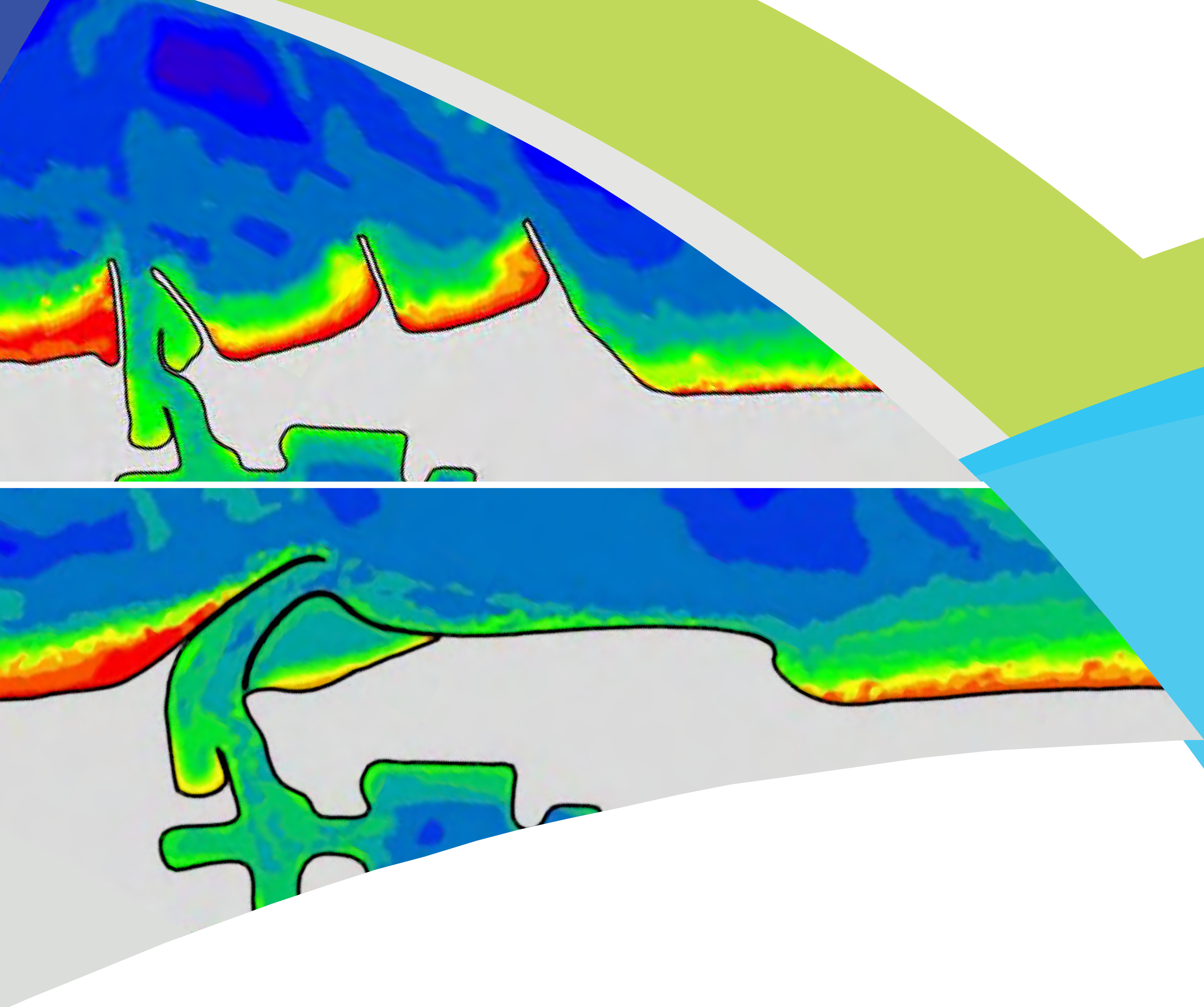


Port Geographe Sand and Seagrass Wrack Modelling Study, Western Australia

March 2011

C Pattiaratchi
S Wijeratne

The University of Western Australia
Achieve International Excellence

ACKNOWLEDGEMENTS

The authors would like to acknowledge the following for their input to this study. James Holder provided excellent advice and effectively managed of the project on behalf of Department of Transport and the Shire of Busselton. Members of the Steering Committee submitted valuable and constructive comments throughout the duration of the study: James Holder and Maureen Davin (Dept of Transport); Sharon Woodford-Jones (Shire of Busselton); Stuart Barr (Shore Coastal); Matt Eliot (Damara WA Pty Ltd) and Ray Steedman (GHD).

Meteorological data for model forcing were obtained from Bureau of Meteorology. Department of Transport provided water level and wave climate data. Sediment properties for the model simulations were obtained from Damara WA Pty Ltd. Lidar survey data for model bathymetry were obtained from Department of Transport and the 250 m resolution data from Geoscience Australia.

We would also like to thank Ms Reena Lowry (Department of Transport) for facilitating the provision of wave and tide data, Cyprien Bosserelle (UWA) for developing and help with the seagrass wrack model and Ruth Gongora-Mesas (UWA) for assistance with the reporting.

Clients Department of Transport Shire of Busselton		**Client's representative** James Holder
Project title Seagrass dynamics in Geographe Bay, Western Australia.		**Project No** DPI 1062/07
Authors Charitha Pattiaratchi (UWA) Sarath Wijeratne (UWA)		**Date** February 28th 2011
		Approved by Charitha Pattiaratchi
Key words Geographe Bay, Port Geographe Seagrass wrack Hydrodynamics Sand Transport		**Classification** ☒ Open ☐ Internal ☐ Proprietary
Distribution Department of Transport Shire of Busselton UWA	James Holder Sharon Woodford-Jones	**No of Copies** Electronic

EXECUTIVE SUMMARY

Port Geographe, a marina and residential canal estate development was developed in the early nineties with the harbour entrance and a series of groynes built in 1996/97. A sand bypass system was proposed to pump sand across the harbour entrance from the west (upstream) to nourish the beaches in Wonnerup in the east. However, the artificial bypassing has become a challenging issue due to the presence of sea grass wrack, which was more efficiently trapped by the sand trap than sand. This had large implications for the artificial by-pass system with the wrack interfering with the sand pumping. The wrack accumulation resulted in severe environmental problems (e.g. odour, beach use) on the western side of the development and erosion of beaches to the east at Wonnerup. Studies to alleviate these problems were funded by the Department of Transport and the Shire of Busselton and included understanding of the sea grass wrack dynamics in Geographe Bay (Stage 1: Oldham et al., 2010), which only addressed the problem of sea grass wrack. This study, completed as stage 2, includes sand transport and associated bathymetric changes to develop an optimum solution for the problems associated with the Port Geographe developments. In particular the following aspects were the focus of the study: (1) minimise seagrass wrack accumulation along the western beach adjacent to the Port Geographe western breakwater; (2) maintain a navigable entrance channel at Port Geographe; (3) retain a stable beach at Wonnerup; and (4) select scenarios that represent the least possible change to the existing structures and that limit reclamation requirements to reduce costs of the proposed reconfiguration. This was achieved through the development and application of a computer model to simulate the waves, currents, sand and seagrass wrack transport within Geographe Bay with particular emphasis (higher resolution) in the Port Geographe region. Models developed by the Danish Hydraulic Institute (DHI MIKE 2D) were used to predict the waves, currents and changes in morphology. The hydrodynamic fields were then used to simulate the seagrass wrack transport using a model developed as part of the study. The model runs included the existing coastal structured and beach orientations as well as 7 other configurations. Simulation of existing configuration revealed that up to 70,000m^3 of sand and up to 100,000 m^3 of sea grass wrack was trapped along the western side of the marina. An optimum configuration for the coastal structures, to promote natural bypassing of sand and sea grass wrack, included: a curved breakwater the western side of Port Geographe as replacements to the existing breakwater, which is perpendicular to the shoreline; removal of groynes associated with the pocket (Moonlight Bay) beaches to be replaced by a foreshore seawall. For the recommended layout (Scenario 8), the numerical model predicted: (1) enhanced the natural movement of seagrass wrack along the shoreline with limited trapping within the coastal structures; (2) naturally bypassed sediment supply to Wonnerup beaches; (3) limited harbour entrance channel sedimentation; and, (4) limited any detrimental influence on water quality within the canal segments.

The study recommends that the Department of Transport and the Shire of Busselton note that the extensive computer modelling by UWA, with guidance from the steering committee, Department of Transport, The Shire of Busselton, and with regard to the Port Geographe

Sediment and Seagrass Reference Group workshops, has resolved that Scenario 8 presents the optimum solution to the coastal management problems at Port Geographe. This evaluation is based on the following:

- Unnatural seagrass wrack accumulation on the western beach is reduced to the maximum extent considered possible, with this option delivering the best or equal best outcome of any option considered in the course of this extensive study. Seagrass wrack accumulation is a natural seasonal phenomenon in Geographe Bay. The beaches adjacent to the Port Geographe development will remain subject to those seasonal impacts. Occasional trapping of small quantities of seagrass wrack may occur from time to time across the development.
- Siltation to the Port Geographe harbour entrance channel is minimised to the greatest extent considered possible, with this option delivering the best or equal best outcome of any option considered over the study period. The resultant channel maintenance requirements are likely to be altered from the existing situation and this will need to be considered as part of a new coastal maintenance program.
- The modelling demonstrates that once shoreline equilibrium is established on the western beach and improved natural sediment transport from the western beach to Wonnerup can be achieved with the recommended groyne reconfiguration. Erosion at Wonnerup Beach can be transformed from a typically eroding beach to a stable and accreting beach. The model indicates a beach width of between 10 and 20 m will result from the increased sediment delivery to Wonnerup, representing substantial improvement to the current condition and the provision of a beach consistent with the widths of other nearby natural beaches.

CONTENTS

1 INTRODUCTION

1.1 Background

Port Geographe, a marina and residential canal estate development, is located along the coast of Geographe Bay in southwest Western Australia, approximately 200 km to the south of Perth (Figure 1.1). It has been developed in several stages since the early 1990s with the breakwaters and eastern groynes built in 1996/97. The breakwaters were designed to prevent sand bar formation at the harbour channel entrance with a concentrated water flow through the channel to maintain navigable depth, and also to avoid high wave action within the channel itself. These constructions are a common practice to protect port/harbour entrances and are designed to make the harbour entrance channel safe for navigation. However, all these structures have the potential to interfere with the material transport processes in the littoral zone.

The construction of the Port Geographe breakwaters and associated groynes interrupted the prevailing eastward sand transport along this section of the Geographe Bay coastline. This resulted in a reduction in sand supply to the eastern side of the marina leading to erosion at Wonnerup Beach. The intention of the western breakwater at Port Geographe was, in fact, designed to capture sand on the western side and to mechanically bypass it to the Wonnerup beaches to prevent erosion (Interstruct Pty Ltd, 1990). The annual average manual by-pass volume was estimated to be in the order of 50,000 m^3 (Interstruct Pty Ltd, 1990). However, this volume has been considerably higher in recent years with up to 80,000 m^3 being bypassed but bypassing has not been a successful strategy (Shore Coastal, 2010).

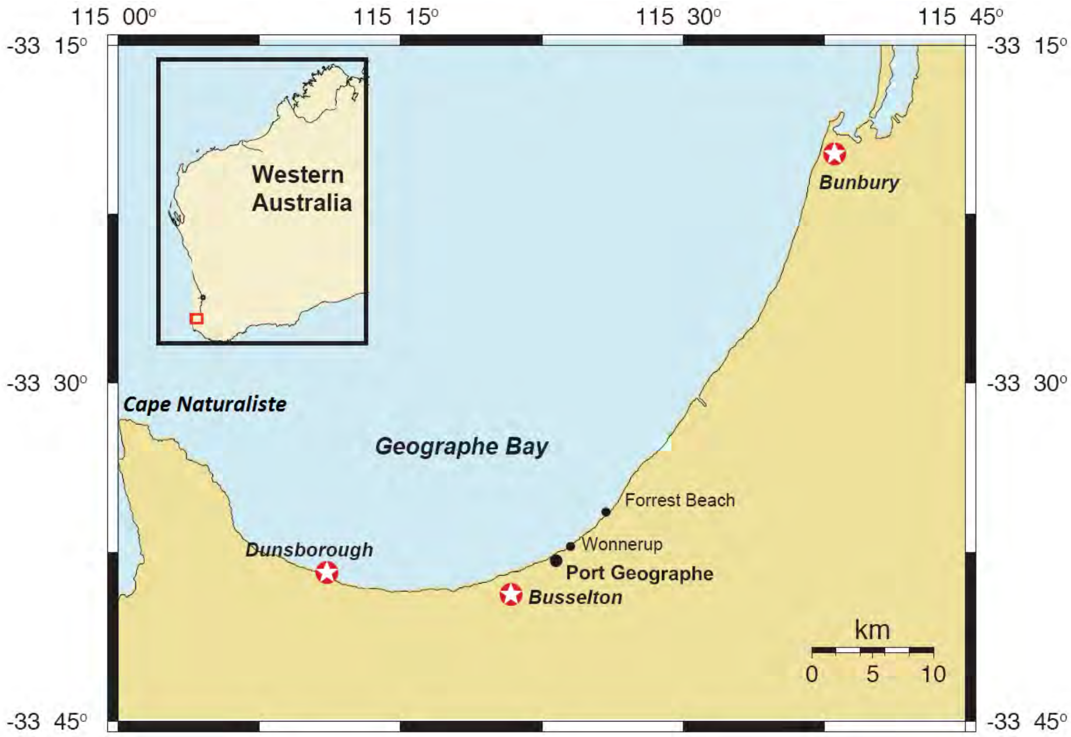


Figure 1.1: Map showing location of Port Geographe within Geographe Bay, south-western Australia.

The existing groynes of the Port Geographe Marina not only act as a barrier to alongshore sand transport but also block natural seagrass wrack movement in the littoral zone. The wrack accumulation extends back along the beaches more than a kilometre to the west of the breakwater and some wrack is also trapped within the eastern groyne fields (Moonlight Bay). It was estimated that ~32,500 tonnes of seagrass wrack is produced annually in Geographe Bay through the natural shedding of leaves and removal of plants during storm events (Oldham et al., 2010). During the winter months, wrack moves onshore and alongshore due to storms and wave action, and results in ~7,500 tonnes of wrack ending up on the beaches of Geographe Bay. The wrack is transported along the beach in an easterly direction in response to the wave induced flow direction, particularly during storm events, and becomes trapped along the beach on the western side of the breakwater originally designed as a sand trap.

The seasonal mean sea level is higher during winter months, peaking in June (Pariwono et al., 1986; Pattiaratchi and Buchan, 1991). A combination of high tides, waves, storm surges and strong winds during the winter months produces extreme water levels on the coast. Thus wrack accumulating on the beaches during a winter storm remains on the beach until a subsequent storm transport the wrack, usually, along the shoreline. The wrack is removed from the beaches when the supply of sea grass wrack from offshore diminishes. No natural flow mechanism exists to transport the wrack, trapped on the western side of the breakwater and within groyne fields, to the eastern beaches. Therefore wrack piles up further and become compacted on the western side of breakwater. Such excess accumulation of seagrass wrack on the beaches has become a major environmental issue to the local community. The wrack is manually removed from beaches using earthmoving machinery during in late winter and early spring. The recent bypassing operations have established that each year up to 100,000 m^3 of wrack arrives and is trapped on shores to the west of Port Geographe. The environmental issues associated with wrack accumulation on the beach were described in the Stage 1 report (Oldham et al., 2010).

Figure 1.2 Nearmap© high-resolution aerial photographs of Port Geographe obtained on (a) February 2010 and (b) December 2010.

The numerical model developed in this earlier study was applied to evaluate the impact of the existing breakwaters and groynes on seagrass wrack transport at Port Geographe. Then the model was used to simulate seagrass transport with physical changes to the Port Geographe coastal structures. The physical and other changes considered for modelling experiments were as below:

- Changes to western breakwater (length, orientation, shape, etc.)
- Changes to eastern groyne field (extend, removing, shape, adding new)
- Changes to western beach shoreline (orientation, beach extend, vertical wall etc.)
- Changes to harbour channel entrance (channel width)
- Changes to channel fluxes (pumping at upper channel segments)

A total of seven scenarios were developed to be tested using the numerical model, as well as the current groyne configuration. The simulations revealed that flow patterns in the vicinity of the marina changed due to the groyne modifications and other morphological changes. It was also found that significant seagrass wrack bypass could be achieved by changing the groyne configuration. Based on the most promising scenario from a wrack bypassing perspective, the Stage 1 study found that Scenario 5 was the optimum groyne configuration for wrack bypassing. However, the final configuration required further investigation to include sand transport in the region. In this study, these aspects were addressed by the use of coupled numerical models for current, waves, sediment and particle transport (seagrass). Finally, coupled model simulations were undertaken to identify the optimal groyne configuration for improved management of both seagrass wrack and sand around Port Geographe.

1.2 Objectives

The objectives of the sand and seagrass wrack numerical model investigation for Geographe Bay are summarised as follows:

(1) To simulate the transport of seagrass wrack and sand under the existing physical setting (breakwaters and groynes).
(2) To simulate the transport of seagrass wrack particles and sand with different physical layouts (changes to breakwaters, groynes and sea walls, etc.).

Ultimately, the hydrodynamics, wave climate, sand and particle (seagrass wrack) transport coupled models were used to identify changes to the coastal structures of Port Geographe for improved management of both seagrass wrack and sand in the Port Geographe area. Finally, the proposed layout is expected to lead to the improved natural by-pass of sediment and seagrass wrack as well as providing a solution to eastern beach erosion.

1.3 Modelling approach

In this section we have summarised the modelling approach with more detailed descriptions provided in the following sections. In order to investigate sediment and seagrass transport processes in the vicinity of Port Geographe, the research utilised Danish Hydraulic Institute

(DHI) Mike modelling tools and the particle transport model developed in the earlier study (Oldham et al., 2010). The coupled models simulated the wave, current, sediment transport and rates of bed level changes in sequence, and included feedback from the developing bathymetry to all modules. Outputs from coupled model such as currents, water levels, wave climate and bed levels were used to force the particle transport model. Prior to scenario simulations, model runs were undertaken with the existing Port Geographe configuration. The model was validated by comparing simulated flow, wave, sediment and seagrass transport with actual field data. Finally, by considering different physical layouts to Port Geographe the study recommends an optimal design for seagrass and sediment bypass management for the region.

1.4 Structure of the report

This report presents the detailed model study results of hydrodynamics, seagrass and sediment transport in the vicinity of the Port Geographe Marina. The background and objectives of the present study are presented in this first chapter and a description of the model set-up is provided in Chapter 2. The model validation of hydrodynamic, sediment and seagrass transport are described in Chapter 3. The model scenario development and simulation results are presented in Chapter 4. Extended model simulation results for selected options are also provided in Chapter 4. The study's conclusions and recommendations are provided in Chapter 5.

2 MODEL SET-UP

Sediment transport in coastal environments, including material such as seagrass wrack, is a continuous process under the combined action of wind, waves, and tides. Extreme weather events, such as storms and cyclones, further accelerate transport processes in coastal regions. These natural processes are modified through human intervention particularly through the construction of coastal structures such as groynes, breakwaters and harbours, etc. The material transported and accumulated in near shore environments can be investigated by coupling hydrodynamic/wave models with appropriate material transport models. Through the assessment of the dominant physical processes, forcing interactions, topography/bathymetry and previous studies (Oldham et al., 2010), we have selected a suite of models developed by the Danish Hydraulic Institute (DHI) MIKE 21 for this study. The software is used extensively throughout the world in the simulation of hydrodynamics, wave dynamics, sediment transport, water quality, and all related processes in estuaries, bays and coastal areas. Further, this software has been used to undertake design data assessment for coastal and offshore structures, to optimize port layouts and to develop and test coastal protection measures. In addition to the DHI modelling tools, an independent model has been developed to investigate seagrass wrack transport in Geographe Bay (Oldham et al., 2010). The particle model, developed in stage 1 of this study (Oldham et al., 2010) was further refined to incorporate temporal depth and shoreline changes (see below).

2.1 Module selection

Taking into account the relatively shallow and un-stratified nature of the Geographe Bay it was decided that a depth-averaged two-dimensional hydrodynamic model was the most appropriate tool for this study. A summary of the different modules of the MIKE 21 modelling system is presented in sections 2.1.1 to 2.1.3. The model set-up schematic is shown in Figure 2.1.

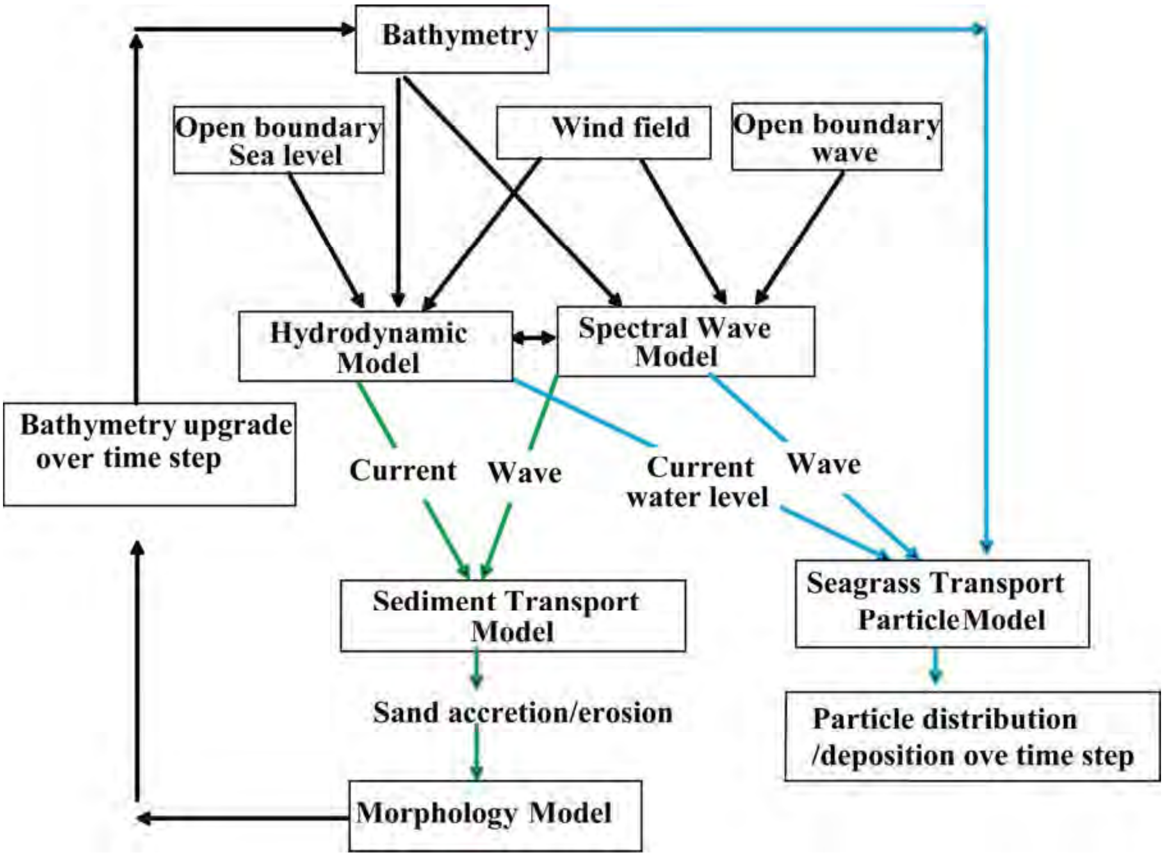


Figure 2.1 Schematic of coupled numerical model flow diagram.

2.1.1 Hydrodynamic (HD) module

The MIKE 21 hydrodynamic model calculates the flow field from the solving of the depth-integrated continuity and momentum equations. A detailed description of the DHI MIKE 21 depth-averaged hydrodynamic flow model set-up for Geographe Bay is presented in the earlier, stage 1 report (Oldham et al., 2010). The major change to the flow model in this study is its coupling with the hydrodynamic, spectral wave and sediment transport models. This means that the movable sea bed is dynamically updated at each computational time step and the hydrodynamic flow calculations are always carried out with a dynamic bathymetry. The hydrodynamic model is forced with water levels, waves along the open boundaries and winds on the surface. The sea surface pressure variation over the domain is also included. Water levels and velocities within the domain were set to zero as model initial conditions. Fluxes through closed land boundaries were also set to zero. The MIKE 21 hydrodynamic model set-up parameters are:

- Open boundary: water level variation over the time and along the boundary.
- Wind forcing: wind shear stress at the surface (varying over time and domain), wind friction varying with wind speed linear variation; e.g. friction 0.001255 for speed 7 ms^{-1} and 0.002425 for 25 ms^{-1})
- Bed resistance: Manning type; and constant over the domain
- Wave driven currents through the radiation stresses (obtained every time step from MIKE 21 Spectral Wave model)
- Coriolis forces: included
- Momentum dispersion: through Smagorinsky formulation
- Model time step: 15 minutes
- Model outputs: sea levels and velocity components covering model domain in 15-minute intervals.

2.1.2 Spectral wave (SW) module

The transformation of offshore waves as they propagate to near shore areas is simulated by use of MIKE 21 SW FM, which is a fully spectral model capable of simulating the evolution of a 2-dimensional wave energy spectrum with time. Wave-current interaction was simulated by iteratively coupling the depth-averaged hydrodynamic (HD) model to the spectral wave (SW) model. The model simulates the growth, decay and transformation of wind generated waves and swells in offshore and coastal areas. The model includes all relevant wave phenomena such as shoaling, breaking, refraction, and swells generation due to local winds. The SW model's open boundaries are specified with incoming waves. The winds, varying over time and domain, were provided to generate local swell waves. Thus model-predicted waves inside the bay area are a combination of waves propagated through open boundaries and locally generated wind swells. The wave parameters were refined to an area of interest using the higher resolution mesh used for the hydrodynamic simulations. The model simulates the distribution of wave height, wave periods, wave direction and spreading of waves and calculates radiation stresses, which drive the longshore current. The SW model set-up parameters are:

- Spectral formulation: Fully spectral formulation
- Spectral discretization: 360 degree rose

- Water level and current condition: from hydrodynamic simulation
- Open boundary: wave climate parameters (significant wave height, wave direction and period)
- Wind forcing: Varying in time and over domain
- Wave diffraction included
- Wave breaking: Ruessink et al., (2003) functional form
- Outputs: Significant wave height, mean wave direction, peak wave direction, peak wave period

2.1.3 Sediment Transport (ST) module

The MIKE 21 ST model has been widely used to simulate sand transport investigations in different environments; tidal inlets, estuaries, coastlines, and human constructions such as harbours and breakwaters, etc. The MIKE 21 ST model calculates the rates of non-cohesive sediment (sand) transport for both pure current and combined waves and current situations. Tide, wind, wave and current can all be taken into consideration for optimum precision in the simulations. Apart from the sediment-transport components, the initial rates of bed level change associated with the time-averaged sediment transport are also output from the MIKE 21 ST simulation. The ST model reads the output of the hydrodynamic model to integrate the water level and flow information, and it reads significant wave height, wave period and mean wave direction from the SW model.

The model requires information on mean grain size, the standard deviation and relative density of the sand. The transport rates and morphological evolution are calculated on the flexible mesh (see below). The following MIKE 21 ST model parameters were selected for this study:

- Forcing: both wave and current (HD), and current and wave field (SW) model simulation
- Sediment properties: varying over domain but assumed constant over time
- Boundary condition: Zero sediment flux gradient

2.1.4 Seagrass Transport model

The formulation of a particle dispersal model was described in the earlier report (Oldham et al., 2010). The code was further adapted to include morphological change in the model, which is necessary to accurately calculate the assumed log profile of velocities as well as the calculation of bottom shear stresses. The bathymetry changes were taken from the sediment transport morphological model output and linearly interpolated to the dispersal model time step. Although this task significantly increased computation time, it avoided unrealistic jumps in bottom shear stresses calculations. The coupled model outputs such as currents components (E-W and N-S), sea level, wave climate and still water depths were used to force the particle dispersion model.

2.2 Model extent, bathymetry and mesh grid

The model extent covering Port Geographe is shown in Figure 2.2, which was chosen to ensure that the model simulation results in the area of interest not being affected by boundary effects. Also, as described in earlier modelling work in Geographe Bay, the model domain was selected to ensure that it covered locations where data were available to force the model and validation.

The accuracy and resolution of the bathymetry is the most important aspect in any flow model set-up, particularly near shore sediment transport/morphological modelling applications. Shallow-water wave transformation strongly depends on near shore bathymetry. We have obtained depth measurements from various sources and used this to construct the initial model bathymetry. The model bathymetry includes 250-m horizontal resolution data from Geoscience Australia's offshore region, high resolution (> 10-m horizontal), the Department of Transport's near shore hydrographic survey data around Port Geographe as well as recently acquired coastal LIDAR (Light Detection And Ranging) survey data around Port Geographe. All depth data were standardized to the Australian Height Datum (AHD). All spatial coordinates were projected to Geocentric Datum of Australia (GDA94) Map Grid zone 50 (MGA50) coordinates. Bathymetric data was linearly interpolated over the mesh grid to construct the initial model domain bathymetry as shown in Figures 2.3 and 2.4. LIDAR survey was conducted in late 2008. Thus detailed bathymetric data available through a range of different sources was used to define the initial input bathymetry for the model runs beginning in 2009.

Triangular elements of variable size were used to discretize the model domain and to obtain adequate resolution in areas of particular interest as described in the previous report (Oldham et al., 2010). However, in this modelling exercise we have further refined the mesh grid to develop finer meshes around the Port Geographe area (2 km either side of the marina). The flexibility associated with finer meshes allows the accurate representation of land/water boundaries and physical structures (e.g. small groynes at Wonnerup beach etc.). Thus the developed meshes were sufficiently dense near structures and near the vicinity of Port Geographe to model the flow field in detail. The generated mesh for the present groyne configuration is shown in Figure 2.5. In this same manner, we have generated mesh grids for a number of different layouts (Section 4). The same mesh grids were used for spectral wave, sediment transport and practical transport models. Thus, all parameters such as water levels, flows, wave climate, and sediment transport description are refined (with the mesh) towards the area of interest.

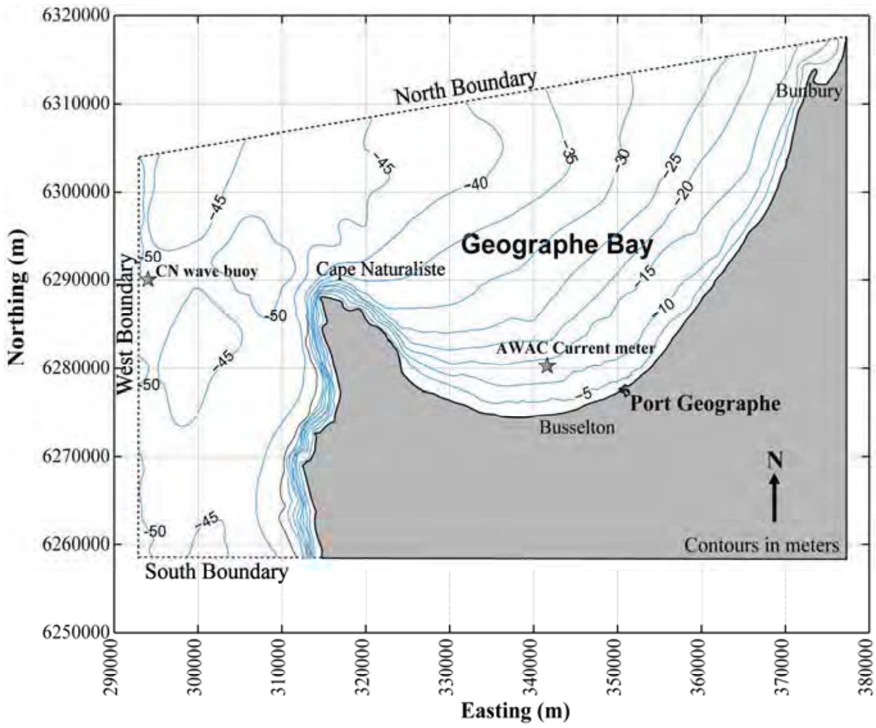


Figure 2.2 Map of Geographe Bay showing the model boundaries, general bathymetry and the locations of model input data (tide gauge, wave gauge, current meter, and the meteorological stations at Cape Naturaliste, Busselton and Bunbury).

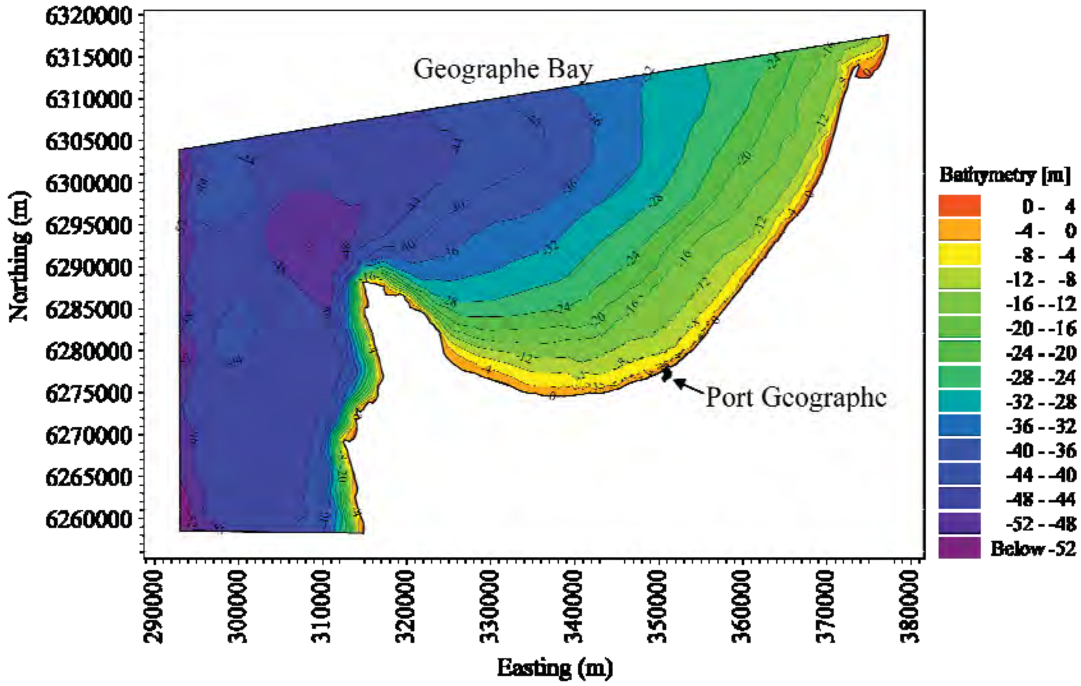


Figure 2.3: Initial model bathymetry of Geographe Bay in the current configuration.

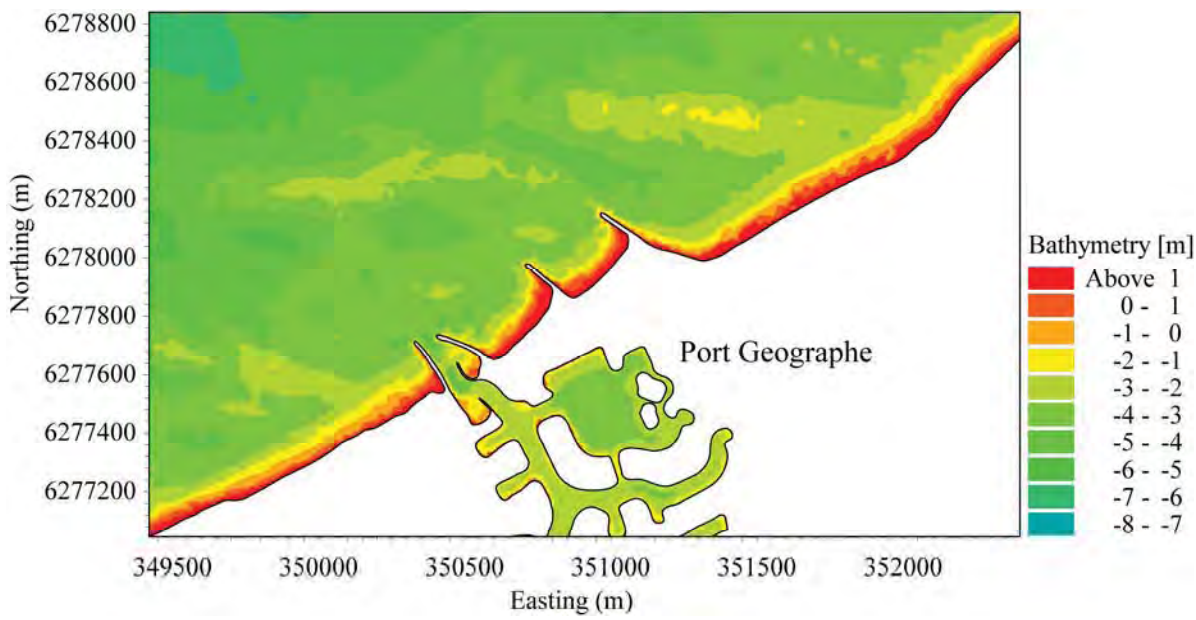


Figure 2.4: Initial model bathymetry of Port Geographe and Wonnerup areas in the existing configuration.

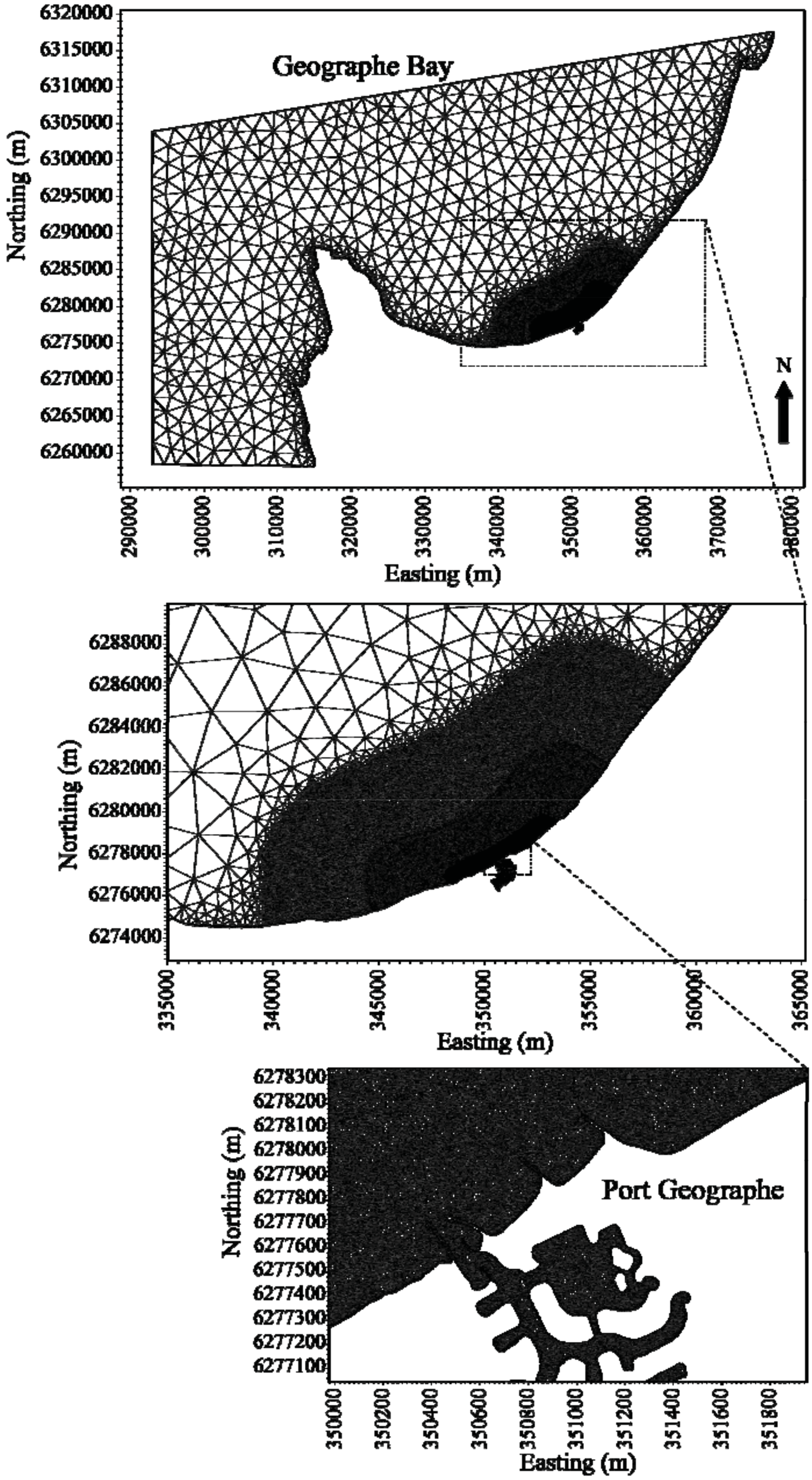


Figure 2.5 Model mesh grid of Geographe Bay showing different scales used for the model domain. Fine grids are used in the Port Geographe and near shore regions of Geographe Bay.

2.3 Model forcing data

2.3.1 Open boundary

The open boundaries are located along the three offshore edges of the model domain (Southern, Western and Northern boundaries). The open boundaries were specified using sea levels and wave climate parameters in the Hydrodynamic and Spectral Wave models, respectively. The model period was selected to ensure that it covered storms and sufficient data were available to force and calibrate the model. Analysis of tide gauge records from the region revealed that 2009 was a significantly stormy year.

2.3.1.1 Sea levels

The sea levels along the open boundaries were specified by combining the observed tide gauge records at Bunbury and interpolated sea levels as described in Stage 1 report (Oldham et al., 2010). Bunbury tide gauge records in 2009 are shown in Figure 2.6. The raw time series data were processed to remove data spikes and filtered to remove oscillations less than two-hour periods from the record. Tidal and residual (weather bands, surges etc.) sea level components of sea levels are shown in Figures 2.7 and 2.8, respectively. It can be clearly seen that tidal ranges are largest during June and July. The visual observation of the residual component reveals that storms surges were dominant during May to July, relatively small surge events occurred from August to October, and no surge events occurred from November to mid May. Based on water levels, the largest storm surge occurred on 20–21 May, while several moderate surges occurred during May and through to the end of September 2009.

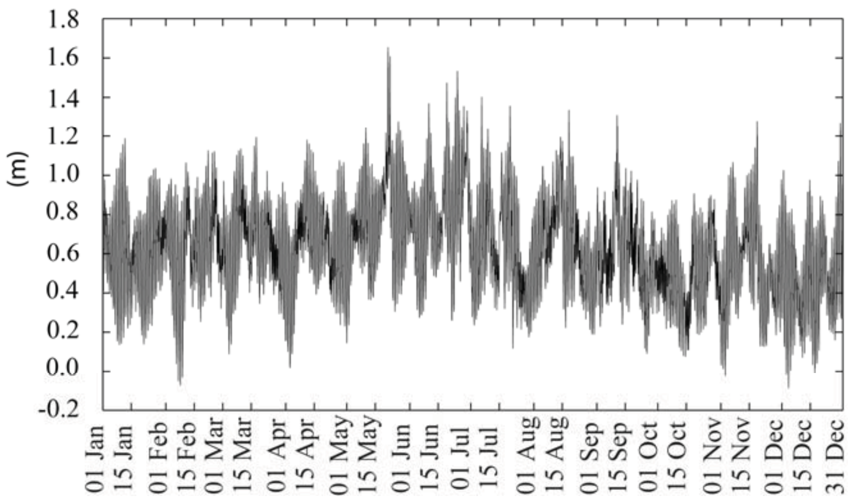


Figure 2.6 Open boundary water level forcing data in 2009, from the Bunbury tide gauge (Source: Western Australian Department of Transport).

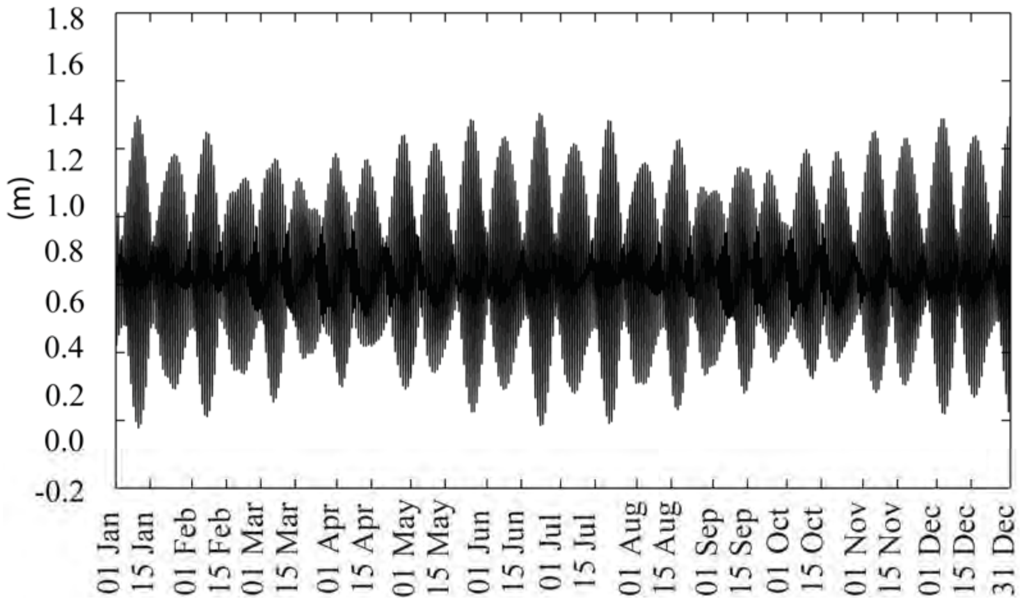


Figure 2.7 Tidal water level variation in 2009 extracted from the Bunbury tide gauge records. (Source: Western Australian Department of Transport).

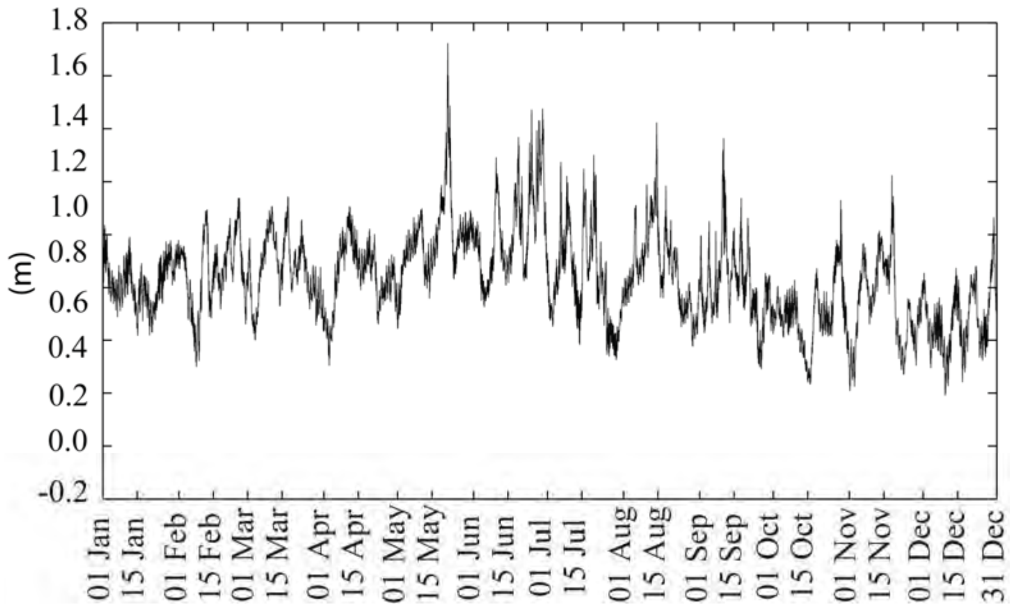


Figure 2.8 Residual sea level variation in 2009 extracted from the Bunbury tide gauge record.

2.3.1.2 Wave parameters

The SW model required the inclusion of significant wave height, peak wave period and mean wave directions at open boundaries. The wave parameters along the open boundaries were obtained from the Department of Transport (Transport) and NOAA Wave Watch III model data. Transport's wave buoy measured wave parameters at Cape Naturaliste (location: 33.52°S, 114.78°E) and this data is shown in Figure 2.9. The wave buoy measured hourly wave height and period, but did not record direction in 2009. Global Wave-Watch III wave model predicted wave direction at the nearest grid point, which was extracted and interpolated to an hourly time scale. Directional wave data became available from Transport's wave buoy from February 2010. A detailed description of wave climate in Geographe Bay is provided in the stage 1 report (Oldham et al., 2010), including wave parameters at Cape Naturaliste in 2009 and 2010. A wave recorder also obtained significant wave heights close to Busselton, which were less than half the measured heights at Cape Naturaliste. The swell wave periods at Cape Naturaliste are 10–20 seconds (s) and significant wave heights are mostly larger than 2 metres (m), exceeding 5 m during winter storms. The wave periods at Busselton are 4–12s and heights are smaller than 1m from October to April. The swell heights are relatively larger during winter, exceeding 2m during winter storms. South-west swell waves dominated at Cape Naturaliste through the 2009 (Figure 2.10). The swell wave direction at Busselton is mainly from the north-west, through refraction at Cape Naturaliste but the direction varies particularly under storm periods. The swell wave direction at Busselton is dependent upon wind direction (Figure 2.10) although the wave heights were generally < 0.5 m. These results indicate that local wind generated swells are the dominant source of wave energy except during the winter months. During winter, offshore storms generate waves that propagate to the inner waters of Geographe Bay (see also Fahrner and Pattiaratchi, 1994).

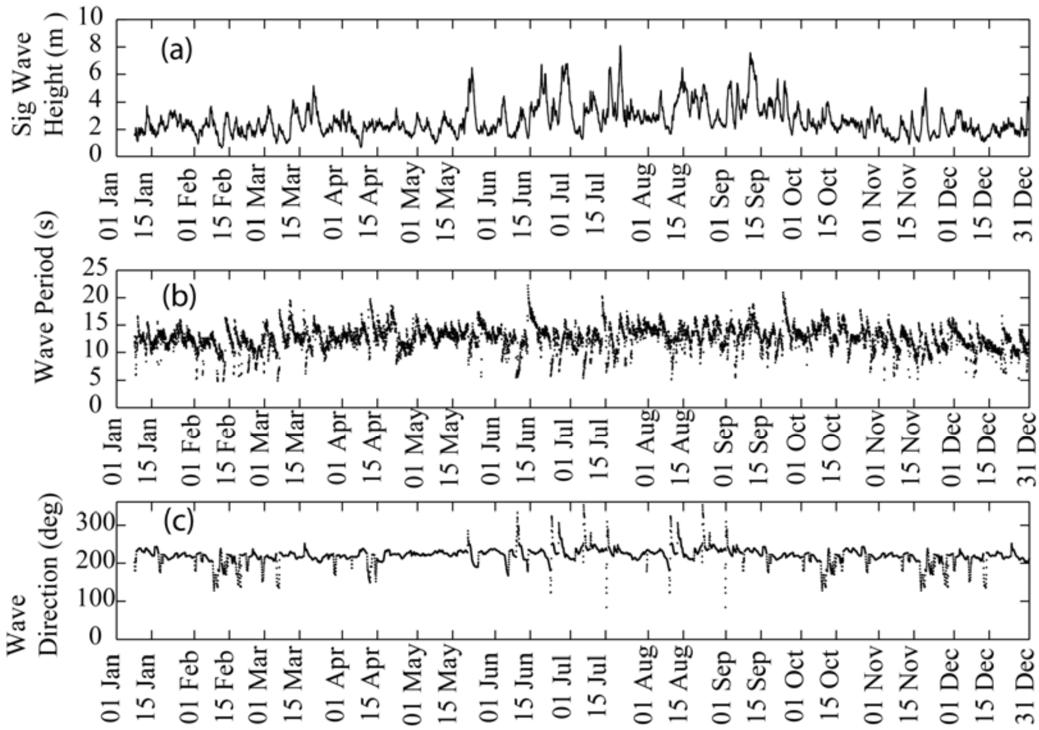


Figure 2.9 Open boundary wave climate forcing data for 2009, obtained from the Cape Naturaliste Wave Buoy and the Global Wave-Watch III wave model: (a) Significant wave height, (b) Mean wave period and (c) Mean wave direction.

