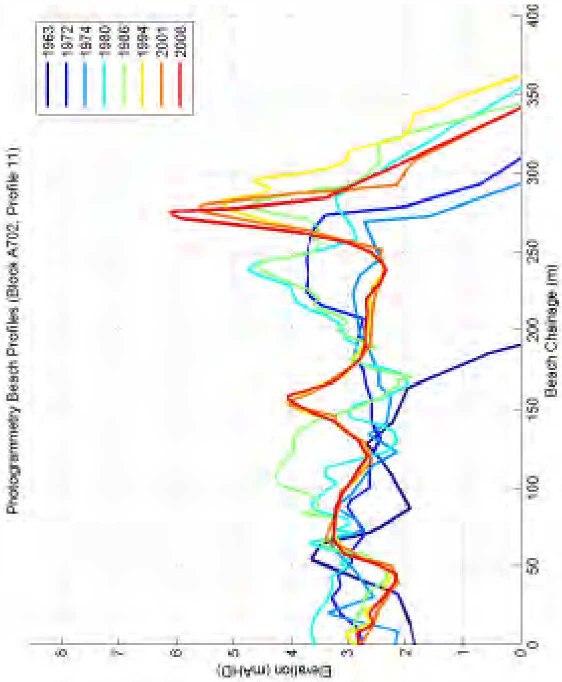

Photogrammetry Beach Profiles (Block A702, Profile 8)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008

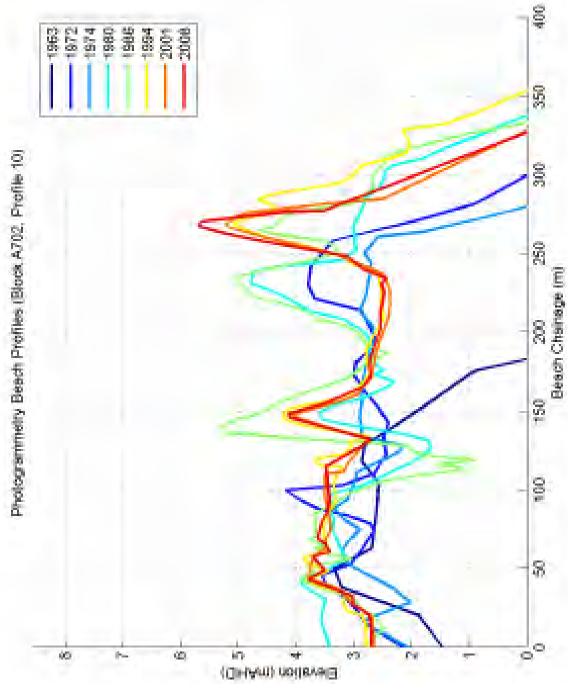

Photogrammetry Beach Profiles (Block A702, Profile 7)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008

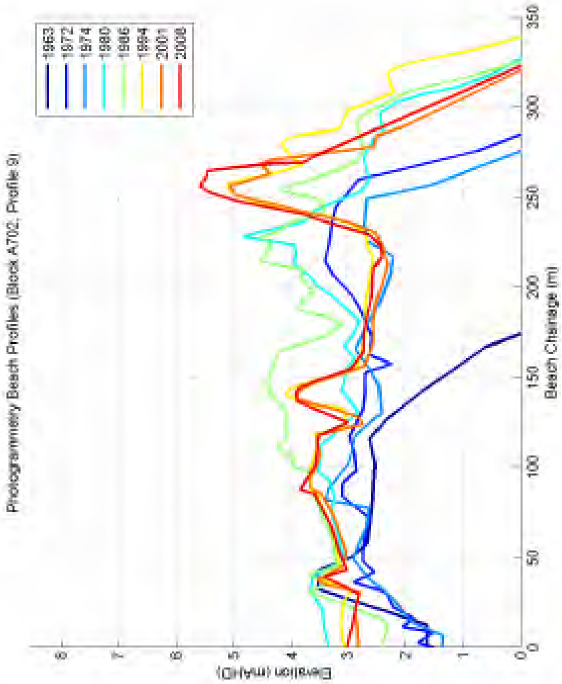

Photogrammetry Beach Profiles (Block A702, Profile 6)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 5)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 12)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 11)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 10)
Elevation (mAHD)
Beach Chainage (m)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 9)
Elevation (mAHD)
Beach Chainage (m)
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1
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300
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1963
1972
1974
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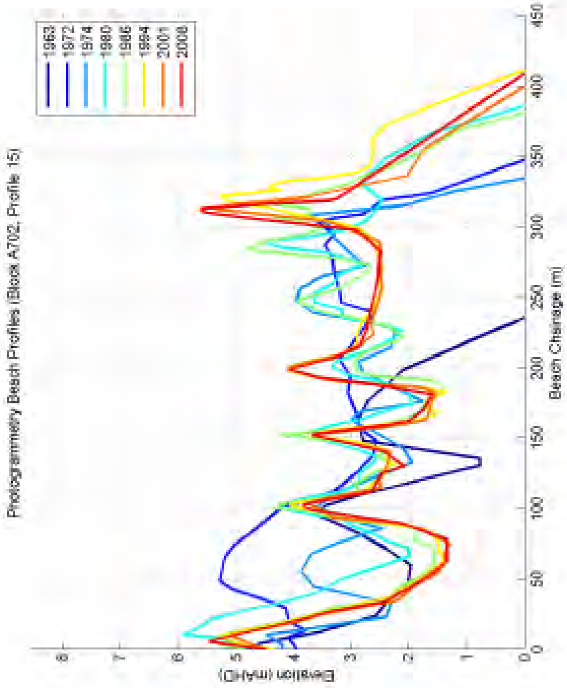
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 15)
Elevation (mAHD)
Beach Chainage (m)
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1
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100
150
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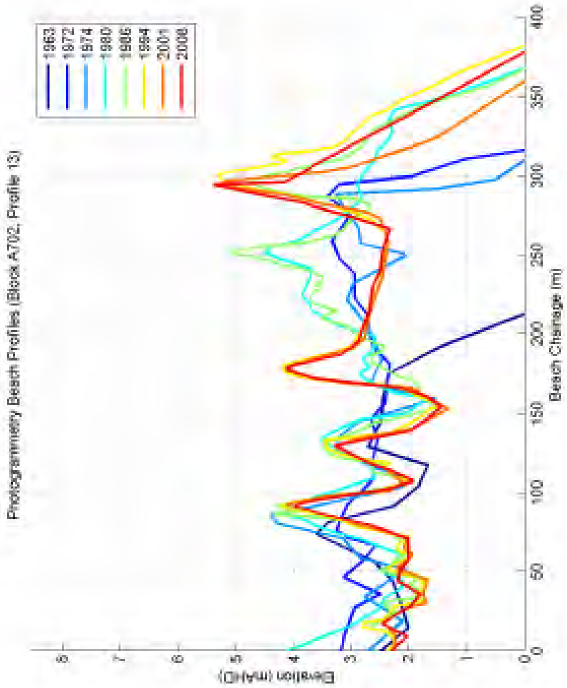
300
350
400
450
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 13)