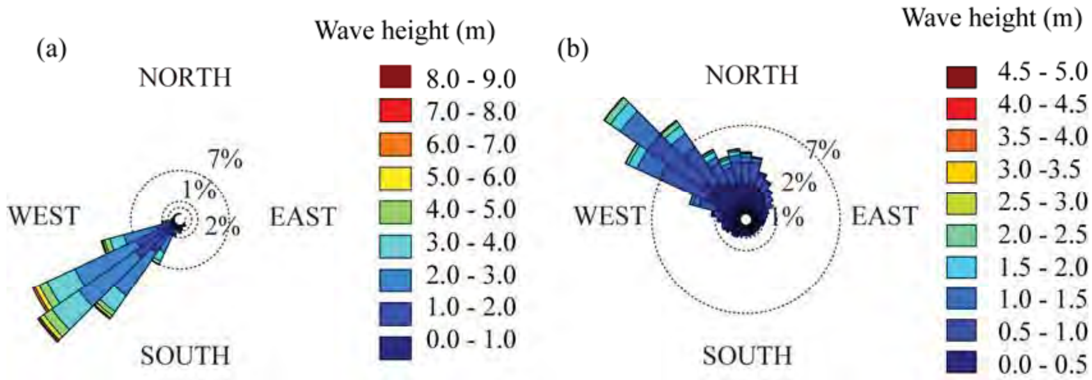


Figure 2.10 Wave rose diagrams showing predominant wave climate at (a) Cape Naturaliste; and, (b) AWAC site at Busselton (wave heights are in m).

2.3.2 Surface wind forcing

Temporal and spatial resolution of wind data are crucial for flow/wave modelling in coastal seas like Geographe Bay. Both wind speed and direction play a dominant part in circulation and swell wave generation in such an open bay environment. It also directly and indirectly affects the movement of seagrass wrack suspended in the water column and floating on the water surface. A detailed description of the wind climate in the Geographe Bay area can be found in the earlier study report (Oldham et al., 2010). Wind speed and direction data were obtained from the Bureau of Meteorology for the period January 2009 to October 2010, the period of model simulation. Figures 2.11–2.13 show time series of wind speeds and direction for 2009 at Cape Naturaliste, Busselton and Bunbury. Ten-minute wind speed and direction data at these stations were used to construct temporally and spatially varying wind-fields over the model domain, based on a moving average interpolation. Data gaps of smaller than six hours duration were filled using linear interpolation before analysis. As an example, a snapshot of the wind vectors over the model domain, over a single time step, is shown in Figure 2.14. The sea surface pressure variations over the temporal and spatial domain were also constructed based on a moving average interpolation. Time series of wind speed and direction (Figures 2.11–2.13) clearly indicate there is a cyclic pattern with stronger winds from May to October associated with low pressure systems. These cyclic strong winds are consistent at all three stations and are related to the passage of frontal systems.

A comparison of wind speeds at the three stations clearly shows that Cape Naturaliste winds are stronger compared to the winds at Bunbury and Busselton. The wind speeds at Cape Naturaliste sometime exceed 20m s^{-1} during the winter months (May to September). At Bunbury maximum wind speeds are less than 15m s^{-1}. The annual mean speed at Cape Naturaliste, Busselton and Bunbury calculate at 7 m s^{-1}, 6.1 m s^{-1} and 5.7 m s^{-1}, respectively. The wind rose diagrams (Figures 2.11–2.17) illustrate the wind patterns in Geographe Bay in 2009. The strong wind regime is dominated by south-westerly winds.

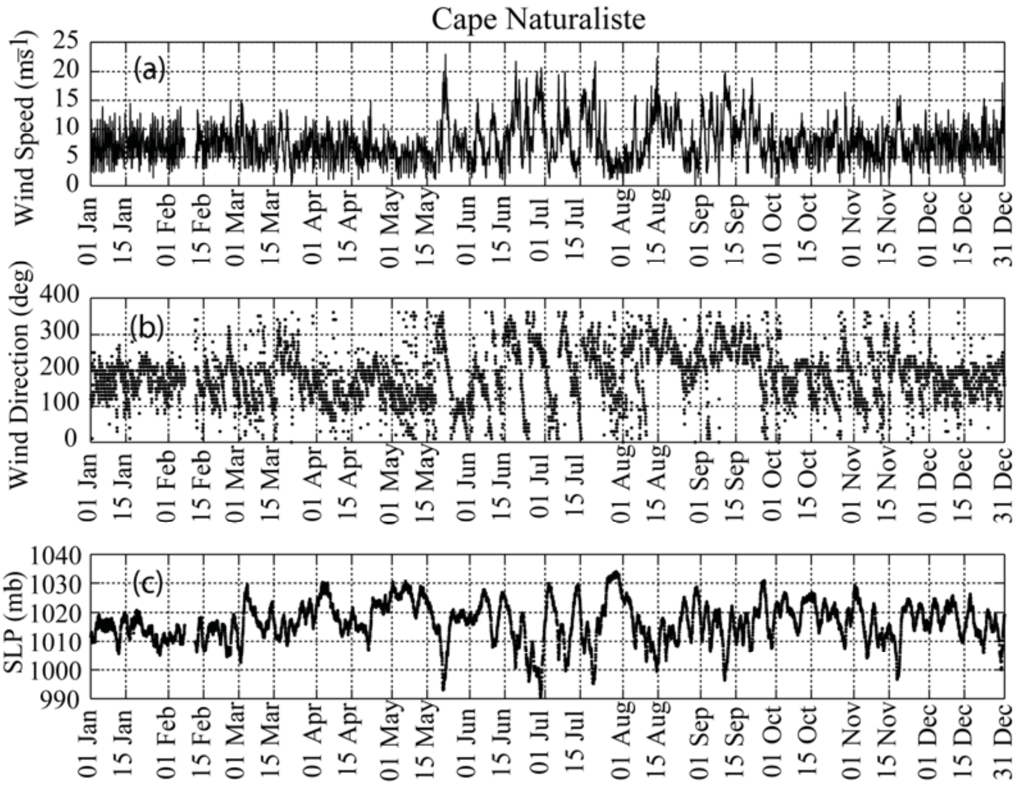


Figure 2.11 (a) Wind speed; (b) Direction; and (c) Sea surface pressure data from Cape Naturaliste meteorological station in 2009.

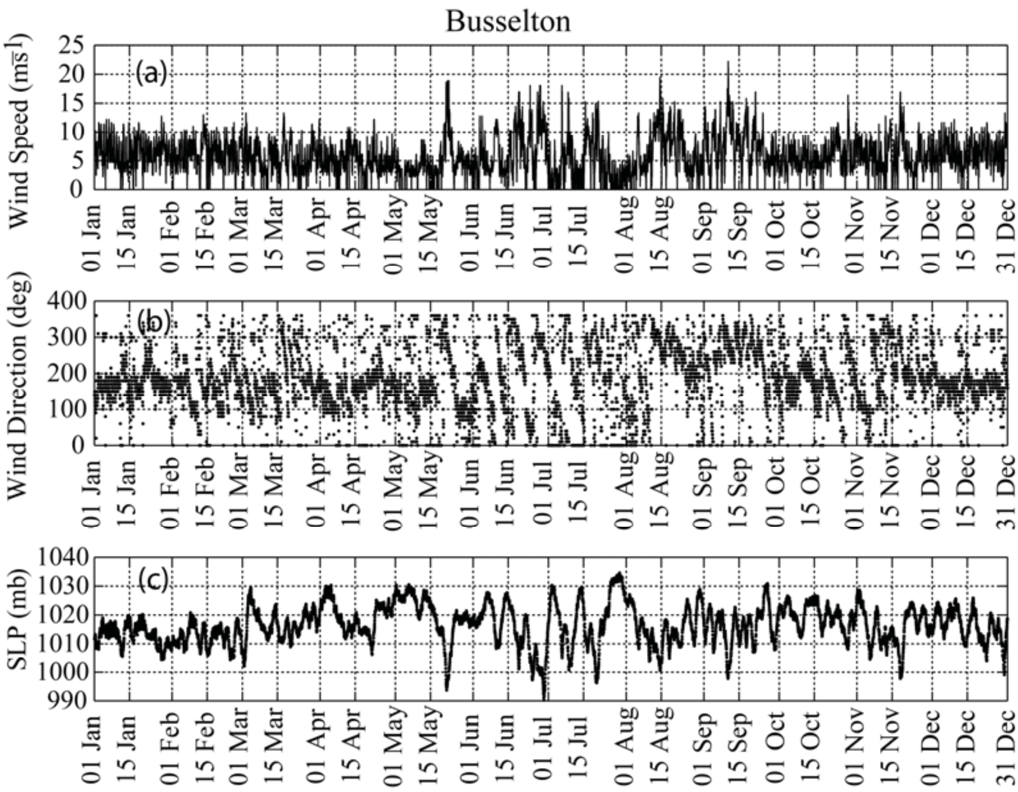


Figure 2.12 (a) Wind speed; (b) Direction; and (c) Sea surface pressure data from Busselton meteorological station in 2009.

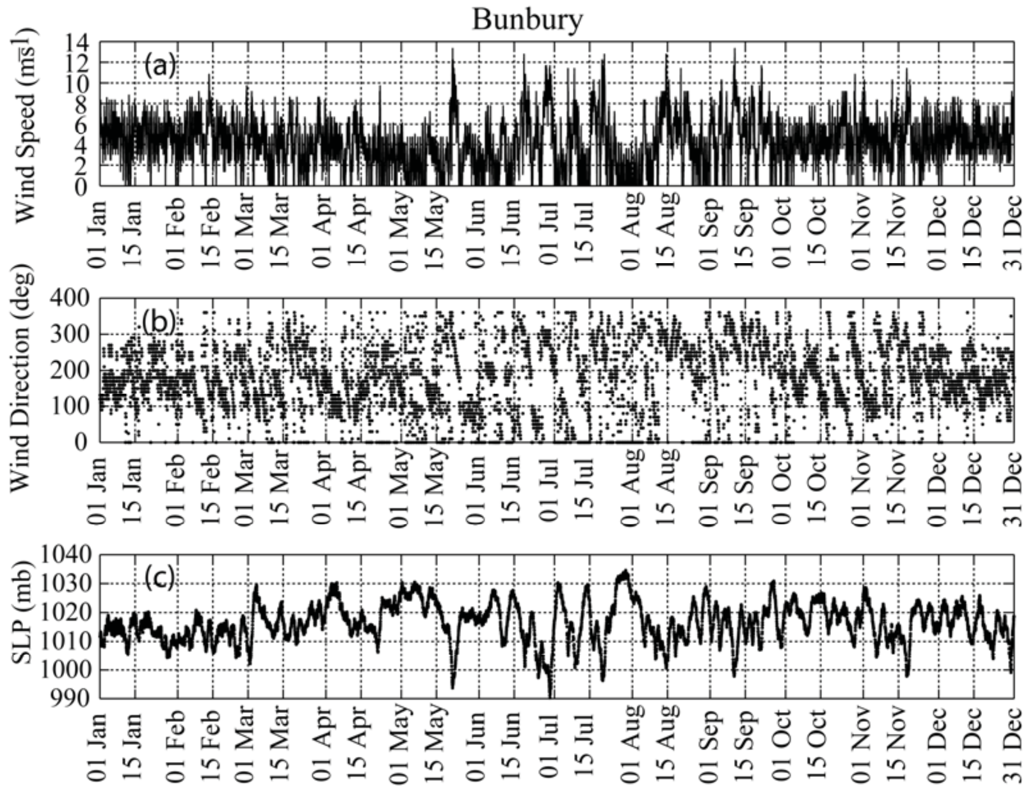


Figure 2.13 (a) Wind speed; (b) Direction; and (c) Sea surface pressure data from Bunbury meteorological station in 2009.

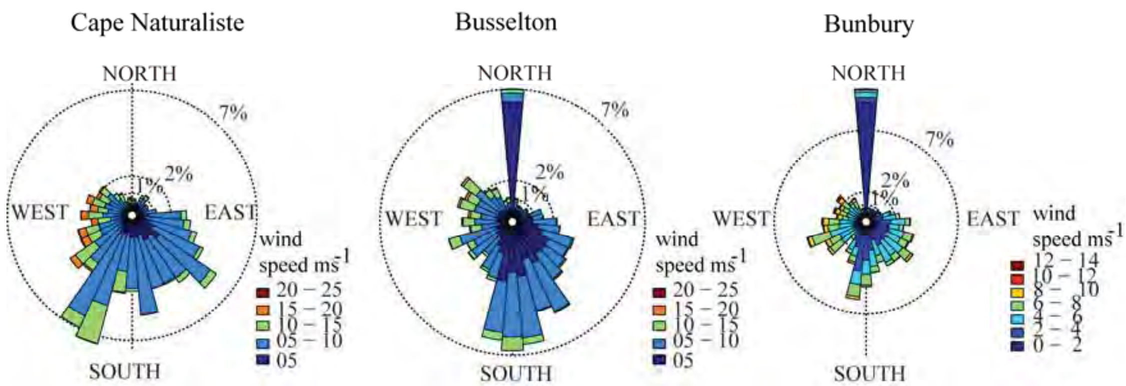


Figure 2.14 Wind rose diagrams at Cape Naturaliste, Busselton and Bunbury based on meteorological station data in 2009.

2.3.3 Bottom sediment parameters

The model requires information on mean sand grain size, the standard deviation and relative density of the sand. The sediment properties were obtained from Damara WA Pty Ltd, which was based on sediment sample collection and analysis along the shoreline of Geographe Bay. Sediment samples were collocated in January 2010. Geographe Bay is composed of medium to fine grained sand. The size of sand grains (median diameter D_{50}) varied from slightly less than 0.2mm in sheltered areas and offshore from the inter-tidal zone up to 0.3 mm for the more exposed beaches at the central and northern ends of the bay. This means that the sand within the study area is relatively easily mobilised by waves, currents and wind. Sand that has been suspended from the seabed into suspension is easily kept in suspension by the currents.

2.3.4 Particle initialization (seagrass wrack)

At model start-up, particles were randomly seeded in the region inside Geographe Bay between the 3.5-m and 12-m depth contours; stage 1 study found this to be the wrack catchment area for Geographe Bay (Figure 2.15).

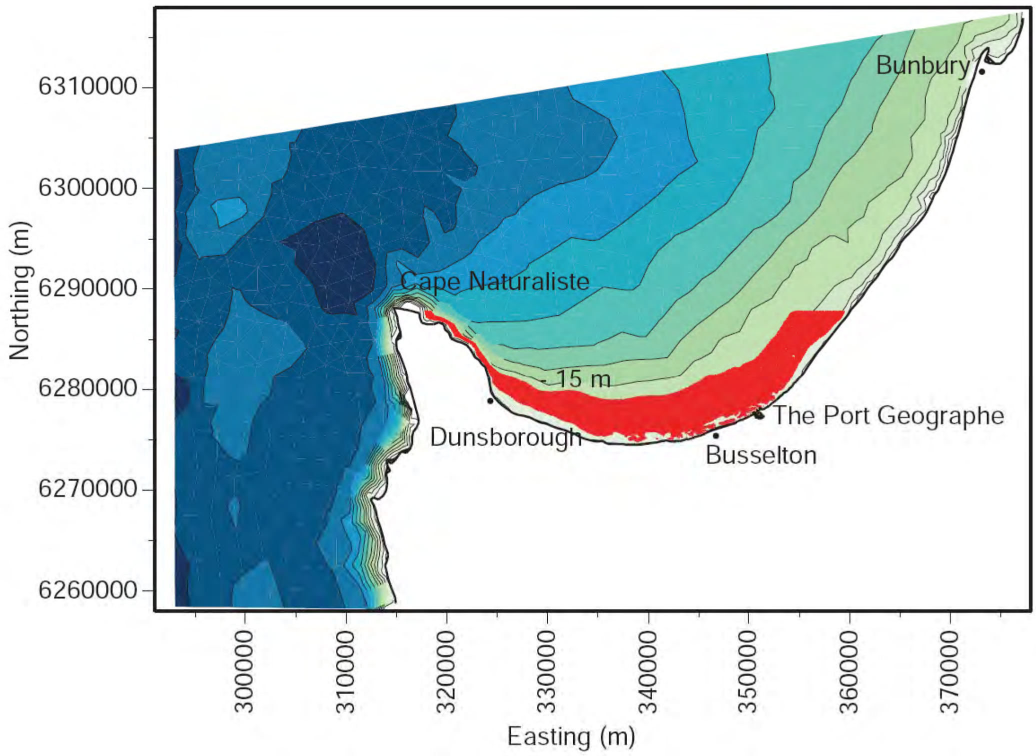


Figure 2.15 Model input: initial seagrass particle distribution.

2.4 Conclusions

A fully coupled 2D numerical model for waves, currents, sand transport and morphological changes (MIKE 21 FM) incorporating a particle transport model has been developed and applied to Geographe Bay. The sand transport model together with the morphological model provided a better comparison of the effectiveness of structures of different layouts for Port Geographe for sand by-passing and to determine the navigability of the marina entrance channel.

The model extent was chosen to ensure that the model simulation results in the area of interest were not influenced by boundary effects. The model initial bathymetry was based LIDAR survey data in late 2008, the Department of Transport's near shore hydrographic survey high resolution (>10 m horizontal) dataset around Port Geographe and 250 m resolution Geoscience Australia offshore dataset. A flexible triangular unstructured mesh was chosen to generate model mesh grid and in a way to represents smooth and fine grids for the region. The maximum mesh area of 150 m^2 was defined in the Port Geographe area this provided a grid resolution of ~10 m in the nearshore region of Port Geographe.

3. MODEL CALIBRATION AND VALIDATION

The model was initially run with the existing Port Geographe structural configuration as a base simulation. Validation was undertaken for both the hydrodynamic and spectral wave models by comparing model prediction with measured time series of water levels, current speeds, directions and wave statistics data from two stations inside Geographe Bay (Figure 2.2). The hydrodynamic and spectral wave models predictions and measured currents, water levels and wave climate were further quantified by estimating the skill levels (Willmott, 1984):

$$Model - skill = 1 - \frac{\sum \left| X_{\mathrm{mod}} - X_{obs} \right|^2}{\sum \left(\left| X_{\mathrm{mod}} - \overline{X_{obs}} \right| + \left\| X_{obs} - \overline{X_{obs}} \right\| \right)^2}$$

where, X_{obs} and X_{mod} are the measured and predicted parameters (e.g. sea level, wave height etc.), respectively.

The sediment transport model was verified by comparing the computed annual sand accretion at the western beach at Port Geographe with the estimates coming from annual sand and seagrass bypass records, (Shore and Beach, 2010). The particle transport model was validated by comparing the computed seagrass wrack accumulation pattern on the beaches against field observations (see Oldham et al., 2010).

3.1 Hydrodynamic model

The MIKE 21 flow model has two main calibration parameters, namely the bed resistance coefficient and the momentum dispersion (eddy) coefficient. The hydrodynamic model was calibrated during the previous phase of this study in relation to seagrass research in Geographe Bay (Oldham et al., 2010). The Chezy type bed resistance parameter was selected for this exercise and the calculated value was 32 $m^{1/2}s^{-1}$. A constant value was considered over the model domain. Horizontal eddy viscosity was the other calibration parameter selected based on the Smagorinsky formulation with a range between $1.8x10^{-6}$ and $1.0x\ 10^{-7}$ m^2s^{-1}. The Smagorinski method provides time-dependent adjustments of eddy viscosities based on simulated velocities.

The model-predicted sea levels were compared against tide gauge data from the Busselton Jetty and the offshore Acoustic Wave and Current device (AWAC) location data (Figure 2.2).

The predicted model and observed sea levels at Busselton during 2009 are shown in Figure 3.1, where black and red lines represent tide gauge data and model-simulated sea levels, respectively. The predicted model tide and surge components were in good agreement with tide gauge measured data (skill level was 0.97) as shown in Figures 3.2 and 3.3, respectively. It can also be seen that the model accurately captured all peak surges seen in the observations.

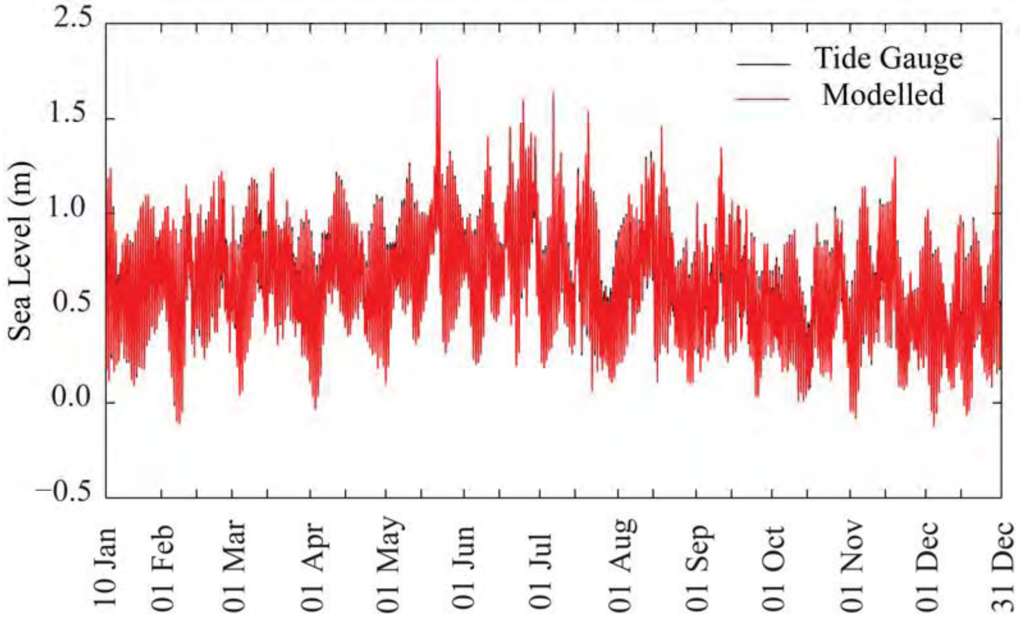


Figure 3.1 Measured and predicted water levels at the Busselton tide station in 2009. Black lines denote observed data and red lines denote model output.

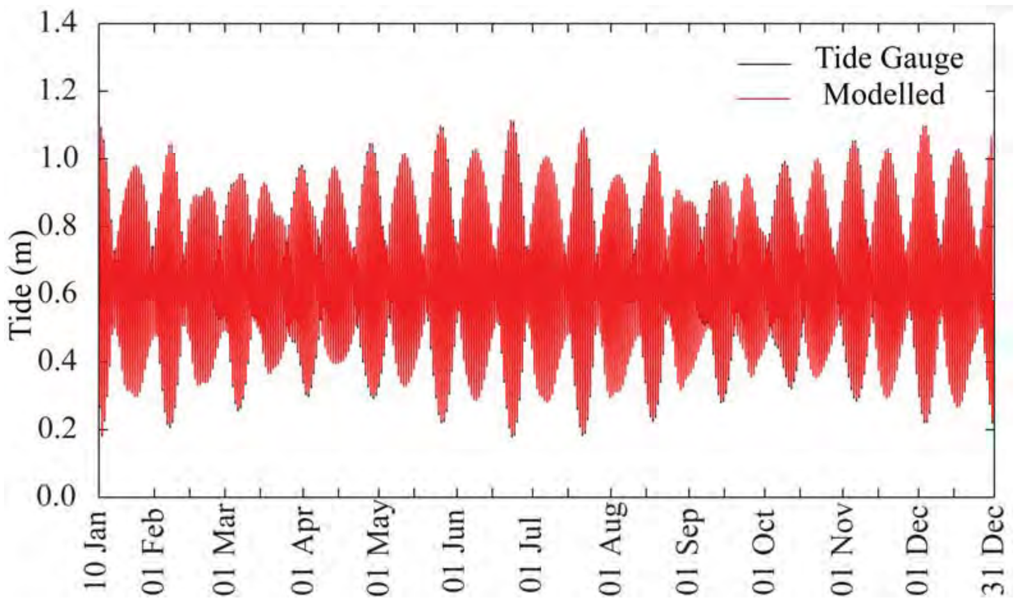


Figure 3.2 Measured and predicted tides at the Busselton tide station in 2009. Black lines denote observed data and red lines denote model output.

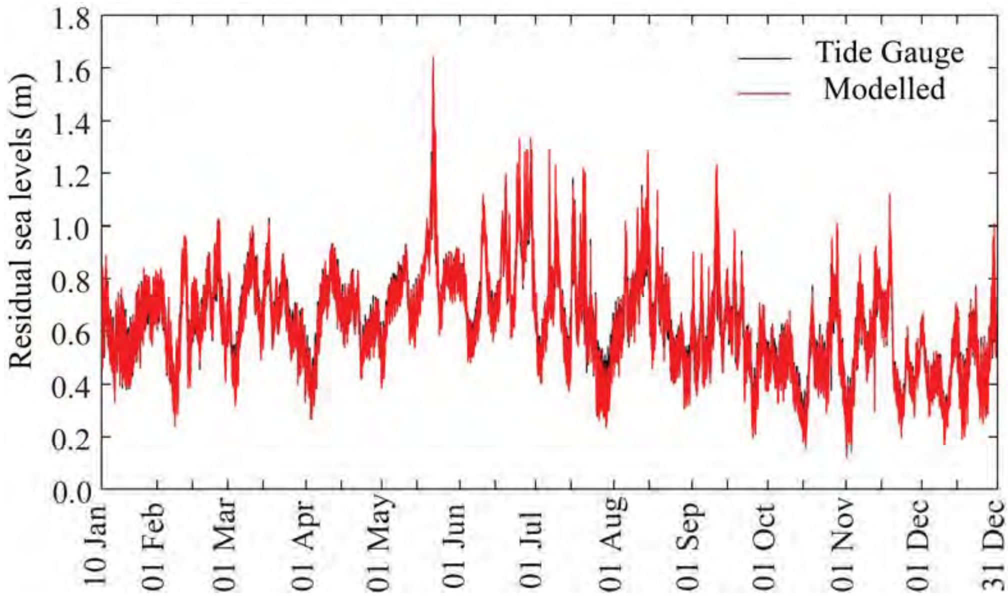


Figure 3.3 Measured and predicted residual sea levels at the Busselton tide station in 2009. Black lines denote observed data and red lines denote model output.

Figure 3.4 shows a comparison between the AWAC measured and the modelled current vectors: East–West and North–South components spanning the 2009 year. The AWAC type current profiler is located about 7 km from the coast at a depth of 15 m; it has measured current speeds and directions in one-metre thick layers from the surface to seabed in 10-minute intervals. All layer data has been averaged to obtain depth averaged velocity components. Visual comparison of the time series indicated that the East–West current component was in good agreement with the measured components, but the modelled currents did not reproduce the sudden peaks in the measured data. This could be due to the influence of local meteorological effects. The modelled North–South currents were also in reasonably good agreement with the measured component. The modelled North–South current speeds reported were slightly lower during winter. The influence of regional currents (such as the Leeuwin current) were not included in the model as their ability to directly influence coastal sand and wrack transport is minimal (Oldham et al., 2010). The estimated skill levels (in relation to the current model correlation with the observed data are 0.88 and 0.75 in east-west and north-south components, respectively and represents an achievement of good correlation.

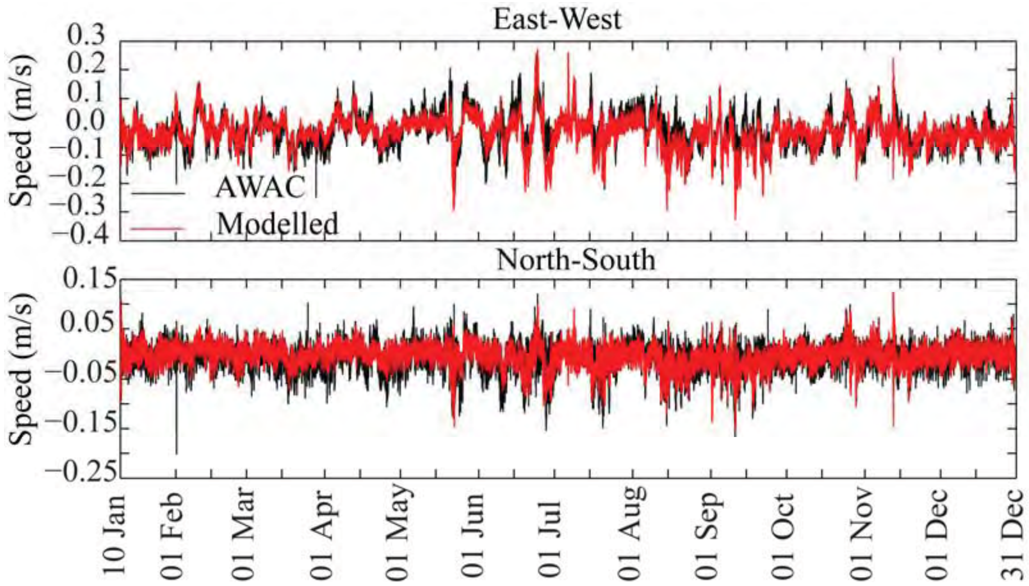


Figure 3.4 Comparison of modelled and measured current components at the AWAC site during 2009. Upper and lower panels show east-west and north-south components, respectively. Black lines denote observed data and red lines denote model output.

3.2 Wave climate

The snapshots of model-predicted wave heights and mean wave directions during typical south-west storm events in Geographe Bay are shown in Figures 3.5 and 3.6. The wave shadowing effect of Cape Naturaliste on the predominant south-west swells can clearly be seen as they refract into Geographe Bay. At Cape Naturaliste the wave rays spread out as they are refracted toward the coast.

The Spectral Wave (SW) model outputs were directly compared with the measured wave climate (significant wave height, mean wave period and direction). The comparison between modelled and measured wave parameters at the AWAC site is shown in Figures 3.7 to 3.9. It can be seen that there was good agreement between modelled and measured wave heights, with all important spikes and lows found in the measured waves being captured by the model. The measured and predicted wave directions were generally in good agreement; the model slightly underestimated the incoming waves from the north direction. The model slightly overestimated wave periods, but the trend was well correlated with measured values (Figure 3.9). Comparisons of modelled and measured wave climate are also shown in the rose diagram in Figure 3.10.

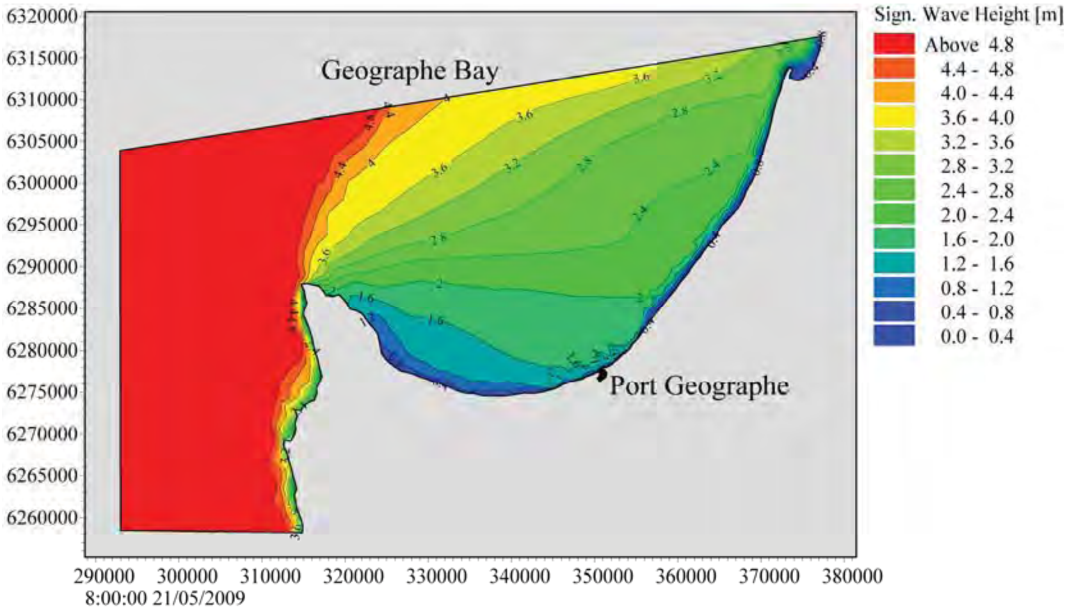


Figure 3.5 Model-predicted wave height distribution showing wave refraction at Cape Naturaliste during typical southwest storms (on 21 May 2009).

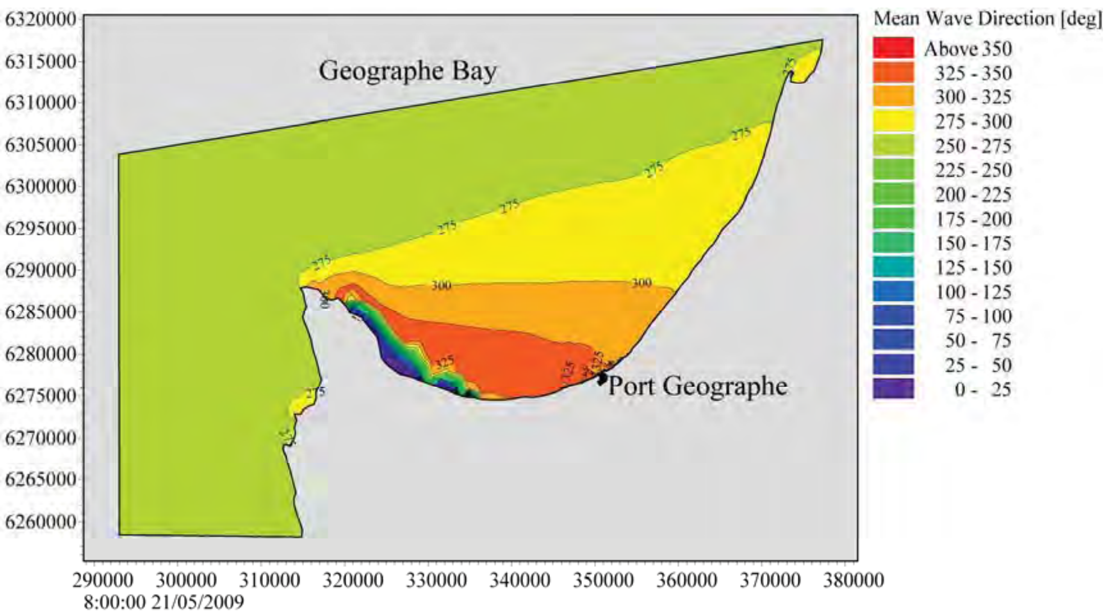


Figure 3.6 Model-predicted mean wave direction showing wave refraction at Cape Naturaliste during typical southwest storms (on 21 May 2009).

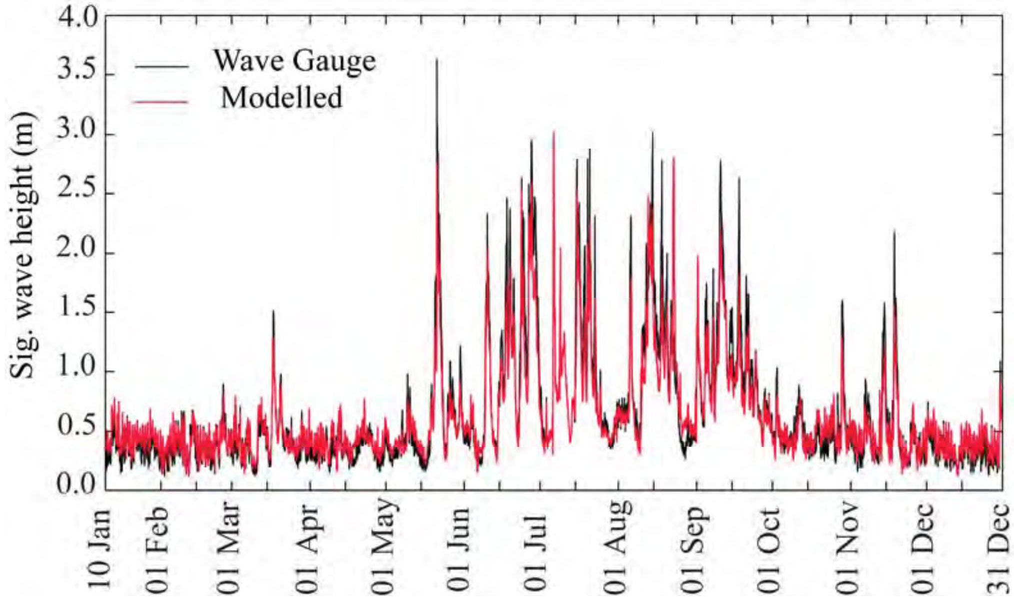


Figure 3.7 Measured and predicted significant wave height at the AWAC site in 2009. Black lines denote observed data and red lines denote model output.

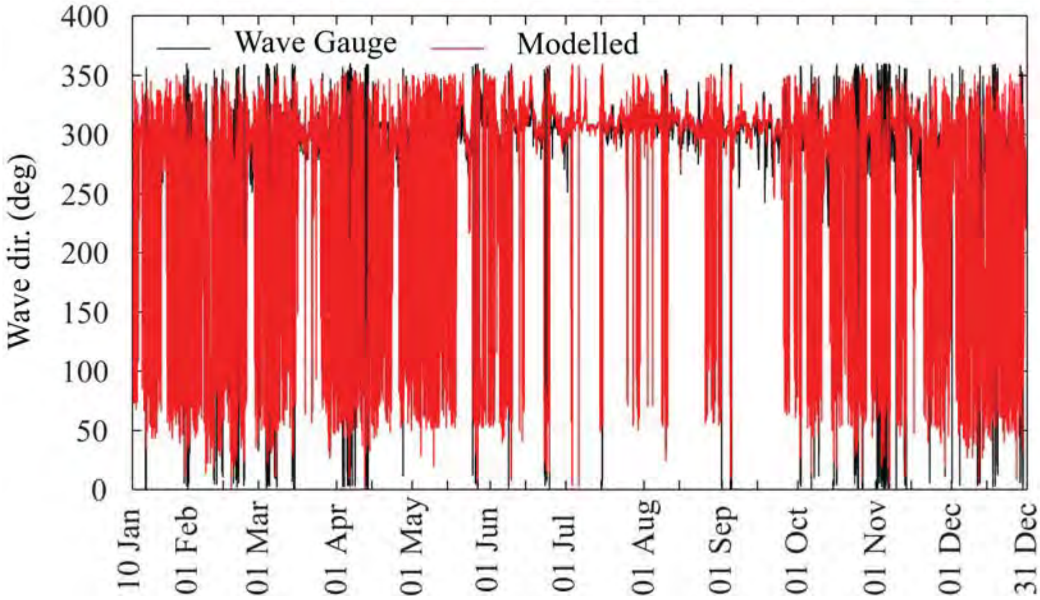


Figure 3.8 Measured and predicted mean wave direction at the AWAC site in 2009. Black lines denote observed data and red lines denote model output.

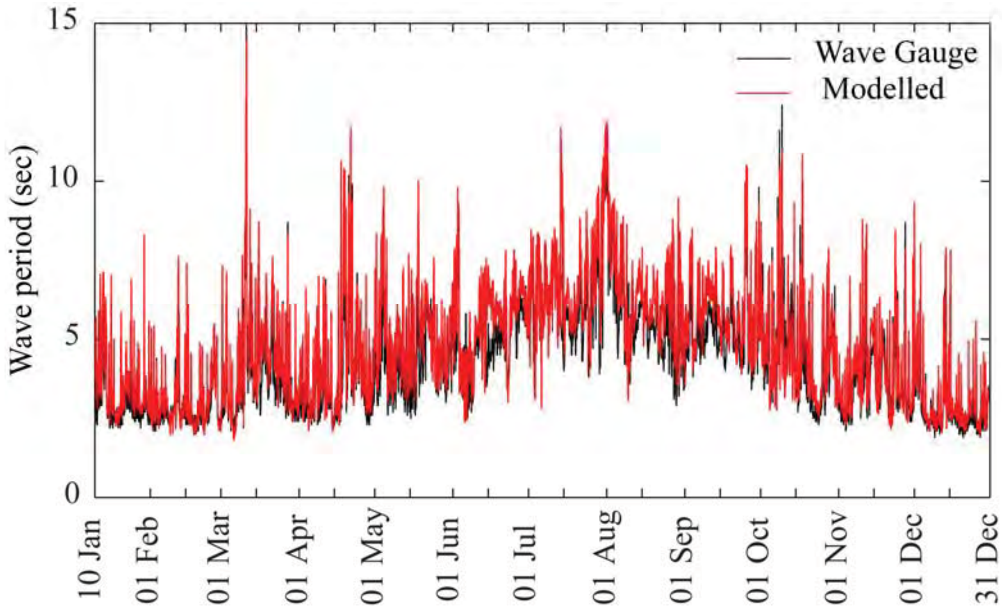


Figure 3.9 Measured and predicted mean wave periods at AWAC site in 2009. Black lines denote observed data and red lines denote model output.

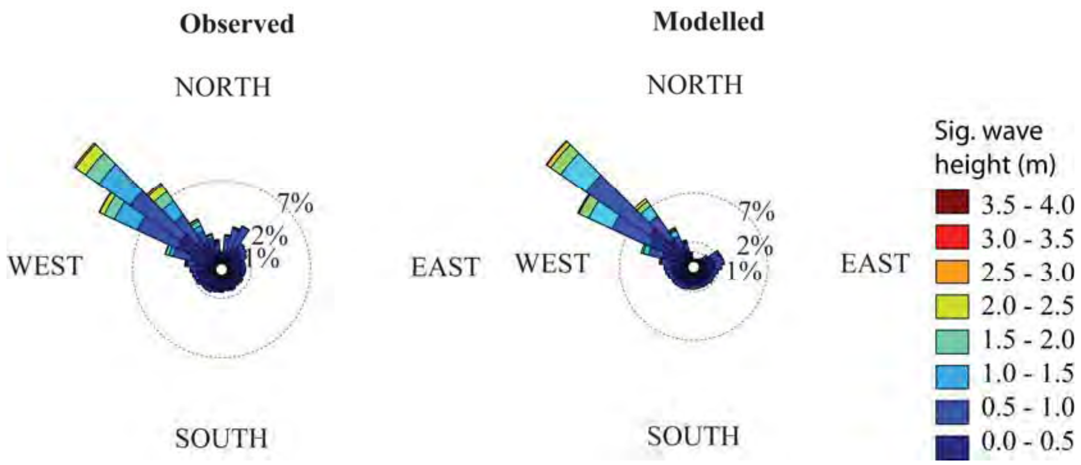


Figure 3.10 Wave rose diagrams (in metres) based on measured and predicted wave climate parameters at AWAC site during 2009.

3.3 Sediment transport

The Sediment Transport (ST) model has been validated based on the volume of sand accumulating on the western side of the Port Geographe Harbour. Figures 3.11 to 3.23 show predicted bed level changes in consecutive months from January to December 2009 and indicate sand accretion on the western side and erosion on Wonnerup beaches, mainly during the winter months.

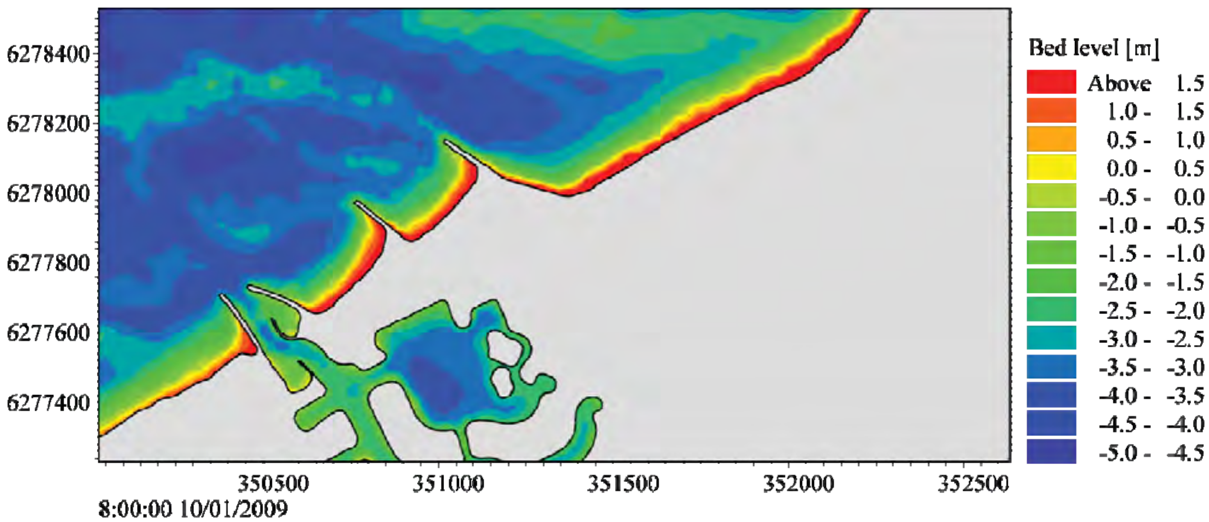


Figure 3.11 Model initial bed levels (bathymetry) in the vicinity of Port Geographe.

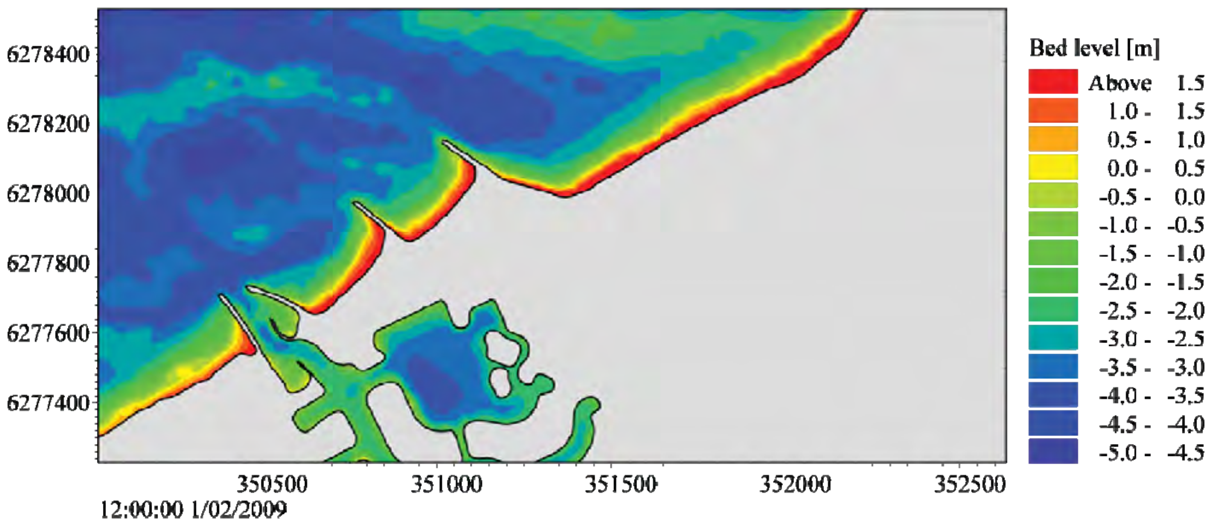


Figure 3.12 Model-predicted bed levels in the vicinity of Port Geographe on 1 Feb 2009.

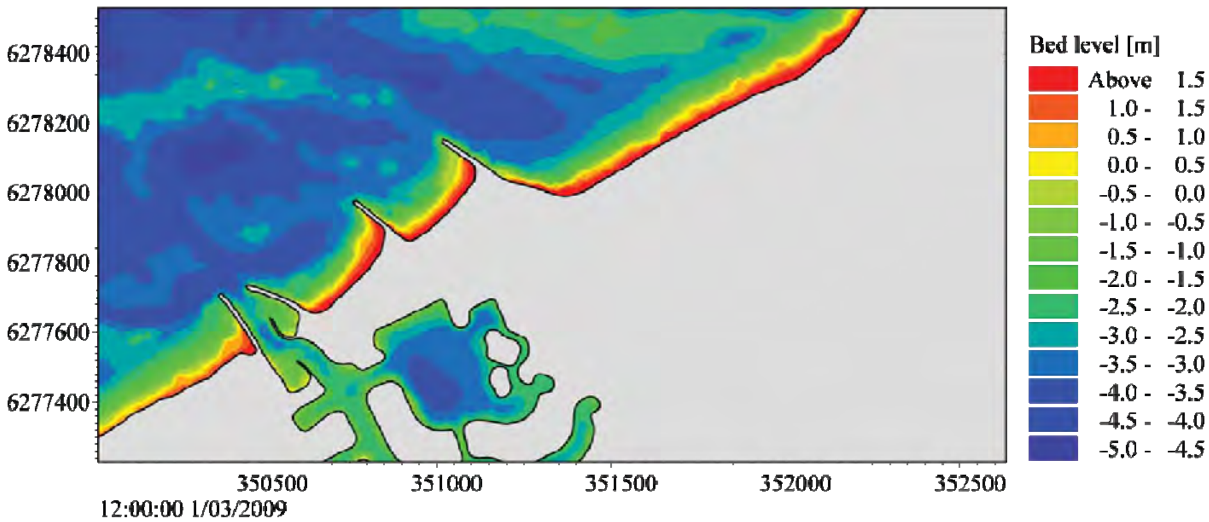


Figure 3.13 Model-predicted bed levels in the vicinity of Port Geographe on 1 March 2009

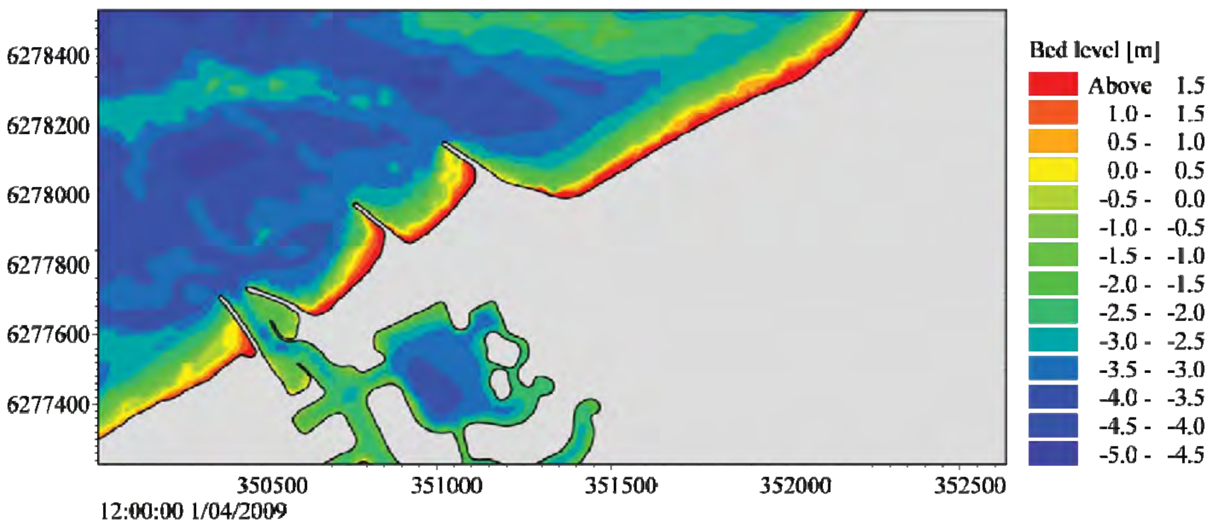


Figure 3.14 Model-predicted bed levels in the vicinity of Port Geographe on 1 April 2009.

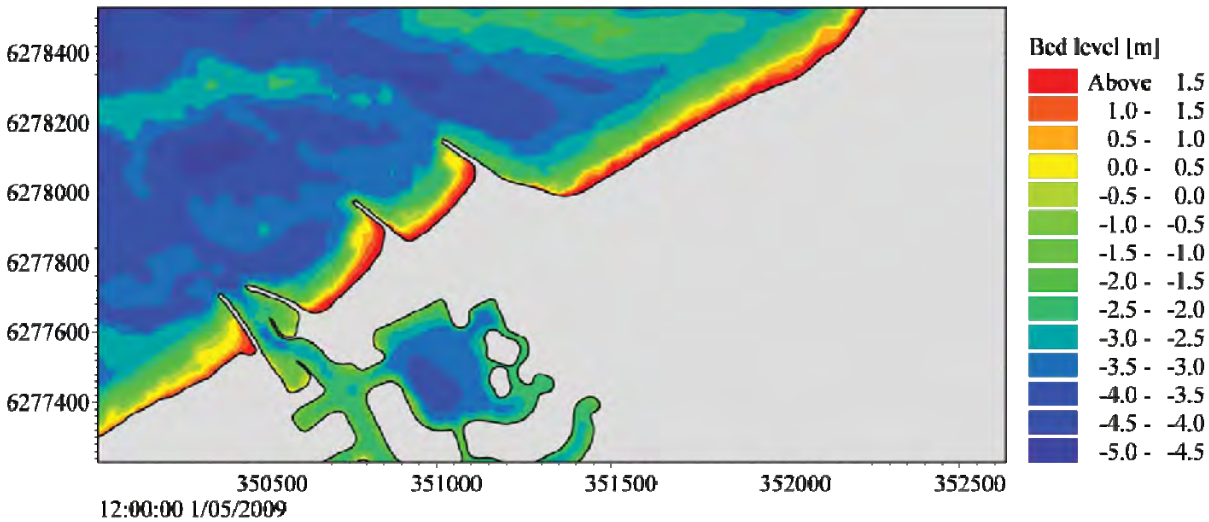


Figure 3.15 Model-predicted bed levels in the vicinity of Port Geographe on 1 May 2009.