Elevation (mAHD)
Beach Chainage (m)
0
1
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1963
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1974
1980
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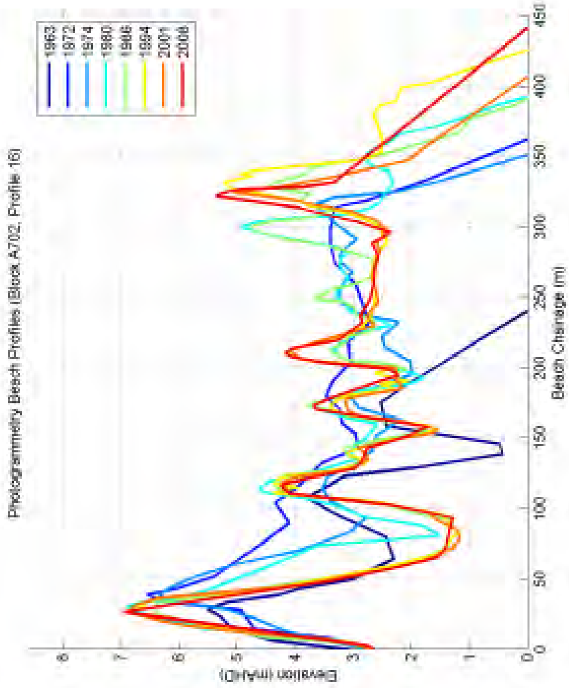
Photogrammetry Beach Profiles (Block A702, Profile 16)
Elevation (mAHD)
Beach Chainage (m)
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1
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1963
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1974
1980
1986
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2001
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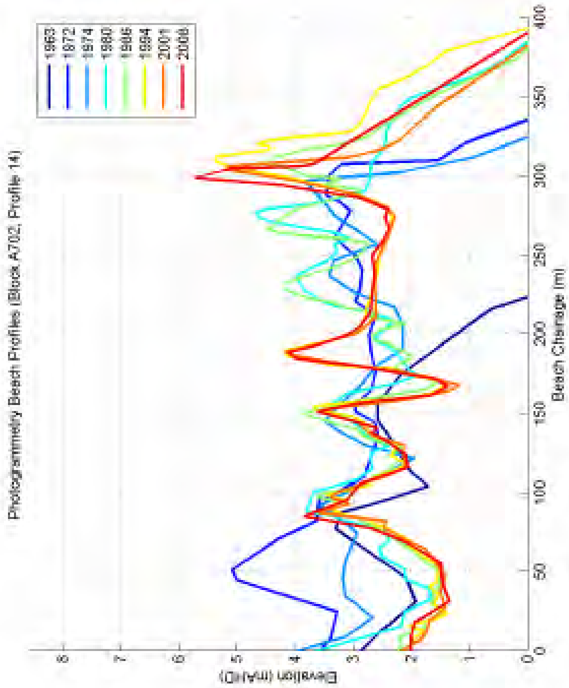
Photogrammetry Beach Profiles (Block A702, Profile 14)
Elevation (mAHD)
Beach Chainage (m)
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1963
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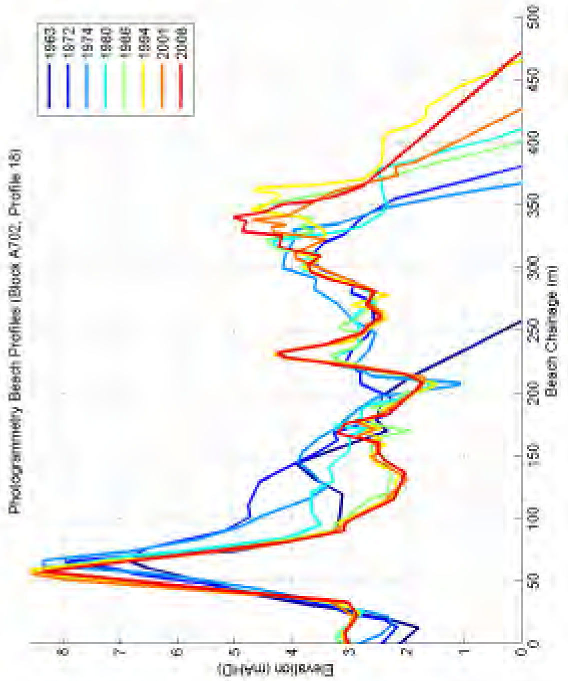
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 18)
Elevation (mAHD)
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8
Beach Chainage (m)
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300
350
400
450
500
1963
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1974
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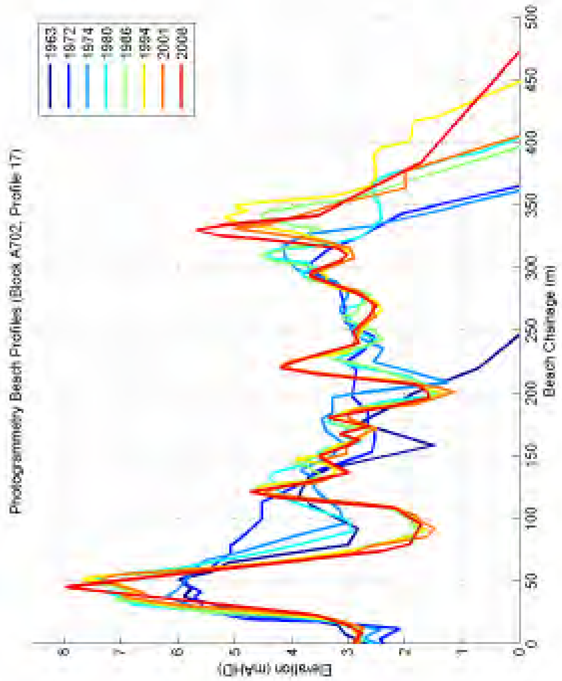
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A702, Profile 17)
Elevation (mAHD)
0
1
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8
Beach Chainage (m)
0
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1963
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1994
2001
2008

WorleyParsons
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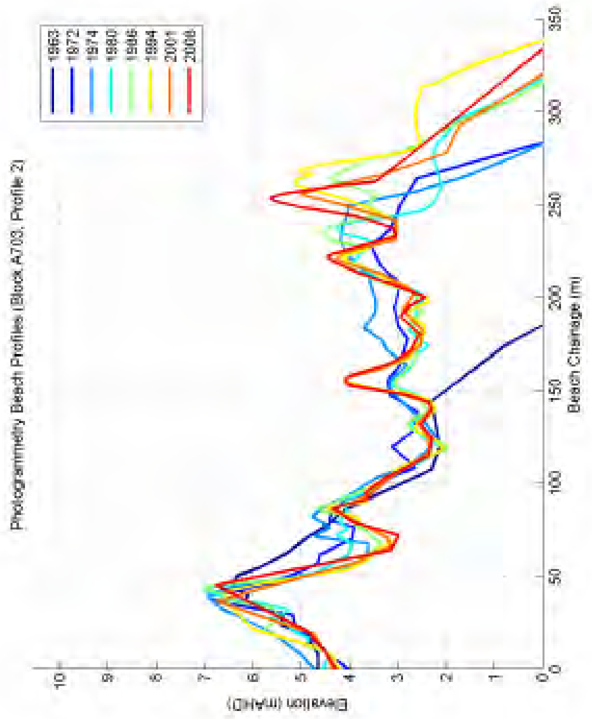
Great Lakes
COUNCIL



Photogrammetry Beach Profiles (Block A703, Profile 2)
Elevation (mAHD)
Beach Chainage (m)
0
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1963
1972
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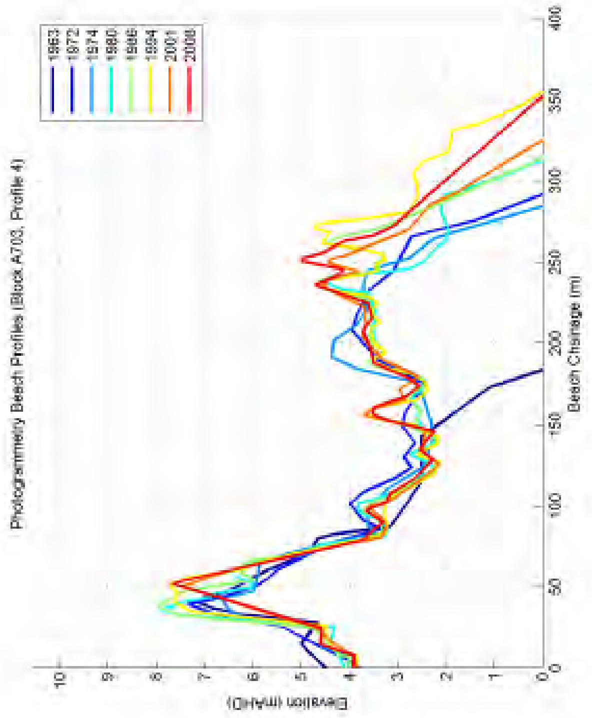
2001
2008



Photogrammetry Beach Profiles (Block A703, Profile 4)
Elevation (mAHD)
Beach Chainage (m)
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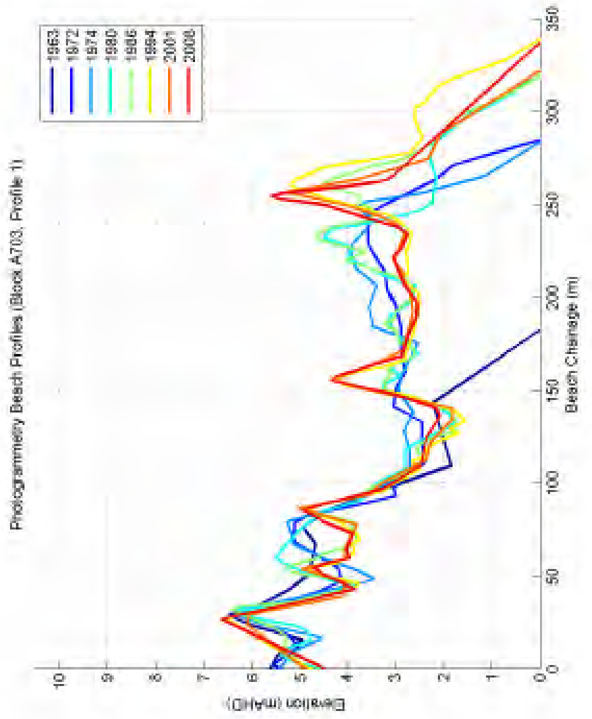

Photogrammetry Beach Profiles (Block A703, Profile 1)
Elevation (mAHD)
Beach Chainage (m)
0
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1963
1972
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1994
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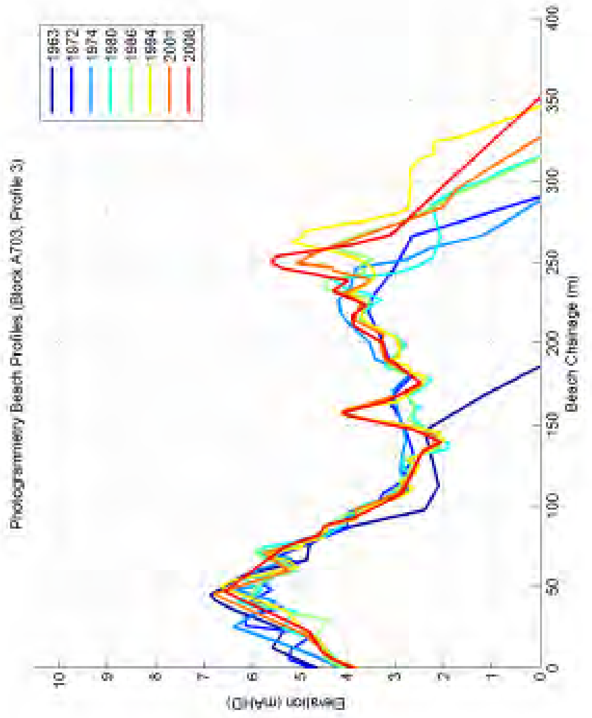
2008



Photogrammetry Beach Profiles (Block A703, Profile 3)
Elevation (mAHD)
Beach Chainage (m)
0
1
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0
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1963
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1986
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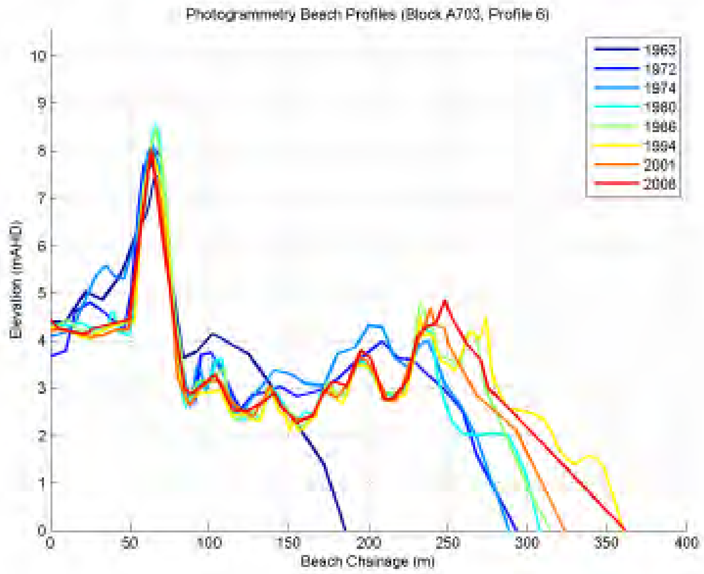