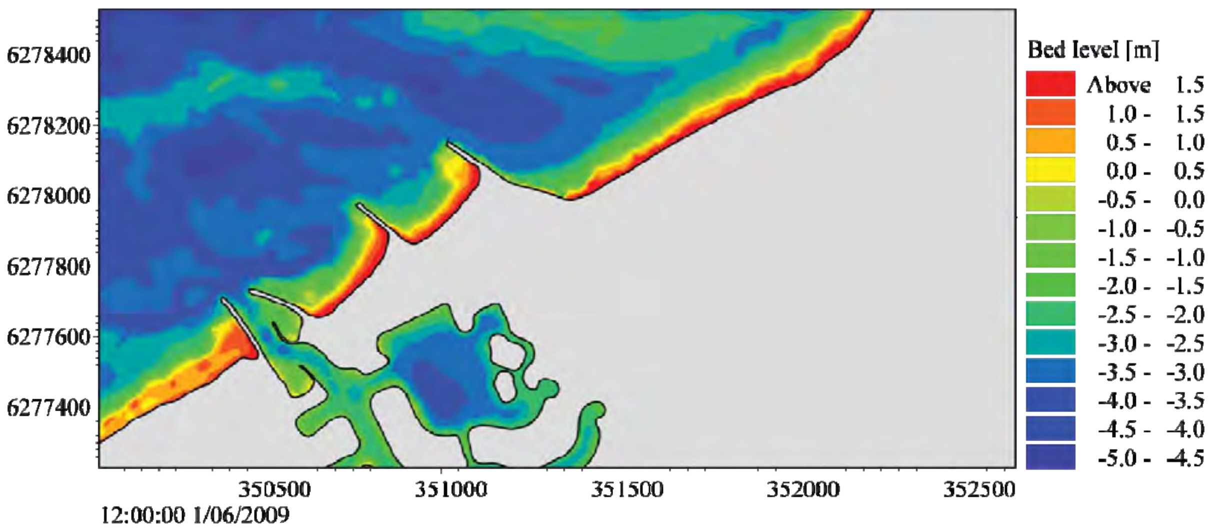


Figure 3.16 Model-predicted bed levels in the vicinity of Port Geographe on 1 June 2009.

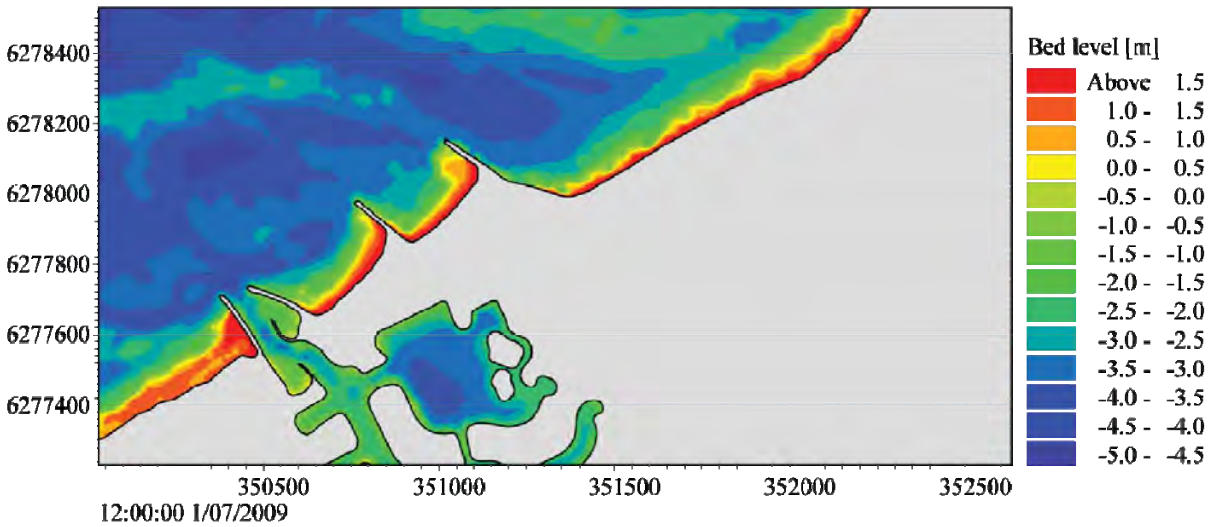


Figure 3.17 Model-predicted bed levels in the vicinity of Port Geographe on 1 July 2009.

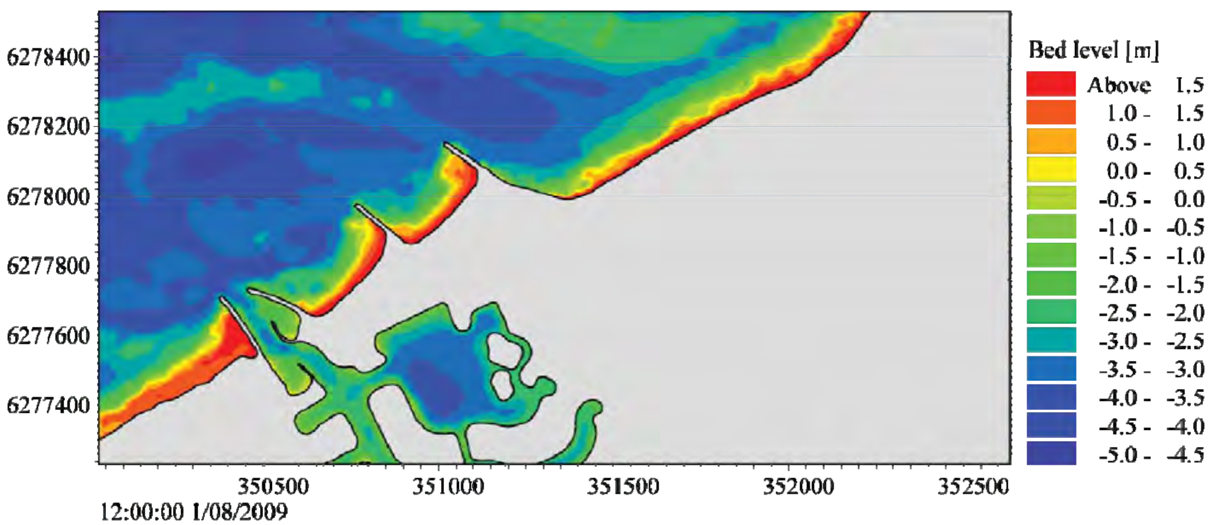


Figure 3.18 Model-predicted bed levels in the vicinity of Port Geographe on 1 August 2009.

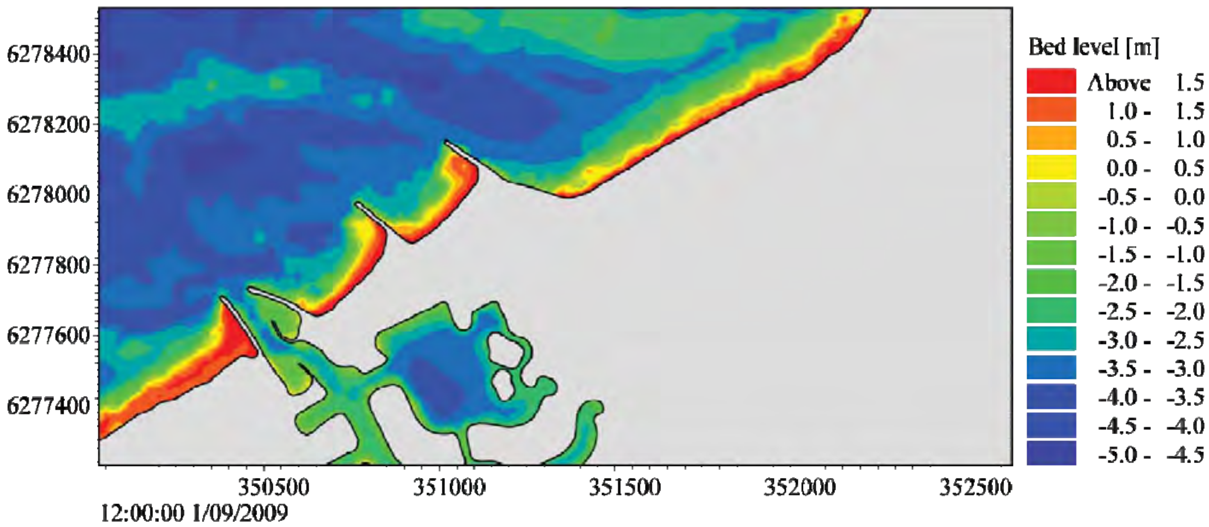


Figure 3.19 Model-predicted bed levels in the vicinity of Port Geographe on 1 September 2009.

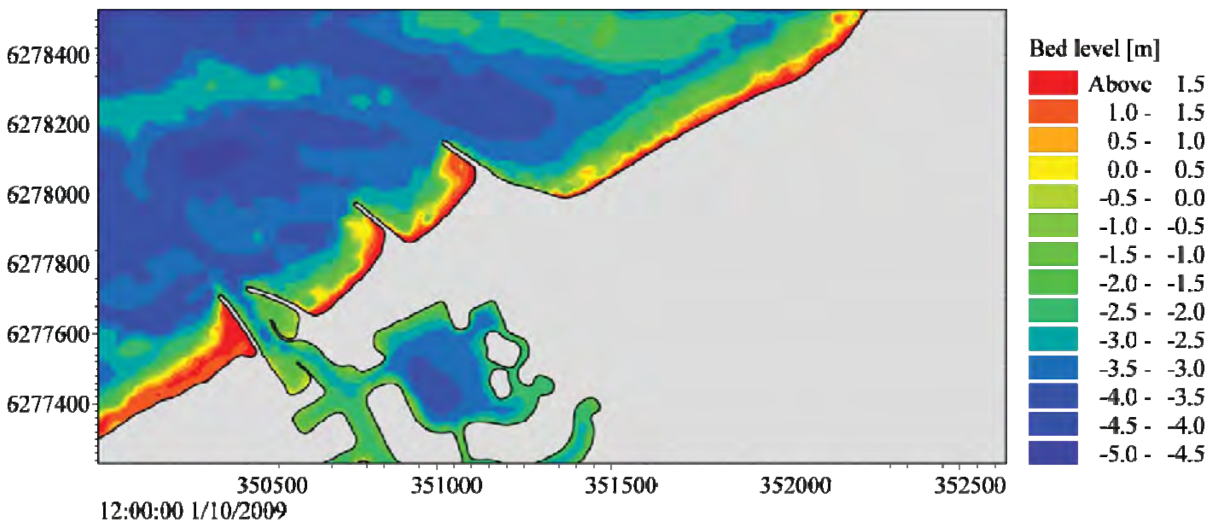


Figure 3.20 Model-predicted bed levels in the vicinity of Port Geographe on 1 October 2009.

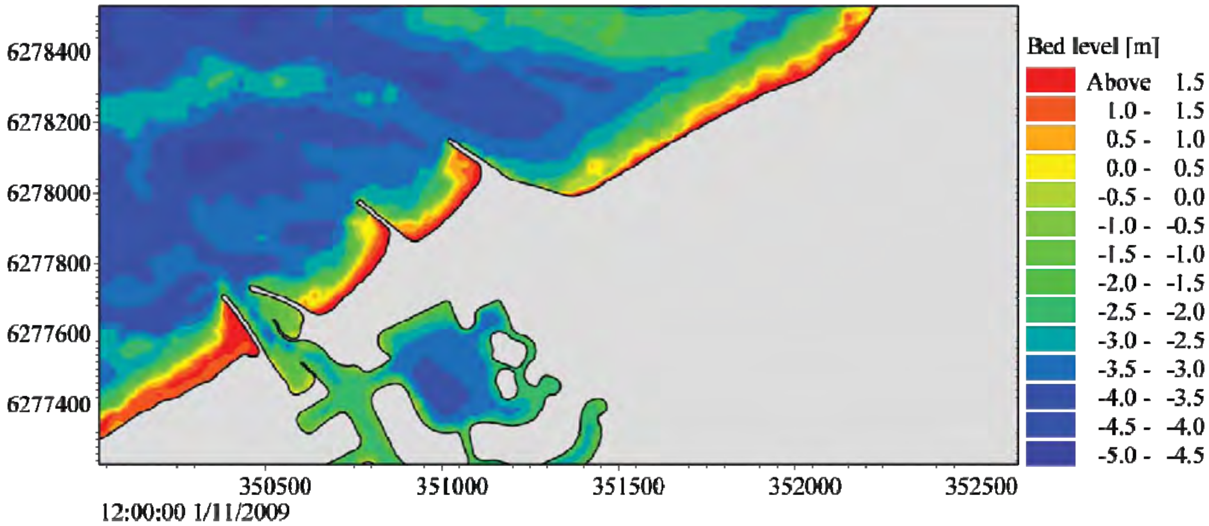


Figure 3.21 Model-predicted bed levels in the vicinity of Port Geographe on 1 November 2009.

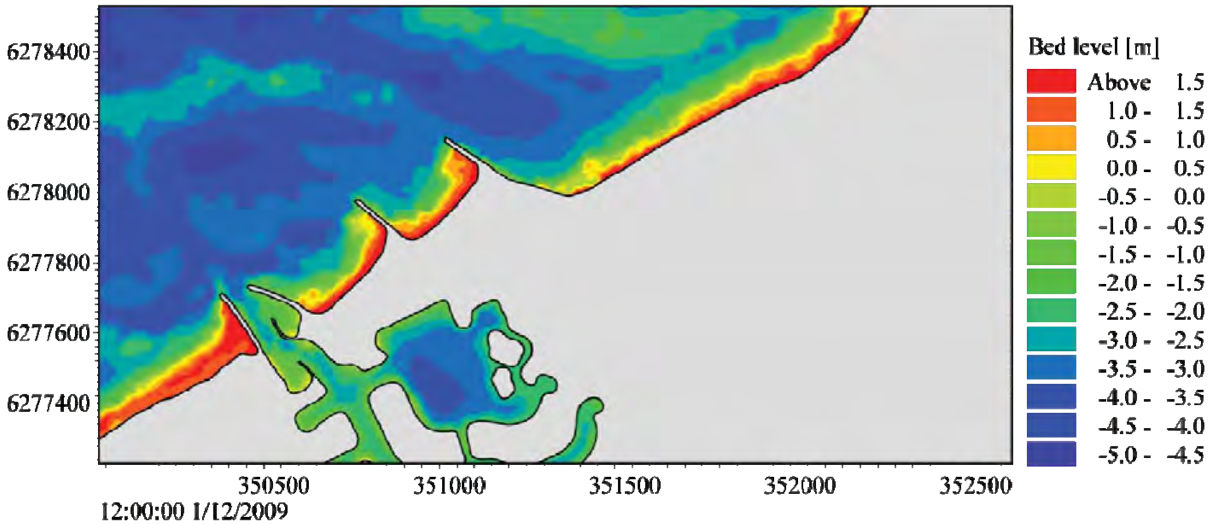


Figure 3.22 Model-predicted bed levels in the vicinity of Port Geographe on 1 December 2009.

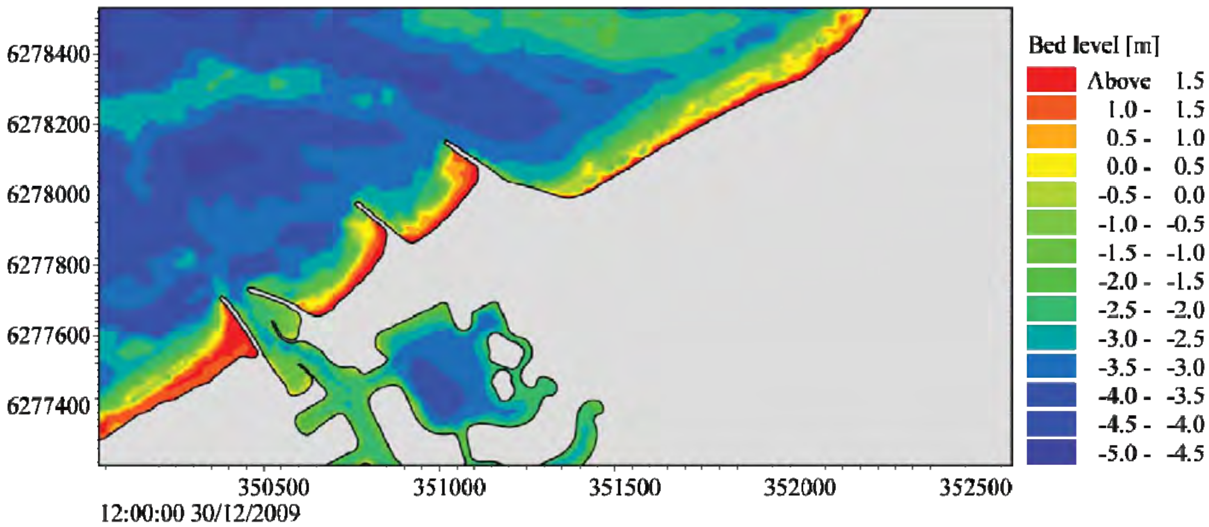


Figure 3.23 Model-predicted bed levels in the vicinity of Port Geographe on 30 December 2009.

The sand accumulation and erosion volumes at the western and eastern beaches were estimated using the predicted bed level changes using:

$$\Delta v^t = \sum_{j=1}^{n} \Delta a_j (h_j^t - h_j^{t-1})$$

Where, Δv is total accumulated or eroded sand volume in a selected area (Figure 3.24), Δa is mesh area, h is bed level. The total number of meshes within the selected area is $j \times n$ and t denotes time step. The monthly sand accretion variation and cumulative volumes areas up-drift of the groyne are shown in Figure 3.25.

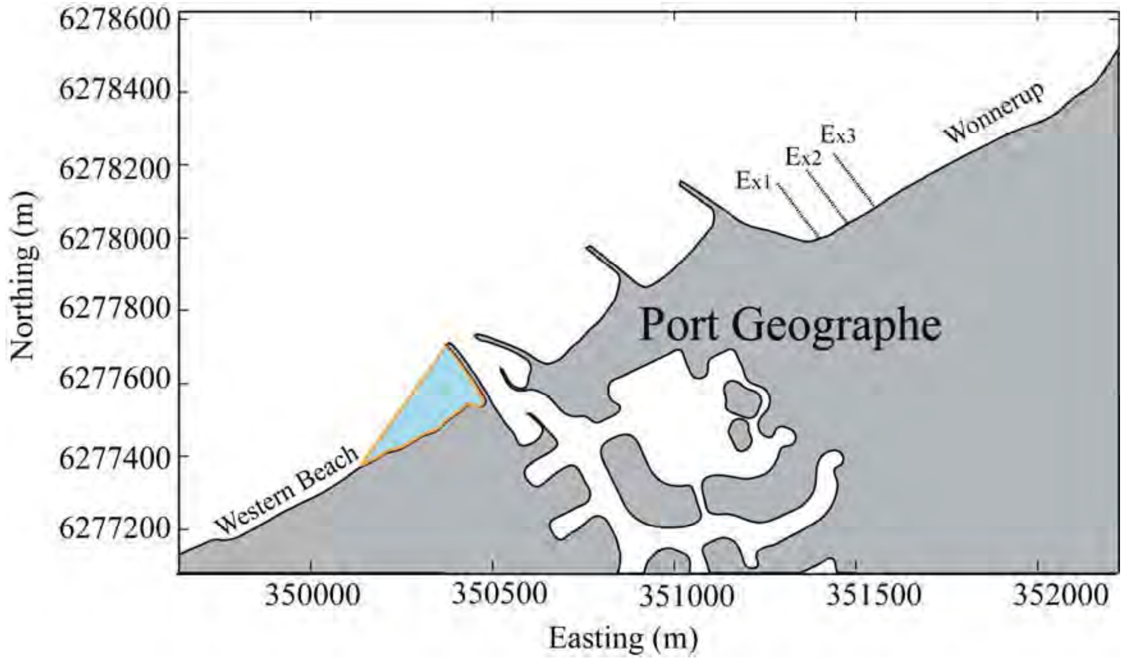


Figure 3.24 Port Geographe: area selected (light blue) to estimate accretion/erosion of sand along the western beach.

As expected the model demonstrated that sand accreted on the western side of the Port Geographe marina while erosion occurred on the eastern Wonnerup beaches. The cumulative sand volume at the western beach was calculated to be about 78,000 m^3 for the year 2009. In recent years annual processes to manually bypass the sand build up from the western beach to Wonnerup Beach has ranged between 50,000 to 70,000 m^3. Sand removed from the sand trap area following the 2009 winter (relatively stormy) was estimated to be 70,000 m^3. Sand removed from sand trap area following the 2010 winter was estimated to be 60,000 m^3. The initial estimates prior to the construction of the development were for 50,0000 m^3 of sand accumulation per year or higher in stormy years.

These figures imply that the volume of sand varies annually depending on the season. Interestingly, in 2009, the amount of sand build up indicated by the model correlated well with the volume that physically accumulated and was subsequently bypassed. A comparison of surveyed and modelled beach profiles to the eastern side of the marina in 2009 is shown in Figure 3.26.

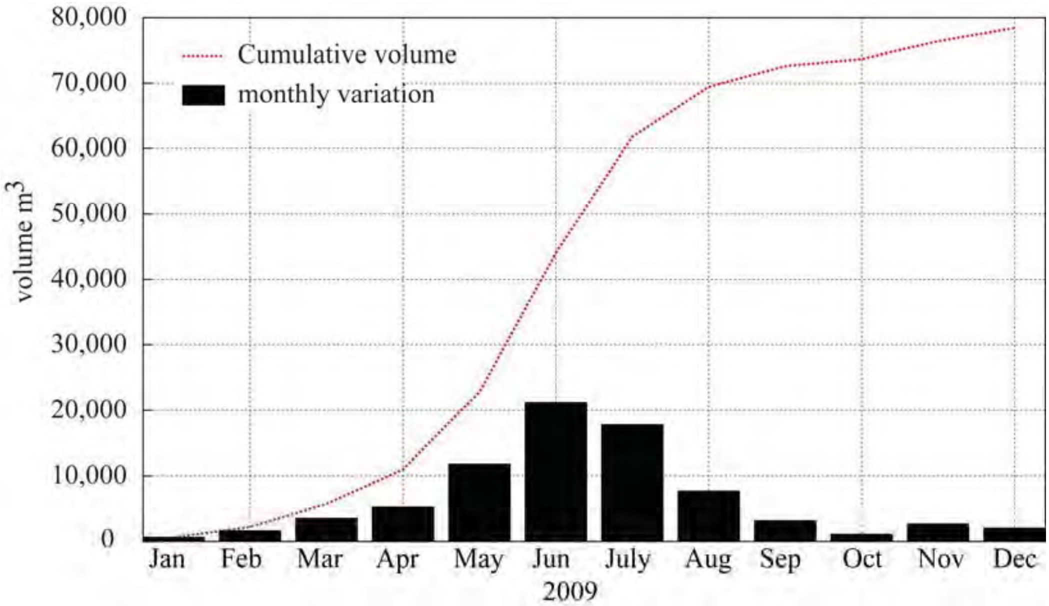


Figure 3.25 Monthly sand accretion variation and cumulative sand volume reported from the model in 2009 on western side of marina.

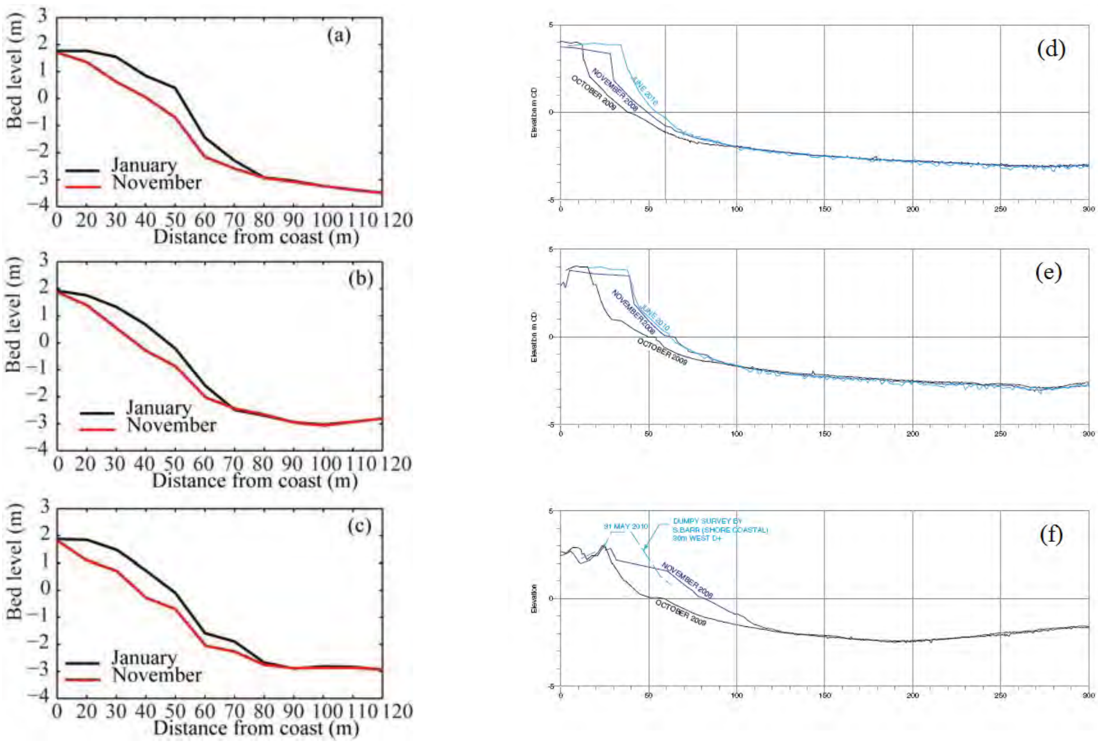


Figure 3.26 Comparison between predicted and measured beach profiles in 2009 along Wonnerup Beach. (a) to (c) predicted profiles; (d) to (f) measured profiles (see Figure 3.24). (a) and (d) for section Ex1; (b) and (e) for section Ex2; and, (c) and (f) for section Ex3.

3.4 Seagrass wrack transport

In the previous modelling experiments associated with the earlier seagrass study, onshore/offshore wrack movements and depositions in the vicinity of Port Geographe were evaluated. However, shoreline changes due to sediment transport were not included in that earlier modelling. In this updated modelling exercise temporal beach variation (i.e. from the coupled sediment transport morphological model) has been incorporated within the wrack transport model. Figures 3.27 to 3.30 show model-simulated seagrass wrack movement along the beach in 2009 and accretion at western parts of the Port Geographe foreshore, with seagrass particles seeded into the model at the end of March. Particles were seeded into the model four times on 31st March 2009 during different tidal states (low, rising mid, high and falling mid); each time 50,000 particles were distributed in the near shore area. Seagrass wrack transport takes place during winter months, and is particularly associated with storm events. At the end of July 2009, it was physically observed on site that most of the seagrass wrack accumulation was on the western shoreline of the harbour and within the groyne fields to the east. Some seagrass wrack had moved into the harbour entrance and deposited within the Port Geographe harbour entrance channel. Consistent with these observations, the model simulations revealed that the strongest accumulation of wrack occurred on the western beach. It can also be seen that some seagrass wrack accumulated within the eastern groyne field, particularly in the western inner corners. Figure 3.31 shows a time series of cumulative wrack (particle) accumulation on the western side of the Port Geographe marina. A total of 47,000 particles were reported trapped at the western side of the breakwater.

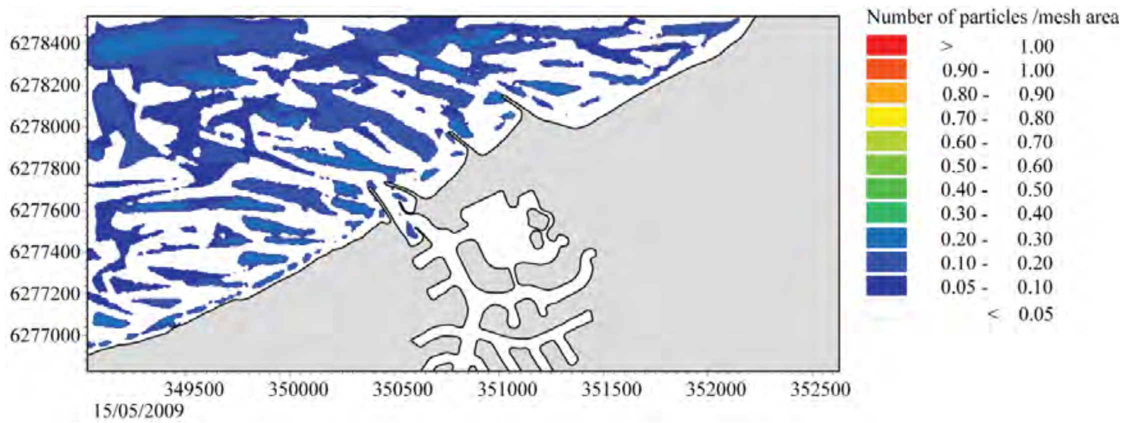


Figure 3.27 Particle distribution in the vicinity of Port Geographe on 15 May 2009.

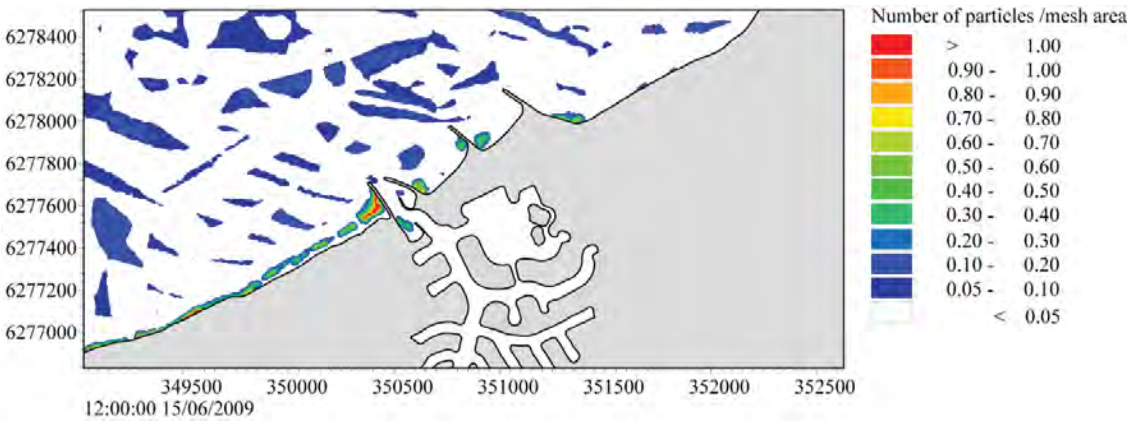


Figure 3.28 Particle distribution in the vicinity of Port Geographe on 15 June 2009.

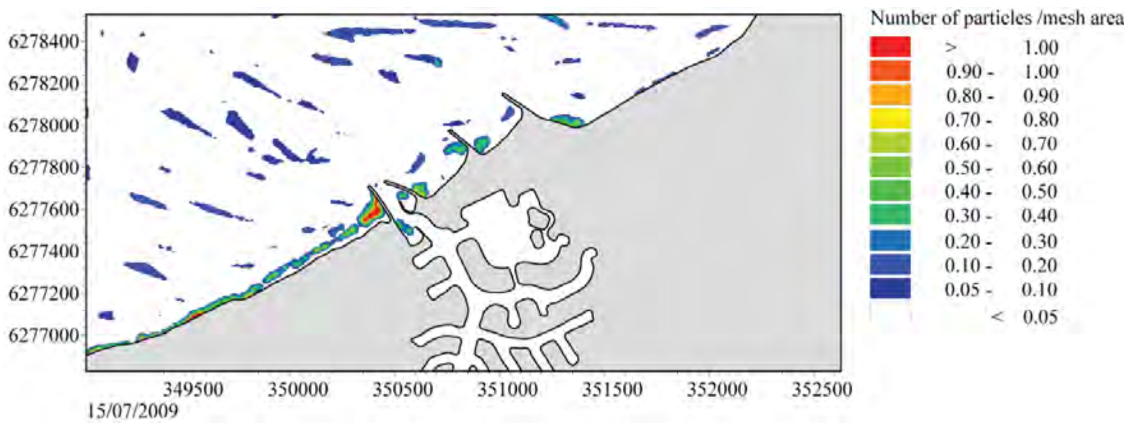


Figure 3.29 Particle distribution in the vicinity of Port Geographe on 15 July 2009.

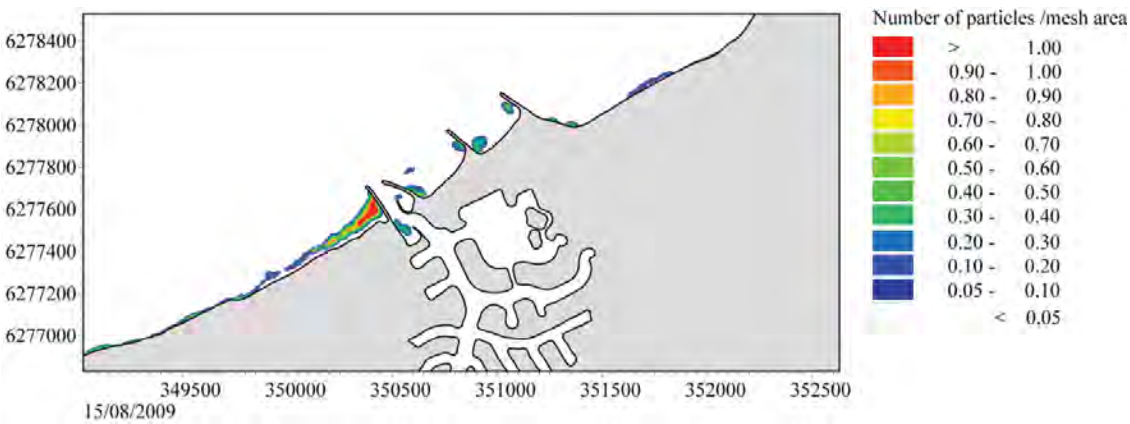


Figure 3.30 Particle distribution in the vicinity of Port Geographe on 15 August 2009.

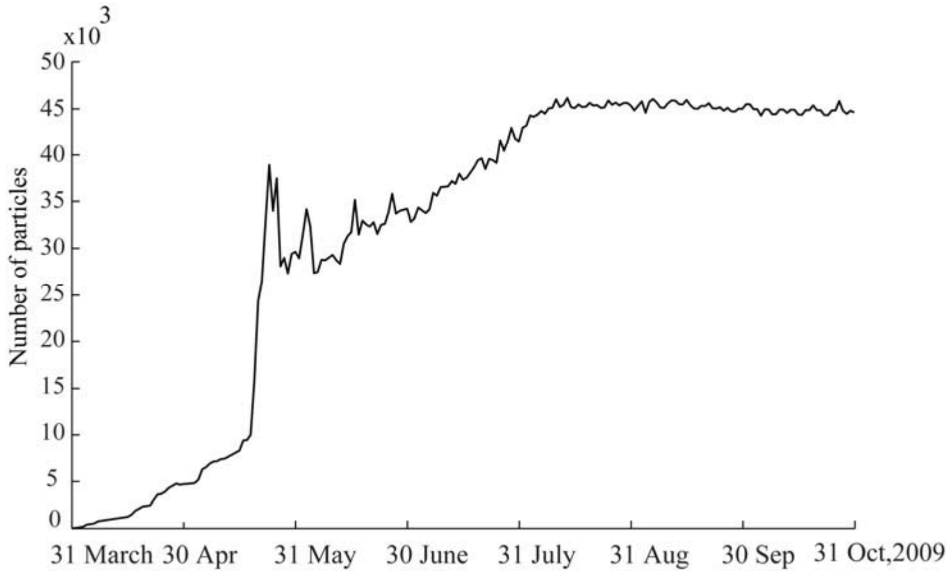


Figure 3.31 Cumulative number of particles, trapped along, western beach, Port Geographe (see Figure 3.24)

3.5 Conclusions

A coupled model validation has been performed successfully in terms of hydrodynamics, wave climate, sand and seagrass wrack transport. There was a good agreement between the predicted sea levels and current velocities with measured data. The model skill level was 0.97 for measured and predicted sea levels at near shore Busselton AWAC site. The model-predicted wave parameters also agreed with measured data in terms of wave height, period and direction.

The sediment transport and morphological models were validated against annual littoral sand transport capacity in the vicinity of Port Geographe. The predicted volume of sand trapped along the western side of Port Geographe in 2009 was ~78,000 m^3. This compared well with the annual bypass volumes from the western beach to Wonnerup beach of 50,000 to 70,000 m^3 (Shore and Beach, 2010).

The particle transport model-predicted temporal and spatial distributions of particles were found to be well correlated with observed seagrass wrack movements. As observed (Oldham et al., 2010), predicted particle movement revealed that during winter, the wrack continuously accumulated on the beaches and were transported towards the east, while particles on the western side of beaches were trapped along the training wall at western side of Port Geographe. A total of 47,000 particles were trapped at the western side of the training wall, i.e. nearly one quarter of particles of initial seeded amount. The model demonstrated that the majority of particles were trapped from May to July and were associated with early winter storms.

4 MODEL SCENARIOS

4.1 Introduction

Groynes are normally built perpendicular to the shoreline with the purpose of protecting a section of the shoreline by interrupting the littoral sand drift, whereby sand (sediment) accumulates on the upstream side of the groyne. However, any structure that interrupts the natural longshore transport of sediment will eventually be saturated and sand will start bypassing the structure. The region upstream of the groyne accumulates sand and results in accretion of the shoreline, which may take several years to achieve an equilibrium state, dependent on the rate of longshore transport. The trapping of sand in such structures causes changes to the sand budget (balance of sand quantities on each side) and results in erosion on the lee side (or down-drift) of the structure due to a deficit in the sand supply. Often curved groynes, considered to be hydrodynamically ’smooth’, are constructed in some harbour inlets (see Brøker et al., 2003) to avoid sand deposition at the entrance and to naturally bypass sand to downstream areas once the groyne is saturated.

At Port Geographe, perpendicular breakwaters (or groynes) were built to avoid sand deposition at the harbour entrance and to maintain sufficient depth through the harbour entrance channel to ensure safe navigation. A sand bypass system was also planned to pump sand from the west to the east on to Wonnerup Beach. Unfortunately, it has become clearly evident that these breakwaters and groynes have become the primary structural cause of the seagrass wrack accretion on the western beach of the Port Geographe development and within eastern side groyne fields and pocket beaches. Removing the structural cause of the problem will achieve a reduction in seagrass wrack accumulation, maintain amenity in areas currently affected by sediment and seagrass wrack accumulation and ensure a natural bypass of seagrass wrack to beaches east of the development. However, the complete removal of groynes would cause siltation of the harbour entrance and result in many other environmental problems to the Port Geographe marina and canal estate.

Previous modelling exercises (Oldham et al., 2010), examined alternative physical layouts to Port Geographe in terms of seagrass wrack accumulation. Two layouts (Options 3 and 6) proposed by MJ Paul Associates (2005) were selected for initial model experiments (Scenarios 1 and 2), which were considered representative of the key design elements within the MJ Paul configurations. Based on the results of these, five additional design layouts were modelled, which were suggested by the Port Geographe Study Steering Committee (Scenarios 3 to 7). The physical and other changes considered for seagrass wrack modelling included modifications to:

- western breakwater (length, orientation, shape, etc.)
- eastern groyne field (extend, remove, shape)
- eastern sea wall to reduce erosion at the western end of Wonnerup Beach (shape).
- western beach shoreline (orientation, beach extent, etc.)
- harbour entrance (navigable width)
- harbour entrance channel waterway fluxes (pumping at upper canal segments)

A total of seven different layouts were modelled, plus the current configuration. Based on the most promising scenario from a seagrass wrack by-passing perspective, it was concluded that Scenario 5 was the optimal groyne configuration for improved management of seagrass wrack around Port Geographe. However, due to the nature of the previous model set-up, which excluded sediment transport, the model did not have the ability to dynamically upgrade hydrodynamic fields due to seasonal shoreline/bathymetry changes. Also, morphological changes to the system as a result of the structural changes were unknown, as well as the implications of the changes on the navigability of the harbour entrance channel.

In the modelling studies detailed here, the simulations were undertaken with a new model set-up as described in Section 2 (i.e. a coupled hydrodynamic, wave, seagrass and sediment transport model). The model simulations used the existing groyne configuration as a base case (Scenario 1). Then, the Scenario 5 layout from the previous model runs (Oldham et al., 2010) utilised both seagrass and sediment transport simultaneously, using the coupled model. Based on model outcomes further changes were made to the Port Geographe layout to obtain an optimal configuration for both seagrass wrack and sand management problems. The aim of each of the model layouts were to:

(1) minimise seagrass wrack accumulation along the western beach adjacent to the Port Geographe western breakwater;

(2) maintain a navigable entrance channel at Port Geographe;

(3) retain a stable beach at Wonnerup; and

(4) select scenarios that represent the least possible change to the existing structures and that limit reclamation requirements to reduce costs of the proposed reconfiguration.

The performance of the different layouts was evaluated quantitatively (in terms of the predicted seagrass wrack accumulation and sand deposition) by comparing with the existing case in key areas of interest: the western beach, Port Geographe harbour entrance channel and Wonnerup Beach.

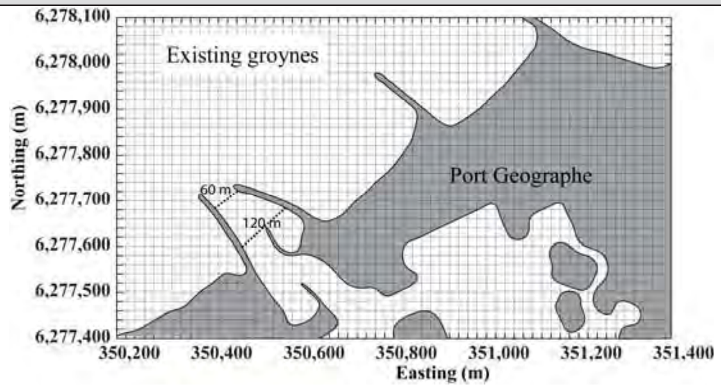
During the modelling of different scenarios, other issues such as water quality in the Port Geographe canals resulting from physical changes to the existing configuration were also considered. Whilst the aim of the modelling experiments was to obtain an improved layout for the coastal structures at Port Geographe, a secondary consideration related to how water quality within the canal network might be affected by the proposal.

A total of eight scenarios, including the existing configuration, were tested and are summarised in Table 4.1 (see also Figures 4.1 and 4.2).

Initially, each scenario was run with the 2009 bathymetric and meteorological data, following which, selected scenarios were extended into further testing across 2010 conditions. Table 4.2 shows the simulated periods for each of the model scenarios.

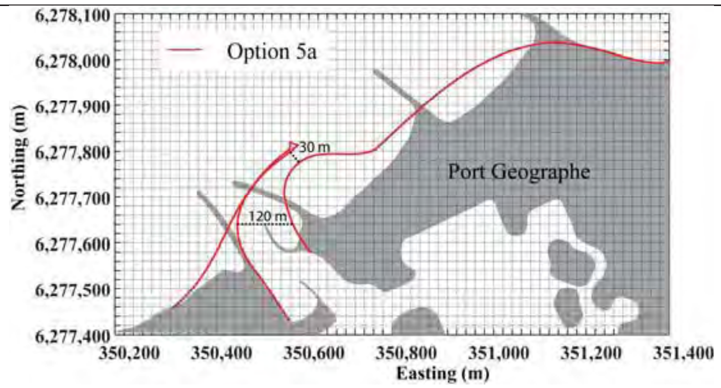
The model mesh grids were reconstructed for each of the proposed groyne re-configurations. The initial bathymetry for all scenarios was based on LIDAR survey data undertaken in August 2008. The results obtained from the coupled model simulations with different layouts are discussed in the following section.

Table 4.1 Summary of key features of the Port Geographe structural layouts for each of the scenarios.

<table>
<tr><th>Scenario/ Option</th><th>Layout</th><th>Physical dimensions of western breakwater, entrance channel and seawall/groynes</th></tr>
<tr><td>1/Existing</td><td>


</td><td>Breakwater perpendicular to the coast and tip at 180 m from the coast.

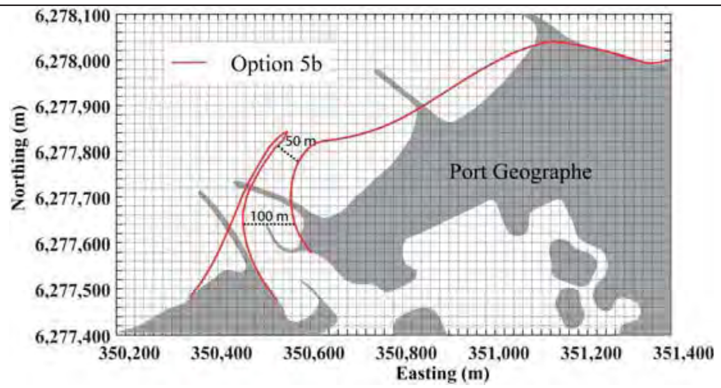
Harbour entrance 60-m wide at mouth and 120 m at mid channel section.

3 quasi-perpendicular groynes to the eastern side of harbour entrance.</td></tr>
<tr><td>2/5a</td><td>


</td><td>Curved western breakwater, tip at 160 m from the coast.

Harbour entrance 30 m at mouth and 120-m wide at mid channel section.

Seawall with concave bulge at harbour entrance.

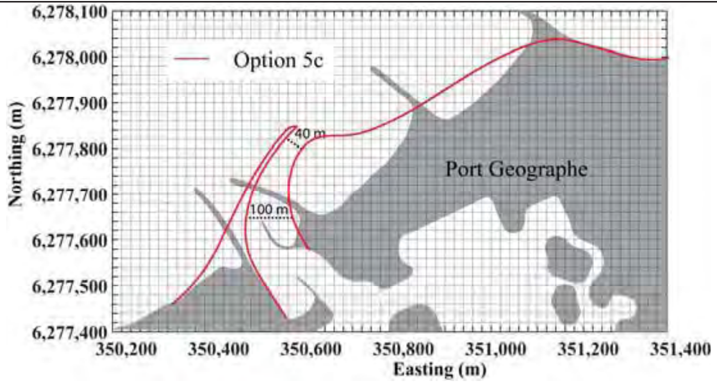
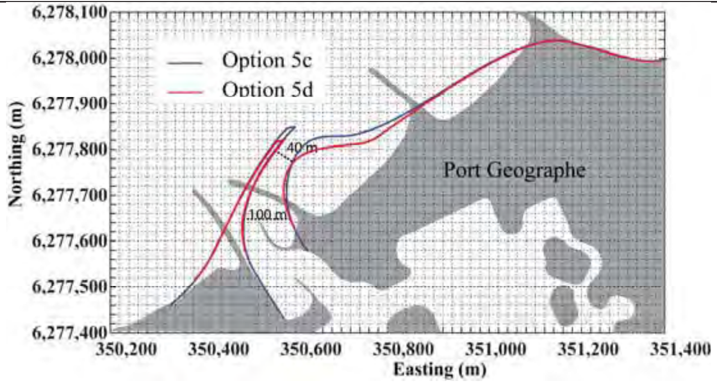
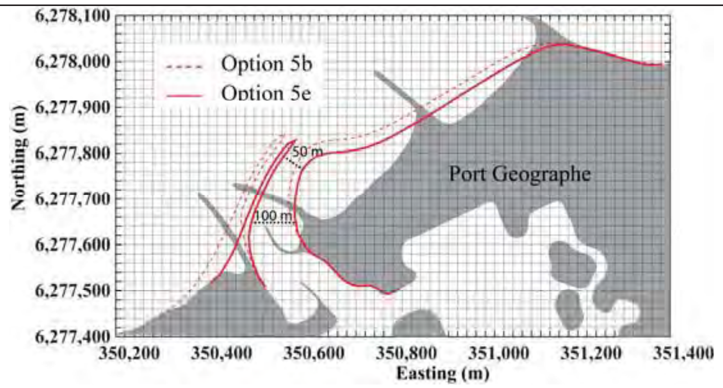
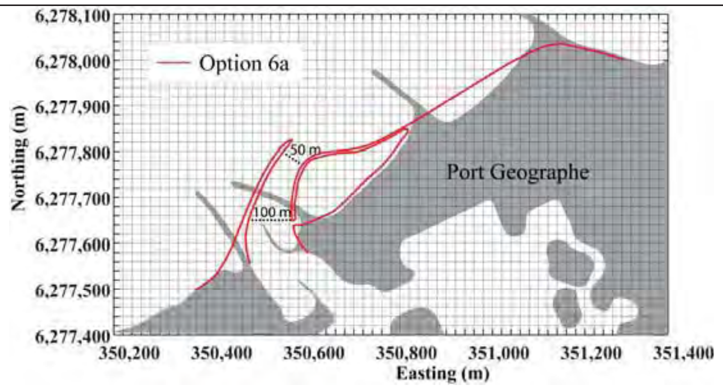
Seawall is nearly parallel to shore line.</td></tr>
<tr><td>3/5b</td><td>


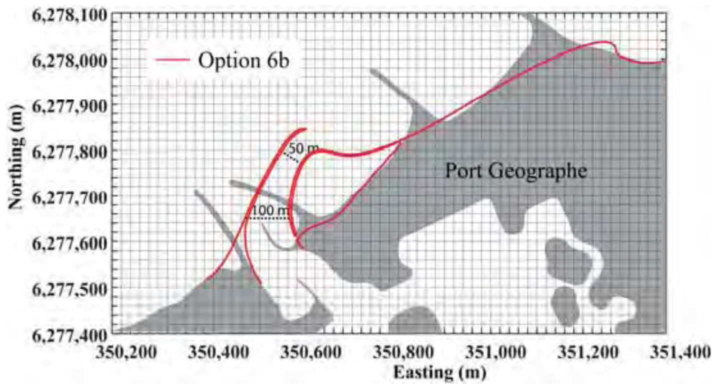
</td><td>Curved western breakwater, tip at 180 m from the coast.

Harbour entrance 50 m at mouth and 100-m wide at mid canal section.

Seawall with concave bulge at harbour entrance.

Seawall is oblique to shore line.</td></tr>
</table>

4/5c		Curved western breakwater, tip at 180 m from the coast. Harbour entrance 40 m at mouth and 100-m wide at mid channel section Seawall with concave bulge at harbour entrance. Seawall is oblique to shore line.
5/5d		Curved western breakwater, tip at 170 m from the coast. Harbour entrance 40 m at mouth and 100-m wide at mid channel section. Seawall with concave bulge at harbour entrance. Seawall is oblique to shore line.
6/5e		Curved western breakwater, tip at 160 m from the coast. Harbour entrance 50 m at mouth and 100-m wide at mid channel section. Seawall with concave bulge at entrance. Seawall is oblique to shore.
7/6a		Curved western breakwater, tip at 160 m from the coast. Harbour entrance 50 m at mouth and 100-m wide at mid channel section. Seawall with concave bulge at harbour entrance. Seawall is oblique to shore line. Small lagoon is included behind seawall.

8/6b		Curved western breakwater, tip at 175 m from the coast. Harbour entrance 50 m wide at mouth and 100-m wide at mid channel section. Seawall with concave bulge at harbour entrance. Seawall is oblique to shore line. Small lagoon is included behind seawall.

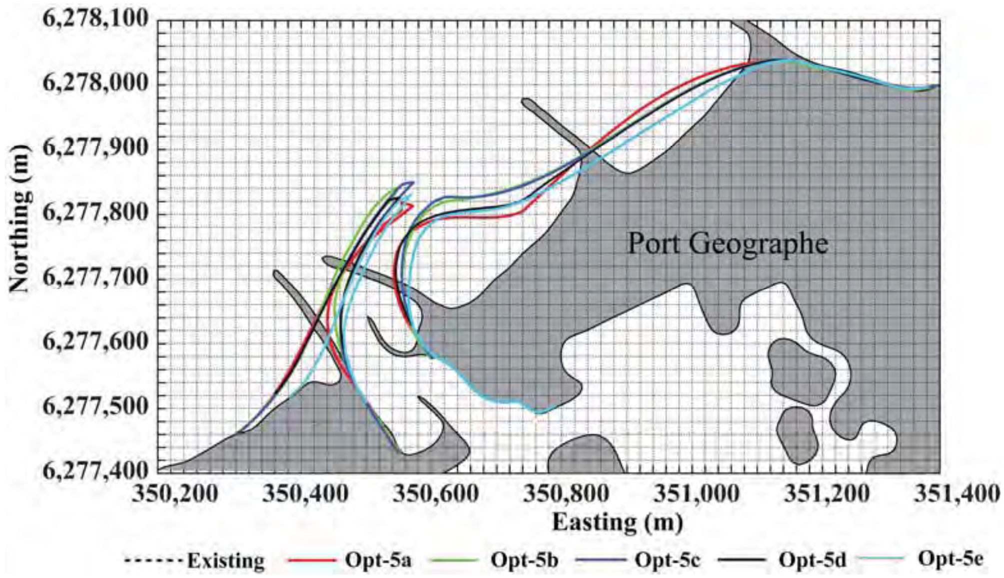


Figure 4.1: Layouts for scenarios 2 to 6, which examined different alignments of the western breakwater, harbour entrance channel dimensions and alignment of the seawall to the east of the harbour entrance.

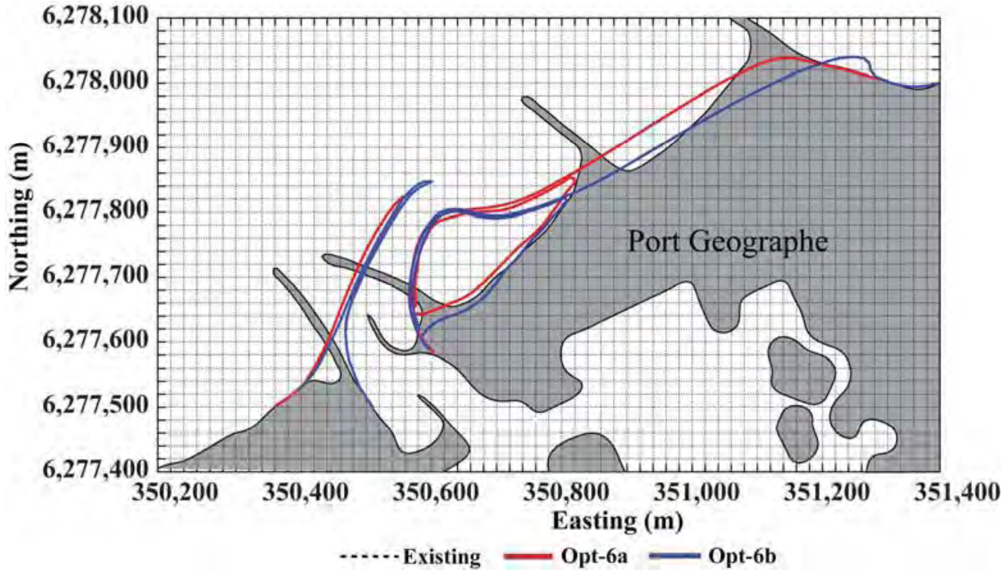


Figure 4.2: Layouts for scenarios 7 and 8 with the inclusion of a small lagoon behind the seawall.

Table 4.2: Model run periods for the different scenarios

Scenario/ layout	Period of model runs	Total length of model runs
Scenario 1/Existing	January - December, 2009; January-30 September, 2010	21 months
Scenario 2/ layout 5a	March - November, 2009	09 months
Scenario 3/ layout 5b	March - October, 2009	08 months
Scenario 4/ layout 5c	April - September, 2009	06 months
Scenario 5/ layout 5d	March - October, 2009	08 months
Scenario 6/ layout 5e	March - December, 2009	10 Months
Scenario 7/ layout 6a	March - December, 2009	10 months
Scenario 8/ layout 6b	March - December, 2009 Repeat Jan - Dec, 2009 January – September, 2010	33 months

4.2 Model Simulations: Scenario 1 (existing configuration)

The annual longshore sand transport along the Port Geographe shoreline has been estimated as varying between 50,000 and 100,000 m^3/yr. The seaward extent of the western side of the breakwater is about 180m from the shoreline. Thus, we might expect the beach on the western side of Port Geographe to be saturated within 1–2 years. The model runs of Port Geographe under the existing configuration in 2009 revealed that the beach at the western side of the breakwater was almost saturated at the end of December 2009. The model runs were extended for 2010 with the aim of evaluating whether there could be natural by-passing of sand and seagrass wrack when the western beach was saturated (i.e. the beach is extended seaward to the end of the breakwater).

The coupled (hydrodynamic, wave, sediment and seagrass wrack transport) model set-up for Geographe Bay with the existing groyne configuration was described in Section 2. The model was validated by comparing predicted hydrodynamics (sea levels, currents), wave climate, sediment and seagrass wrack transport with measured/observed data in 2009 as described in Section 3. The model was forced with water levels, wind and wave climate data in 2010 as shown in Figures 4.3 to 4.7 respectively. Analysis of water levels, wave and wind data revealed that 2010 was a less stormy year when compared to the meteorological conditions of 2009. The model initial bathymetry (i.e. model-predicted bed levels for 31 December 2009 in the 2010 simulation) is shown in Figure 4.14.

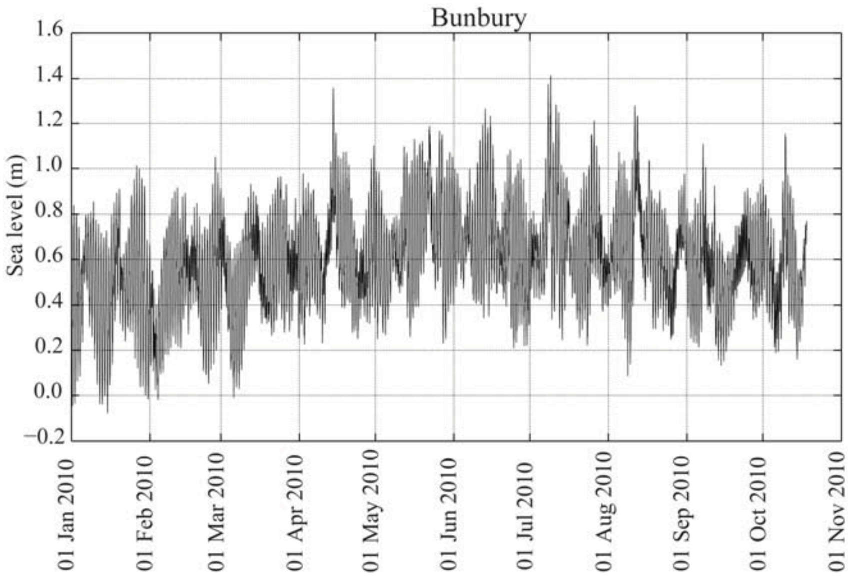


Figure 4.3 Open boundary water level forcing data in 2010 from the Bunbury tide gauge (source: Western Australian Department of Transport).

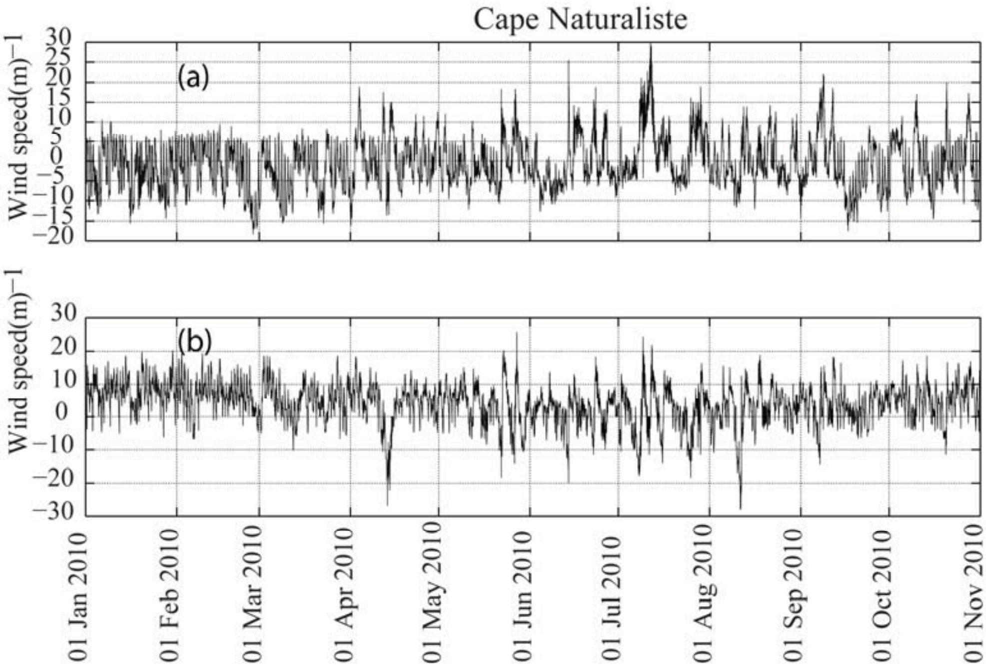


Figure 4.4 Wind speed (a) North-South (b) East-West components from Cape Naturaliste meteorological station in 2010 (source: Bureau of Meteorology).

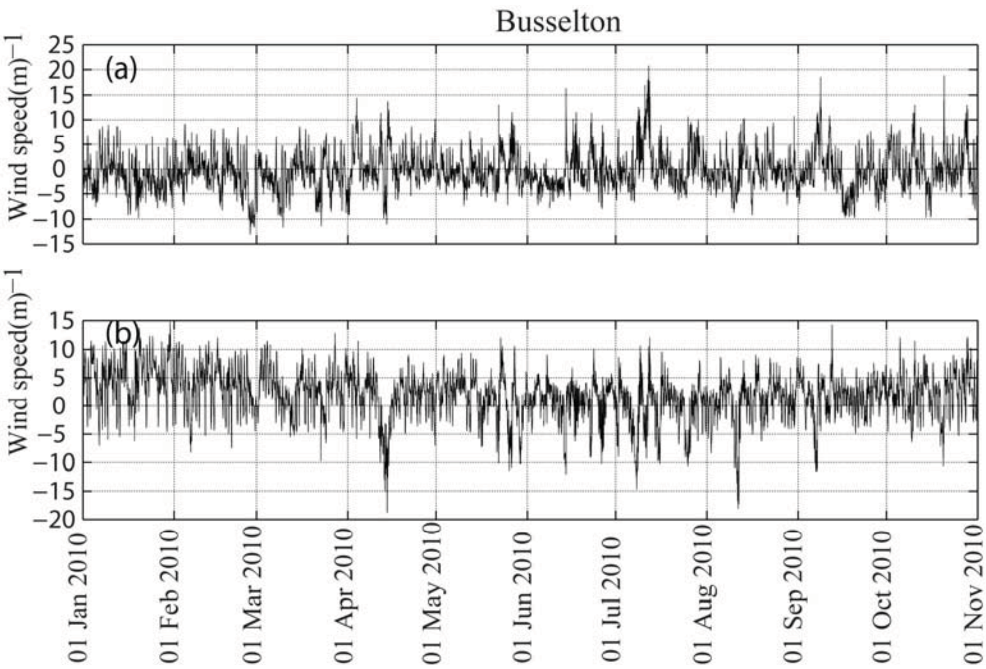


Figure 4.5 Wind speed (a) North-South (b) East-West components from Busselton meteorological station in 2010 (source: Bureau of Meteorology).

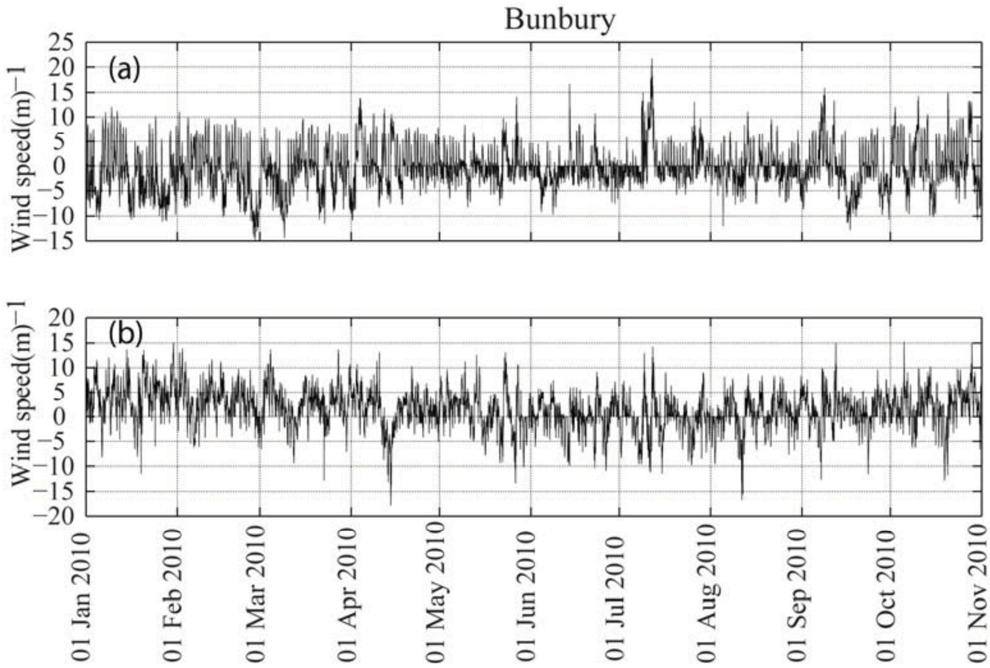


Figure 4.6 Wind speed (a) North-South (b) East-West components from Bunbury meteorological station in 2010 (source: Bureau of Meteorology).

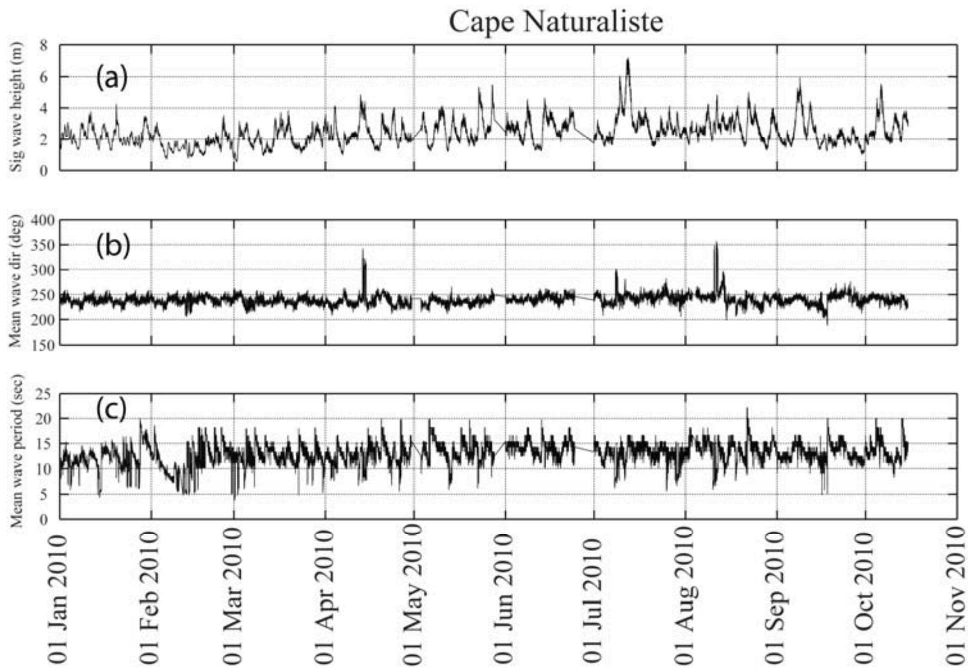


Figure 4.7 Open boundary wave climate forcing data in 2010, obtained from the Cape Naturaliste Wave Buoy (source: Western Australian Department of Transport). (a) Significant wave height, (b) mean wave direction and (c) mean wave period.

4.2.1 Currents and wave climate

Currents usually transport the sediment mobilised by wave action. Knowledge of the current regime is therefore necessary to understand the erosion and accretion pattern. Vector plots of currents in the vicinity of Port Geographe during the 20–22 May 2009 storm are shown in Figures 4.8–4.11. It can clearly be seen that there is a strong variation in current pattern during the storm in relation to wind speed and direction. The velocity field during north-easterly winds generated the anti-clockwise eddy circulation in the lee of the groynes; clockwise eddy circulation occurred during south-westerly winds. During periods of wind direction changes and low wind speeds, current eddy were generated in the offshore sand bar areas. The current pattern at the western side of Port Geographe changed significantly with beach extent. The flows were smoother and nearly parallel to the coast with a saturated beach.

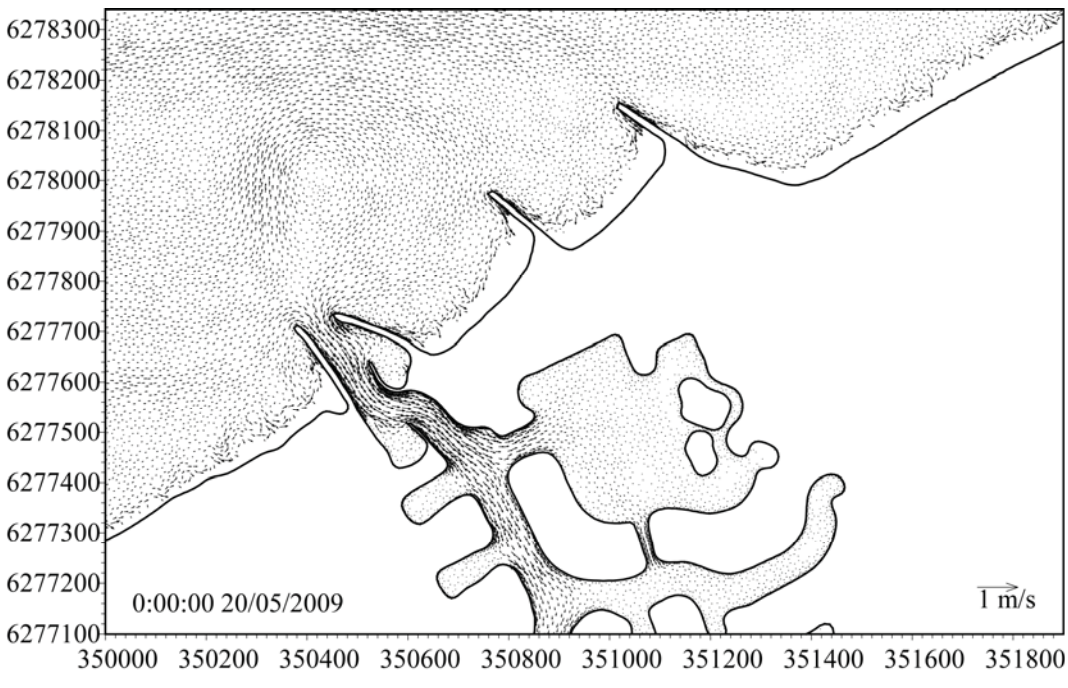


Figure 4.8 Predicted velocity vectors in the vicinity of Port Geographe prior to storm event (0000 hrs, 20 May 2009).

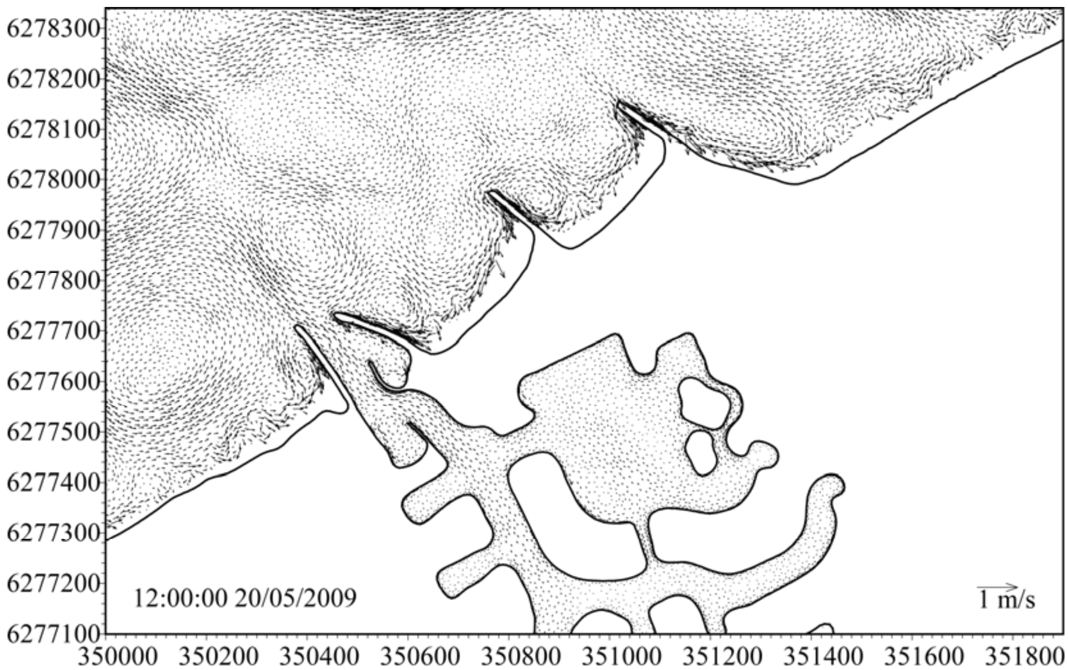


Figure 4.9 Predicted velocity vectors in the vicinity of Port Geographe at the beginning of storm event (1200 hrs, 20 May 2009).

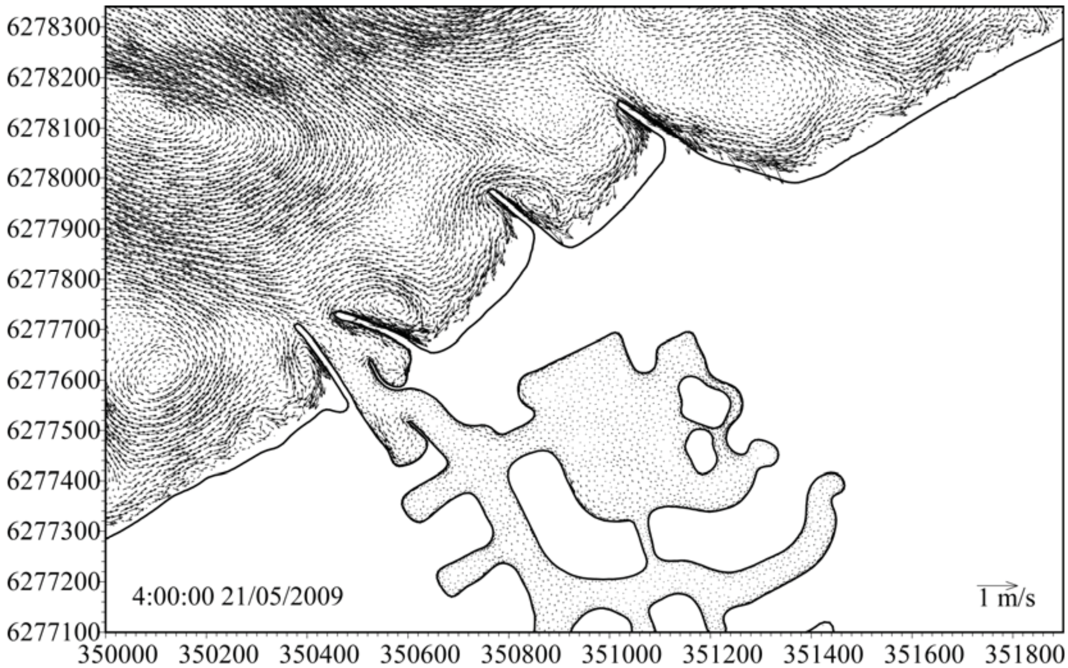


Figure 4.10 Predicted velocity vectors in the vicinity of Port Geographe during storm event (0400 hrs, 21 May 2009).

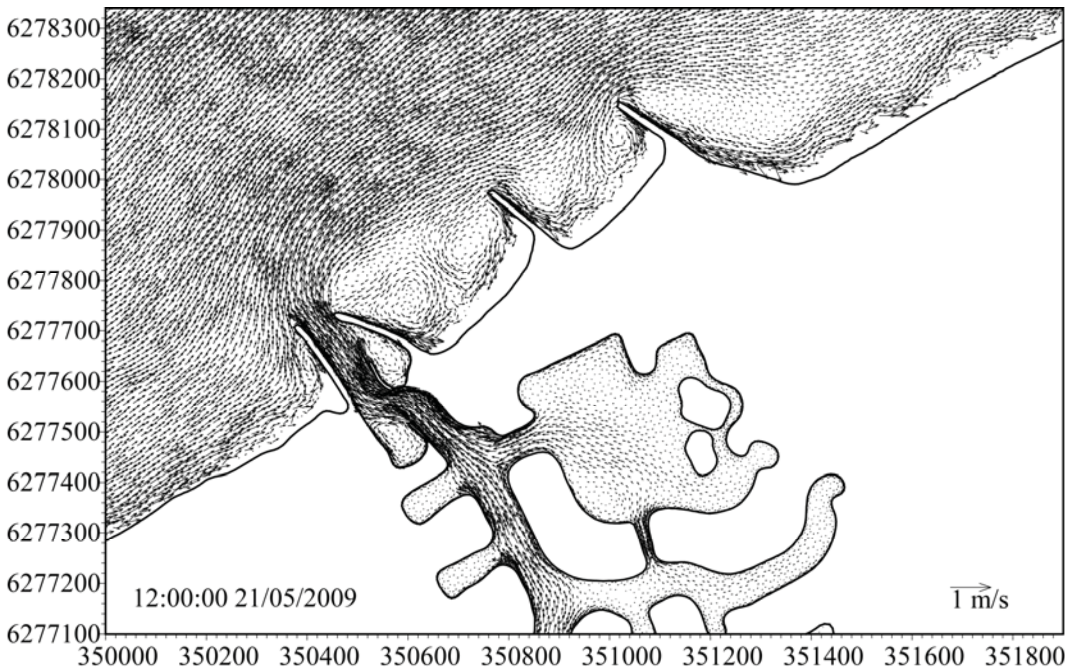


Figure 4.11 Model-predicted velocity vector plots in the vicinity of Port Geographe at the peak of storm event (0400 hr, 21 May 2009).

Wind driven surface currents normally flow at about 3% of the wind speed and these currents dominate the depth averaged barotropic flows in shallow waters. This means that by taking strong wind velocities associated with winter storms (with winds of 10 to 20 ms^{-1}) around Port Geographe, wind-driven surface currents could be up to 0.6 ms^{-1} or larger. Current speed generally increases when the wind direction is parallel to the coast. Thus the longshore component of water velocities was generally stronger than the cross-shore component.

Tidal currents are weak in Geographe Bay, where the spring tidal range is about 0.5 m. Therefore wrack movement and sand transport in the nearshore regions of Port Geographe are dominated by waves and wind driven currents, particularly during the winter months (May to September). However, flows through the Port Geographe canal segments are mainly driven by the pressure gradient set-up by sea level gradient between Geographe Bay and the inner canal segments. Thus we would expect that siltation or erosion within the entrance channel would be affected by tidal flow asymmetry, particularly during lower mean sea levels (shallow depths). The mean sea level in the Geographe Bay is low during autumn and summer (October–February), thus relatively high siltation in the entrance channel can be expected during this period.

The model predicted significant differences in the wave height distribution patterns in Geographe Bay between summer and typical winter storms as shown in Figures 4.12 and 4.13, respectively. It can be clearly seen that waves refracted around Cape Naturaliste arrive at different sections of the coast with varying heights and angles. Relatively larger waves approach the coast at Port Geographe from a northwest direction during the winter months (May–September). The wave periods are also relatively large during winter months. During summer months swell wave heights are much smaller and tend to approach the coast from a wider range of directions. Thus, during the summer months it is probable that the net sediment transport be close to zero, or that there may even be a small net easterly transport. Coastal observations certainly indicate lower sediment transport rates over the summer months.

Sediment distribution along the shoreline of Geographe Bay appears to be well correlated with wave height distribution in the bay. Fine-grain sediment (less than 0.2 mm) occurs in wave-sheltered areas (within the southern part of the bay) and medium size grains (0.3 mm) are found on the more exposed beaches in the central and northern sides of the bay.

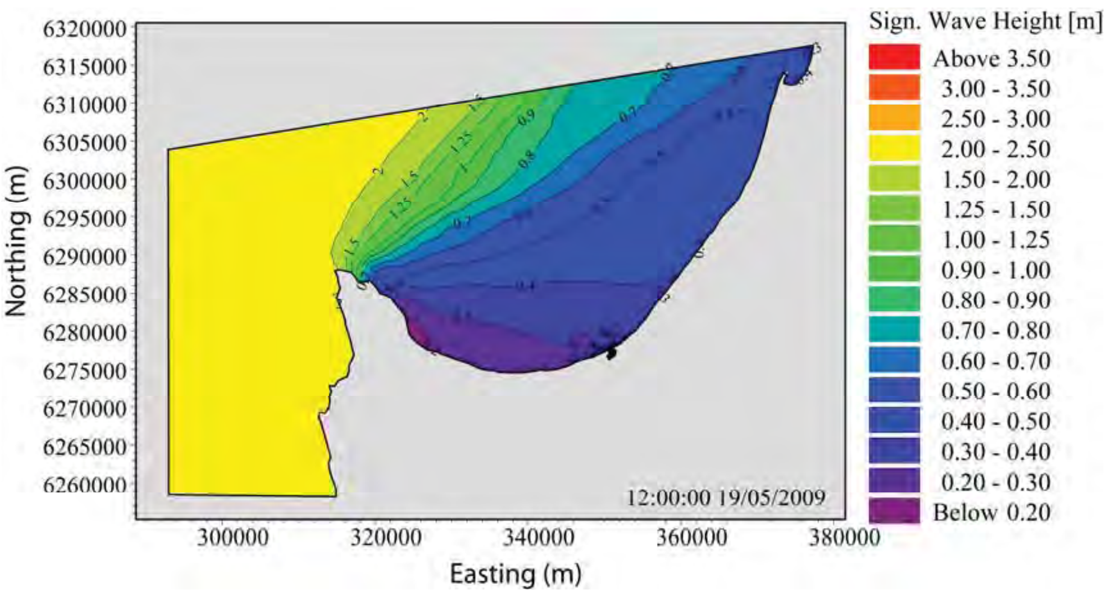


Figure 4.12 Snapshot of predicted wave height distribution before a storm event (on 19 May 2009).

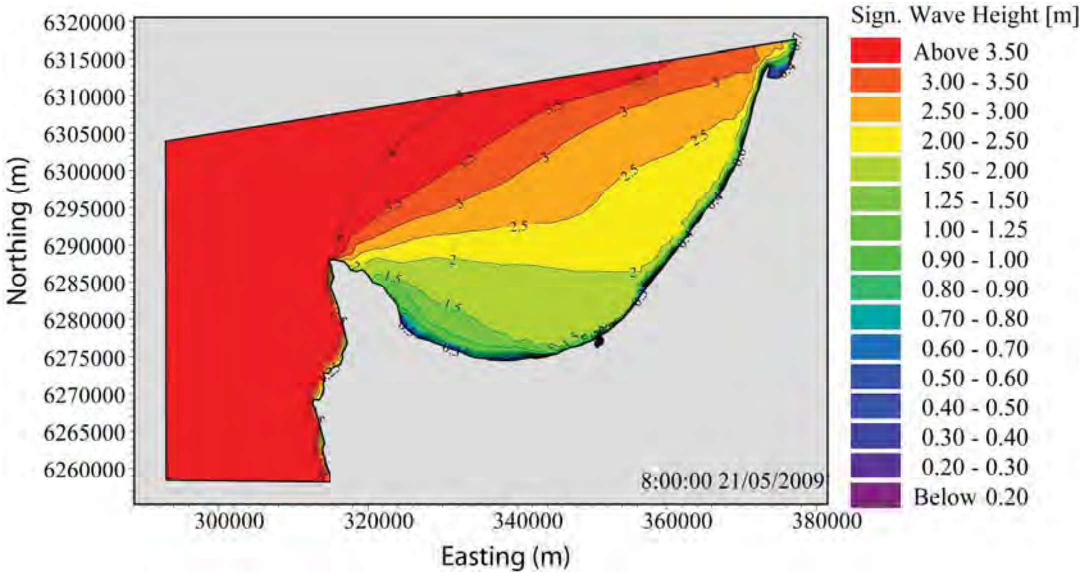


Figure 4.13 Snapshot of model-predicted wave height distribution during a storm event (on 21 May 2009).

4.2.2 Sand accretion and erosion

The model results obtained from the 2009 data demonstrated (as observed on site) that the majority of sand transport occurred during the winter months (see Figures 3.11 to 3.23 and 3.25). The results (Figure 3.25) confirmed that the western breakwater at Port Geographe performed as a total sand trap, as per its intended design. Snapshots of model-simulated bed levels changes in 2010 are shown in Figures 4.14–4.17.

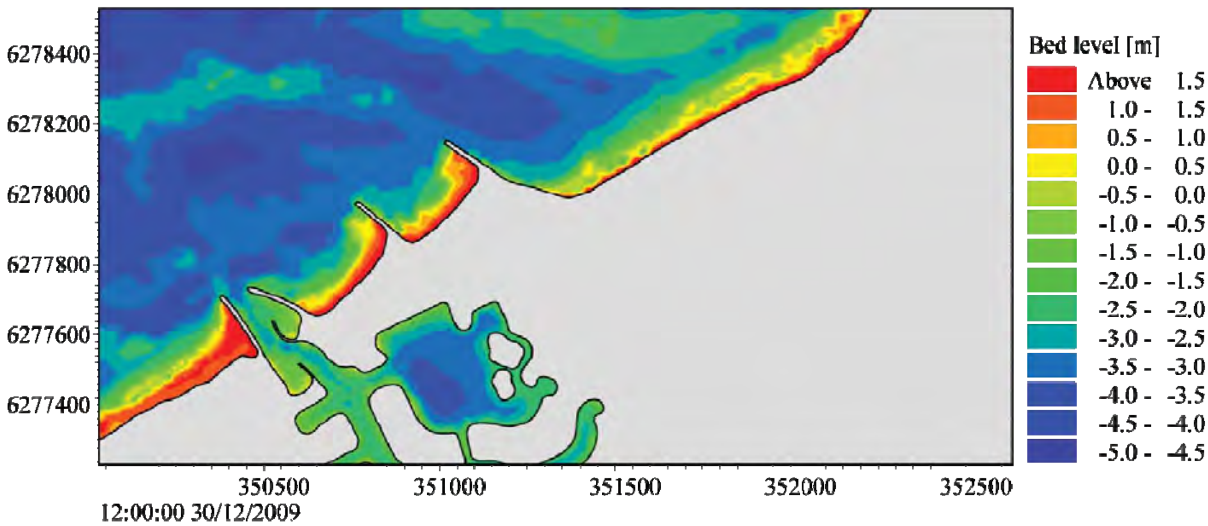


Figure 4.14 Model-predicted bed levels in the vicinity of Port Geographe on 30 December 2009 (The initial bathymetry used for the 2010 model run).

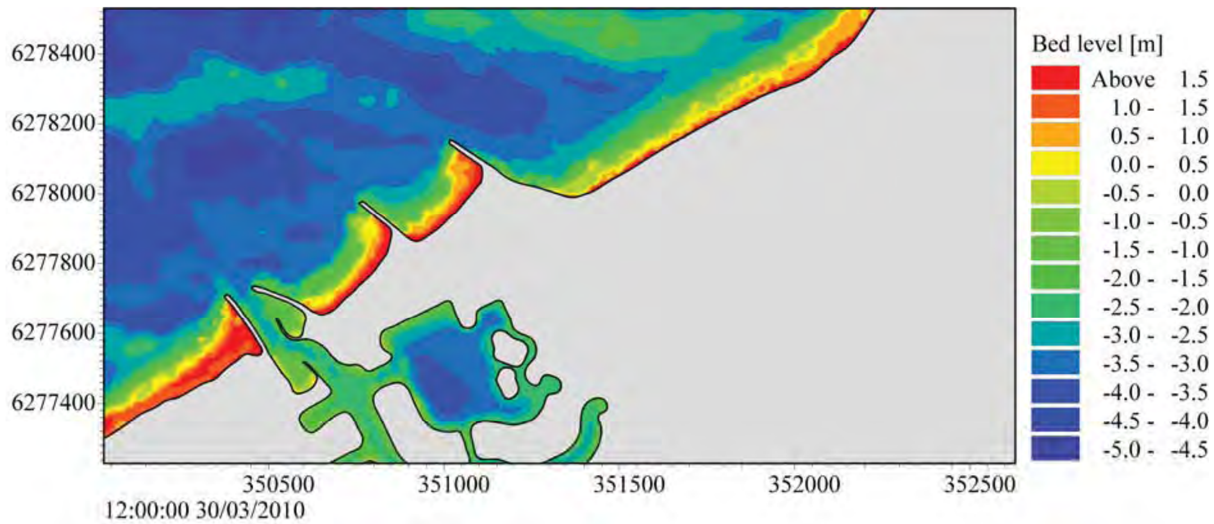


Figure 4.15 Model-predicted bed levels in the vicinity of Port Geographe on 30 March 2010.

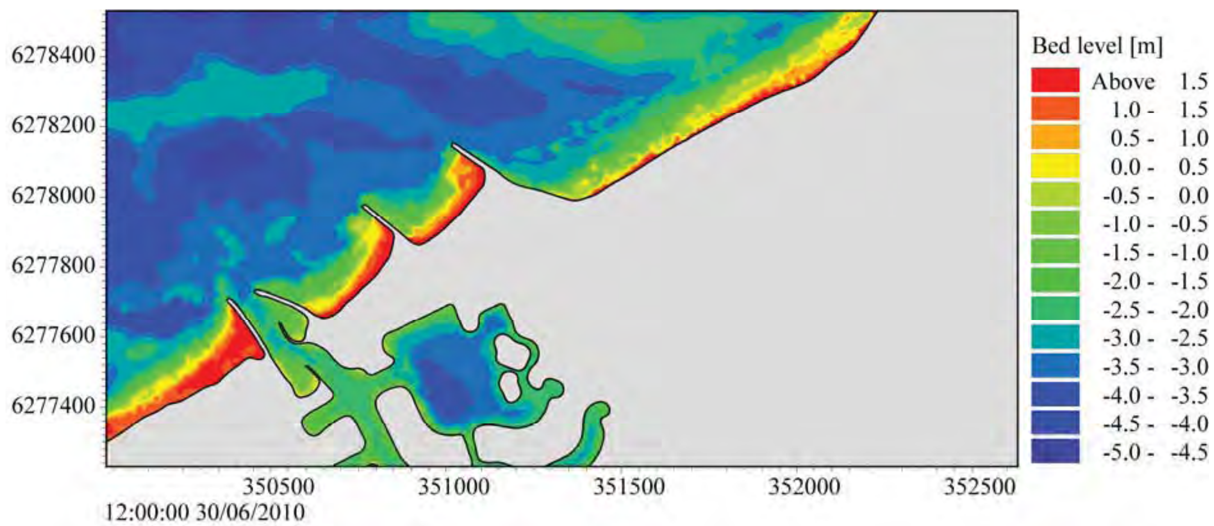


Figure 4.16 Model-predicted bed levels in the vicinity of Port Geographe on 30 June 2010.

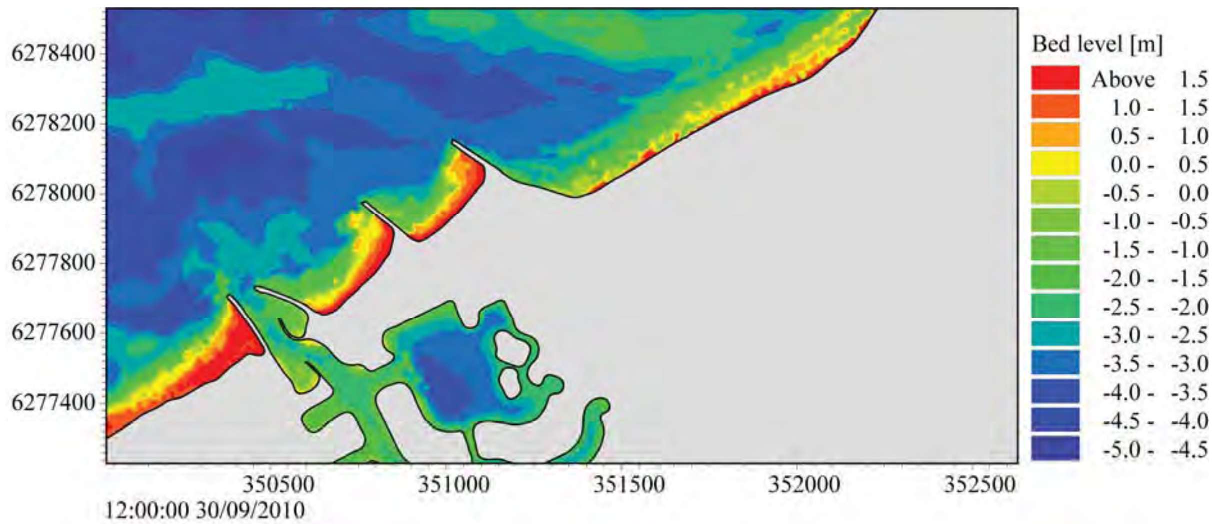


Figure 4.17 Model-predicted bed levels in the vicinity of Port Geographe on 30 September 2010.

A review of the model-predicted bed level maps (Figures 4.14 to 4.17) in 2010 revealed that significant sand bypass would occur at the western breakwater (in the absence of artificial bypassing). The model indicates that sand that bypassed the western breakwater was deposited at the front of the harbour entrance, within the harbour entrance channel and on the eastern side of the harbour entrance where it again became trapped by the eastern groynes. Erosion at Wonnerup Beach continued to be observed within the model during 2010.

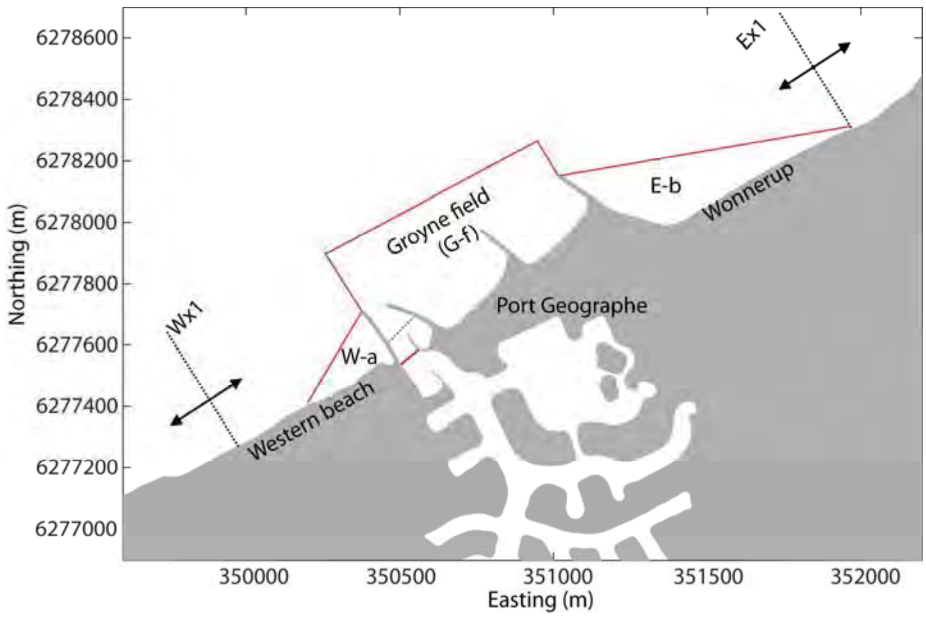


Figure 4.18 Map showing areas used to calculate the sand budget. W-a (western beach); G-f (Port Geographe foreshore); and, E-b (Wonnerup foreshore). Cross-sections to predict bedload sand transport are shown as Wx1 (western section) and Ex1 (eastern section).

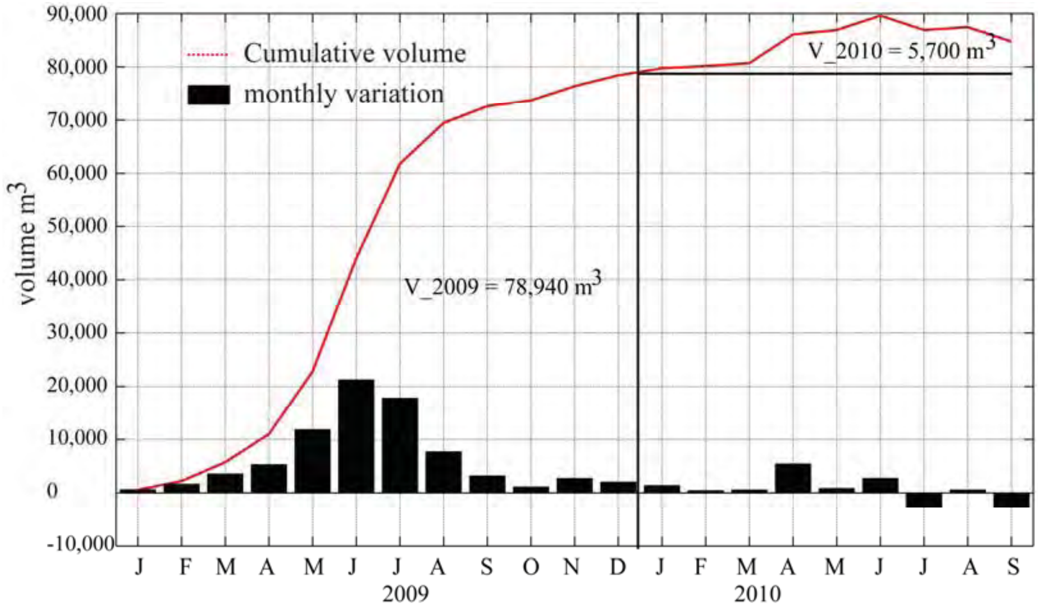


Figure 4.19 Predicted monthly sand accretion (black bars) and cumulative sand volume (red line) from January 2009 to 30 September 2010 along the western side of Port Geographe.

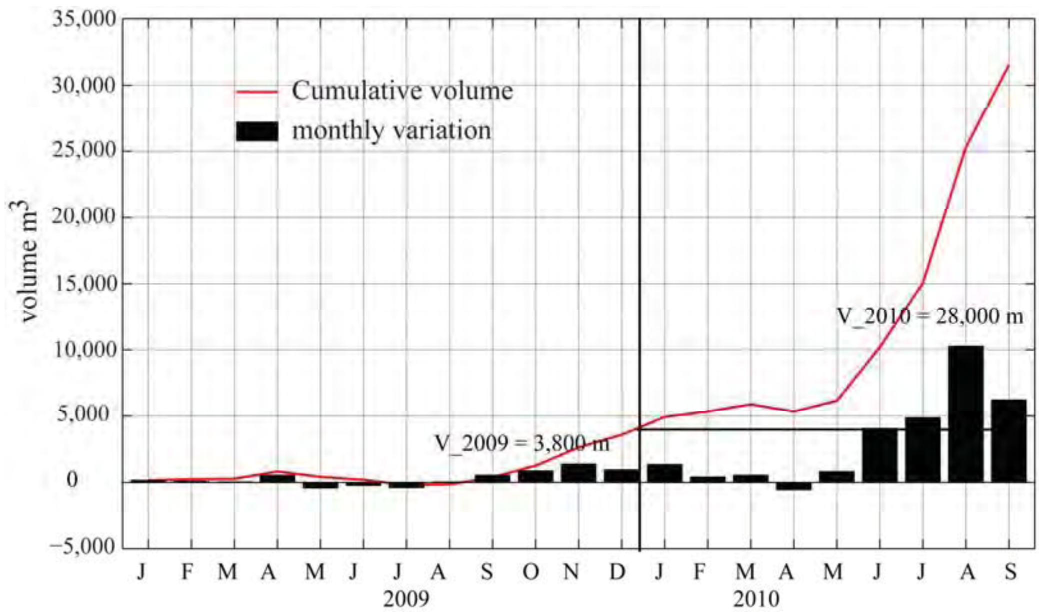


Figure 4.20 Predicted monthly sand accretion (black bar) and cumulative sand volume (red line) from January 2009 to 30 September 2010 within the groyne fields and the harbour entrance.

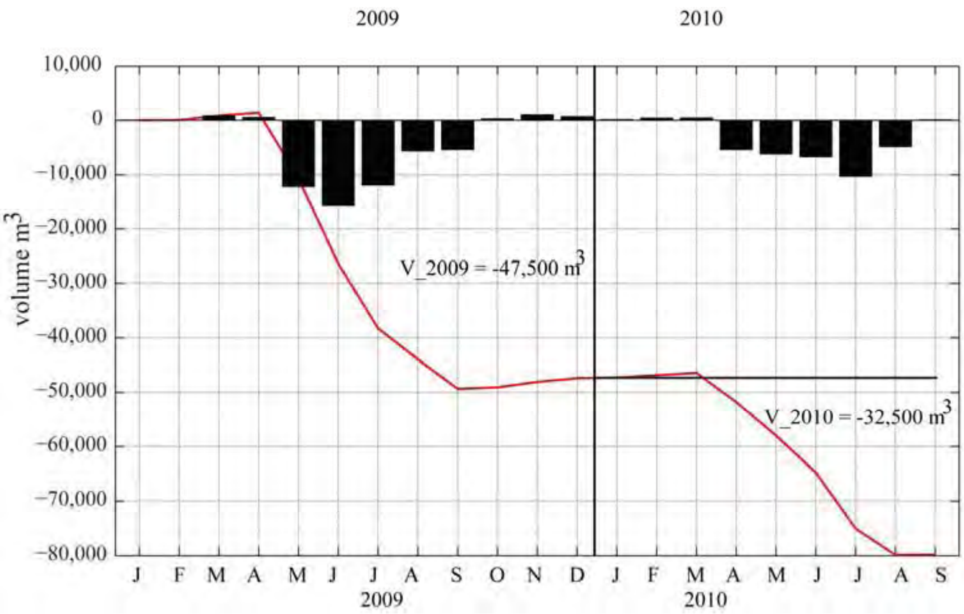


Figure 4.21 Predicted (negative) monthly sand accretion (black bars) and cumulative (red line) sand volume from January 2009 to 30 September 2010 on the eastern beach (Wonnerup). (Note: negative values signify erosion).

The rate of accretion determined from Figure 4.19 (the red line indicates cumulative sand volume and bars shows the accumulated or eroded volume for each month) was computed over the full period under consideration (i.e. from 01 January 2009 to 30 September 2010) on the western side of Port Geographe (see Figure 4.18 for selected beach areas). The cumulative sand volume at the western beach was estimated to be ~78,000 m^3 in 2009 and 5,700 m^3 in 2010 (January to September). Similar sediment accretion/erosion volume graphs were developed for other key areas including the harbour entrance channel, eastern groyne fields (Area G-f in Figure 4.18), and Wonnerup Beach (Area E-b in Figure 4.18), and these are shown in Figures 4.20 and 4.21, respectively. The model demonstrated that Wonnerup Beach eroded continuously in 2009 and 2010 with sand deficits of 47,500 m^3 and 32,500 m^3 respectively. Accretion of sand was predicted within the harbour entrance and within the groyne fields (G-f) in 2010; the estimated cumulative volume was ~28,000 m^3.

Predicted total sand accretion (western side of marina, W-a and harbour entrance, front and eastern side groyne field, G-f) from January to end of September 2010 was ~33,000 m^3. From January to the end of September 2009 the model-predicted accretion was ~75,000 m^3. These results indicate that the longshore sand transport was significantly lower in 2010 compared to 2009. The volume of sand eroded from Wonnerup beach in 2010 was estimated to be in the same order of sand accumulated in the western beach at Port Geographe. This indicates that without the presence of coastal structures at Port Geographe there would be a stable beach at Wonnerup.

The model-predicted bed level variations across the harbour entrance indicated that both erosion and siltation at the harbour entrance would occur subject to conditions (Figure 4.22). Between January and April 2009 (low wave conditions) accretion was followed by erosion between April and August 2009 coinciding with relatively stormy winter months. After August 2009 there was continuous siltation of the harbour channel particularly between April and September 2010 (Figure 4.22). The winter of 2010 was particularly mild by comparison with the winter of 2009.