2008


Photogrammetry Beach Profiles (Block A703, Profile 6)
Elevation (mAHD)
Beach Chainage (m)
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1963
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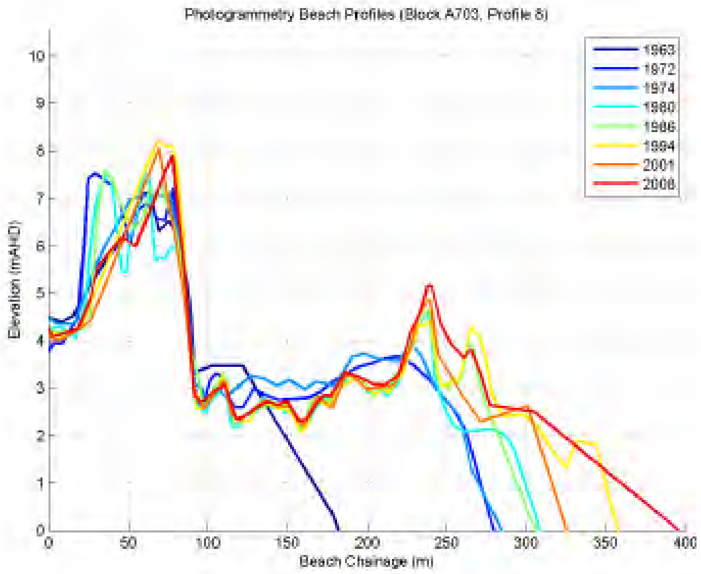
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 8)
Elevation (mAHD)
Beach Chainage (m)
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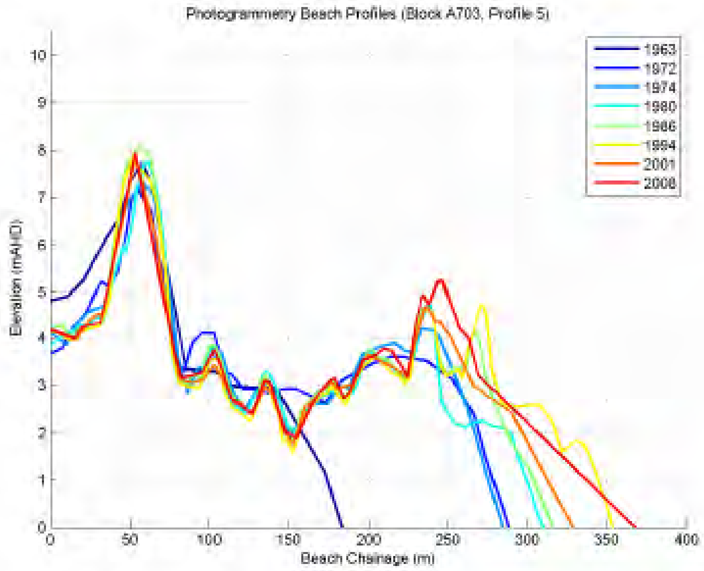
2008


Photogrammetry Beach Profiles (Block A703, Profile 5)
Elevation (mAHD)
Beach Chainage (m)
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1963
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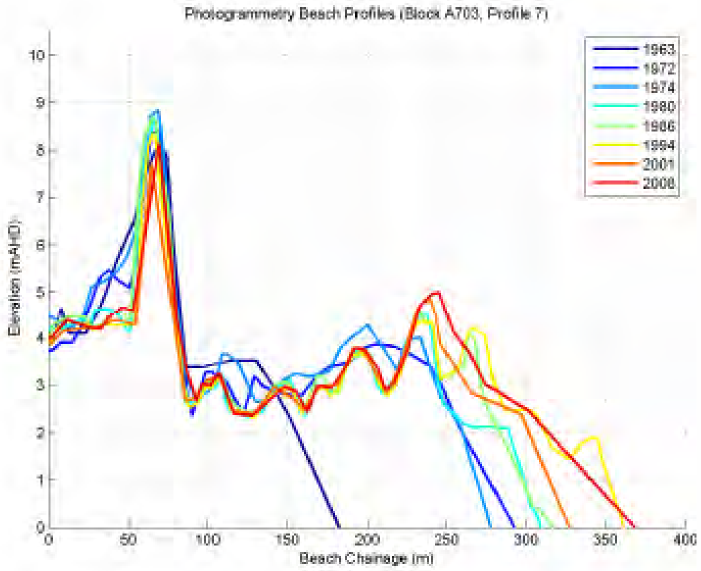
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 7)
Elevation (mAHD)
Beach Chainage (m)
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1963
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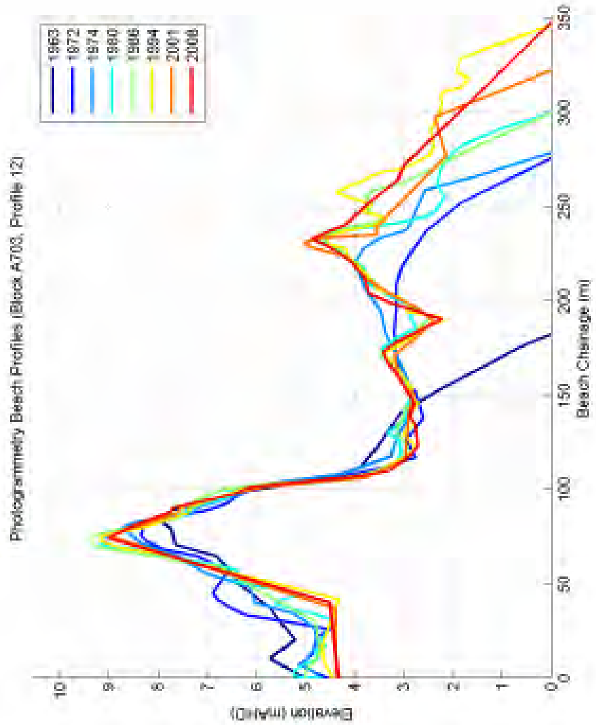
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 12)
Elevation (mAHD)
Beach Chainage (m)
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1963
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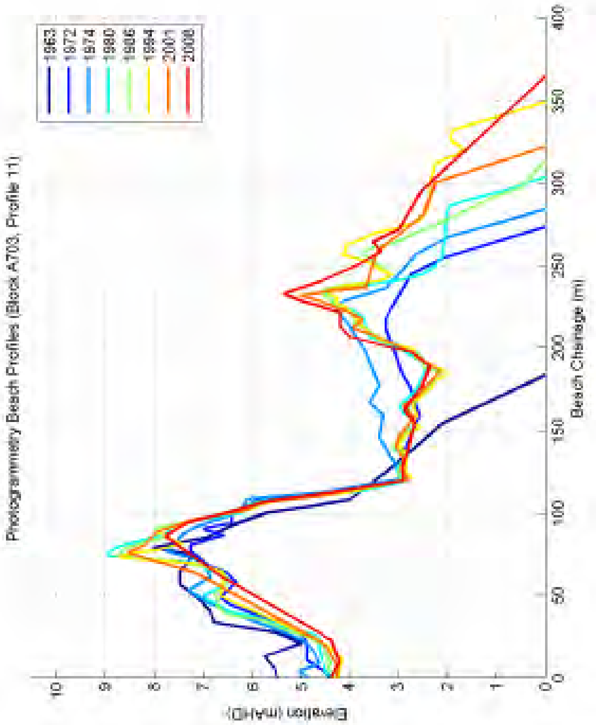
Photogrammetry Beach Profiles (Block A703, Profile 11)
Elevation (mAHD)
Beach Chainage (m)
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1963
1972
1974