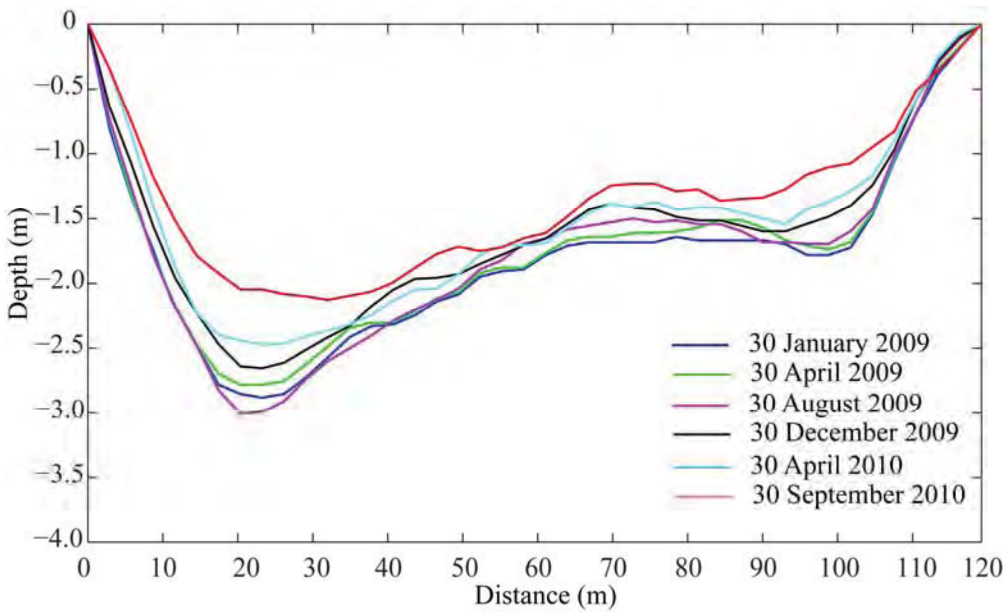


Figure 4.22 Predicted bed levels across the entrance channel (section A-B) of Port Geographe from January 2009 to September 2010.

The predicted total (bed and suspended) sediment transport through western and eastern sections of Port Geographe (see Figure 4.18) were greatest during winter months (Figure 4.23) with the cumulative load through the western (Wx1section) section estimated to be ~190,000 m^3 in 2009 and 2010.

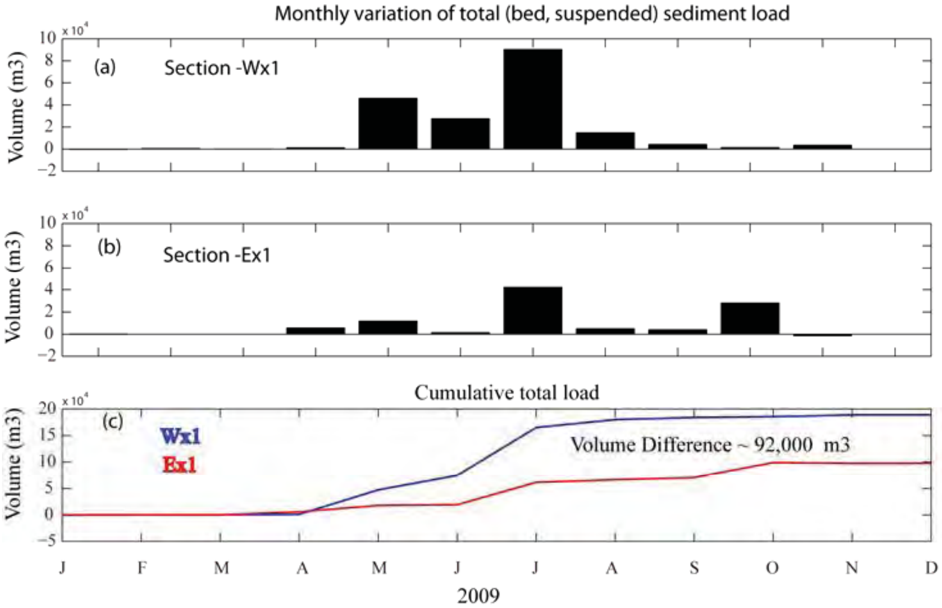


Figure 4.23 Predicted total sediment load transport. (a) monthly variation of total load through western section; (b) monthly variation transport through eastern section; and, (c) cumulative load through western (blue line) and eastern sections (red line)

The following morphological changes occurred in the vicinity of Port Geographe during the simulation period:

- The western beach accreted continuously during 2009.
- Wonnerup beach eroded during 2009 and 2010.
- Shoreline changes were confined to a relatively narrow surf zone, in water depths less than two meters.
- Some small changes in bed levels were observed in the nearshore sand bars.
- The western breakwater acted as a sediment trap in 2009 and was almost fully saturated by the end of 2009.
- The eastward sand transport within the littoral zone was completely blocked by the Port Geographe structures during 2009.
- Accretion (western beach) and erosion (eastern beach) occurred mainly during the winter months.
- When the shoreline had moved close to the tip of the western breakwater (full saturation), significant bypassing of sand occurred.
- Siltation of the harbour entrance channel subsequently occurred in 2010.

4.2.3 Seagrass wrack transport

The seagrass wrack behaviour was simulated in a similar manner as described in Section 3.4. Here, within the model 200,000 particles representing offshore seagrass were seeded into the model four times on 31 March 2010 during different tidal states (low, rising mid, high and falling mid); with 50,000 particles distributed in the nearshore area (see Figure 2.15). The predicted seagrass wrack (particles) accretion onto the western beach is shown in Figure 4.24. In 2009, the maximum seagrass particle accumulation along the western beach occurred in late May and continued to mid August. There was less seagrass wrack accumulated along the western beach in 2010 compared to 2009. In 2010, only 22,000 particles were trapped at the western side of the breakwater, which was ~50% of the amount accumulated in 2009. However, it is important to note that forcing conditions, particularly the wind wave climate were very different between 2009 and 2010 with the latter experiencing a lower number of storm events. At the end of September 2010, with the western beach sand trap saturated, the majority of seagrass wrack was transported to the east and was deposited either in the pocket beaches (Moonlight Bay) or within the harbour entrance (Figure 4.25).

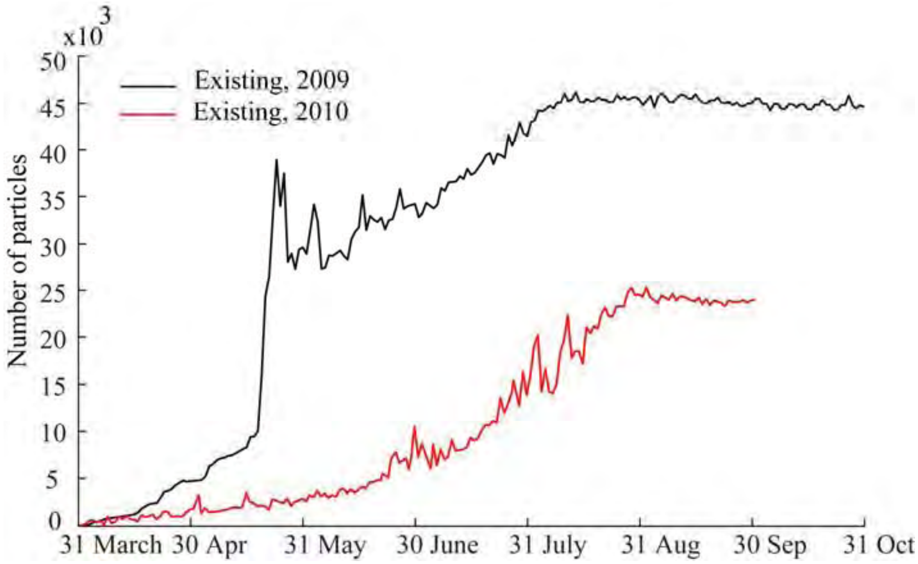


Figure 4.24 Comparison of the cumulative number of particles, representing seagrass, at the western beach, Port Geographe in 2009 and 2010 with current configuration.

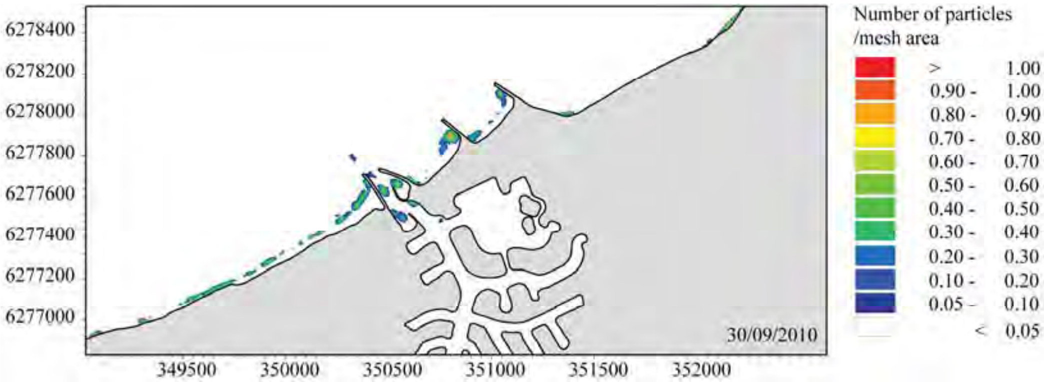


Figure 4.25 Particle distribution in the vicinity of Port Geographe on 30 September 2010.

4.3 Model Simulations: Scenario 2

The physical layout of Scenario 2 is shown in Figure 4.26. The layout dimensions were presented in Table 4.1 showing a 30-m entrance, widening to 120 m in the central section of the entrance channel. The mesh grid was constructed to represent fine grids covering Port Geographe, and the western and eastern beaches as described in Section 2.2. Figure 4.27 shows the unstructured mesh and the initial model bathymetry generated based on LIDAR survey data obtained in late 2008. The western beach adjacent to Port Geographe was extended further as shown in Figure 4.27. The model runs were for a period of eight months starting from 01 March 2009. All other conditions, such as forcing data, initial condition, model control parameters etc., were the same as for the existing case scenario (Scenario 1) model set-up.

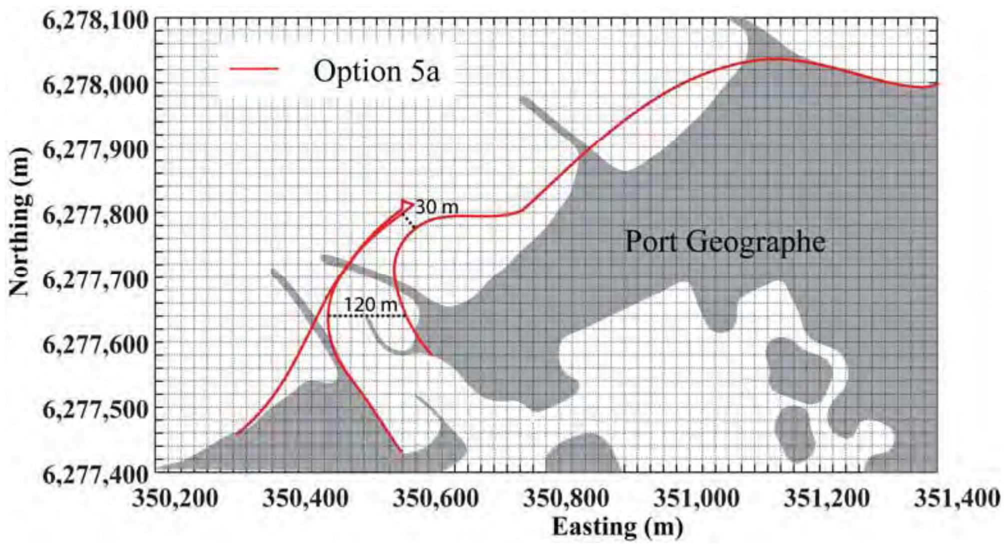


Figure 4.26 Scenario 2 (red) proposed modified layout of Port Geographe.

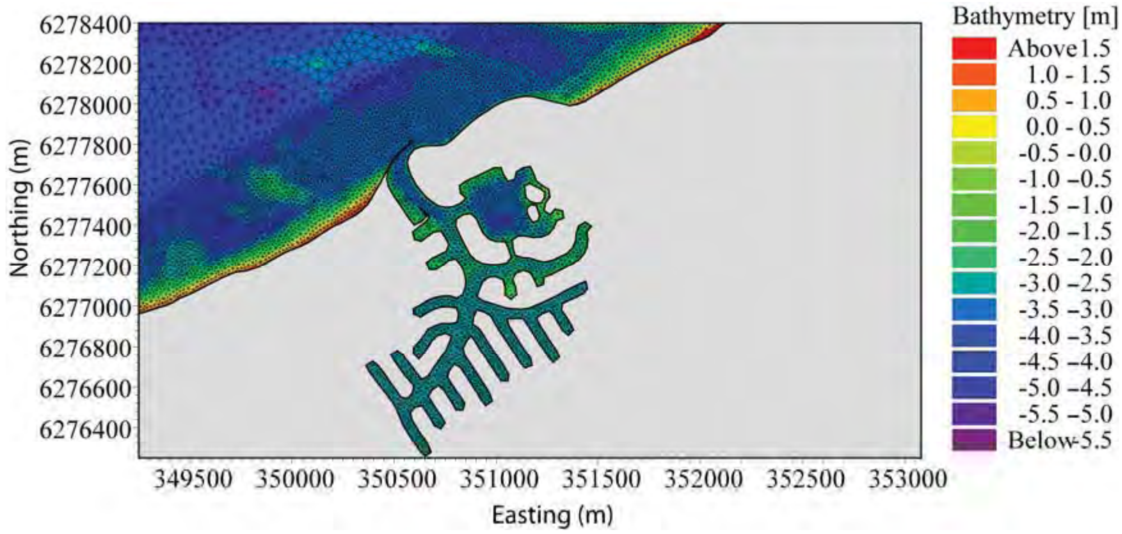


Figure 4.27 Scenario 2 mesh grid and initial model bathymetry.

4.3.1 Hydrodynamics (Scenario 2)

Comparison of the predicted velocities for the existing structures (Scenario 1) and the revised structures (Scenario 2) clearly indicated significant changes in the flow pattern in the vicinity of Port Geographe. The predicted flow patterns during the storm event on 20-22 May 2009 are shown in Figures 4.28–4.31. Flows were smooth and less eddy circulations were observed during storms in the vicinity of Port Geographe. Comparison of the predicted flows for Scenario 1 and Scenario 2 showed that the curved breakwater enhanced current speeds along the western shoreline. Thus this scenario would allow seagrass wrack to be bypassed from the western side of the harbour entrance to the eastern side during periods of stormy weather.

With regard to Scenario 2, jet-like inflows and outflows were observed within the harbour entrance channel during flood and ebb tides, respectively. As was expected, the narrowing of the harbour entrance clearly increased the velocities of both the ebb and flood flows. This had a tendency to erode the harbour entrance but also permit sand accretion inside the wider inner part of the entrance channel where velocities decreased.

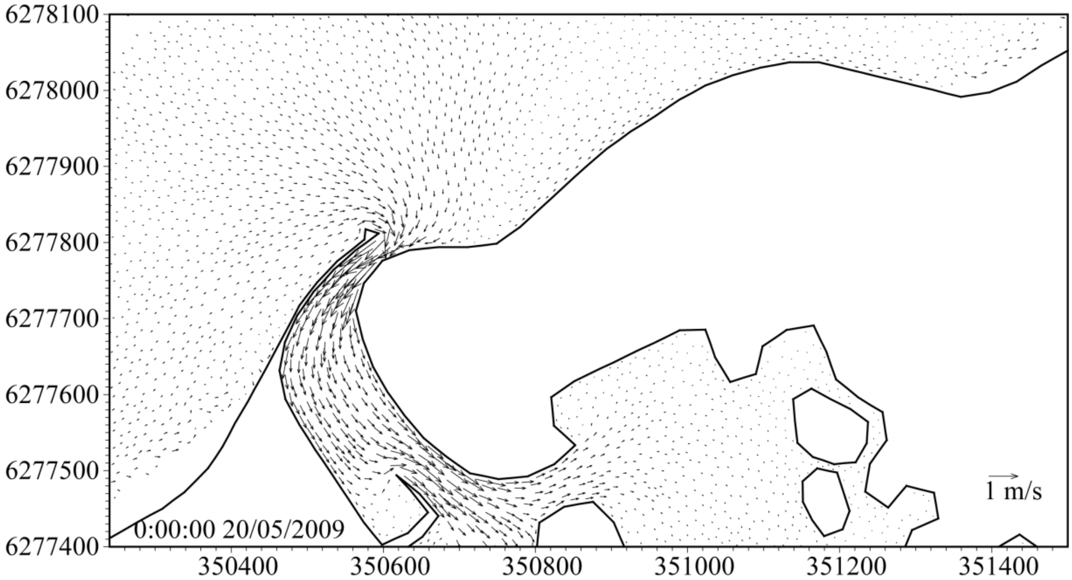


Figure 4.28 Model-predicted current pattern in the vicinity of Port Geographe for Scenario 2 (Option 5a) prior to storm event (0000 hr, 20 May 2009).

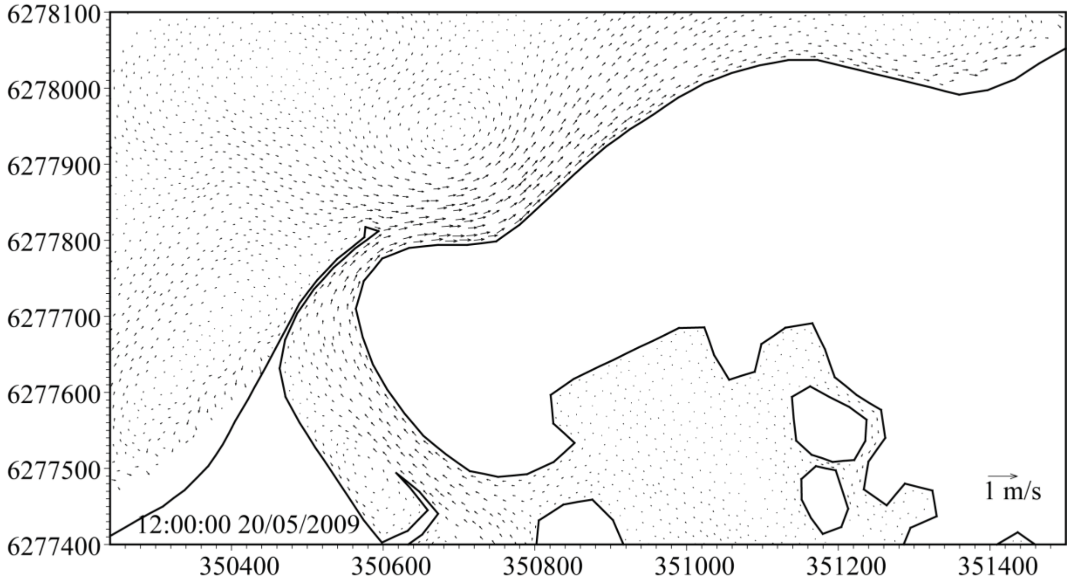


Figure 4.29 Model-predicted current pattern in the vicinity of Port Geographe for Scenario 2 (Option 5a) at the beginning of a storm event (1200 hr, 20 May 2009).

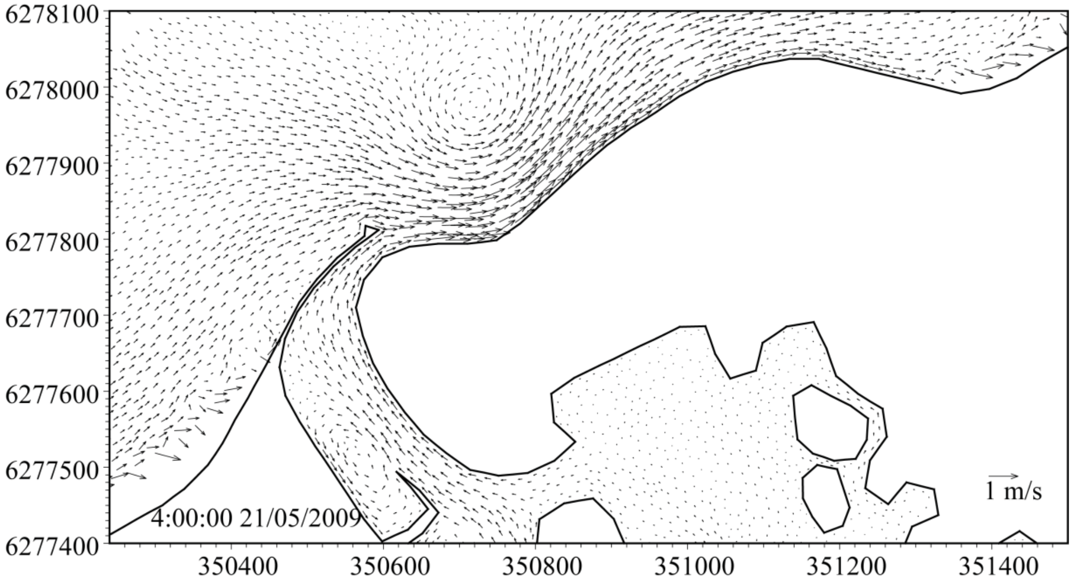


Figure 4.30 Model-predicted current pattern in the vicinity of Port Geographe for Scenario 2 (Option 5a) during a storm event (0400 hr, 21 May 2009).

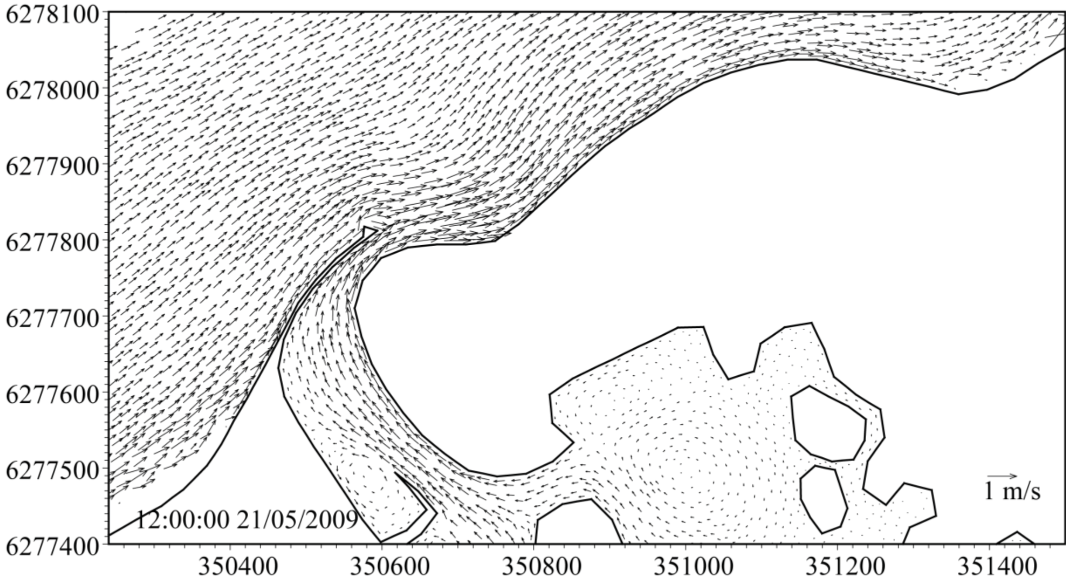


Figure 4.31 Model-predicted current pattern in the vicinity of Port Geographe for Scenario2 (Option 5a) at peak of storm event (1200 hr, 21 May 2009).

4.3.2 Sediment transport (Scenario 2)

The predicted bed levels in the vicinity of Port Geographe for Scenario 2 in 2009 are shown in Figures 4.32 to 4.36. The results from the modelling demonstrated an improved natural sand bypass for this configuration from the west to east but with accretion occurring at the eastern side of the entrance. There was no visible erosion at Wonnerup beach.

Within the harbour channel entrance, significant siltation occurred back towards the wider section of the channel and erosion (deepening) occurred within the narrow entrance area. The model-predicted bed level profiles at the wider section of the harbour entrance channel (cross-section x-y) are shown in Figure 4.38. Initial cross-section average depth was ~2.9 m AHD, but at the end of September 2009 it was reduced to ~1.5 m AHD, whilst the edge of the channel entrance deepened to more than 4 m.

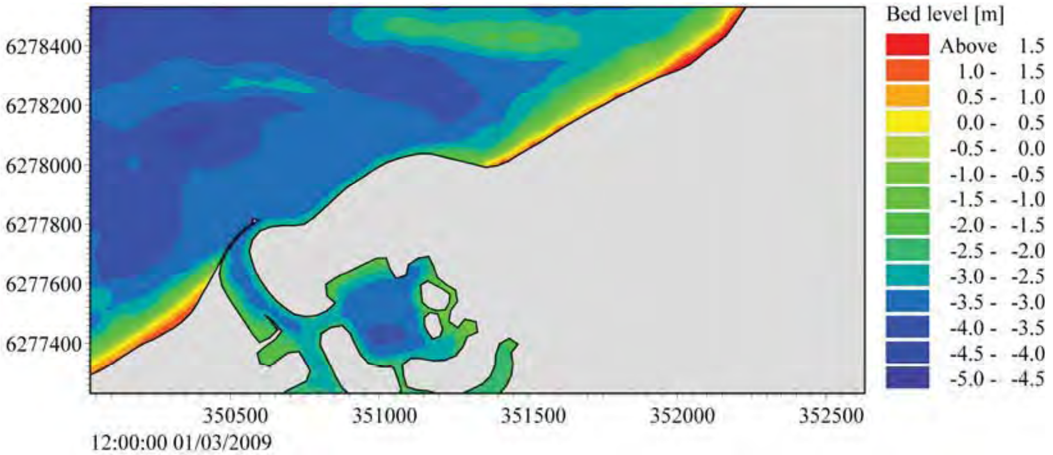


Figure 4.32 Model initial bed levels in the vicinity of Port Geographe for Scenario 2 on 01 March 2009.

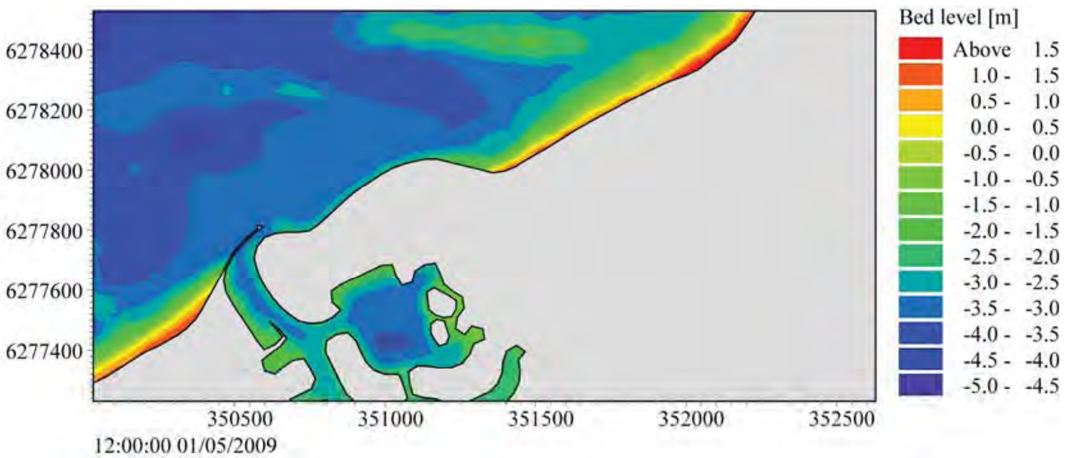


Figure 4.33 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 2 on 01 May 2009.

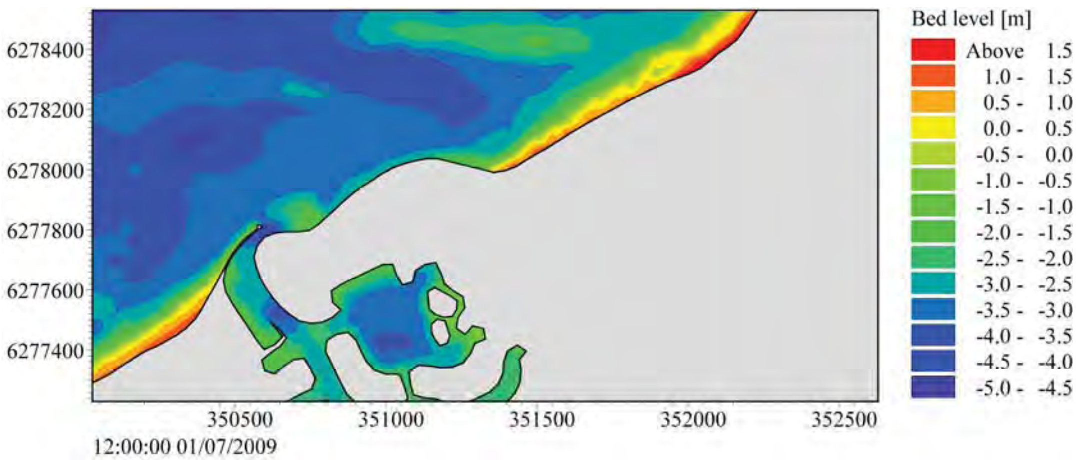


Figure 4.34 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 2 on 01 July 2009.

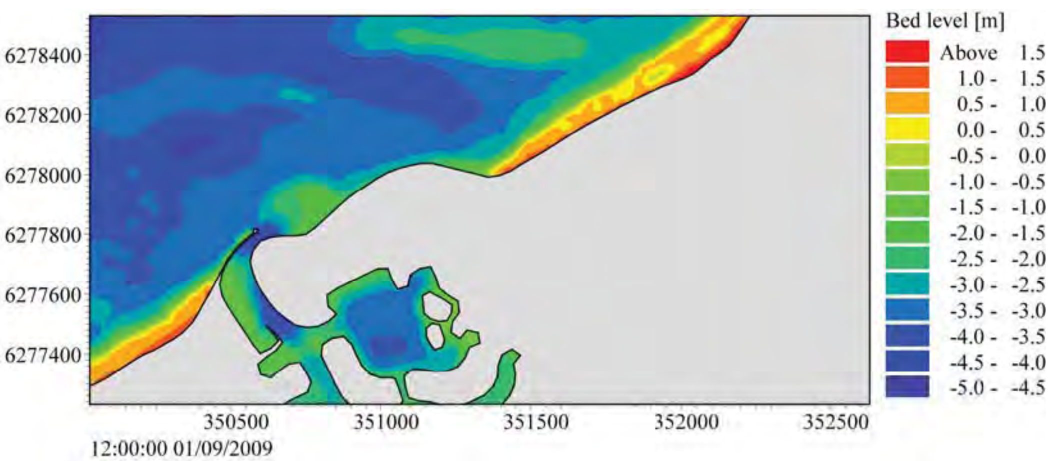


Figure 4.35 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 2 on 01 September 2009.

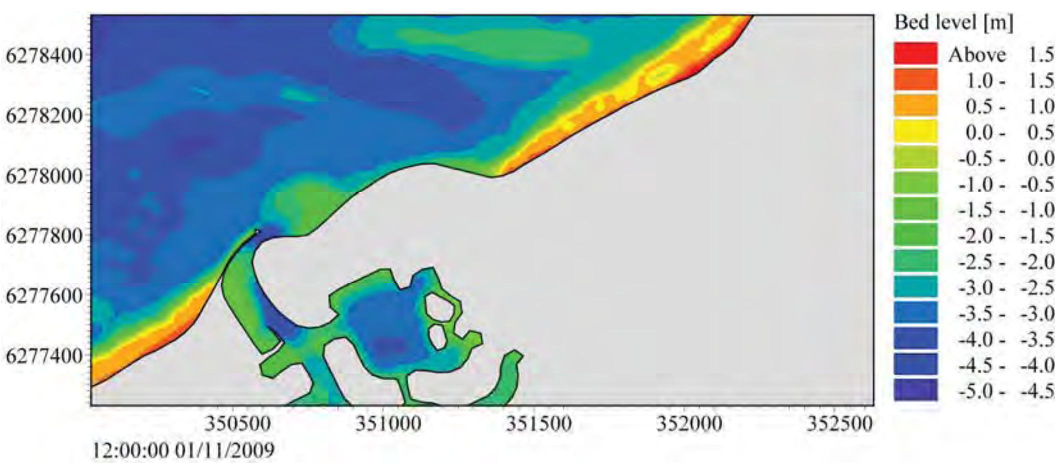


Figure 4.36 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 2 on 1 November 2009.

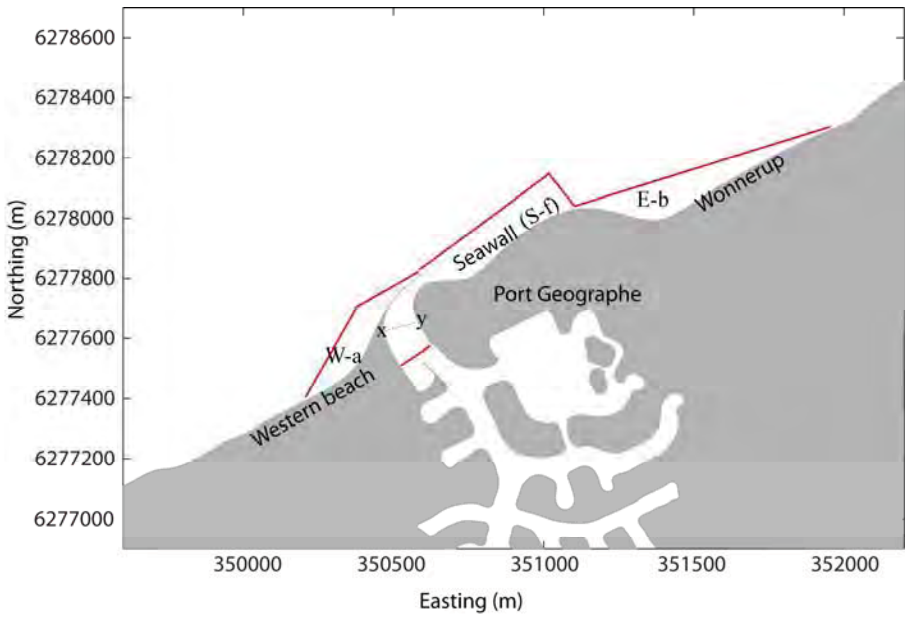


Figure 4.37 Areas selected to estimate accretion/erosion of sand and seagrass wrack for Scenario 2. W-a (western beach), S-f (front of seawall) and E-b (Wonnerup). Cross-section x-y at the harbour entrance was selected to evaluate bed level changes.

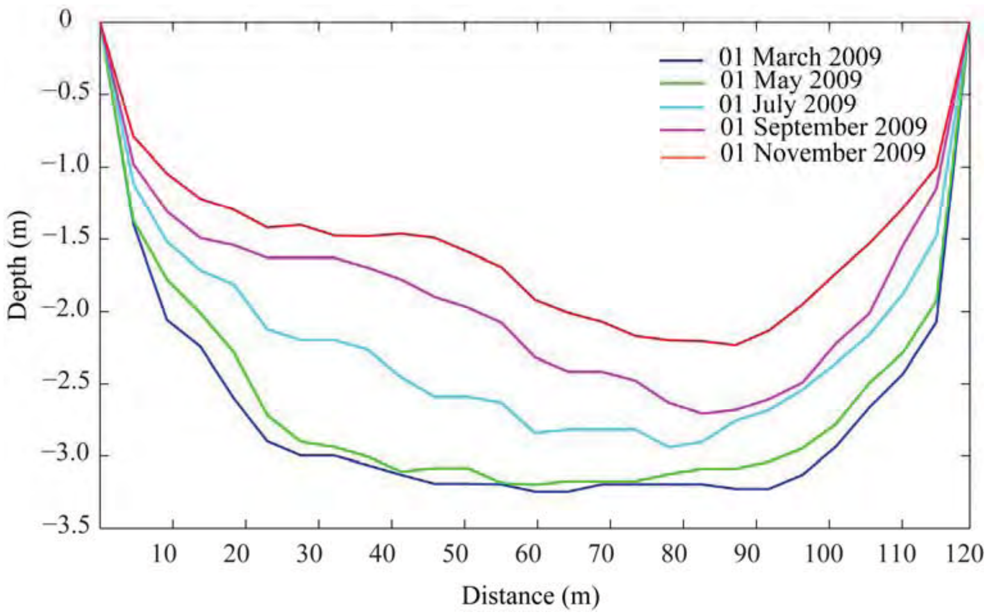


Figure 4.38 Predicted bed levels (in AHD) across the harbour entrance channel (Section x-y) of Port Geographe for Scenario 2 during March to November 2009.

The model predicted sand accretion and erosion across the different sections of the Port Geographe development under Scenario 2 (refer to Figure 4.37) and these are shown in Figures 4.39, 4.40 and 4.41. During the period March to November 2009, less than 20,000 m^3 of sand accumulated between the western beach (9,800 m^3), the channel entrance and in front of the seawall (9,000 m^3). The total predicted longshore sand transport across the whole development for the same period was ~70,000 m^3 (see Figure 4.19). Thus under Scenario 2 nearly 50,000 m^3 sand would have naturally bypassed to Wonnerup Beach between March and November 2009.

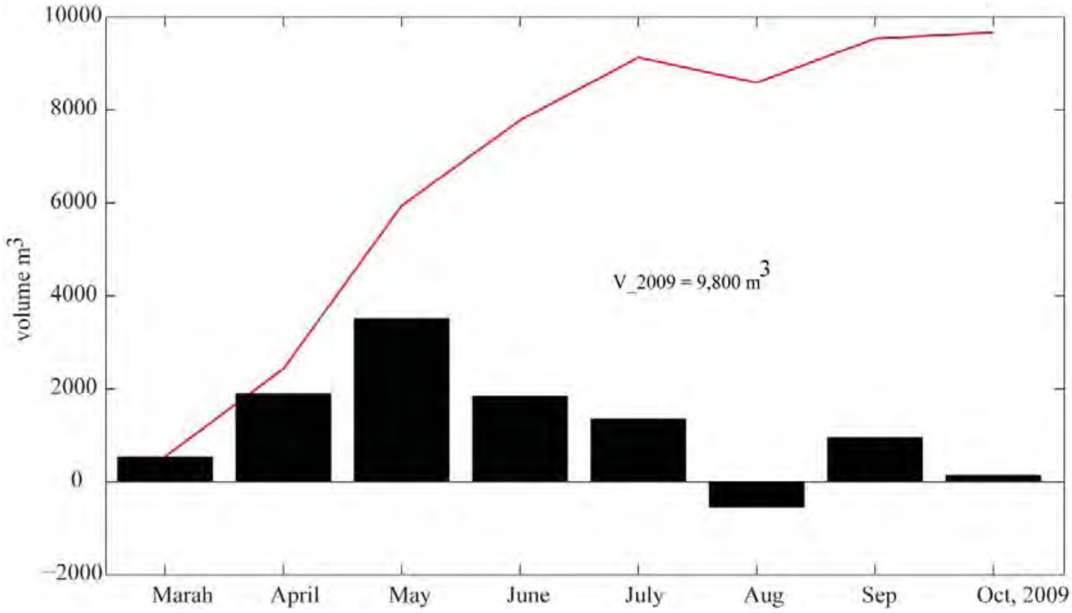


Figure 4.39 Predicted monthly sand accretion and cumulative sand volume from 1 March to 1 November 2009 along the western beach (see Figure 4.37 for selected area) under Scenario 2.

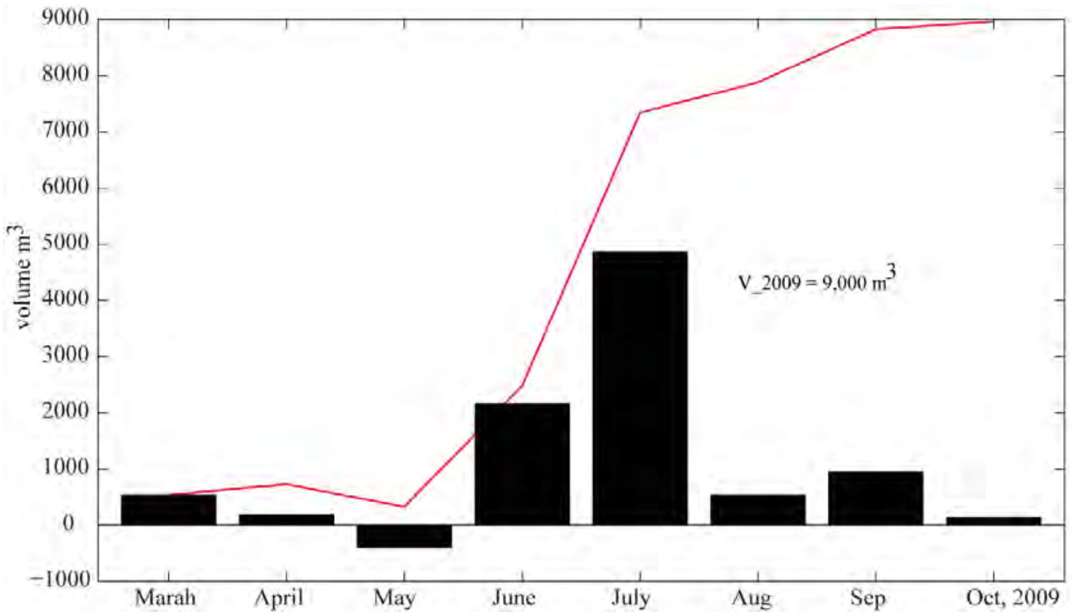


Figure 4.40 Predicted monthly sand accretion and cumulative sand volume from 01 March to 01 November 2009 in front of seawall (see Figure 4.37 for selected area) under Scenario 2.

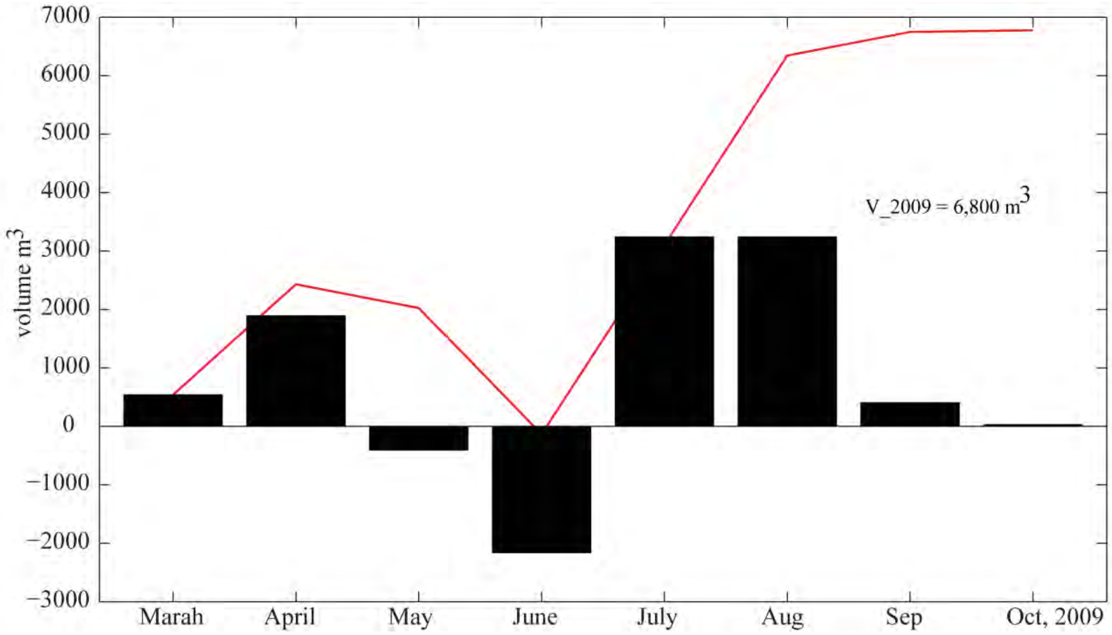


Figure 4.41 Predicted monthly sand accretion and cumulative sand volume from 1 March to 1 November 2009 along the eastern side of the harbour entrance (see Figure 4.37 for selected area) beach under Scenario 2.

4.3.3 Seagrass transport (Scenario 2)

The comparison of model-simulated seagrass wrack (particles) accretion at the western side of Port Geographe under Scenario 2 and the existing configuration are shown in Figure 4.42. The forcing and initial conditions were similar for both cases in 2009. More than 45,000 particles were trapped at the end of September with the existing configuration but less than 5,000 particles were trapped at the western side of beach with Scenario 2 for the same period. Thus, predictions of seagrass wrack accumulation for Scenario 2 indicate that it is possible to alter the orientation of the western breakwater such that seagrass wrack will not unnaturally accumulate along the western beach. The model-predicted seagrass wrack distribution in the vicinity of Port Geographe between 30 June 2009 and 30 September 2009 is shown in Figures 4.43 and 4.44, respectively. Some seagrass wrack accumulated inside the harbour entrance channel and on the eastern seawall at the end of September 2009, as shown in Figure 4.38, but the volume of wrack appeared to be significantly less compared to the existing configuration.

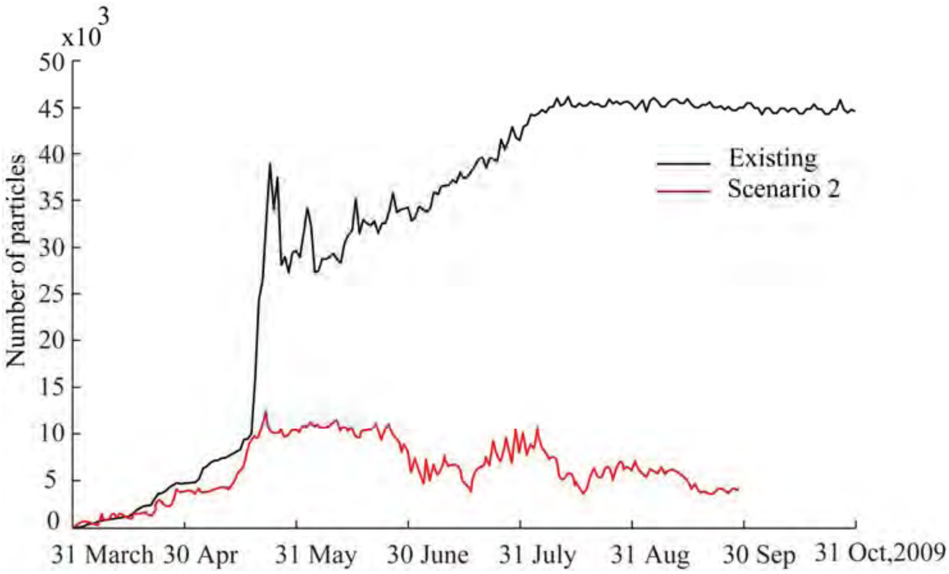


Figure 4.42 Comparison of seagrass wrack accumulation and bypass between Scenario 2 and the existing configuration. The graph depicts the numbers of simulated cumulative particles from the model at the western beach, Port Geographe in 2009.

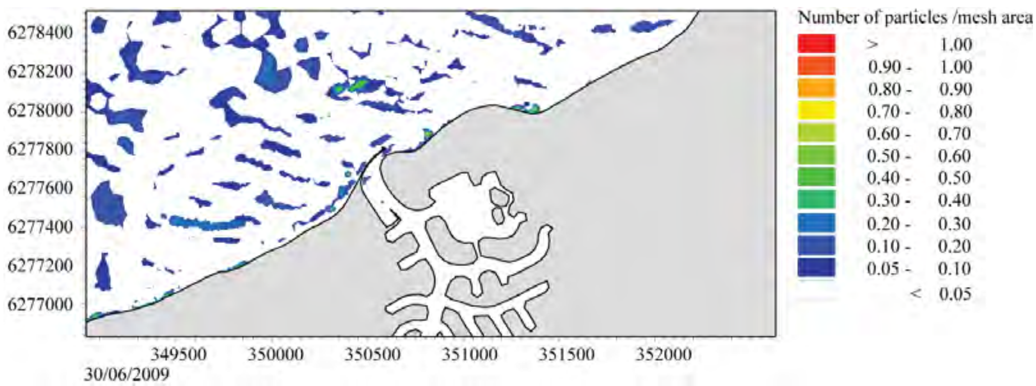


Figure 4.43 Model-simulated particle distribution for Scenario 2 in the vicinity of Port Geographe on 30 June 2009.

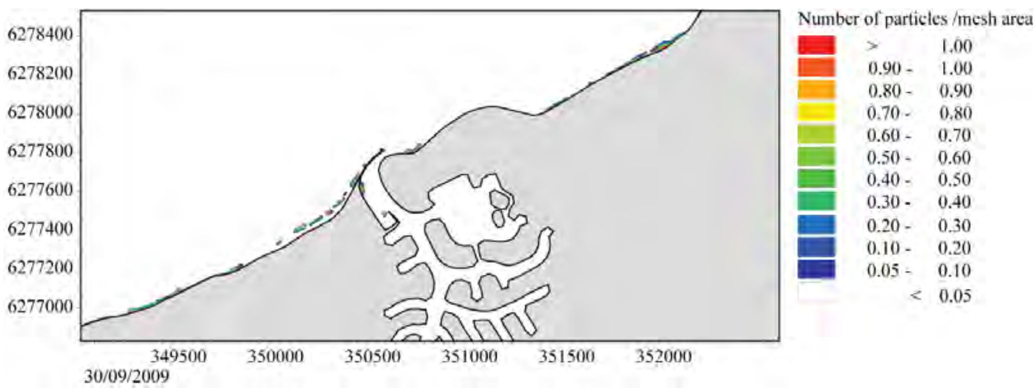


Figure 4.44 Model-simulated particle distribution for Scenario 2 in the vicinity of Port Geographe on 30 September 2009.

The results of Scenario 2 may be summarised as follows:

- Both seagrass and sand have been transported from the western to eastern beaches with minimal trapping, indicating an effective natural bypass system.
- No beach erosion was observed at Wonnerup.
- Some seagrass wrack accumulated within the harbour entrance channel and along the seawall.
- Harbour entrance channel has significantly silted in the central section with the channel depth reducing to 1.5 m by November 2009.

4.4 Model Simulations: Scenario 3

The model results of Scenario 2 (section 4.3) revealed that efficient natural sand and seagrass bypass could be achieved with a curved breakwater on the western side of Port Geographe. However, a shoal developed in the lee of the entrance breakwater, which in turn acted as a sand supply to the harbour entrance. Asymmetrical flow through the entrance channel (convergence at the opening of the harbour entrance and divergence at the mid part of the entrance channel) resulted in higher siltation rates in the wider section of the channel.

In the Scenario 2 layout, sedimentation in the mid part of the harbour entrance and in front of the entrance was assumed to be caused by a combination of several mechanisms:

- Rapid change of current speeds (jet like flows) through the harbour entrance;
- Change of flow direction due to channel curvature; and
- Clockwise eddy generation in the lee of the western breakwater.

To minimise seagrass wrack and sediment trapping on the western beach adjacent to Port Geographe, the western breakwater should generally extend as little as possible from the shoreline. However, to minimise sedimentation at the harbour entrance impacting on safe navigation, the tip of the western breakwater should generally extend to a water depth well beyond the active littoral zone. Further examination of model results of Scenario 2 revealed that seagrass wrack accumulation inside the harbour entrance could be minimised by increasing channel flows (or narrowing the entrance), but this also resulted in higher siltation of the wider section of the harbour entrance. Therefore, a compromise needed to be reached through consideration of both seagrass wrack and sand transport processes.

In order to obtain optimal harbour entrance dimensions, model runs were undertaken with different channel widths. The layout for Scenario 3 is shown in Figure 4.45, where the entrance width was widened to 50 m and the mid section of the channel was reduced to a width of 100 m. The eastern section of seawall was angled to create a slope towards Wonnerup Beach. The mesh grid and model initial bathymetry for the Scenario 3 layout are shown in Figure 4.46. The model runs were undertaken for a nine-month period with the same forcing conditions as Scenario 2 from 1 March to 1 November 2009.

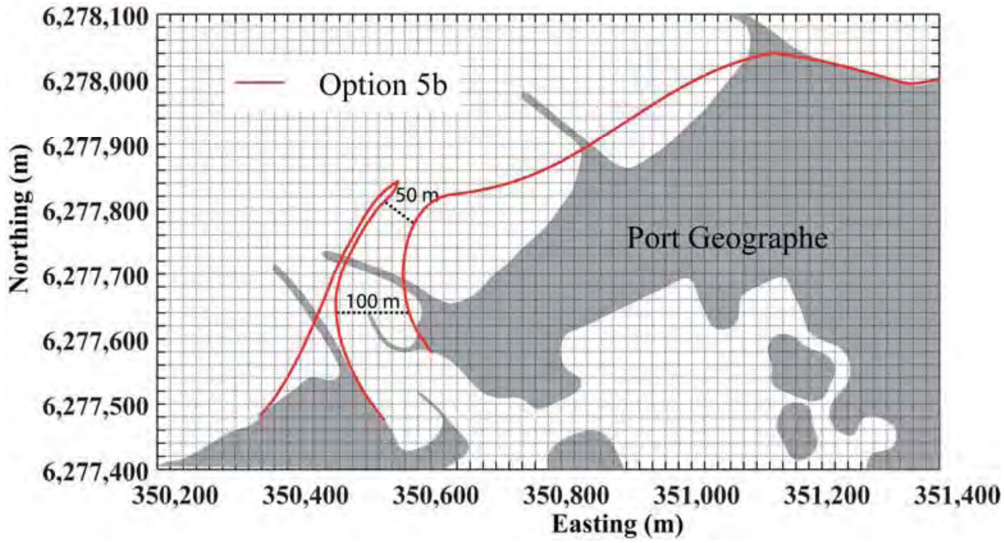


Figure 4.45 Layout of Port Geographe for Scenario 3.