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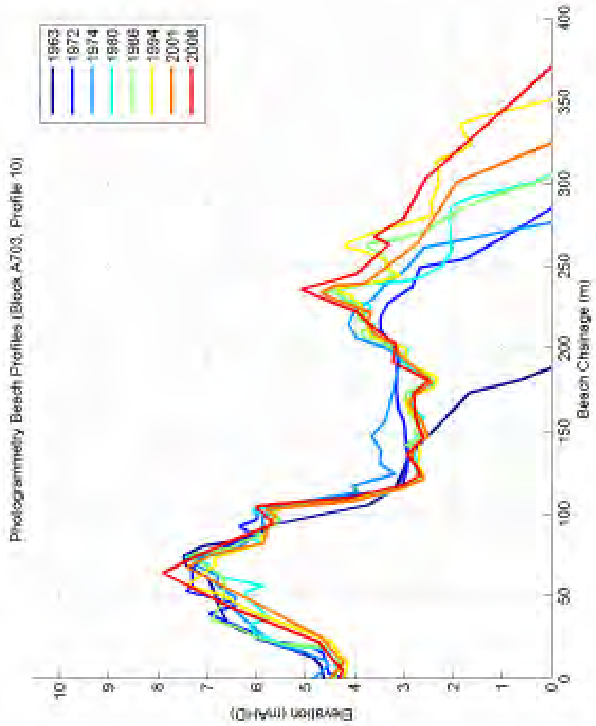
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 10)
Elevation (mAHD)
Beach Chainage (m)
0
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1963
1972
1974
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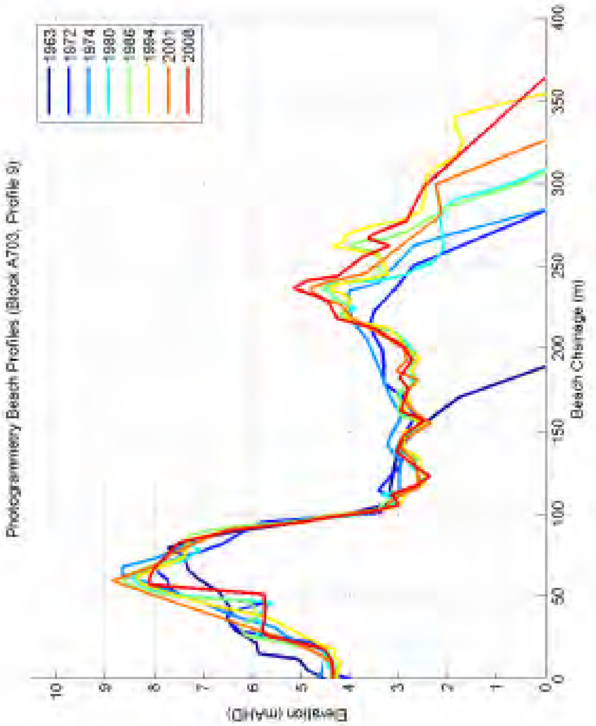
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 9)
Elevation (mAHD)
Beach Chainage (m)
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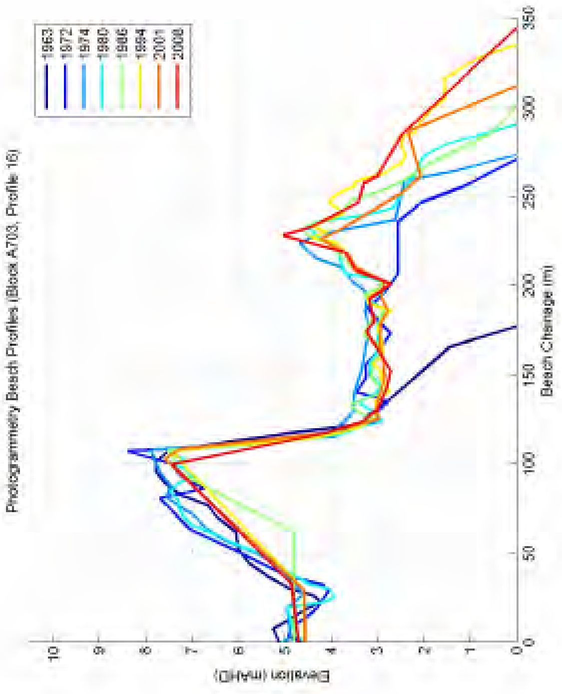
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 16)
Elevation (mAHD)
Beach Chainage (m)
0
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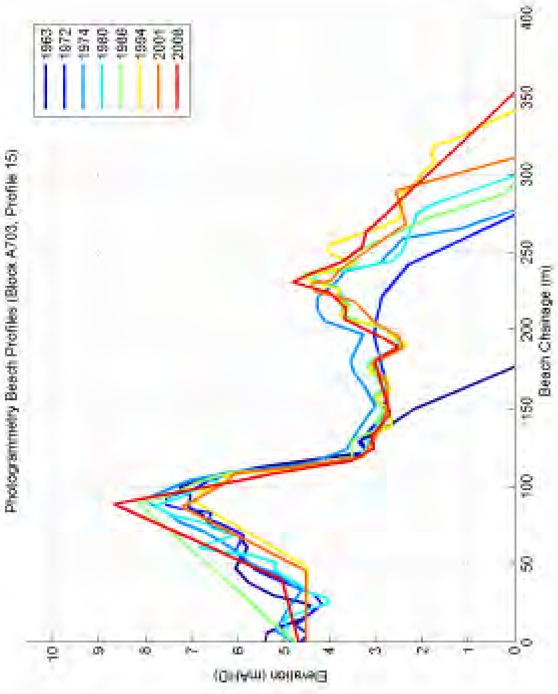
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 15)
Elevation (mAHD)
Beach Chainage (m)
0
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100
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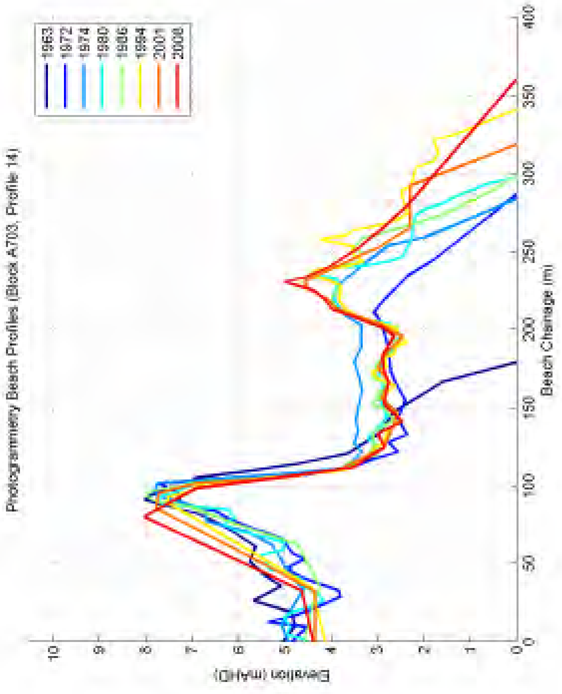
400
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 14)
Elevation (mAHD)
Beach Chainage (m)
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1986
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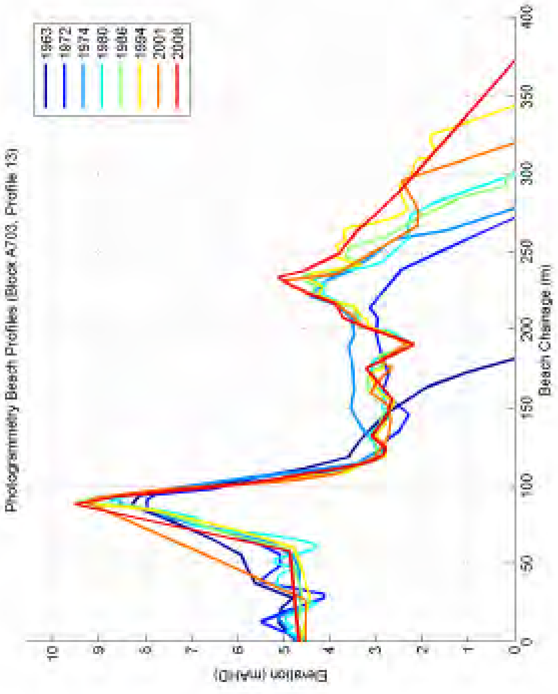
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 13)
Elevation (mAHD)
Beach Chainage (m)
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1963
1972
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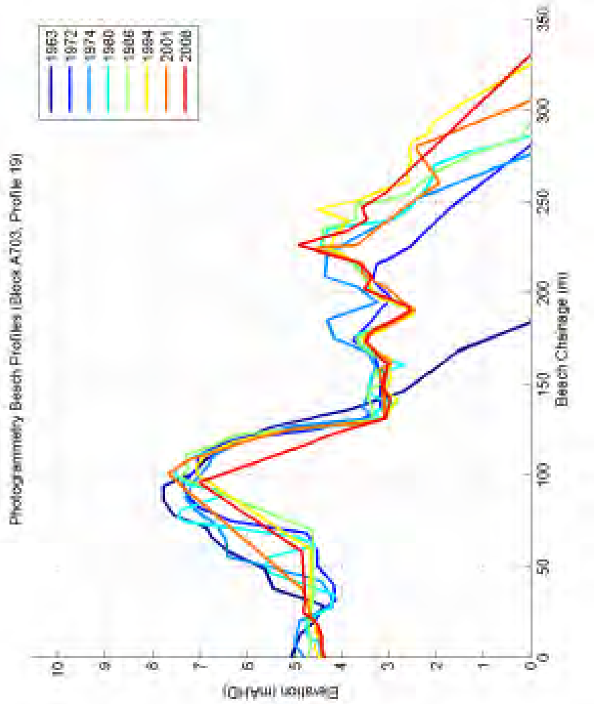
Photogrammetry Beach Profiles (Block A703, Profile 19)
Elevation (mAHD)
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6
7
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10
Beach Chainage (m)
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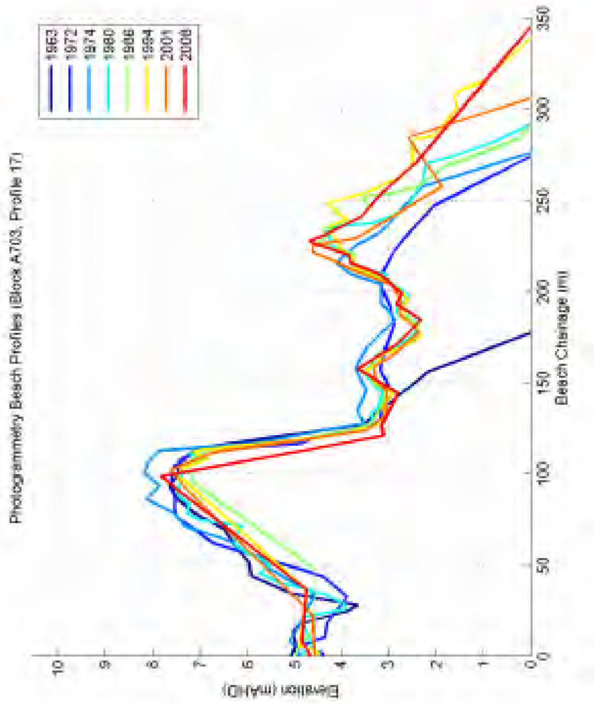
100
150
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 17)
Elevation (mAHD)
0
1
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10
Beach Chainage (m)
0
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100
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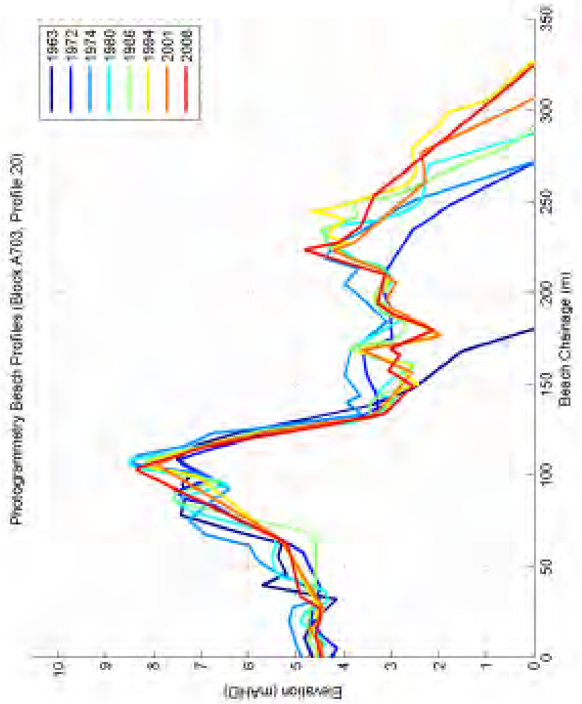
200
250
300
350
1963
1972
1974
1980
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 20)
Elevation (mAHD)
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6
7
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Beach Chainage (m)
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100
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300
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1963
1972
1974
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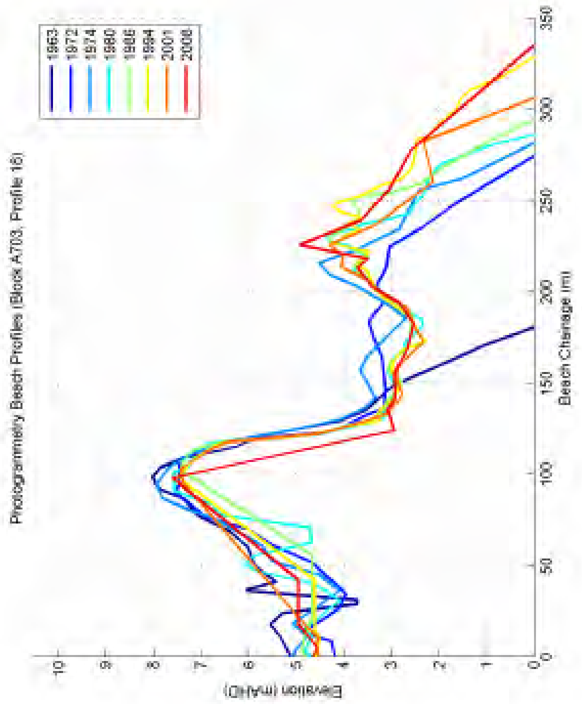
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 18)
Elevation (mAHD)
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8
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Beach Chainage (m)
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200