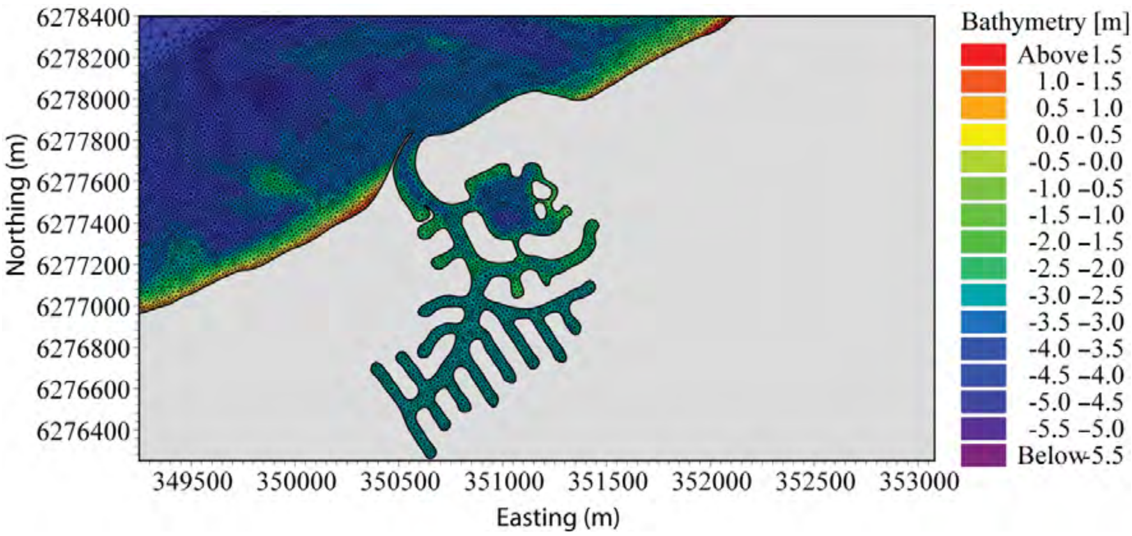


Figure 4.46 Scenario 3 mesh grid and initial model bathymetry of Port Geographe including all inner canal segments.

4.4.1 Sediment transport (Scenario 3)

The predicted bed level maps in different months for Scenario 3 are shown in Figure 4.47. The Scenario 3 layout has significantly reduced the shoal development in the lee of the western breakwater and the sedimentation problem inside the entrance channel. It can be seen that the naturally bypassed sediment from the western beach to the eastern seawall would, with time, develop a bypass shoal and start to feed the down drift beach at Wonnerup. The angled seawall has increased the eastward transport of sediment and reduced the bypass shoal in front of the harbour entrance. The predicted morphology indicates that erosion at Wonnerup beach significantly decreased under Scenario 3.

The model-predicted bed level profiles at the wider part of the entrance channel is shown in Figure 4.48. The average initial depth at the cross-section was 2.9 m at 1 March 2009, reducing to 2.6 m on 1 November 2009. The performance of this layout appears promising with respect to maintaining harbour entrance depths when compared to Scenario 2.

The predicted cumulative volumes of sand at the western beach, in front of the seawall and for Wonnerup Beach are shown in Figure 4.49. The cumulative sand volume on the western side of Port Geographe from 1 March to 1 October 2009 was 25,000 m^3, more than twice that predicted for the Scenario 2 layout. This is to be expected, since the seaward extent of the western breakwater for Scenario 3 was longer than that of Scenario 2. The maximum accumulation occurred in June (13,500 m^3) on the western side of Port Geographe for Scenario 3.

It can clearly be seen that from March to June, the western beach adjacent to Port Geographe continuously accreted, while on the eastern side Wonnerup beach eroded. From July to October, no sand accretion occurred on the western side of Port Geographe, and slight erosion occurred in August and September. The littoral eastward sand drift was estimated to be ~75,000 m^3 from March to October 2009 (see Section 4.1). Thus ~50,000 m^3 of sand was transported past the western breakwater. There was some accretion along the seawall at the end of the simulation period, but this volume appears to be limited to ~7,000 m^3. Thus the amount of sand bypassed to the eastern side (Wonnerup beaches and near-shore area) was estimated to be ~43,000 m^3. However, Wonnerup beach eroded over the model simulation period (from March to October), where the cumulative deficit of sand was estimated to be

~9,000 m^3. Thus total sand lost (supply from western side, 43,000 m^3 + beach eroded, 9,000 m^3) from March to October at Wonnerup beach (littoral zone) was estimated to be ~52,000 m^3.

4.4.2 Seagrass wrack transport (Scenario 3)

The simulated seagrass wrack movement from Scenario 3 in the vicinity of Port Geographe in June 2009 and at the end of September 2009 are shown in Figures 4.50 and 4.51 and indicate efficient natural bypassing of seagrass wrack from west to east. A small amount of wrack was deposited along the western side of the beach adjacent to Port Geographe. Some seagrass wrack had moved into the harbour entrance and was deposited in the inner section of the Port Geographe harbour entrance channel. A comparison of model-simulated seagrass wrack (particles) accretion on the western side of Port Geographe under Scenario 3 (Option 5b layout) and the existing configuration indicated that a total of 5,000 particles were trapped at the western side of the breakwater at the end of September 2009 (Figure 4.52), slightly higher than that predicted in Scenario 2. However, this was much less than that trapped under the existing configuration. Similar to sand accumulation, the majority of seagrass wrack accumulated at the beginning of the winter period when the major storms occurred (May and June).

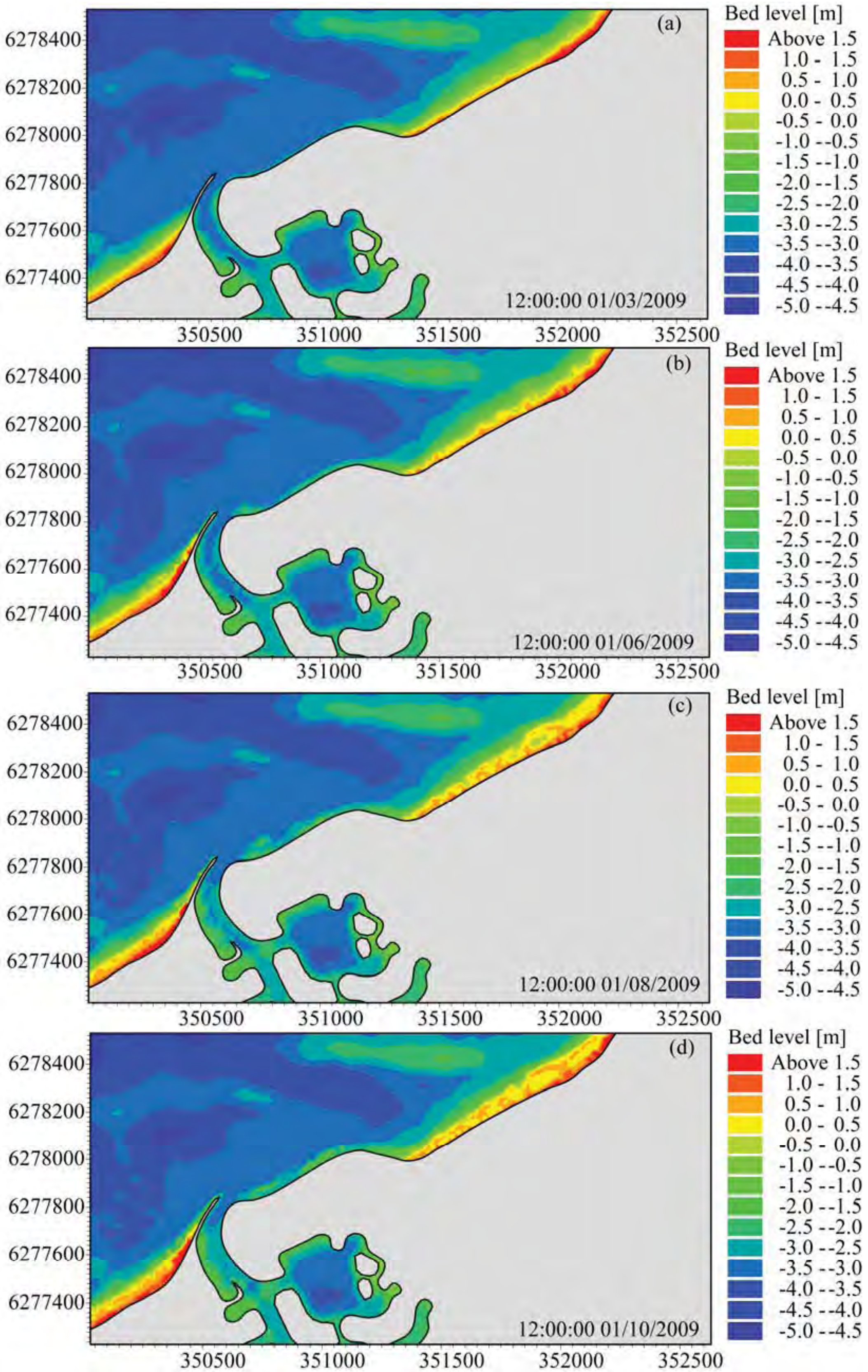


Figure 4.47 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 3 on 1 June 2009. (a) Model initial bathymetry on 1 March 2009; Predicted bed levels on: (b) 1 June 2009; (c) 1 August 2009; and, (d) 1 October 2009.

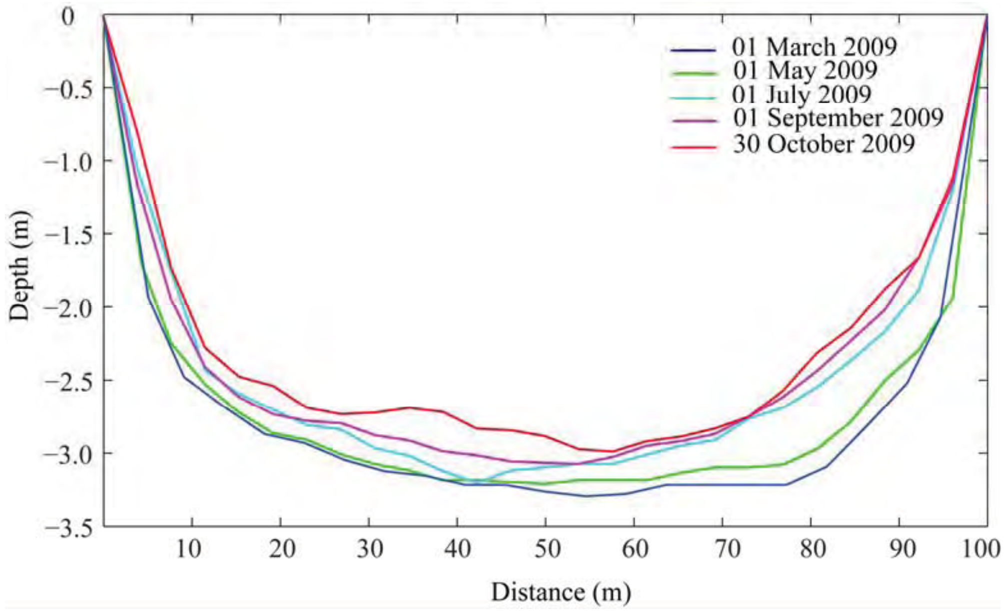


Figure 4.48 Model-predicted bed levels across the harbour entrance channel (Cross-section x-y) of Port Geographe for Scenario 3 during 1 March to 30 October 2009.

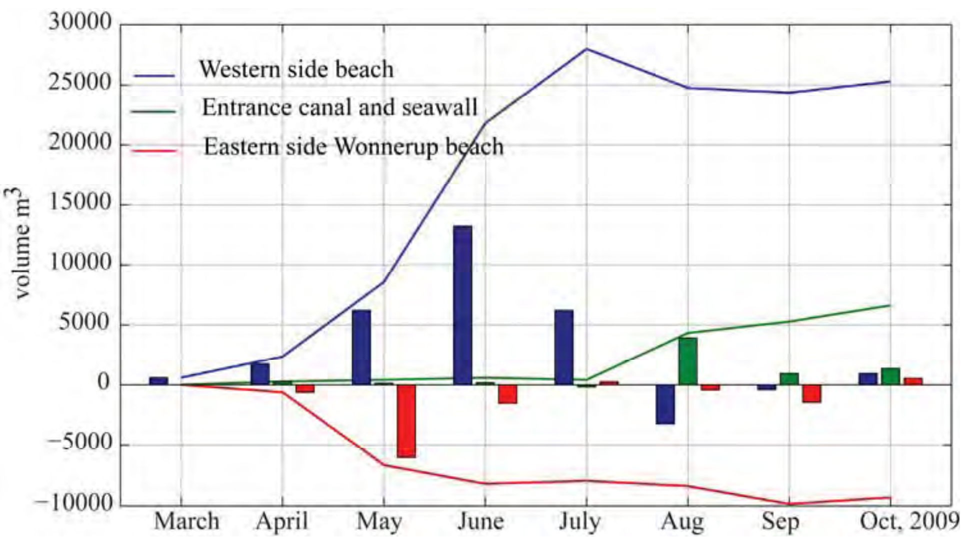


Figure 4.49 Model-simulated monthly sand accretion and cumulative volume during 1 March to 30 October 2009 in different locations of Port Geographe for Scenario 3.

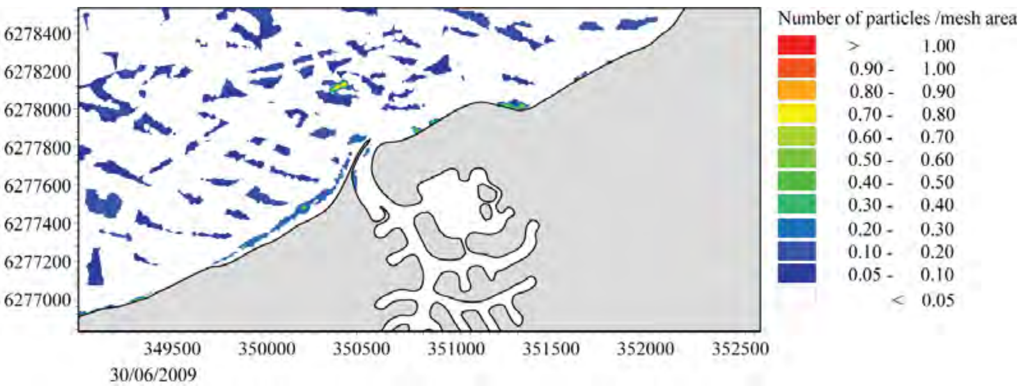


Figure 4.50 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 3.

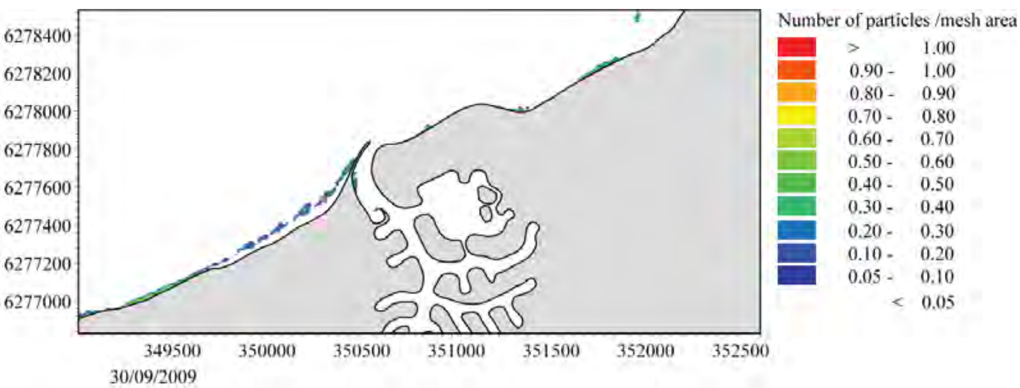


Figure 4.51 Particle distribution in the vicinity of Port Geographe on 30 September 2009 for Scenario 3.

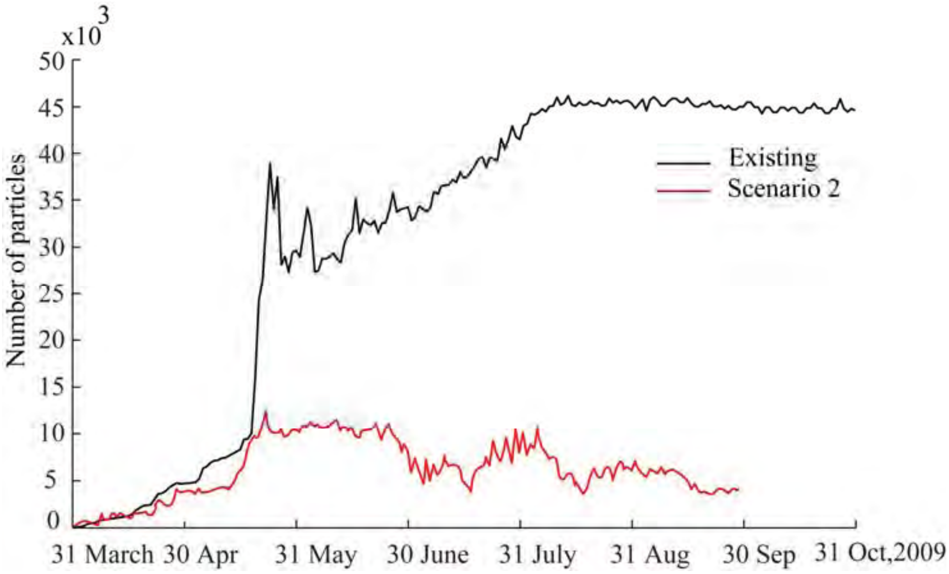


Figure 4.52 Predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenarios 1 and 3.

Results of Scenario 3 may be summarised as follows:

- Both sand and seagrass wrack were efficiently bypassed from the western to the eastern side of the Port Geographe development.
- However, slightly higher amounts of seagrass wrack accumulated along the western beaches compared to Scenario 2.
- Some erosion occurred on Wonnerup beaches.
- Some seagrass wrack has been deposited inside the harbour entrance channel.
- There was no significant siltation in the inner part of the harbour entrance channel.
- No bypassed sand shoal developed in the lee of the western breakwater.

4.5 Model Simulations: Scenario 4

The predicted seagrass wrack accumulation and siltation volumes inside the harbour entrance under Scenarios 2 and 3 were contradictory to each other. Relatively less seagrass wrack accumulated for Scenario 2 (with an entrance channel width of 30 m) compared to Scenario 3 (with an entrance channel width of 50 m). However, high siltation occurred at the mid section of the channel entrance for Scenario 2 whilst no significant siltation occurred for Scenario 3 over the simulation period.

In the Scenario 4 layout, the entrance channel width was set to 40 m and the middle section to 100 m, as shown in Figure 4.53. The aim of this simulation was to evaluate the sensitivity of the entrance channel dimensions on seagrass wrack and sedimentation at entrance. The mesh grid and model initial bathymetry for the Scenario 4 layout are shown in Figure 4.54. The model runs were carried out for eight months with the same forcing conditions from 1 April 2009.

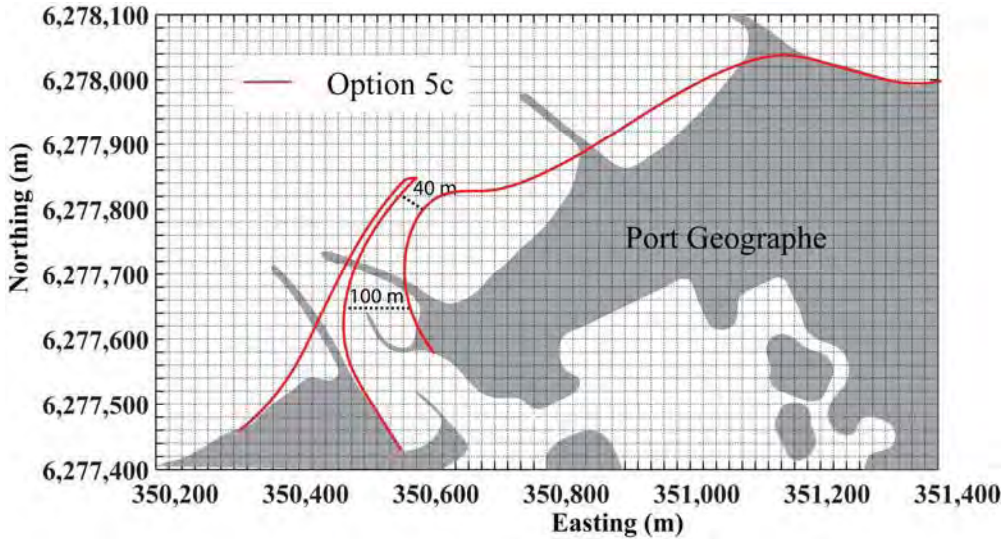


Figure 4.53 Scenario 4 layout of Port Geographe.

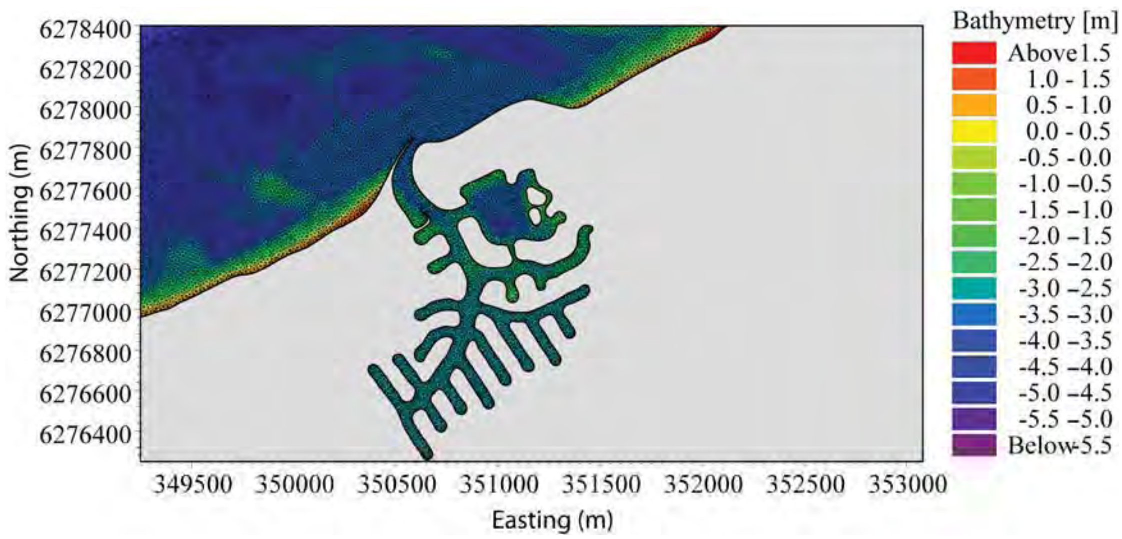


Figure 4.54 Mesh grid and bathymetry in the vicinity of Port Geographe for Scenario 4 including all inner canal segments.

4.5.1 Sand transport (Scenario 4)

The model predicted bed level changes to occur between April and October 2009 (Figure 4.56) with significant siltation at the wider section of the entrance channel. However, no significant bypass shoal developed at the harbour entrance. Similar to Scenario 3, sand bypassed across the western breakwater to the seawall was transported to eastern beaches. Visual inspection of the model-predicted morphology indicated that the erosion on Wonnerup beaches was somewhat larger compared to Scenario 3.

The predicted bed level profiles at the wider part of the harbour entrance are shown in Figure 4.56. The average depth at cross-section was 2.9 m AHD on 1 April and was reduced to 2.25 m AHD on 1 October 2009 with accretion smaller than Scenario 2 but higher than Scenario 3.

The predicted monthly sand accretion and cumulative volumes at different parts of Port Geographe indicated that for Scenario 4, as the seaward extent of the western breakwater was slightly larger than Scenario 3, the cumulative sand volume on the western part of Port Geographe was higher than Scenario 3 (Figure 4.57). The accumulated sand on the western side of Port Geographe was estimated to be ~29,000 m^3 of which ~17,000 m^3cubic metres was accumulated during June 2009.

The accretion and erosion patterns at the different beaches for Scenario 4 were similar to Scenario 3 although the magnitudes were different. Similar to Scenario 3 sediment budget calculations, ~46,000 m^3 of sand was transported from the western side beaches to the east whilst ~6,000 m^3 of cumulative sand volume was present along the seawall and the harbour entrance channel. Thus, the amount of sand bypassed to eastern side of the development (Wonnerup beaches and near-shore area) was estimated to be ~40,000 m^3. The predicted cumulative volume at Wonnerup beach was estimated to be ~-12,500 m^3 (deficit). Thus the total sand lost (supply from western side, 40,000 m^3 + beach eroded, 12,500 m^3) from Wonnerup beach (littoral zone) during model period was ~52,500 m^3 in agreement with the Scenario 3 sediment budget.

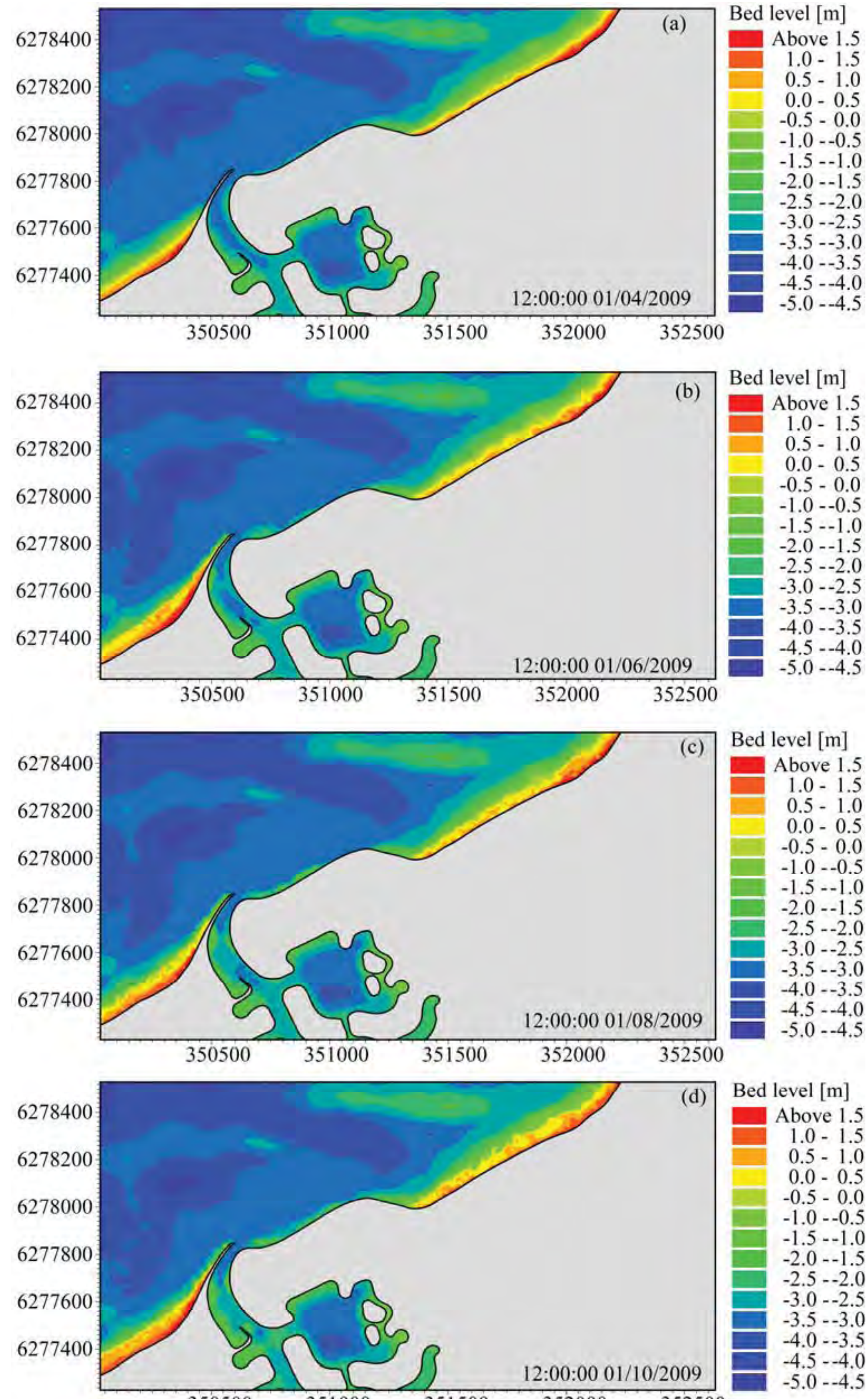


Figure 4.55 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 4. (a) Model initial bathymetry on 01 April 2009 and predicted bed levels on: (b) 01 June 2009; (c) 01 August 2009; and, (d) 01 October 2009.

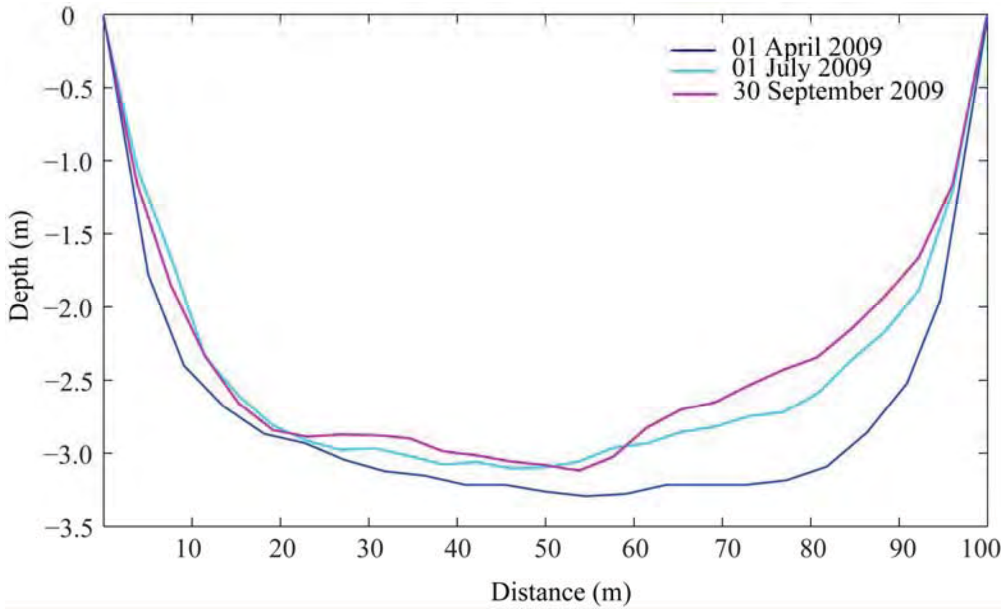


Figure 4.56 Predicted bed levels across the harbour entrance channel (Cross-section x-y) of Port Geographe for Scenario 4 from 01 March to 30 October 2009.

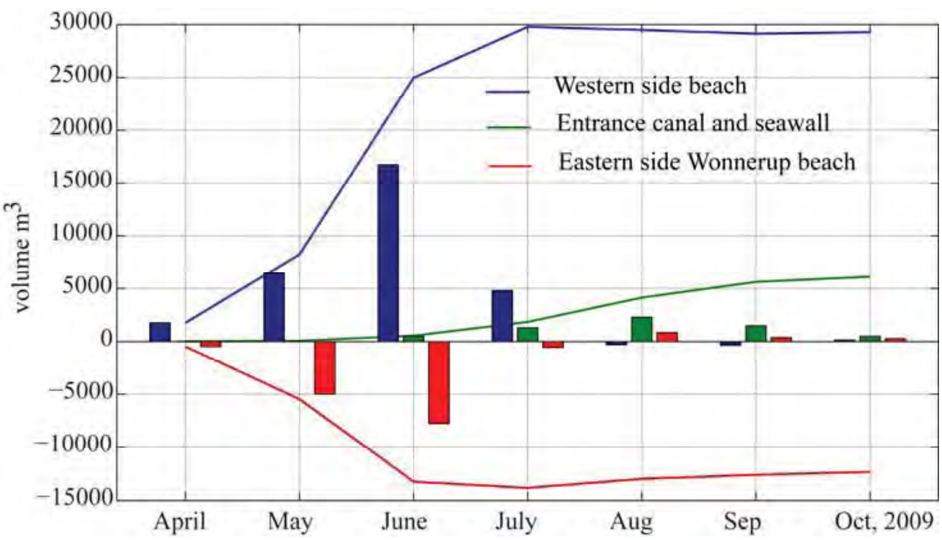


Figure 4.57 Model-simulated monthly sand accretion and cumulative volume from 1 March to 30 October 2009 at different locations of Port Geographe for Scenario 4.

4.5.2 Seagrass wrack transport (Scenario 4)

The predicted seagrass distribution in the vicinity of Port Geographe on 30 June and 30 September 2009 is shown in Figures 4.58 and 4.59. Comparison of model-simulated seagrass wrack (particles) accretion at the western side of Port Geographe under Scenario 4 (Option 5c layout) and the existing configuration is shown in Figure 4.60. A higher number of particles were trapped at the end of September compared to Scenarios 2 and 3, but the amount was much less than the existing configuration. Some seagrass wrack accumulated inside the Port Geographe harbour entrance, but was less than that predicted under Scenario 3.

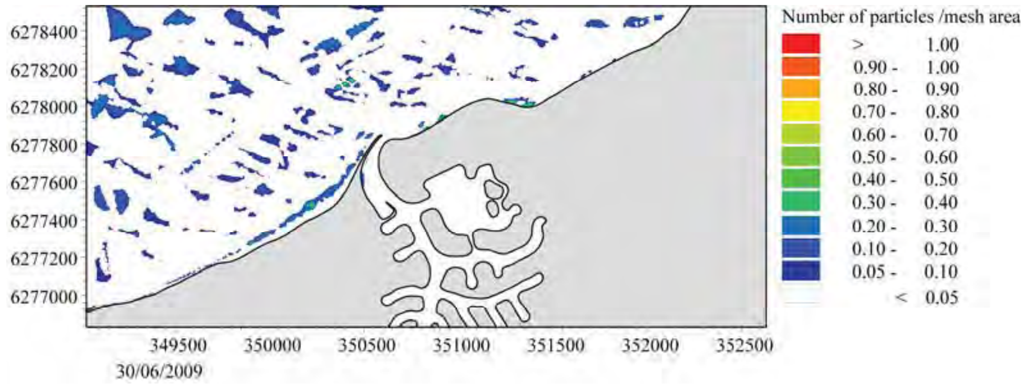


Figure 4.58. Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 4.

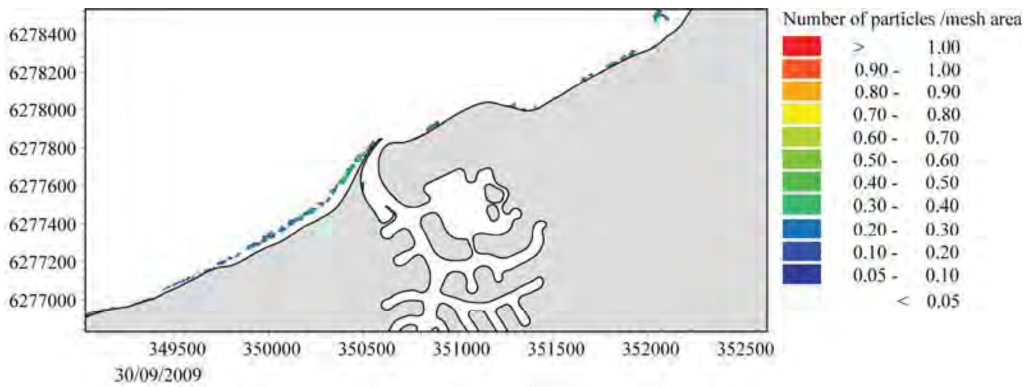


Figure 4.59 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 4.

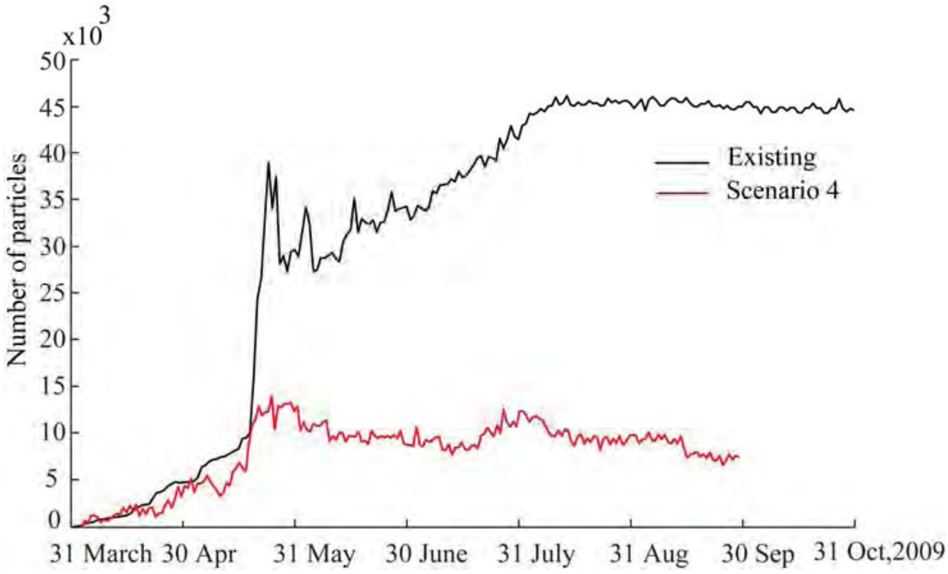


Figure 4.60 Predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenario 4.

The results of Scenario 4 are summarised as follows:

- Both sediment and seagrass wrack were naturally bypassed from the western side to the eastern side of the Port Geographe development.
- The amount of seagrass wrack accumulated on the western side of Port Geographe was higher compared to Scenarios 2 and 3, thus in considering the seagrass bypassing prospective, this scenario (4) is worse than Scenarios 2 and 3.
- Significant siltation occurred in the harbour entrance channel.
- Some seagrass wrack was deposited inside the harbour entrance channel but the amount was less when compared to Scenario 3.

4.6 Model Simulations: Scenario 5

The model results for Scenarios 2, 3 and 4 revealed that development of a configuration for the harbour and development foreshore, which effectively managed both seagrass accumulation and sedimentation at the harbour, was going to be difficult to achieve. This was because of the different thresholds for the mobilisation of sediment and seagrass. In general, sand is transported into the harbour entrance during storms, which result in large waves and associated storm surges. Sand may also be recirculated back toward the harbour entrance by eddies. However, it may be possible to reduce sand entering into the entrance channel by accelerating sand to the east across the harbour entrance and reducing eddy circulation. In addition to wind driven currents, sediment transport capacity along the shoreline (or across the seawall) was determined by incident wave angle. In the following Scenarios 5, 6, 7 and 8, different sea wall alignments have been tested for both sand and seagrass transport.

The Scenario 4 layout was modified to develop the Scenario 5 layout, with the length of breakwater shortened and the eastern side seawall at the harbour entrance moved towards the shoreline as shown in Figure 4.61. The harbour entrance width of 40m was retained as was the entrance channel width of 100m. The model mesh grid and interpolated initial bathymetry onto the meshes are shown in Figure 4.62. The model runs were carried out for nine months with the same forcing conditions from 01 March 2009.

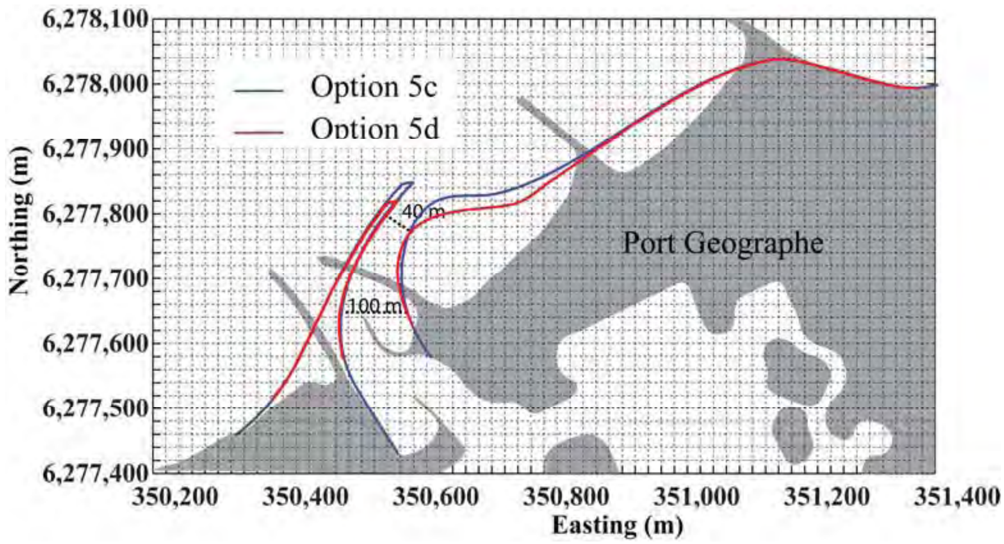


Figure 4.61 Layout for Scenario 5 at Port Geographe. Blue line shows Scenario 4 - layout and the red line shows the layout for Scenario 5.

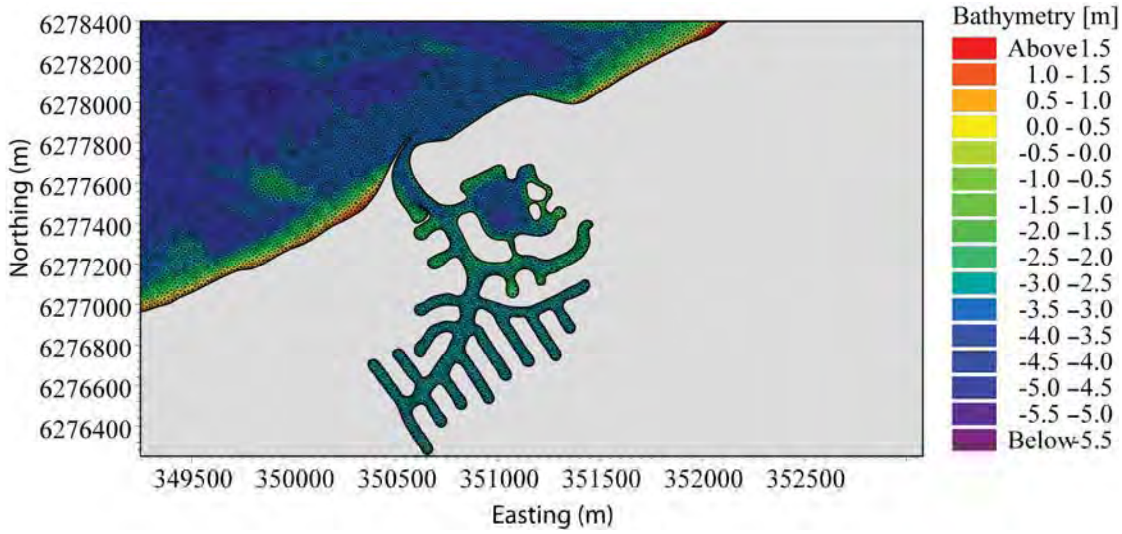


Figure 4.62 Mesh grid and initial bathymetry in the vicinity of Port Geographe for Scenario 5 including all inner canal segments.

4.6.1 Sediment transport (Scenario 5)

The predicted bathymetric changes in different months in the vicinity of Port Geographe for Scenario 5 are shown in Figure 4.63. A visual comparison of predicted bed level maps for Scenario 4 versus Scenario 5 indicates results were similar for both cases. No significant changes in harbour entrance siltation could be attributed to the Scenario 5 layout. The model-predicted bed level profiles in the wider section of the harbour entrance are shown in Figure 4.64. The average initial depth at cross-section was 2.9 m at 01 March 2009 and model-predicted averaged depth was reduced to 2.2 m at 30 October 2009.

It can be seen that the monthly change in accumulation of sand on the western side of Port Geographe for Scenario 5 was also followed a similar pattern of accretion and erosion as seen in Scenarios 2, 3 and 4. Sand accreted from March to June followed by no further significant accretion. The predicted cumulative volume of sand on the western side of Port Geographe from 1 March to 30 October 2009 was estimated to be 26,000 m^3; the amount was lower compared to the predicted sand volume for Scenario 4. The maximum accumulation of 12,500 m^3 occurred in June on the western side of Port Geographe for Scenario 4. About 5,200 m^3 of sand accumulated on the seawall and harbour entrance over the model period. The total sand transported to the eastern side of the marina (Wonnerup beach) was calculated to be 43,800 m^3. The model-predicted volume of sand eroded from Wonnerup beach was 9,500 m^3. The estimated total sand lost from Wonnerup beach during March to October was about 53,300 m^3. This amount was the same order of magnitude predicted for the Scenarios 2, 3 and 4. The predicted volume of eroded sand at Wonnerup beaches for the existing condition for same period was estimated to be about 47,500 m^3.

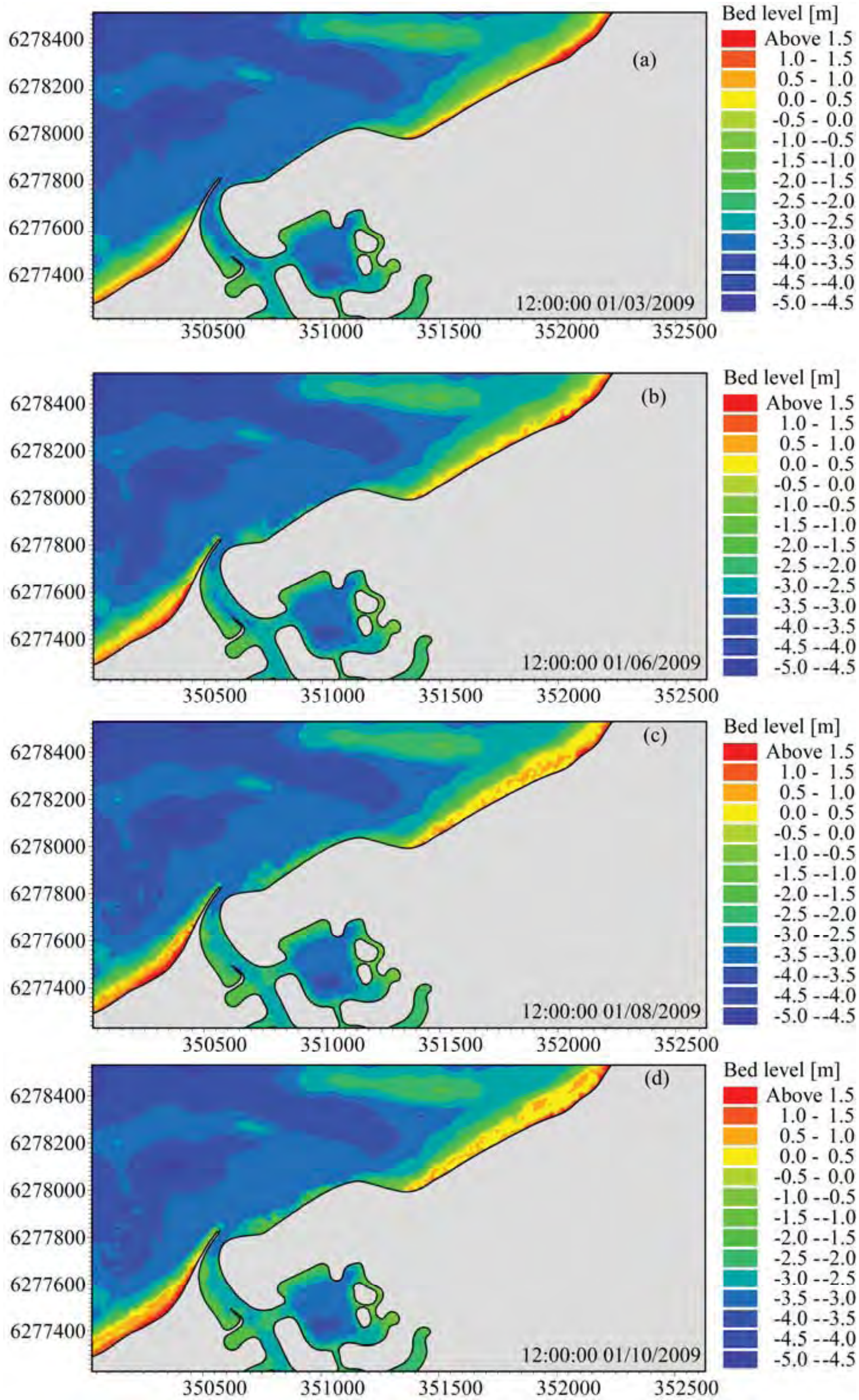


Figure 4.63 Predicted bed levels in the vicinity of Port Geographe for Scenario 5. (a) Model initial bathymetry on 01 March 2009 and Predicted bed levels on: (b) 1 June 2009, (c) 1 August 2009 and (d) 1 October 2009.

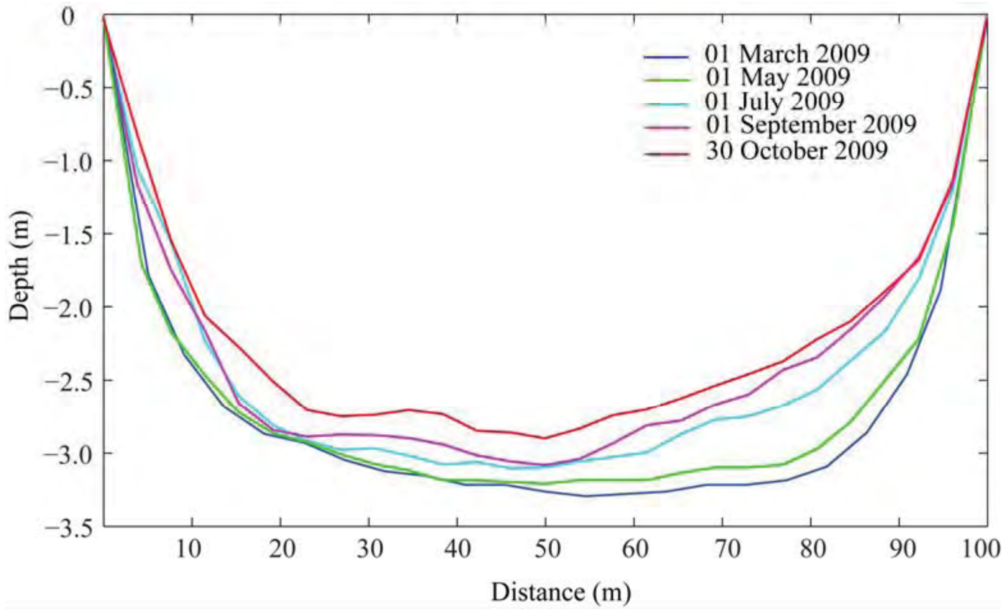


Figure 4.64 Model-predicted bed levels across the harbour entrance channel (section x-y) of Port Geographe for Scenario 5 during 01 March to 30 October 2009.

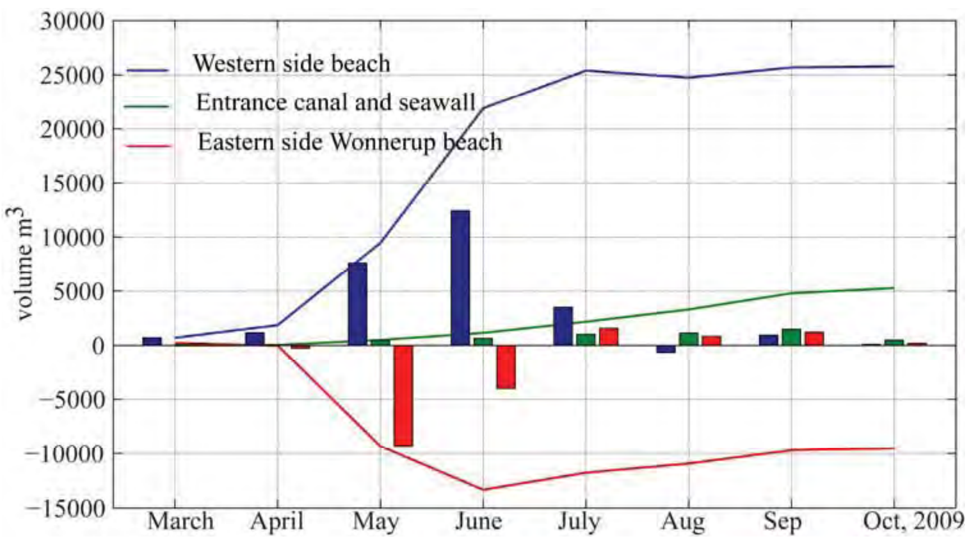


Figure 4.65 Model-simulated monthly sand accretion and cumulative volume during 01 March to 30 October 2009 at different locations of Port Geographe for Scenario 5.

4.6.2 Seagrass transport (Scenario 5)

The predicted seagrass distribution in the vicinity of Port Geographe on 30 June and 30 September 2009 are shown in Figures 4.66 and 4.67. At the end of the seagrass model run (30 September 2009), most of the seagrass wrack was deposited along the shoreline. Seagrass wrack accumulated on the western side of Port Geographe on the seawall and eastern side beaches. A comparison with the predicted seagrass wrack accumulation in Scenarios 4 and 5 highlighted that less seagrass wrack accumulated inside the harbour entrance channel for Scenario 5 but more seagrass wrack accumulated on the seawall for Scenario 5.

A comparison of the predicted cumulative particles (seagrass wrack) for Scenario 5 and existing configuration are shown in Figure 4.68. A total of 6,000 particles accumulated on the western side of Port Geographe beach.

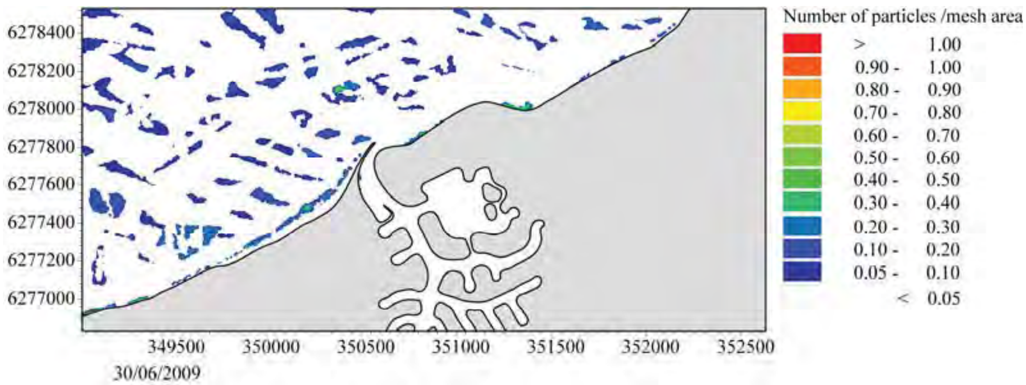


Figure 4.66 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 5.

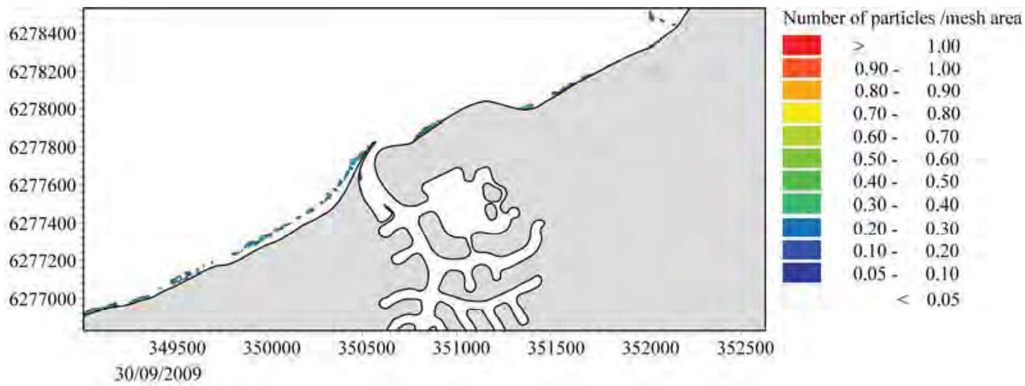


Figure 4.67 Particle distribution in the vicinity of Port Geographe on 30 September 2009 for Scenario 5.

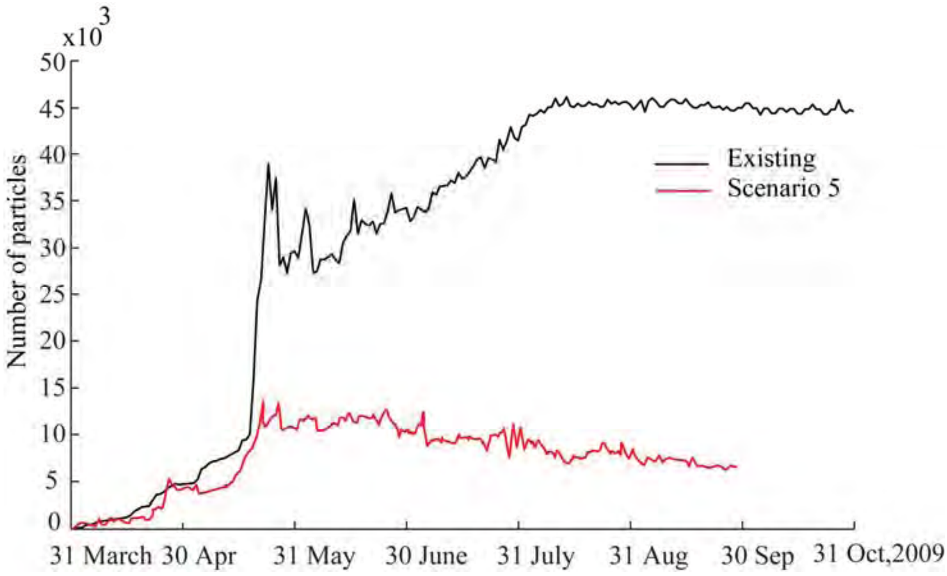


Figure 4.68m Predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenario 5.

The model results of Scenario 5 are summarised below:

- Both seagrass and sand have been transported from the western to eastern beaches with minimal trapping, indicating an effective natural bypass system.
- The amount of seagrass wrack accumulated on the western side of Port Geographe was higher compared to Scenarios 2 and 3, but less compared to Scenario 4.
- Significant siltation occurred in the harbour entrance.
- Some seagrass wrack was deposited inside the entrance channel but was less compared to Scenarios 3 and 4.

4.7 Model Simulations: Scenario 6

Comparison of predicted harbour channel bed levels for Scenarios 2, 3, 4 and 5 indicated that minimum siltation occurred under Scenario 3. However, slightly higher volume of seagrass wrack accumulated inside the harbour entrance channel. In Scenario 3, the width of the entrance was 50m. Scenario 6 was developed through modifications to Scenario 3 with the western breakwater moved towards the shoreline, retaining the angles and channel configurations as shown in Figure 4.69.

The mode initial bathymetry and mesh grid in the vicinity of Port Geographe for Scenario 6 are shown in Figure 4.70. The model runs were started from March and extended up to December 2009.

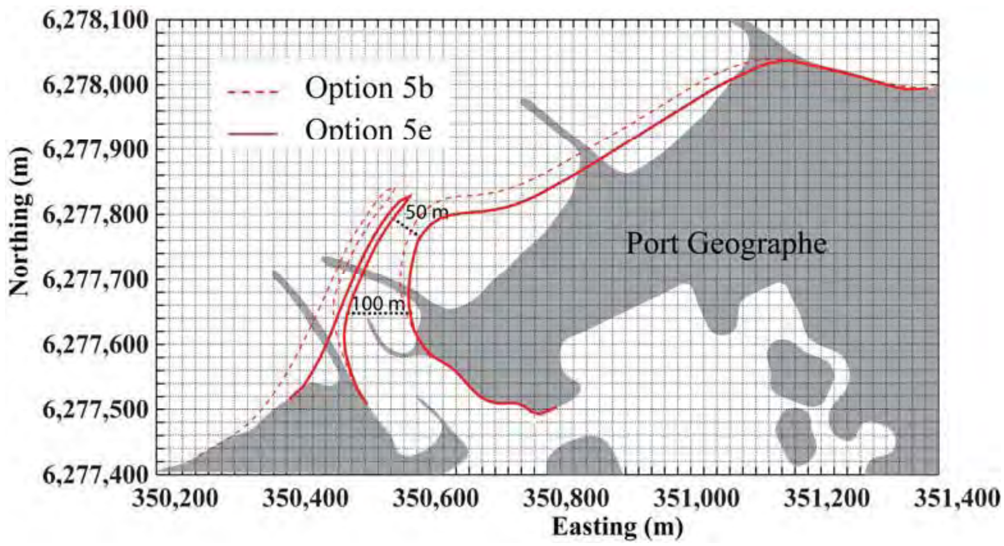


Figure 4.69 Scenario 6 layout of Port Geographe. Black dotted line shows existing Port Geographe layout, red dotted line shows layout of Scenario 3 and red solid line shows layout of Scenario 6.

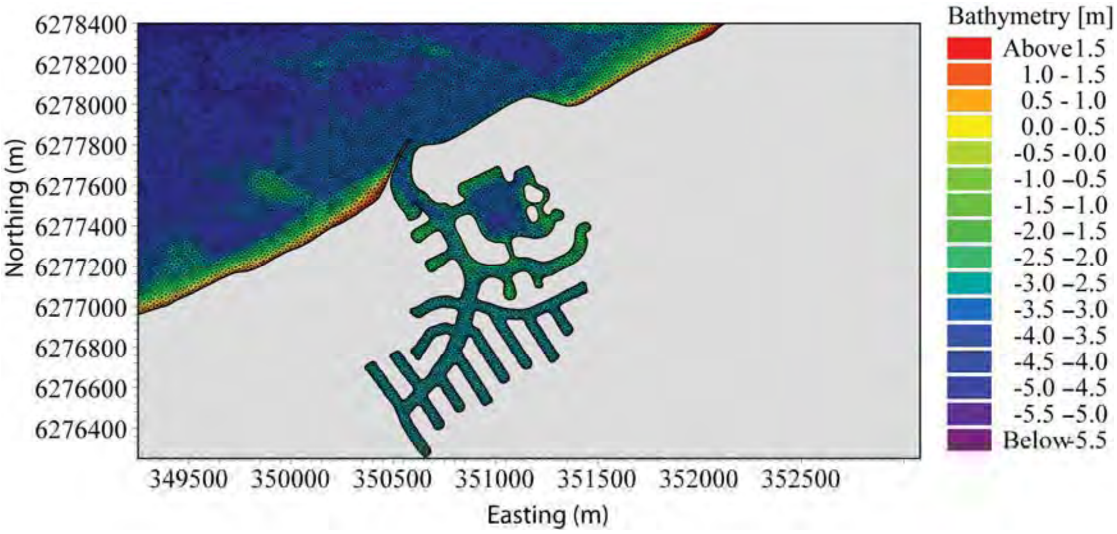


Figure 4.70 Mesh grid and initial bathymetry in the vicinity of Port Geographe for Scenario 6 including all inner canal segments.

4.7.1 Sediment transport (Scenario 6)

The predicted bed levels in the vicinity of Port Geographe indicated that there was no significant siltation at the harbour entrance (Figure 4.71). The predicted bed level profiles at the wider part of the harbour entrance from March to December indicated that the mean initial depth at cross-section was 2.9 m at 1 March 2009 and changed to ~2.65 at the end of December 2009 (Figure 4.72), a slightly improved mean depth compared to Scenario 3.

The predicted cumulative sand volume at the western beach from March to October was limited to be about 22,500m^3 for Scenario 6. Furthermore, relatively low erosion appears to occur at the eastern side Wonnerup beach with the eroded volume ~5,000 m^3. The cumulative volume of sand on the seawall for Scenario 6 was estimated to be 11,500 m^3, however, more than the predicted volume for Scenario 3 at 7,000 m^3.

The littoral sand transport from March to October 2009 was estimated to be ~75,000m^3, i.e. similar to the predicted total trapped volume of sand at the western side of Port Geographe under the existing configuration (see Section 3.3). Therefore, about 41,000 m^3 of sand was bypassed to the eastern side of Port Geographe (Wonnerup beach and near shore area) under this layout. The eroded volume of sand at Wonnerup beach was ~5,000 m^3, thus the total volume of sand lost from the eastern side of marina was estimated to be 46,000 m^3.

However, for Scenarios 3, 4 and 5, the total volume of sand loss was > 50,000 m^3. This difference is attributed to off shore transport.

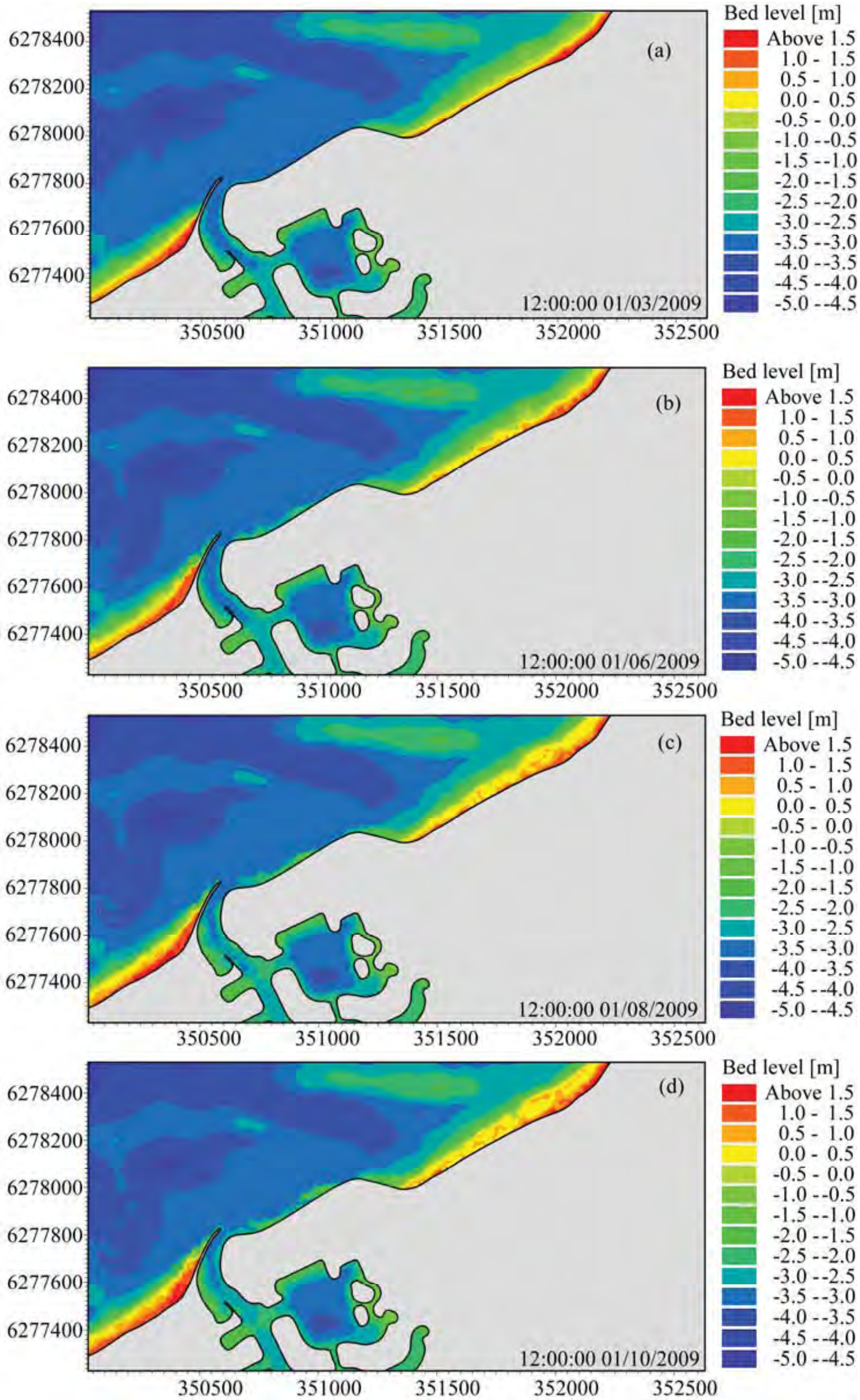


Figure 4.71 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 6. (a) Model initial bathymetry on 01 March 2009 and predicted bed levels on (b) 1 June 2009; (c) 01 August 2009; and, (d) 01 October 2009

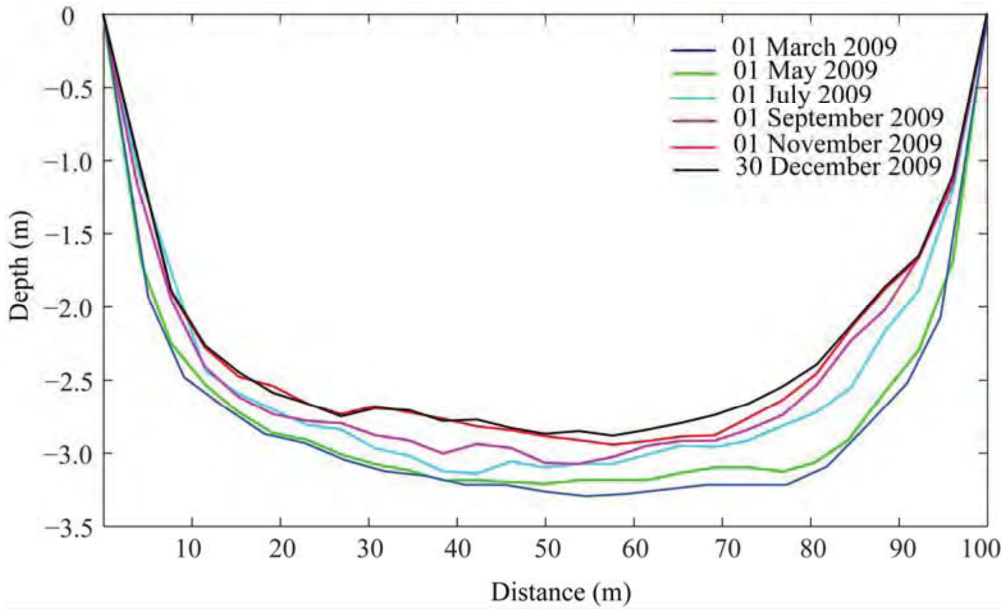


Figure 4.72 Predicted bed levels across the entrance canal (section x-y) of Port Geographe for Scenario 6 from 1 March to 30 December 2009.

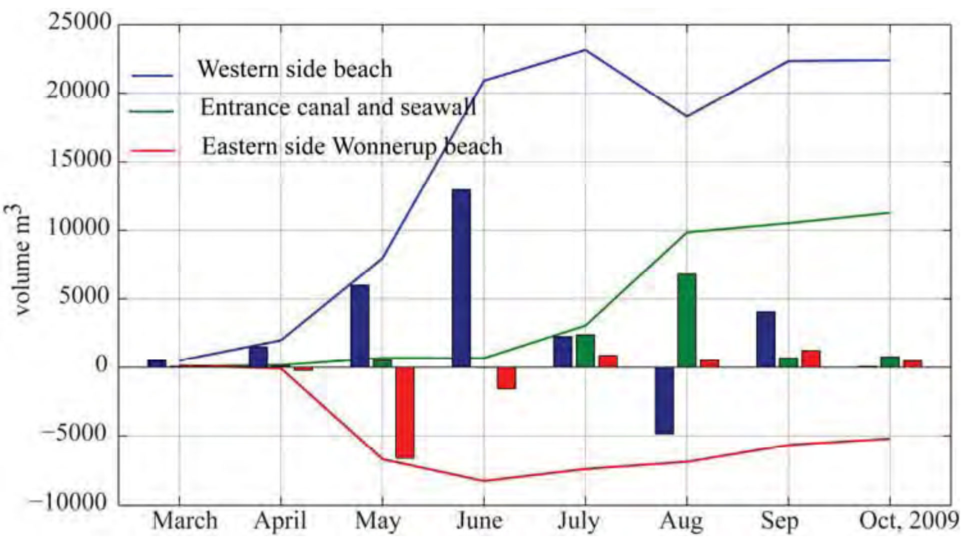


Figure 4.73 Model-simulated monthly sand accretion and cumulative volume during 01 March to 30 October 2009 at different locations of Port Geographe for Scenario 6.

4.7.2 Seagrass wrack transport (Scenario 6)

The predicted seagrass wrack distribution in the vicinity of Port Geographe on 30 June and 30 September 2009 are shown in Figure 4.74 and 4.75, where seagrass model runs were made from 30 March to 30 September 2009. The same initial condition was used for all seagrass model runs as described in previous sections. It can be seen that a similar pattern of seagrass distribution was predicted for offshore for all scenarios. This is to be expected, since flow conditions in offshore region are not affected by the Port Geographe layout changes. Some seagrass wrack had moved into the harbour entrance and was deposited in the western bend part of the harbour entrance channel.

A comparison of model-simulated cumulative seagrass wrack (particles) on the western side of Port Geographe under Scenario 6 and existing configurations are shown in Figure 4.76. Less than 5,000 particles were trapped at the western side of the breakwater at the end of September 2009.

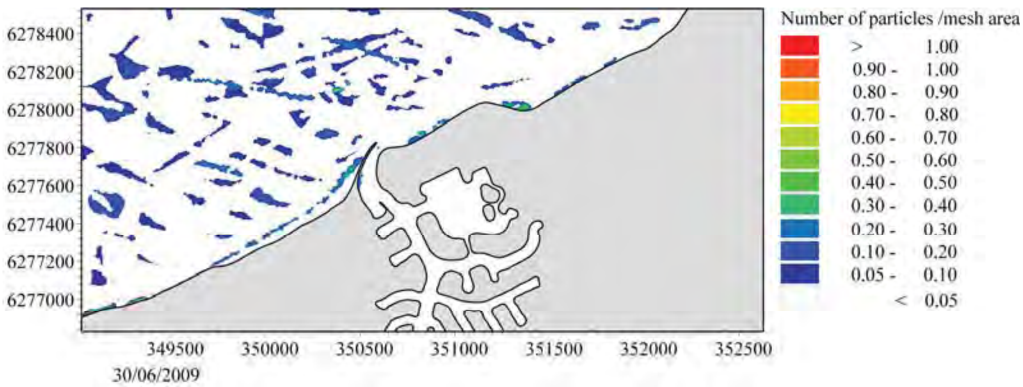


Figure 4.74 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 6.

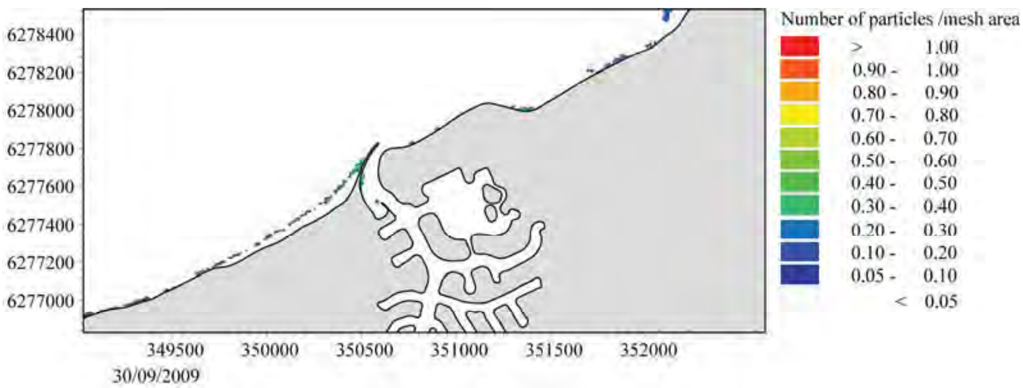


Figure 4.75 Particle distribution in the vicinity of Port Geographe on 30 September 2009 for Scenario 6.

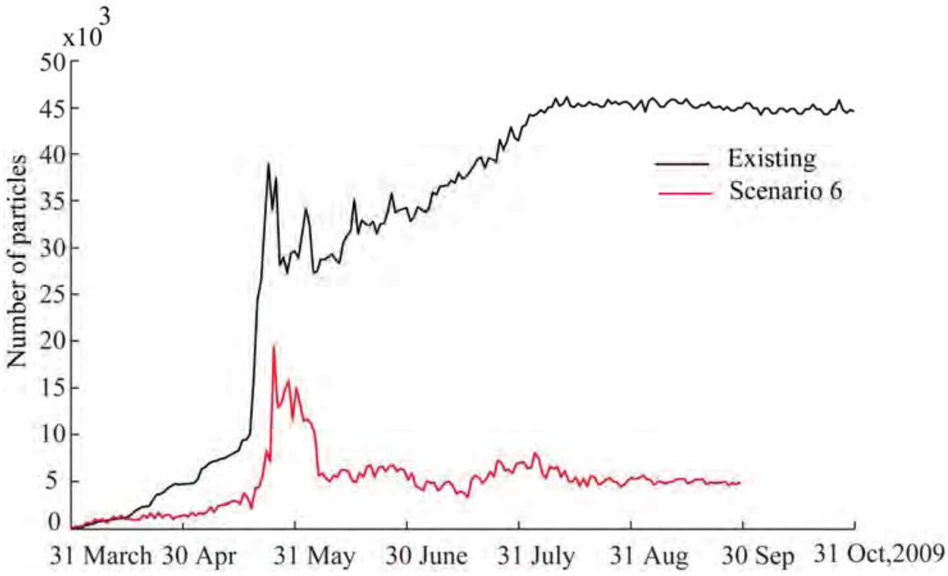


Figure 4.76 Predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenario 6.

The model results of Scenario 6 are summarised below.

- Both seagrass and sand have been transported from the western to eastern beaches with minimal trapping, indicating an effective natural bypass system.
- Erosion of Wonnerup beaches was evident, but less compared to Scenarios 3, 4 and 5.
- Seagrass wrack deposited inside the harbour entrance.
- There was no significant siltation in the inner part of the harbour entrance.
- No shoal was developed in the lee of the western groyne.

4.8 Model Simulations: Scenario 7

The Scenario 7 layout was similar to Scenario 6 layout, except that a small lagoon has been included behind the western section of the seawall as shown in Figure 4.77. The incorporation of a lagoon was considered desirable by some members of the Port Geographe Sediment and Seagrass Reference Group as a means of providing an alternative provide an alternative beach for the local community. It may also have the added benefit of reducing construction (reclamation) costs. The surface area of the lagoon is ~22,000 m^2 and the lagoon entrance width was set to 10 m. The maximum lagoon depth at the centre was 2m. The proposed lagoon was not expected to have a substantial impact on the harbour entrance hydrodynamics and sediment transport processes. However, in order to prove this assumption, model runs were undertaken from 1 March to 30 December 2009 with the Scenario 7 layout compared to that obtained for Scenario 6. The model mesh grid and the initial bathymetry for Scenario 7 are shown in 4.77.

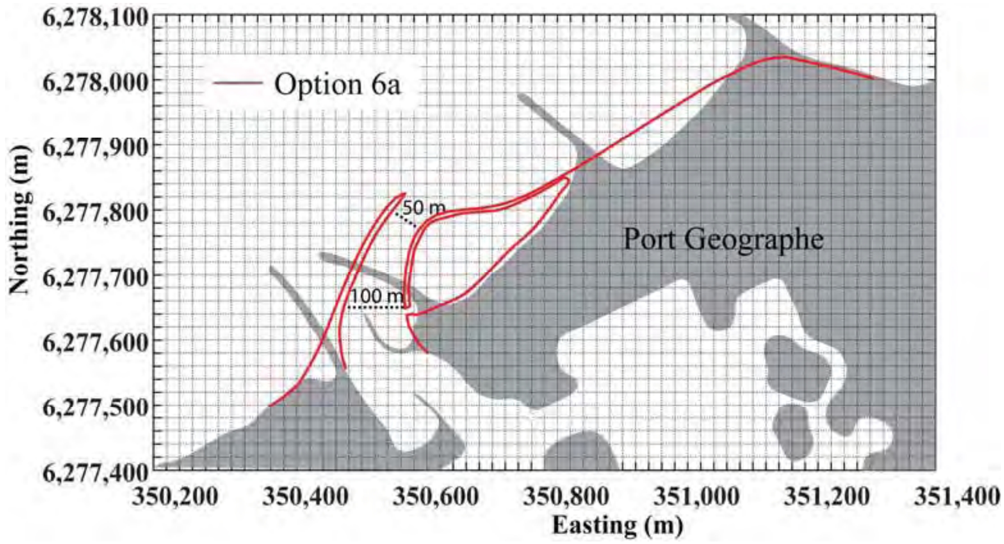


Figure 4.77 Scenario 7 layout of Port Geographe. Black dotted line shows existing Port Geographe layout and red solid lines shows layout of Scenario 7.

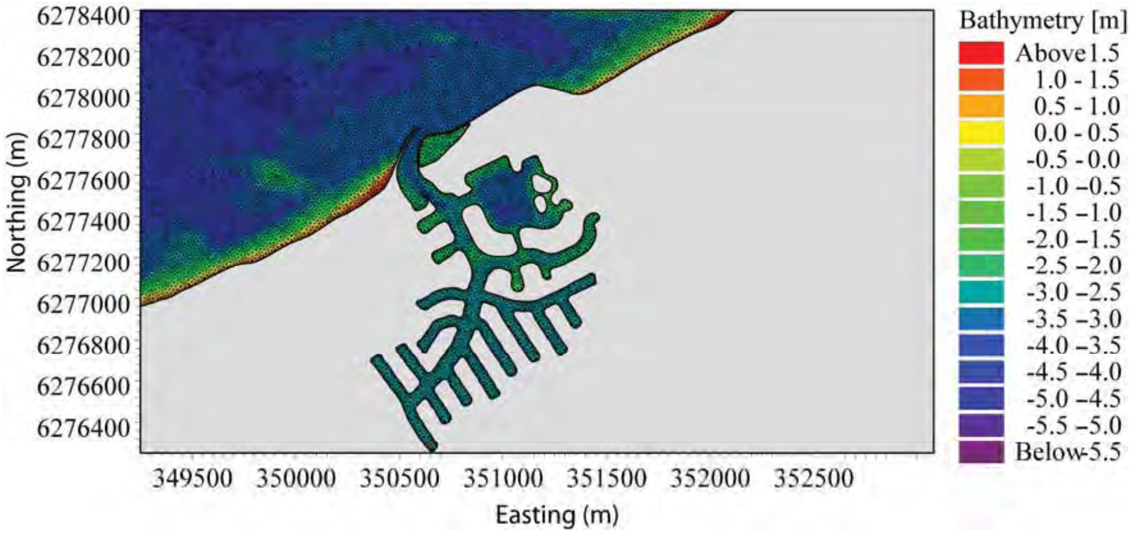


Figure 4.78 Mesh grid and initial bathymetry in the vicinity of Port Geographe for Scenario 7 including proposed lagoon and all inner canal segments.

4.8.1 Sediment transport (scenario 7)

The model-predicted bed levels for Scenario 7 are shown in Figure 4.79. There were no significant differences between the predicted bed level changes for Scenarios 6 and 7. The predicted bed level profiles in the harbour entrance channel cross-section are shown in Figure 4.80. The predicted sediment budget for Scenario 7 (Figure 4.81) was exactly the same as those predicted in Scenario 6.

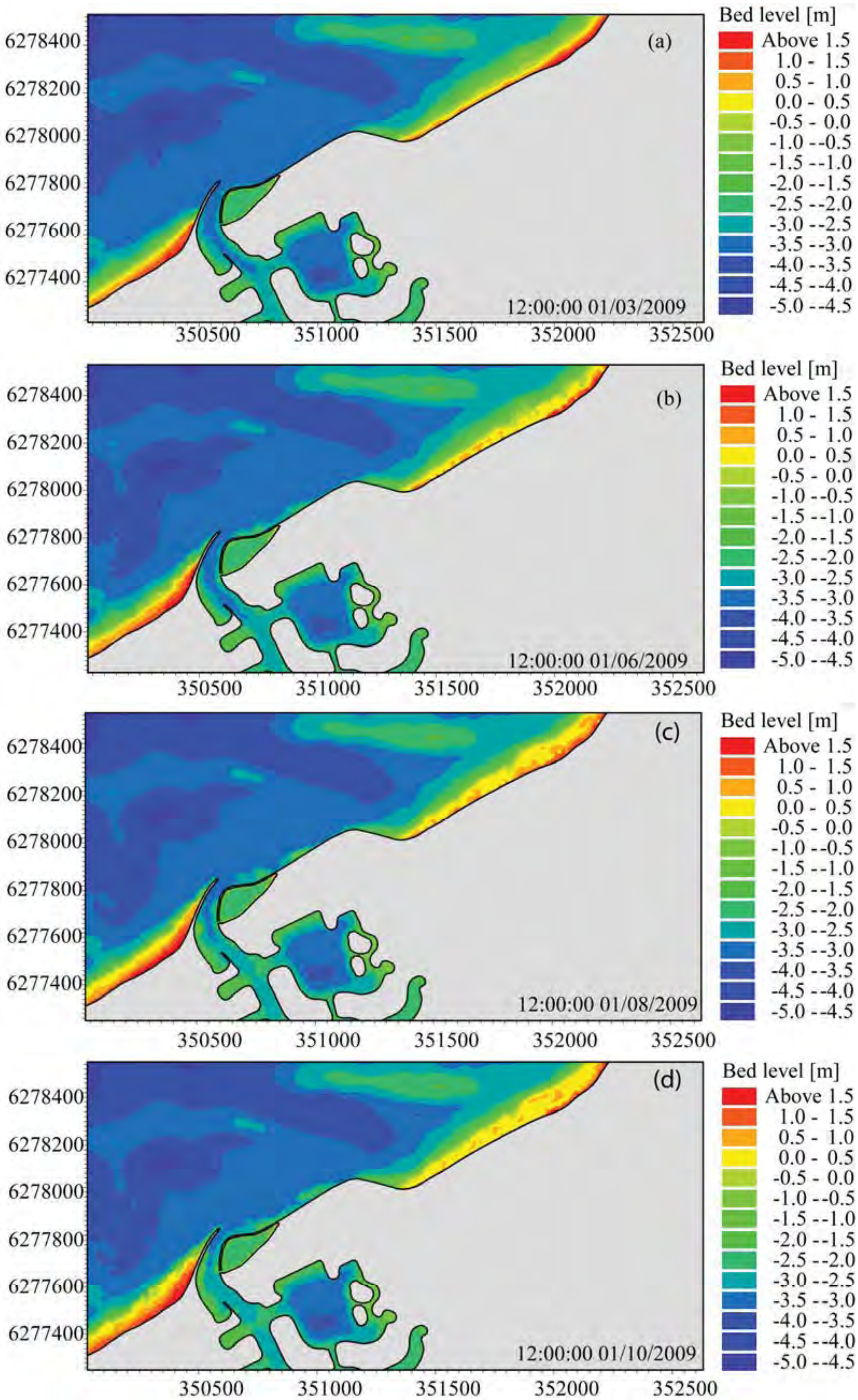


Figure 4.79 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 7. (a) Model initial bathymetry on 01 March 2009 and predicted bed levels on (b) 1 June 2009; (c) 1 August 2009; and, (d) 1 October 2009.

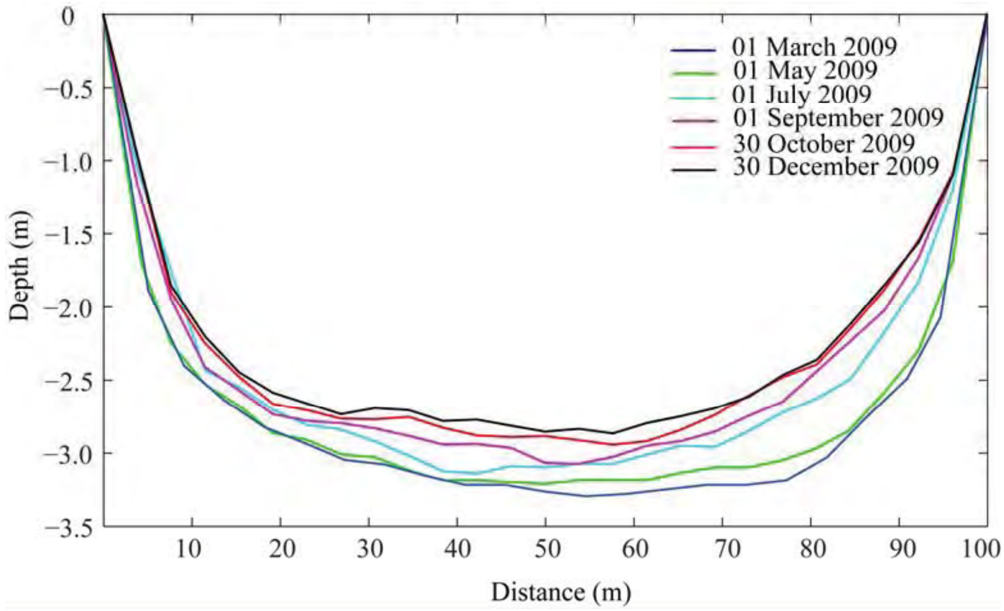


Figure 4.80 Predicted bed levels across the harbour entrance channel (section x-y) of Port Geographe for Scenario 7 from 1 March to 30 December 2009.

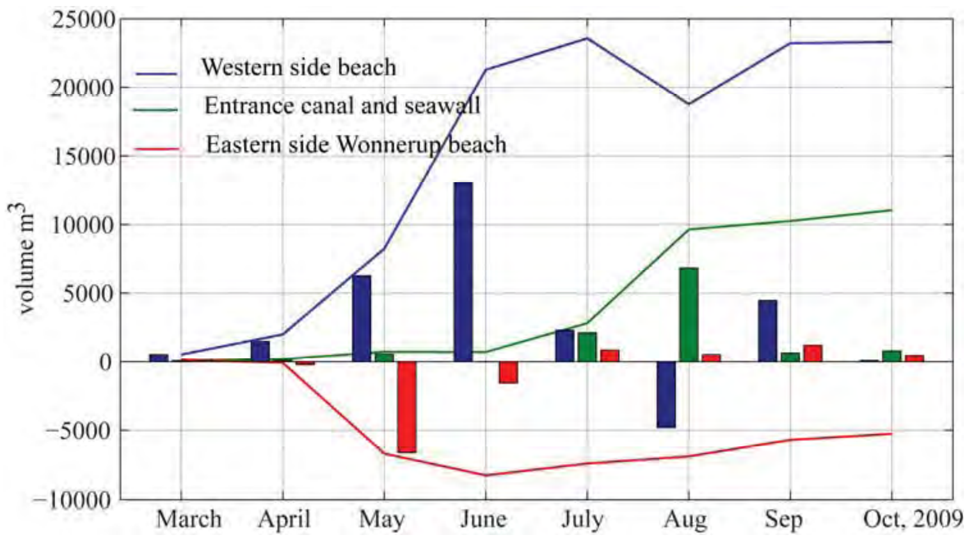


Figure 4.81 Model-simulated monthly sand accretion and cumulative volume from 1 March to 30 October 2009 at different locations across Port Geographe for Scenario 7.

4.8.2 Seagrass wrack transport (scenario 7)

The predicted seagrass wrack distribution was the same as that obtained for Scenario 6 (Section 4.7.2) and the reader is referred to that section for a description of the results. For completeness Figures 4.82 and 4.83 indicate the predicted seagrass wrack accumulations and it should be noted that there was no wrack accumulation inside the lagoon.

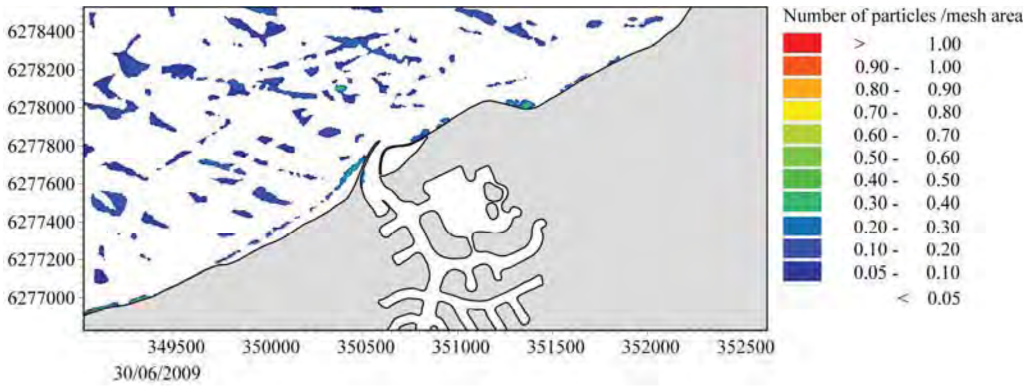


Figure 4.82 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 7

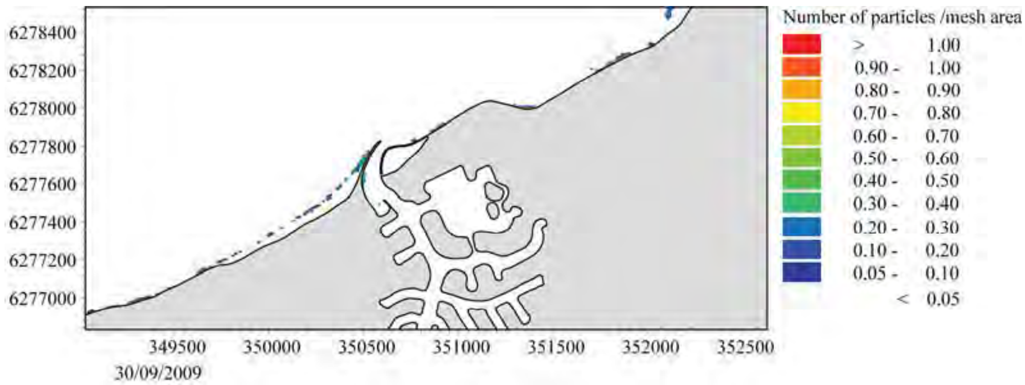


Figure 4.83 Particle distribution in the vicinity of Port Geographe on 30 September 2009 for Scenario 7.

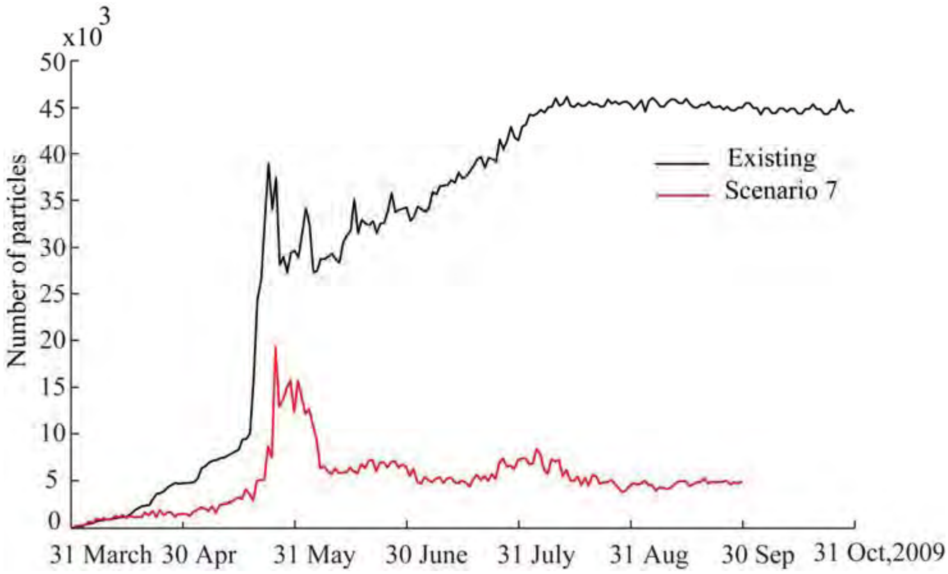


Figure 4.84 Predicted cumulative number of particle (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenario 7.

4.9 Model Simulations: Scenario 8

Scenario 8 was developed by changing the shape of the western breakwater such that the currents were concentrated in front of the entrance channel (Figure 4.85). The eastern side of the seawall was changed by increasing the angle clockwise. A harbour entrance width of 50 m was retained and the mid section of the harbour channel was reduced to 100 m. The seawall was slightly extended towards the east to provide protection by reducing wave reflection and the generation of rip currents, which may, in turn, reduce the erosion at the western end of Wonnerup Beach. The lagoon that was included in this Scenario was slightly smaller when compared with Scenario 7. The surface area of the lagoon was ~18,000 m^2 and entrance width was retained at 10m. The maximum lagoon depth was 2m. Figure 4.86 shows the unstructured mesh and the initial model bathymetry for Scenario 8. The initial Scenario 8 model runs were for a 10-month period from March to December 2009. The model runs were then repeated with a sand saturated beach on the western side of Port Geographe but with same forcing condition as 2009. The model runs were continued into 2010. Forcing data for 2010 was described in Section 4.2.

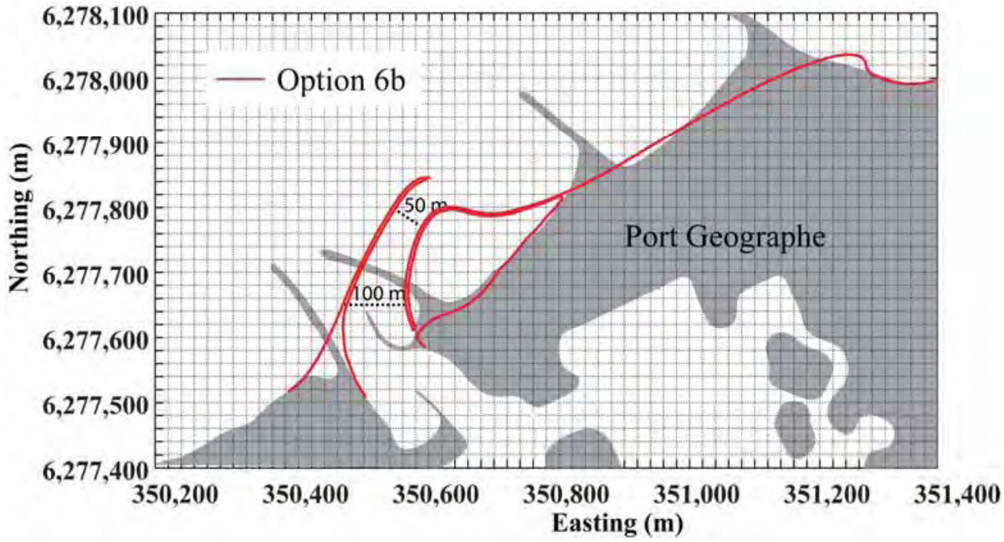


Figure 4.85 Scenario 8 layout of Port Geographe. Black dotted line shows existing Port Geographe layout and red solid lines shows layout of Scenario 8.

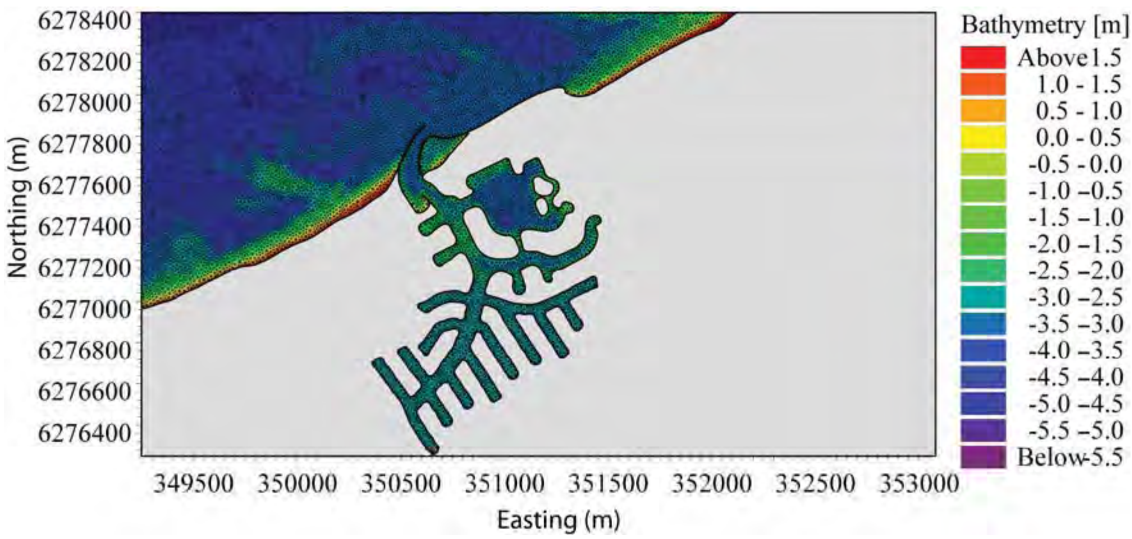


Figure 4.86 Mesh grid and initial bathymetry in the vicinity of Port Geographe for Scenario 8 including proposed lagoon and all inner canal segments.

4.9.1 Sediment transport (Scenario 8)

The predicted bed level maps in 2009 for Scenario 8 (Figure 4.87) indicated a significantly reduced bypass shoal development in the lee of the western breakwater with reduced sedimentation inside the harbour entrance channel. The angled seawall appeared to enhance the eastward transport of sand and reduced the bypass shoal in front of the harbour entrance. The predicted a bed elevation map indicated that the erosion problem on Wonnerup beach has been significantly addressed with the Scenario 8 layout.

The model-predicted bed level profiles at the wider section of the harbour entrance are shown in Figure 4.88. The average initial depth was 2.9m AHD on 01 March 2009 and this was reduced to 2.65 m AHD by 30 December 2009.

The resulting, cumulative volume variation clearly shows a less erosive sand balance for the Scenario 8 layout as shown in Figure 4.89. This result was expected since the increased flow velocities due to the contraction of the streamlines increase the bypass capacity over the harbour entrance. Also, eastward sand transport was increased along the seawall due to the change in the alignment of the seawall.

The cumulative sand volume on the western part of Port Geographe from 1 March to 1 October 2009 was 17,000 m^3. The maximum accumulation of 11,000 m^3 occurred in June along the western side of Port Geographe.

From March to June the beach along the western side of the Port Geographe continuously accreted. The eastward sand transport was estimated to be ~75,000 m^3 from March to October 2009 (see Section 4.1). Thus ~68,000 m^3 of sand was transported from the western to the eastern side of the western breakwater. Some sand accumulated along the seawall at the end of simulation period, but the volume appears to be limited to ~8,000 m^3. Thus the amount of sand bypassed to the eastern side (Wonnerup beaches and near-shore area) was estimated to be ~60,000 m^3. Wonnerup beach accreted over the model period (from March to October), where the cumulative volume was estimated to be ~2,500 m^3. Thus the total sand lost (supply from western side, 60,000 + beach accumulated, 2,500) from March to October at Wonnerup beach (littoral zone) was estimated to be ~57,500 m^3. These results clearly indicate if no sand was trapped (equilibrium beach) on the western side, there would be sufficient sand feed to address the erosion losses to the eastern beaches.

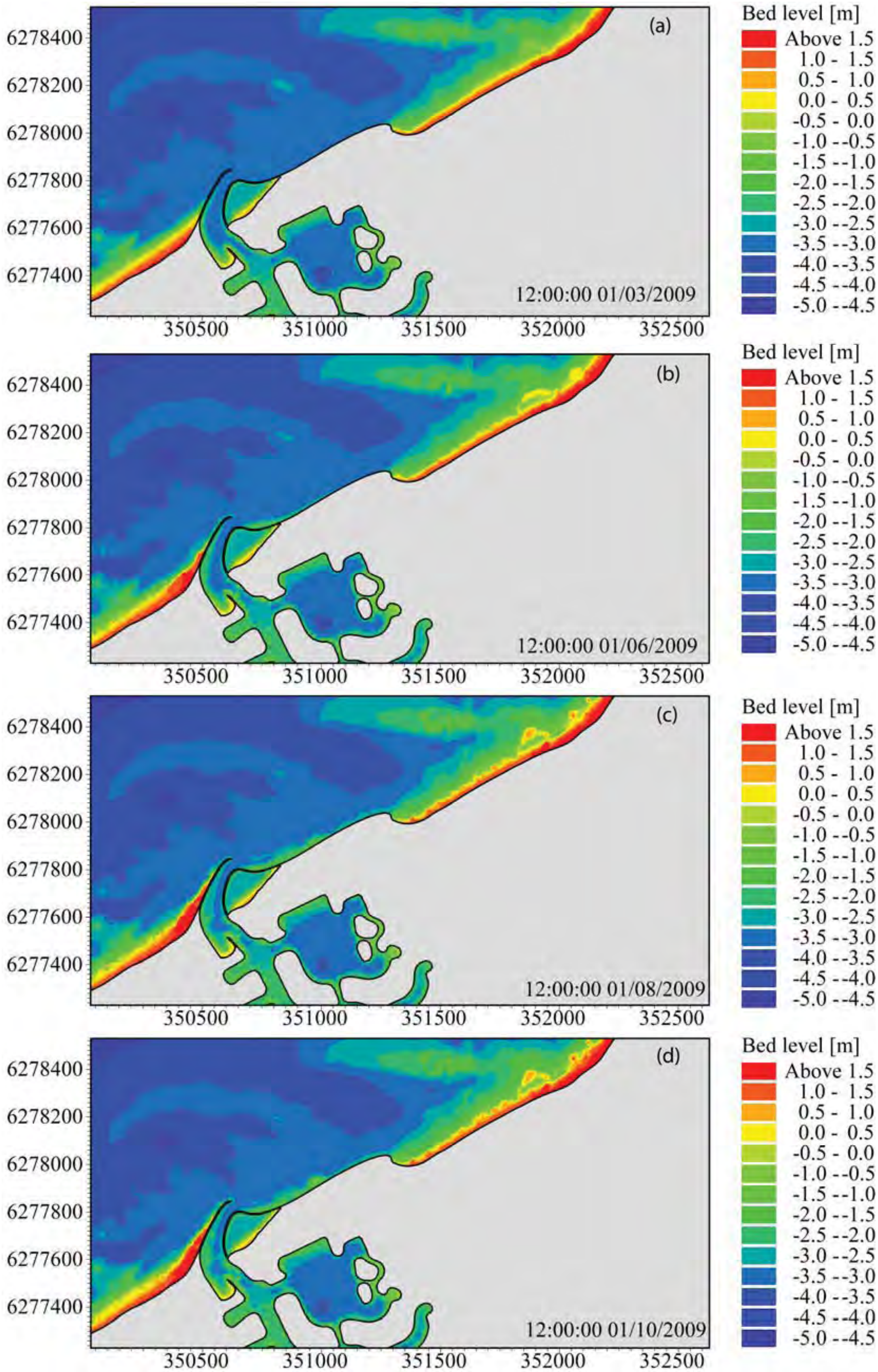


Figure 4.87 Model-predicted bed levels in the vicinity of Port Geographe for Scenario 8.(a) Model initial bathymetry on 01 March 2009, and predicted bed levels on (b) 1 June 2009; (c) 01 August 2009; and, (d) 01 October 2009.