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350
1963
1972
1974
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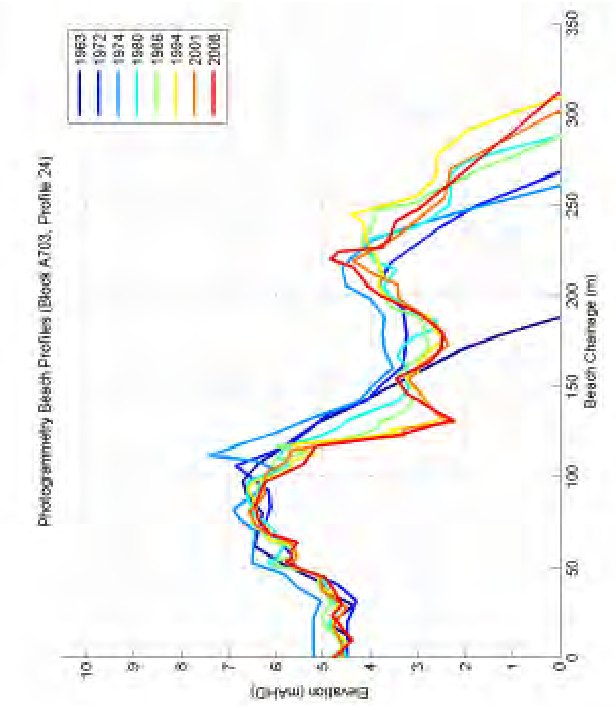
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 24)
Elevation (mAHD)
Beach Chainage (m)
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1963
1972
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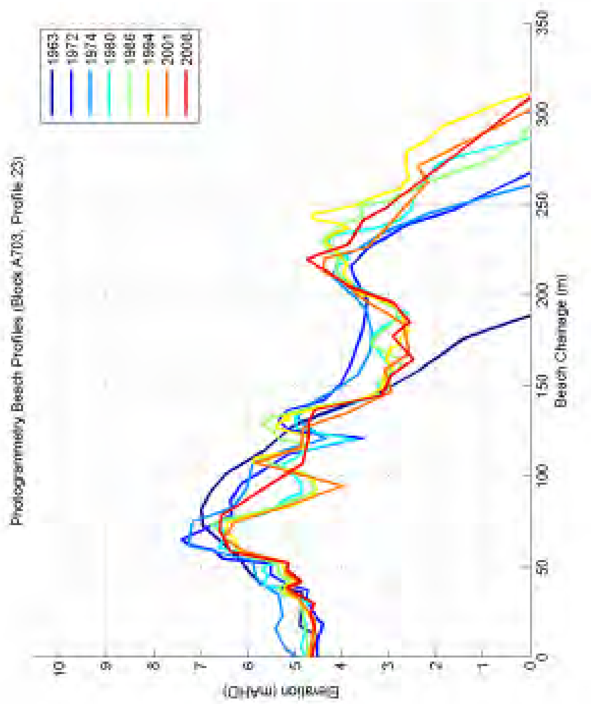
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 23)
Elevation (mAHD)
Beach Chainage (m)
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1963
1972
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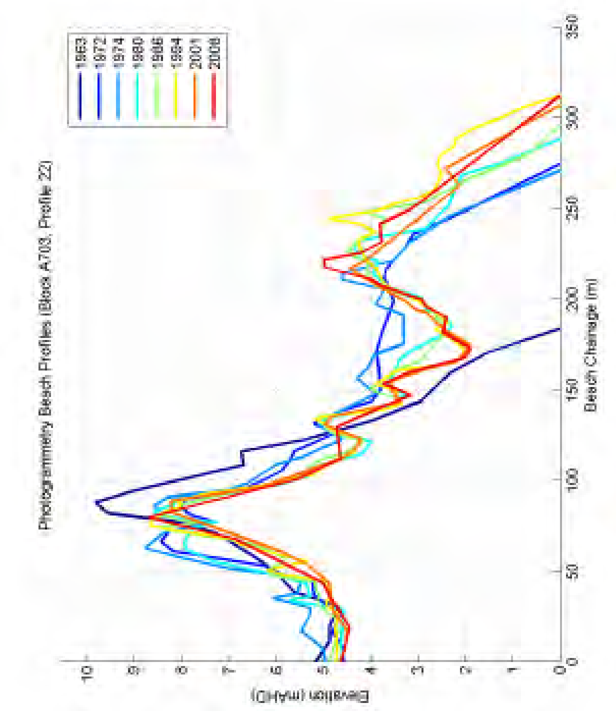
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 22)
Elevation (mAHD)
Beach Chainage (m)
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350
1963
1972
1974
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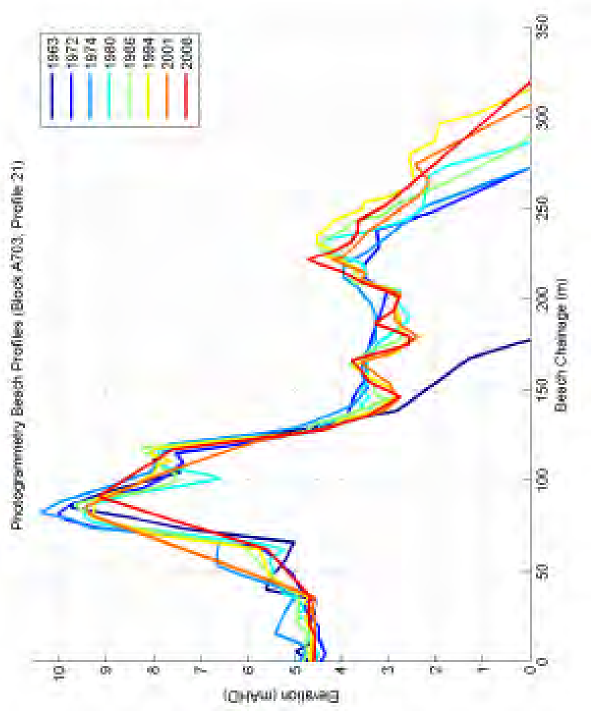
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 21)
Elevation (mAHD)
Beach Chainage (m)
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1963
1972
1974
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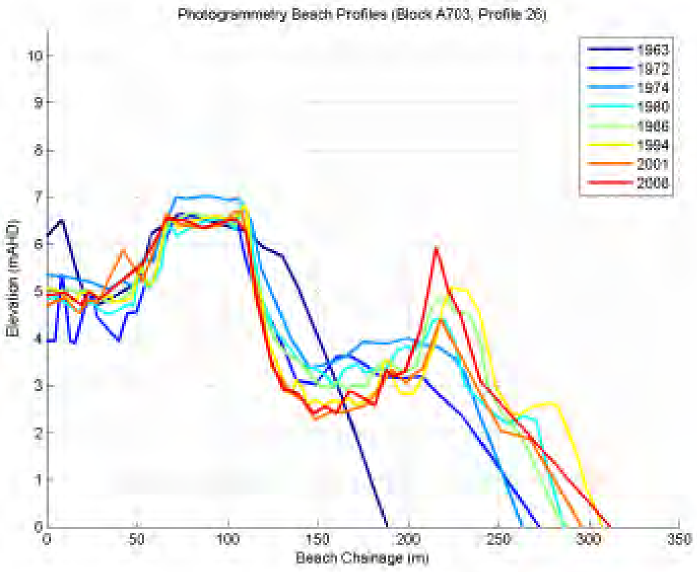
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 26)
Elevation (mAHD)
Beach Chainage (m)
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0
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1963
1972
1974
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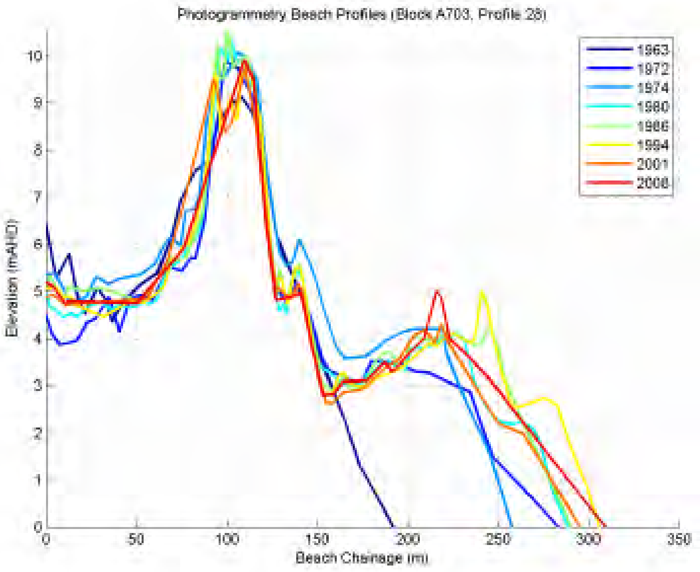
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 28)
Elevation (mAHD)
Beach Chainage (m)
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0
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100
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200
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350
1963
1972
1974
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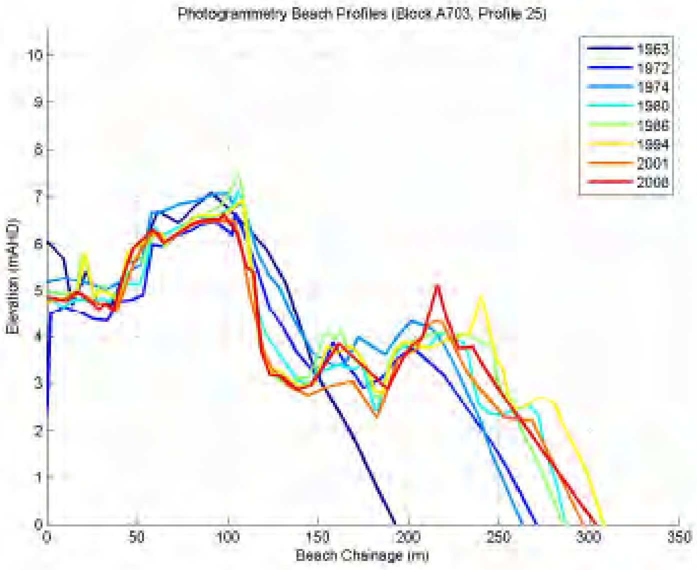
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 25)
Elevation (mAHD)
Beach Chainage (m)
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2
3
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5
6
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0
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100
150
200
250
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350
1963
1972
1974
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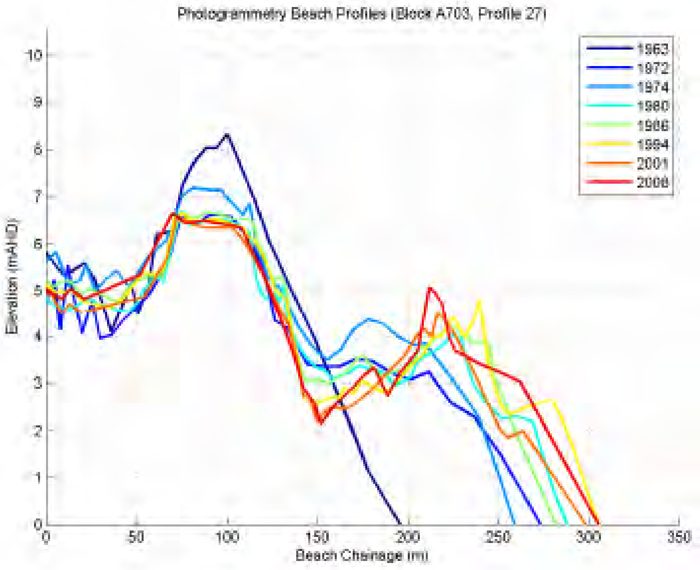
1986
1994
2001
2008


Photogrammetry Beach Profiles (Block A703, Profile 27)
Elevation (mAHD)
Beach Chainage (m)
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1
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6
7
8
9
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0
50
100
150
200
250
300
350
1963
1972
1974
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2001
2008