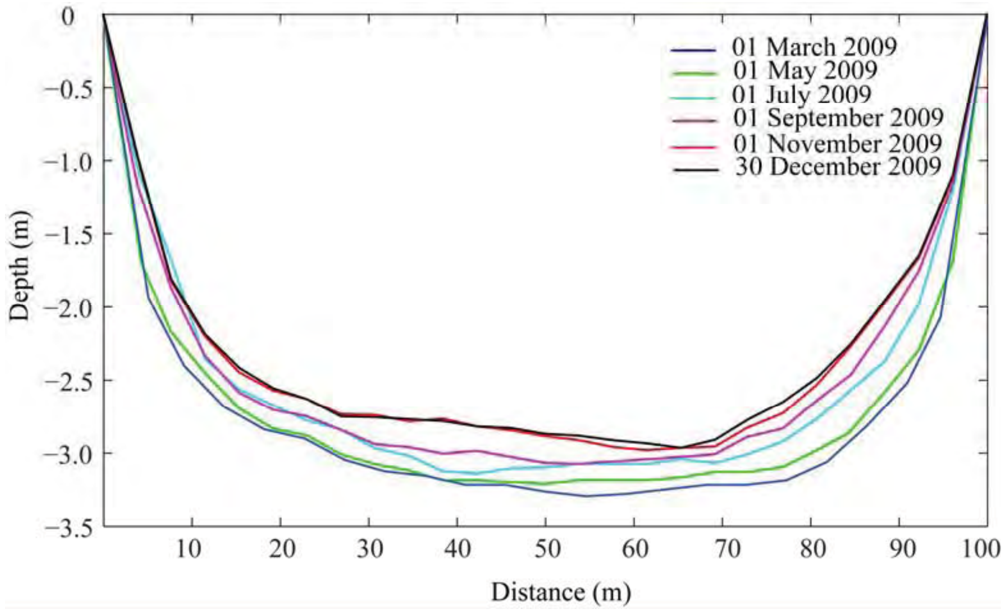


Figure 4.88 Model-predicted bed levels across the harbour entrance channel (section x-y) of Port Geographe for Scenario 8 during 01 March to 30 December 2009.

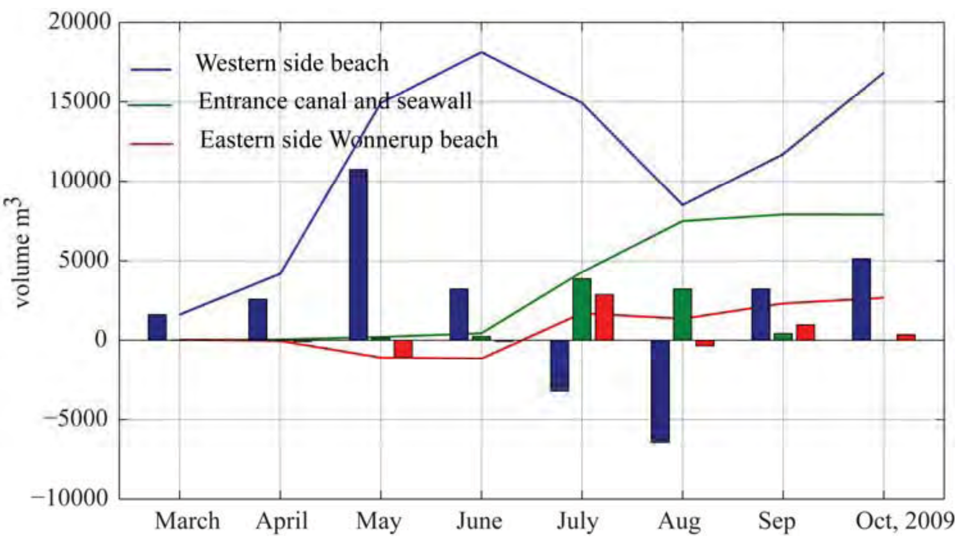


Figure 4.89 Model-simulated monthly sand accretion and cumulative volume during 01 March to 30 October 2009 at different locations of Port Geographe for Scenario 8.

4.9.2 Seagrass wrack transport (scenario 8)

Predicted seagrass wrack movement in the vicinity of Port Geographe in June and at the end of September 2009 are shown in Figures 4.90 and 4.91. It can be clearly seen that under this scenario seagrass wrack was efficiently bypassed across the harbour entrance. Small amount of wrack were deposited along the western side of the breakwater. Some seagrass wrack had moved into the harbour entrance and was deposited in the inner part of the Port Geographe entrance channel. A comparison of model-simulated seagrass wrack (particle) accretion on the western side of Port Geographe for Scenario 8 and for the existing configuration is shown in Figure 4.92. Less than 4,500 particles were trapped to the western side of the breakwater at the end of September 2009. This represents the least amount of particle accumulation of any scenario tested. There was no significant wrack deposited either inside the harbour entrance channel or along the seawall.

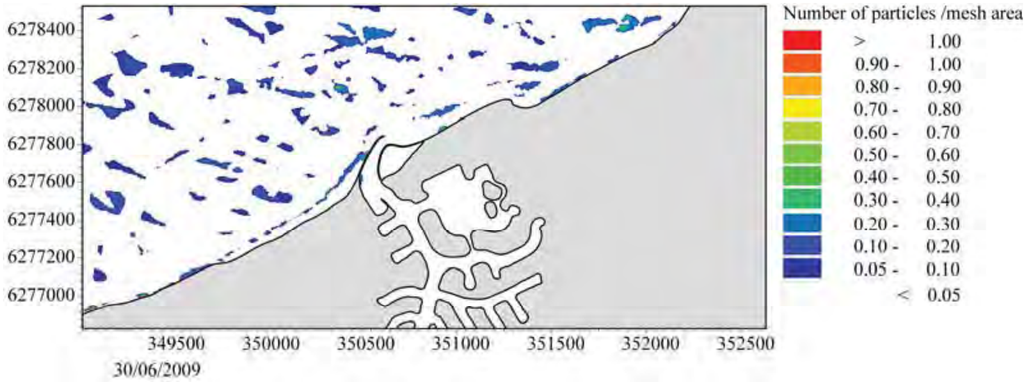


Figure 4.90 Particle distribution in the vicinity of Port Geographe on 30 June 2009 for Scenario 8.

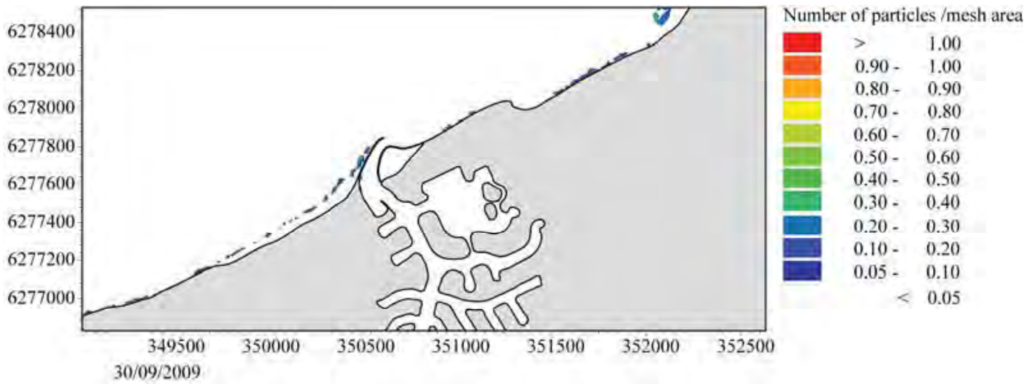


Figure 4.91 Particle distribution in the vicinity of Port Geographe on 30 September 2009 for Scenario 8.

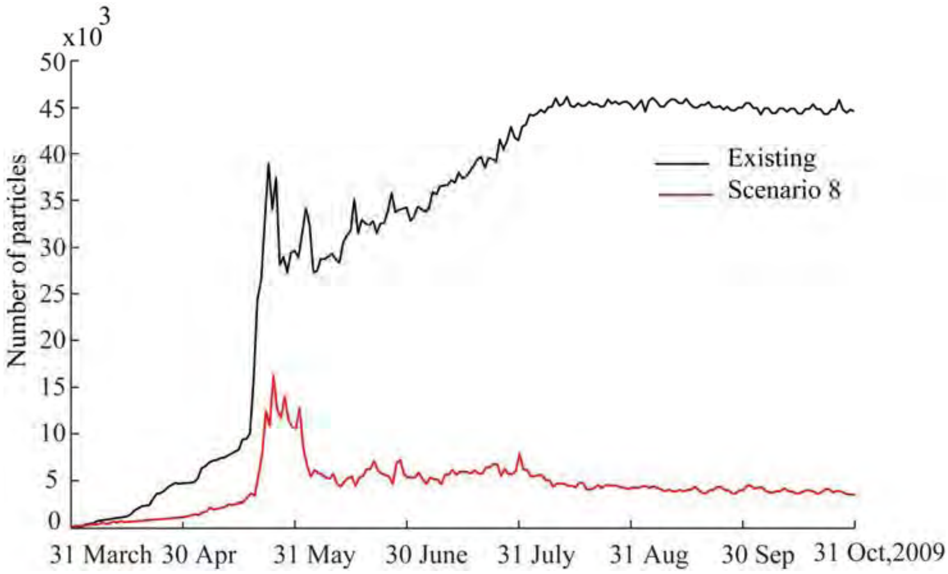


Figure 4.92 Predicted cumulative number of particle (seagrass wrack) at the western beach, Port Geographe from March to October 2009 for Scenario 8.

4.9.3 Model simulations: Scenario 8 (repeated model run for 2009)

The aim of this simulation was to evaluate sediment and seagrass transport with saturated beach on the western side of Port Geographe for Scenario 8. As described in earlier section 3, 2009 year was relatively stormy year. The model runs were repeated with same forcing condition in 2009, but initial model bathymetry for this simulation was upgraded bathymetry from previous simulation. The predicted bed levels in the vicinity of Port Geographe for Scenario 8 were seen in Figure 4.93, which shows the result of a repetition of the simulation of 2009 with the initial saturated bathymetry. The model-predicted cumulative sand volumes at different parts of Port Geographe are shown in Figure 4.94.

The particle transport model runs were repeated as described in previous sections, 200,000 particles were seeded four times on 31 March 2009 during different tidal states (low, rising mid, high and falling mid); each time 50,000 particles were distributed in the near shore area. The cumulative number of particles on the western side of Port Geographe is shown in figure 4.95.

The model results (repeat of 2009) are summarized as below;

- No additional sand accretion occurred on the western side of Port Geographe during repeat runs for 2009.
- A small volume of sand was present adjacent to the seawall: the cumulative volume from January to December 2009 was ~2,000 m^3.
- No accretion or erosion was occurred at Wonnerup beach.
- The total number of particles accumulated along the western side of Port Geographe was < 4,000.

4.9.4 Model simulations: Scenario 8 (extended model runs for2010)

The Scenario 8 model runs were extended for 2010 a calmer year in terms of storms when compared to 2009. The model boundary conditions were specified using measured sea levels, wind and wave climate in 2010 (see section 4.2). The predicted bed levels in the vicinity of Port Geographe for 2010 are shown in Figure 4.96. The predicted cumulative sand volumes at different part of Port Geographe during 2009 and 2010 are shown in Figure 4.97. The model-predicted bed level profiles at the wider part of the entrance canal for 2010 are shown in Figure 4.98. Predicted beach profiles along the Wonnerup beach for Scenario 8 are shown in Figure 4.99. It can be seen that significant sand accretion occurred in the near shore region of Wonnerup.

As described in previous sections, particle transport model runs were made for 2010, where 200,000 particles were seeded four times on 31st March 2010 during different tidal states (low, rising mid, high and falling mid); each time 50,000 particles were distributed in the nearshore area. The cumulative number of particles on the western side of Port Geographe at the end of 30 Sep 2010 is shown in Figure 4.100.

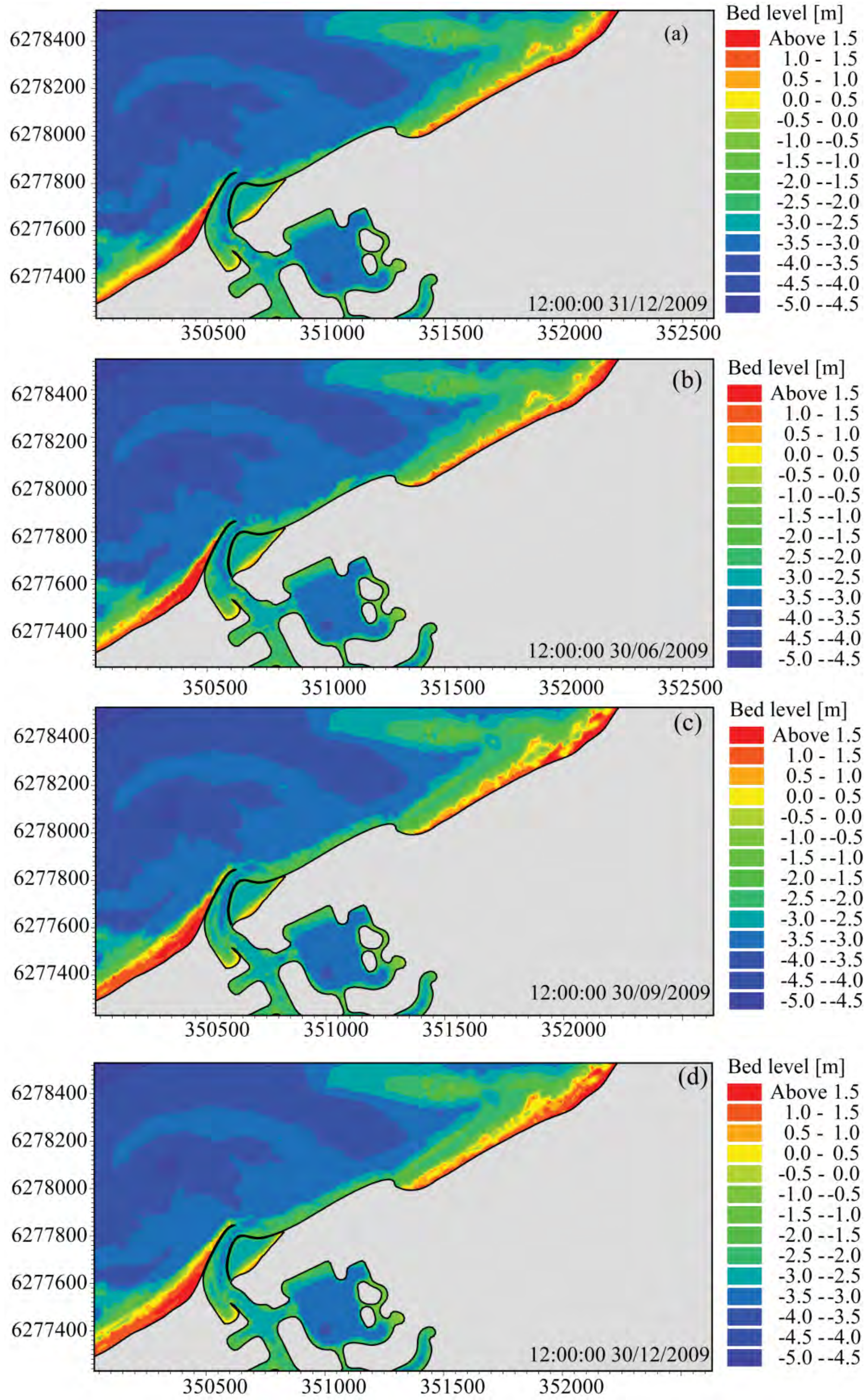


Figure 4.93 Model-predicted bed levels in the vicinity of Port Geographe for scenario 8 with initial saturated beach on the western side of Port Geographe. (a) Model initial bathymetry on 31 Dec 2009, and predicted bed levels on (b) 30 June 2009; (c) 30 September 2009; and, (d) 30 December 2009

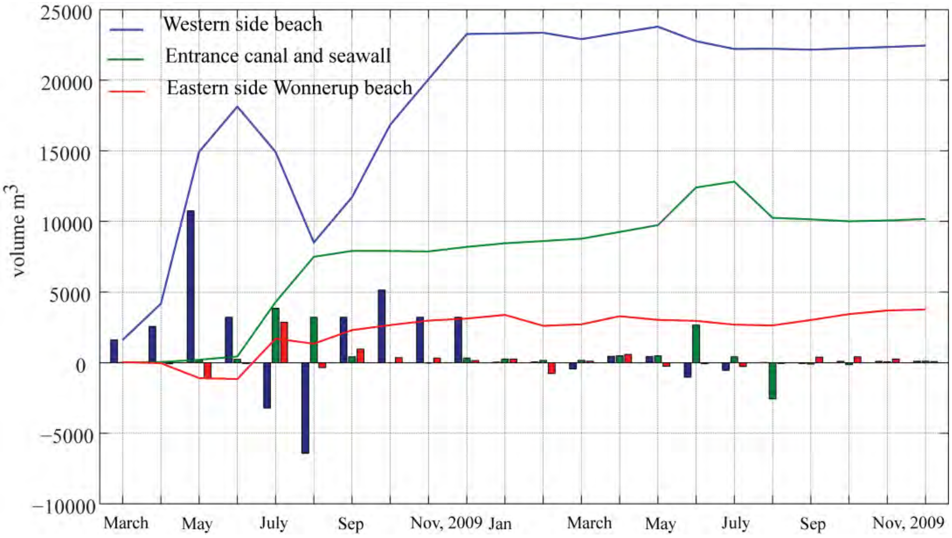


Figure 4.94 Model-simulated monthly sand accretion and cumulative volume during 01 March 2009 to December 2009 and repeat January 2009 to December 2009 at different part of Port Geographe for scenario 8.

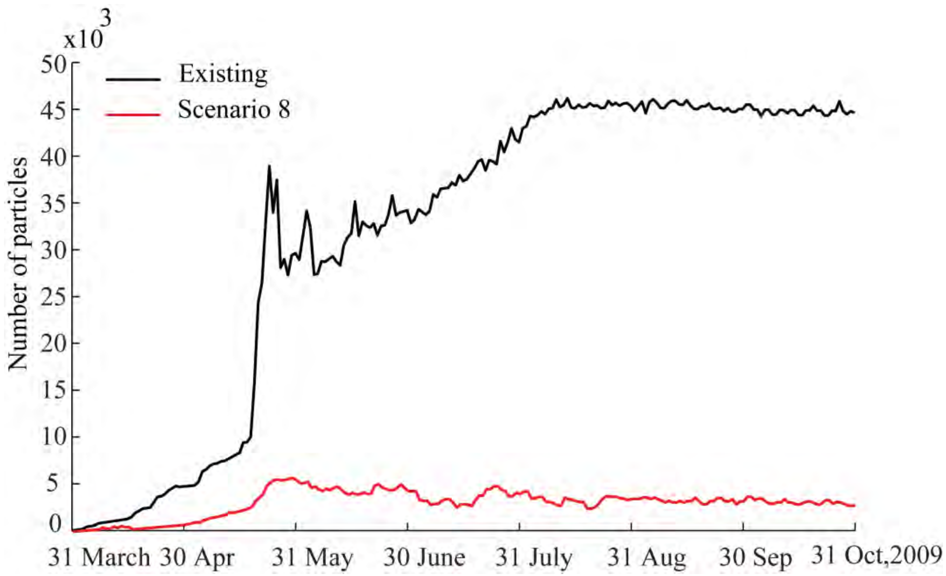


Figure 4.95 A comparison of predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe for Scenario 8 (under a repeat forcing of 2009).

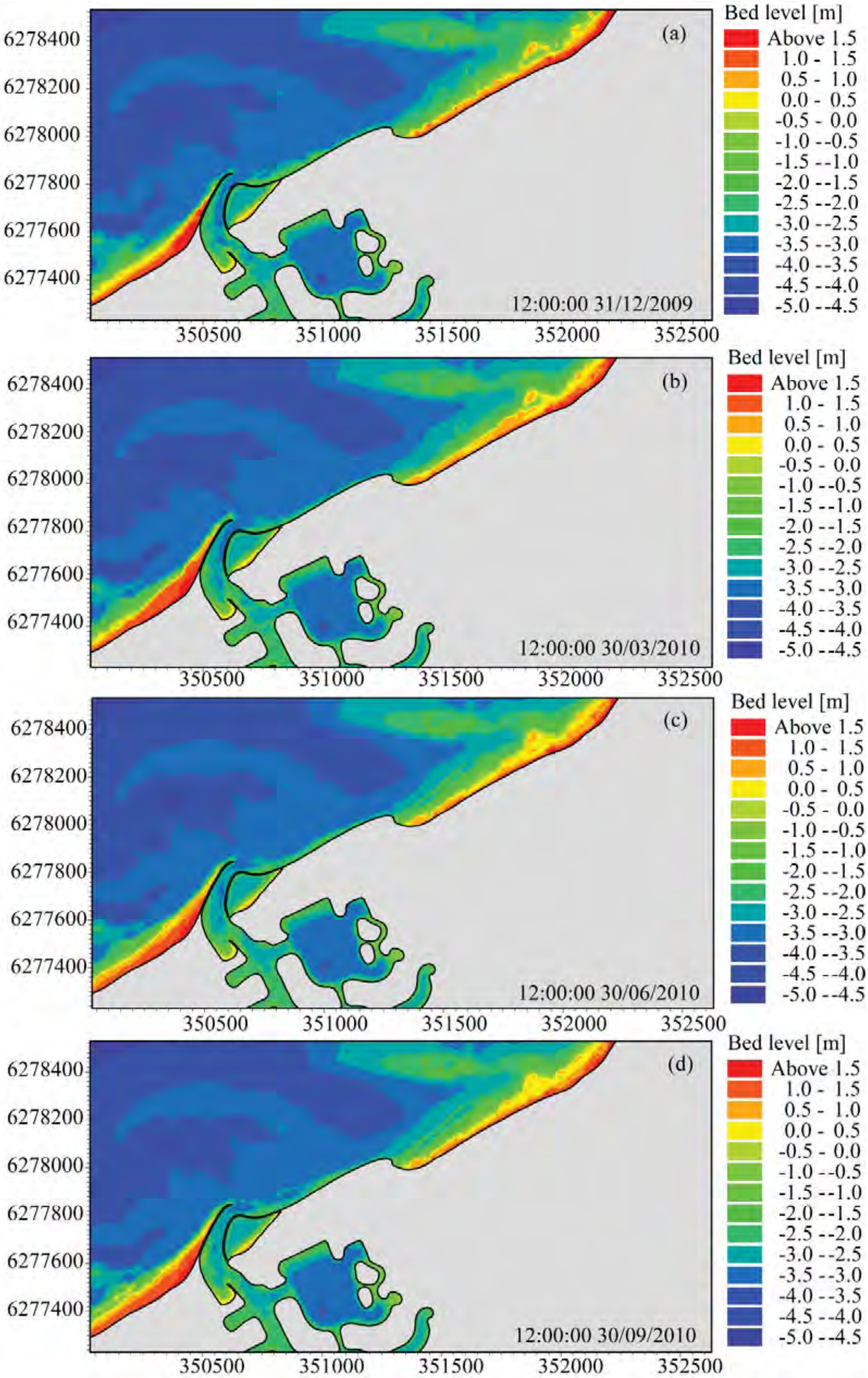


Figure 4.96 Model-predicted bed levels in the vicinity of Port Geographe for scenario 8 for 2010 with initial saturated beach on the western side of Port Geographe. (a) Model initial bathymetry on 31 Dec 2009 and predicted bed levels on (b) 30 March 2010; (c) 30 June 2010; and, (d) 30 September 2010,

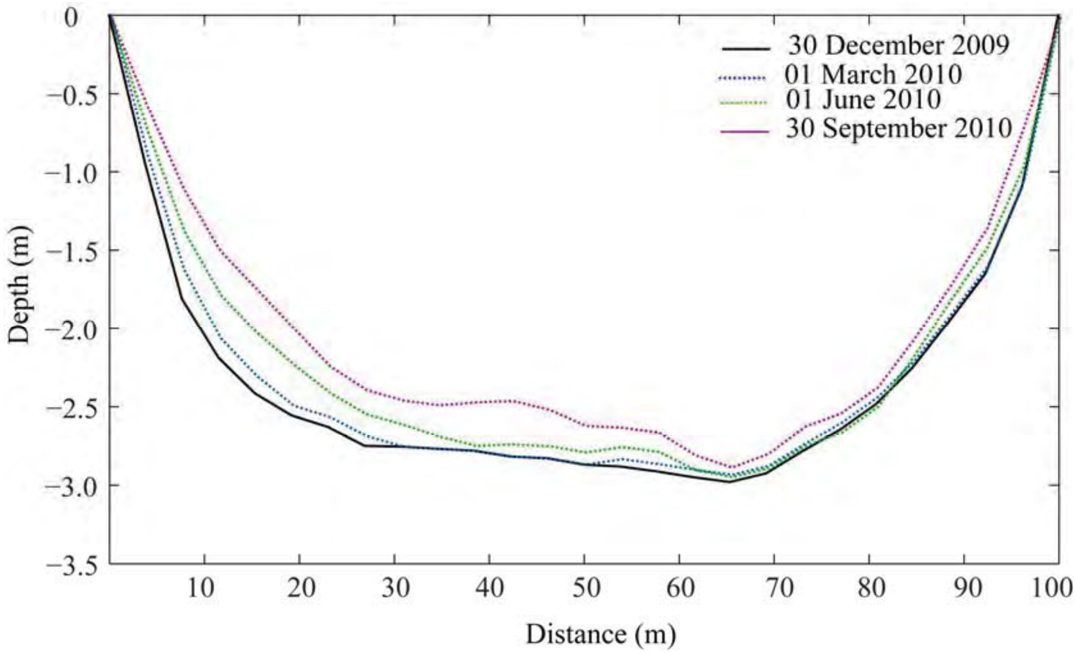


Figure 4.97 Model-predicted bed levels across the entrance canal (section x-y) of Port Geographe for scenario 8 during 01 March to 30 September 2010.

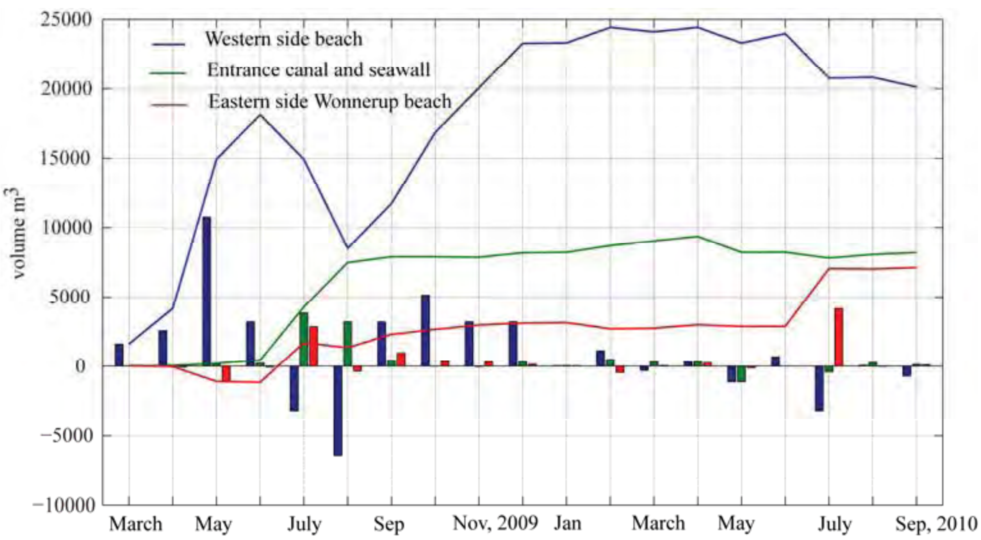


Figure 4.98 Model-simulated monthly sand accretion and cumulative volume during 01 March 2009 to 30 September 2010 at different parts of Port Geographe for scenario 8.

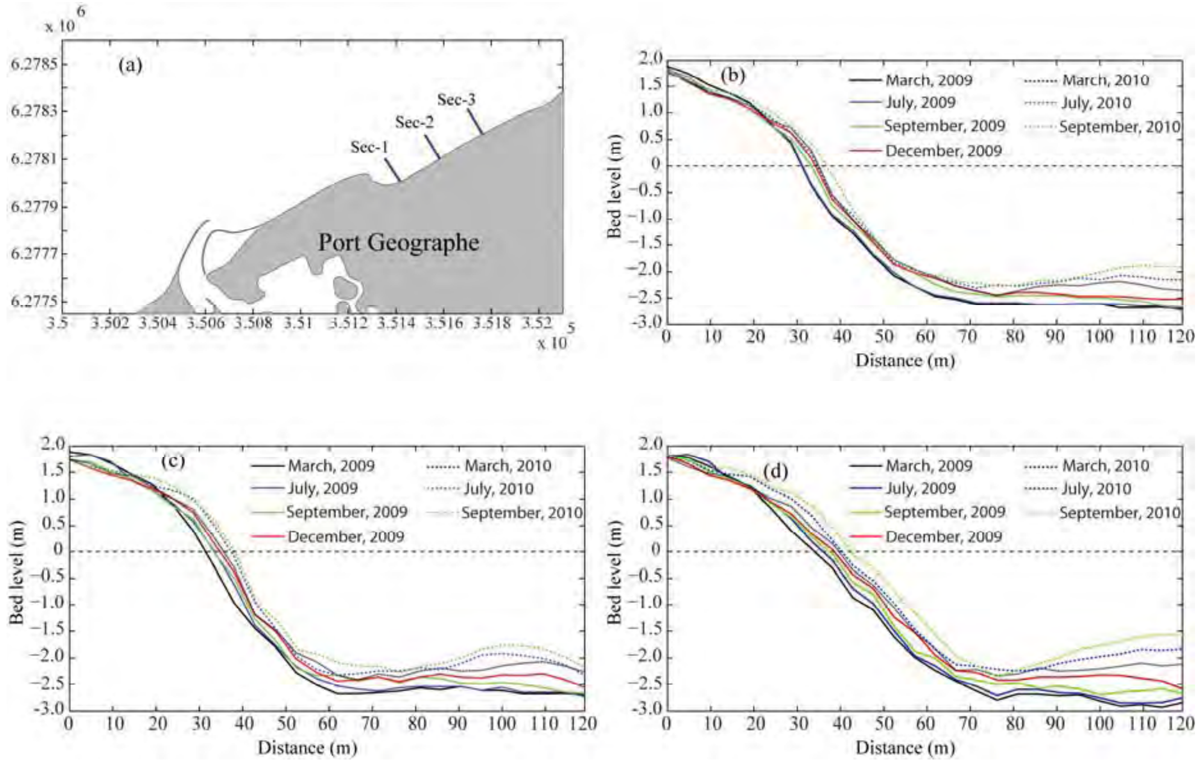


Figure 4.99 Predicted beach profiles in 2009 and 2010 along Wonnerup Beach for Scenario 8. (a) location of cross-sections and predicted profiles for: (b) section 1 (Sec-1); (c) section 2 (Sec-2); and; (d) section 3 (Sec-3).

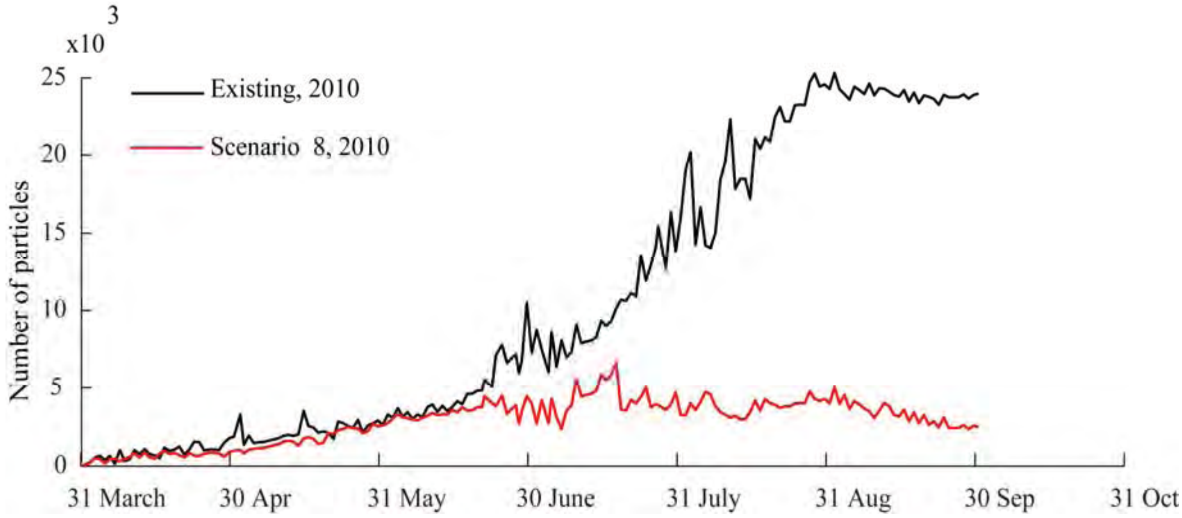


Figure 4.100 A comparison of Scenario 8 and existing condition predicted cumulative number of particle (seagrass wrack) at the western beach, Port Geographe for 2010.

The results for Scenario 8 in 2010 can be summarised as follows:

- Slight erosion occurred on the western side of Port Geographe between January and 30 September 2010.
- No significant accretion or erosion occurred on the seawall
- Significant sand accretion occurred at Wonnerup beach and near shore areas over the between January and 30 September 2010.
- Some sedimentation occurred in the entrance canal segment
- The total number of particles accumulated on the western side of Port Geographe was < 4,000.

4.10 Scenario comparison

Eight different layouts including the existing configuration were considered and tested for seagrass wrack and sediment transport in the vicinity of Port Geographe. The basic concepts and justification for defining and selecting of the various options were presented in Sections 4.3 to 4.9. All of the model results revealed that for all the layouts considered, changes to the western breakwater (Scenarios 2 to 8) provided a better solution when compared to the present configuration in terms of seagrass accumulation. The following are the key issues to be considered in an overall assessment of the various options;

- Seagrass wrack accumulation in the vicinity of Port Geographe;
- Natural sand bypass from the western side to the eastern side of the Port Geographe development;
- Sedimentation within the harbour entrance channel; and
- Water quality in the harbour and canal development.

A quantitative comparison of sand and seagrass transport for the different scenarios are discussed in the following sections

4.10.1 Hydrodynamics and wave climate

Depth-averaged currents throughout the model domain followed a distinct, recurring pattern with each passing weather system. Strong currents exceeding 50 cms^{-1} occurred in the nearshore region during storms events. A comparison of flows for different scenarios revealed that the flow changes were localised and confined to the region in the vicinity of Port Geographe.

Irregular flows and eddy circulations were dominant in the existing configuration. The flow speeds reduced whilst passing through the groyne fields and flows within the eastern groyne fields were dominated by eddy-type circulations. For the existing situation, very irregular currents with rapid direction changes were observed to occur during storms. However, the curved breakwater designs defined in Scenarios 2-8, the flows were smooth and almost parallel to the seawall. An example snapshot of the flow field in the vicinity of Port Geographe during westerly winds for the existing configuration and the Scenario 8 layout are shown in Figures 4.101 and 4.102, respectively.

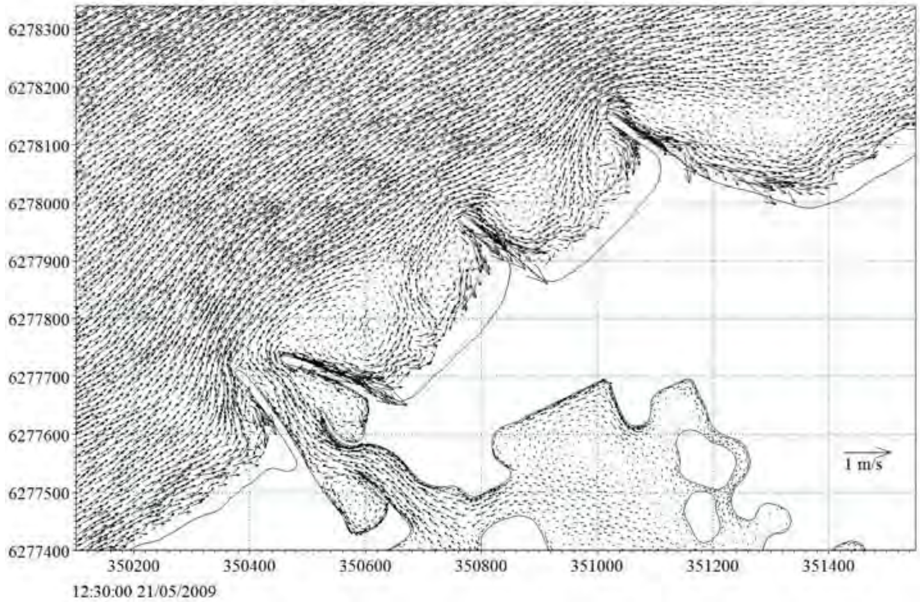


Figure 4.101 Snapshot of predicted current pattern in the Port Geographe area at the peak of storm on May 21 2009 for the existing groyne configuration.

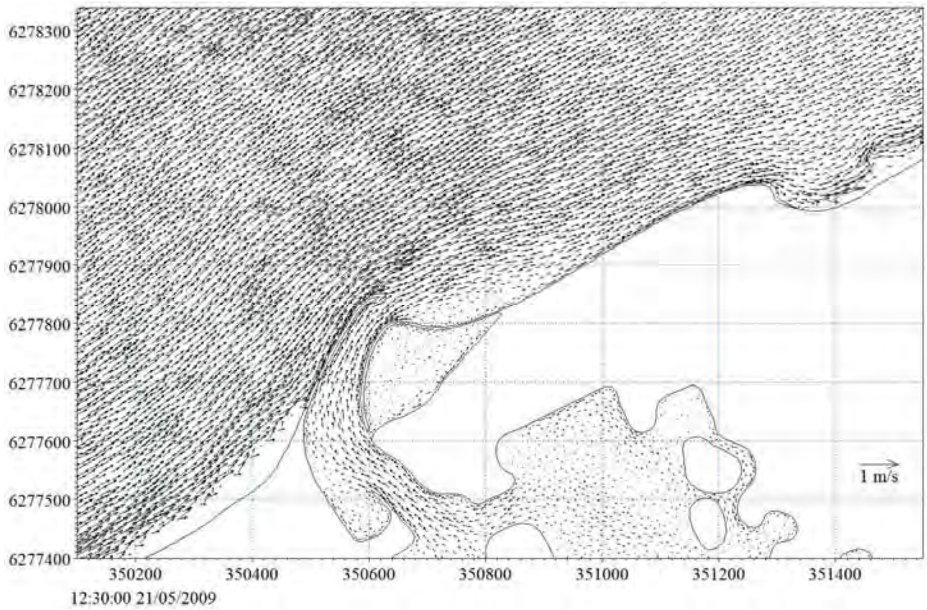


Figure 4.102 Snapshot of predicted current pattern in the Port Geographe area at the peak of storm on May 21 2009 for the Scenario 8.

However, some deviations in flow fields were observed in different layouts, particularly at the harbour entrance and on the eastern side of the harbour entrance. The currents at the harbour entrance were forced by tides and other sea level components setting up a pressure gradient through harbour entrance channel. The flow convergence and divergence through the harbour channel entrance segment were determined by channel edge and width of the central section of the channel entrance. Jet like flows was observed during both flood and ebb tidal cycles under Scenarios 2, 3 and 4. The tidal range inside the harbour entrance channel was defined by the channel width and the mean depth. A significant reduction in the tidal range within the harbour entrance channel was observed for Scenarios 2, 3 and 4. This would have an impact on tidal water exchange and therefore flushing of Port Geographe's inner canal system. There was no significant tidal choking observed through the harbour entrance channel for Scenarios 5, 6, 7 and 8.

The (predicted) significant wave height snapshots for the existing configuration and for Scenario 8 in the vicinity of Port Geographe are shown in Figures 4.103 and 4.104, respectively. Both the model-predicted and the observed wave climate in Geographe Bay revealed that the dominant waves are from the northwest and that they are relatively large during winter months. Under the existing groyne configurations, the Port Geographe harbour entrance is significantly exposed to northwest waves. For the curved breakwater configurations (Scenarios 2-8), the harbour entrance channel was well protected from north-westerly waves.

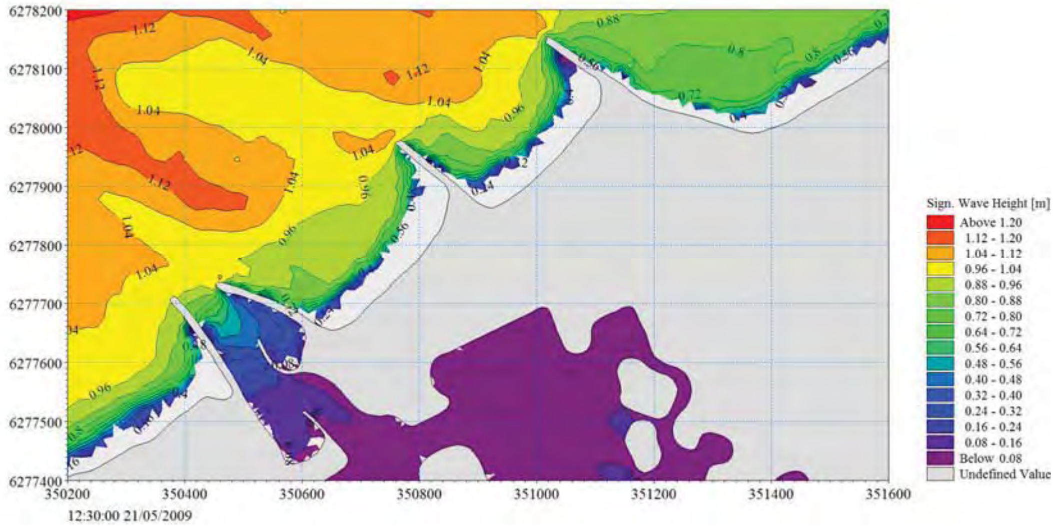


Figure 4.103 Snapshot of predicted significant wave height in the Port Geographe area at the peak of storm on May 21 2009 for the existing groyne configuration.

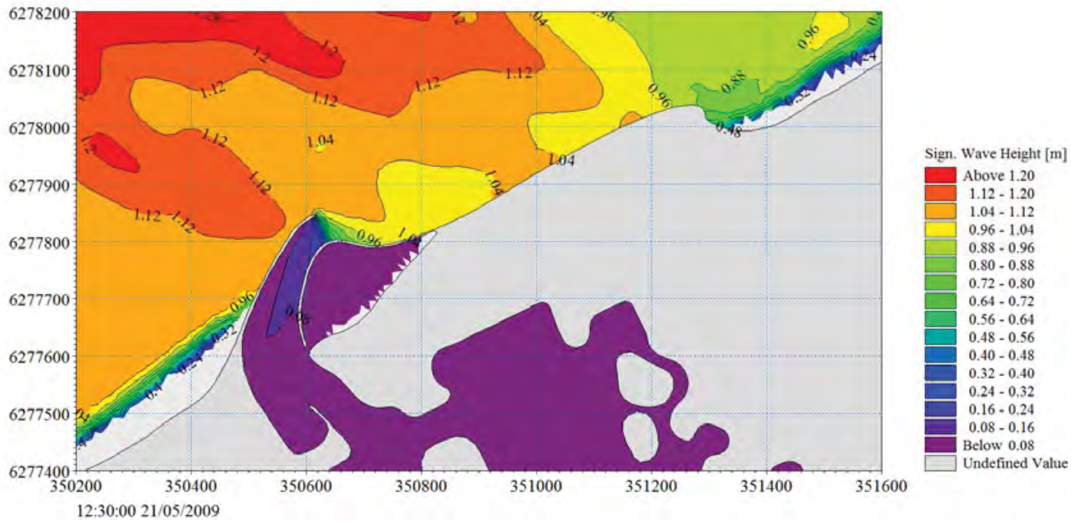


Figure 4.104 Snapshot of predicted significant wave height in the Port Geographe area at the peak of storm on May 21 2009 for the existing groyne configuration.

4.10.2 Sediment transport

A comparison of predicted sediment budget (sediment accretion and erosion) across key sections of the Port Geographe development foreshore in 2009 for each of the scenarios examined is presented on Table 4.3. Predicted sedimentation within the harbour entrance channel (for a selected cross-sectional segment) for the different inlet configurations examined is provided in Table 4.4. A comparison of predicted bed levels profiles on the eastern side of Port Geographe (Wonnerup) for existing configuration and Scenario 8 on 30 September 2010 are shown in Figure 4.105.

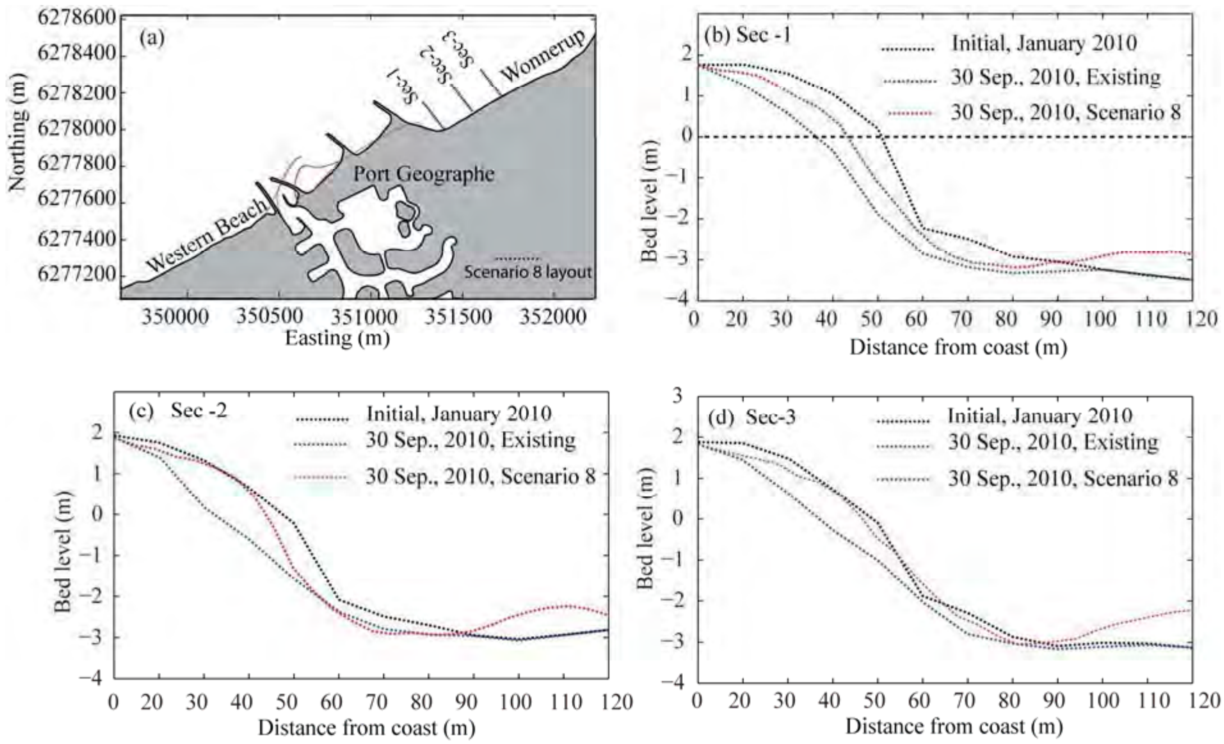


Figure 4.105 Comparison of predicted bed level profiles along the Wonnerup beach for the existing configuration and Scenario 8. (a) location of cross-sections and predicted profiles for: (b) section 1 (Sec-1); (c) section 2 (Sec-2); and, (d) f section 3 (Sec-3)

Table 4.3 Comparison of predicted cumulative sand volumes at different beaches of Port Geographe.

Scenario	Cumulative volume of sand on the western beach (m^3)	Cumulative volume of sand inside harbour entrance and on the seawall (m^3)	Cumulative volume of sand on the eastern beach (m^3)
1	+70,000	+1,500	-49,000
2	+9,800	+9,000	+6,800
3	+25,000	+7,000	-9,000
4	+29,000	+6,000	-12,500
5	+26,000	+5,200	-9,500
6	+22,500	+11,500	-5,000
7	+22,500	+11,500	-5,000
8	+11,000	+8,000	+2,500

Table 4.4 Comparison of different scenarios predicted seagrass wrack, channel depth and tidal range on the Port Geographe entrance channel segment. The tidal range ratio inside and outside were calculated for October 2009.

Scenario	Average depth at the channel's wider section on 30 Oct 2009 (2.9 m AHD)	Number of seagrass particles accumulated within entrance channel segment on 30 September 2009	Tidal choking Tidal range inside the harbour / Tidal range outside
1	2	8620	0.95>
2	1.8	1220	0.5<
3	2.6	1570	0.95>
4	2.25	650	0.78>
5	2.2	750	0.82>
6	2.65	880	0.95>
7	2.6	680	0.95>
8	2.65	580	0.95>

The following conclusions may be derived from the sediment/morphological model runs in 2009 for the different scenarios:

- An efficient sediment bypass can be achieved with a downdrift curved breakwater (Scenarios 2 to 8) located along the western side of Port Geographe.
- A comparison of bed level profiles at Wonnerup Beach for existing configuration and Scenario 8 indicated that an accreting beach can be achieved with the Scenario 8.
- Entrance channel sedimentation was observed to occur with the use of a narrower entrance channel, with the rate of highest sedimentation of the entrance channel occurring in Scenario 2.
- The efficiency of sediment bypass achieved at the western breakwater was determined by its angle relative to the beach, where the most efficient bypass occurred in Scenario 8.
- Scenario 8 demonstrated the best results in terms of addressing erosion at Wonnerup Beach.

Considering each of the scenarios for its effectiveness to bypass sediment, minimise entrance channel sedimentation and erosion at Wonnerup Beach, the arrangement depicted by Scenario 8 provided the optimal configuration for Port Geographe.

4.10.3 Seagrass wrack transport

A comparison of the number of (seagrass) model particles accumulated on the western side of Port Geographe for the different scenarios (Figure 4.106) indicated a significant decline in the number of trapped particles for all the scenarios. Table 4.4 shows the number of particles accumulated inside the harbour entrance channel for the different scenarios. In summary;

- Curved breakwater layouts vastly improved the natural seagrass wrack bypass, with only ~10% of particles being trapped for Scenarios 2-8 compared to the existing configuration.

- The maximum number of seagrass wrack accumulation (along the western beach) occurred in late May 2009 for each scenario after which the accumulations declined between July and September.

- For the existing configuration, in 2009 the particle movement to the east was prevented by the western breakwater.
- For the existing configuration continuous accretion occurred up to end of July and no bypass occurred between August and September.
- In Scenario 8, the least number of particles were trapped on the western side of Port Geographe and in the harbour entrance channel by comparison with any other scenario.

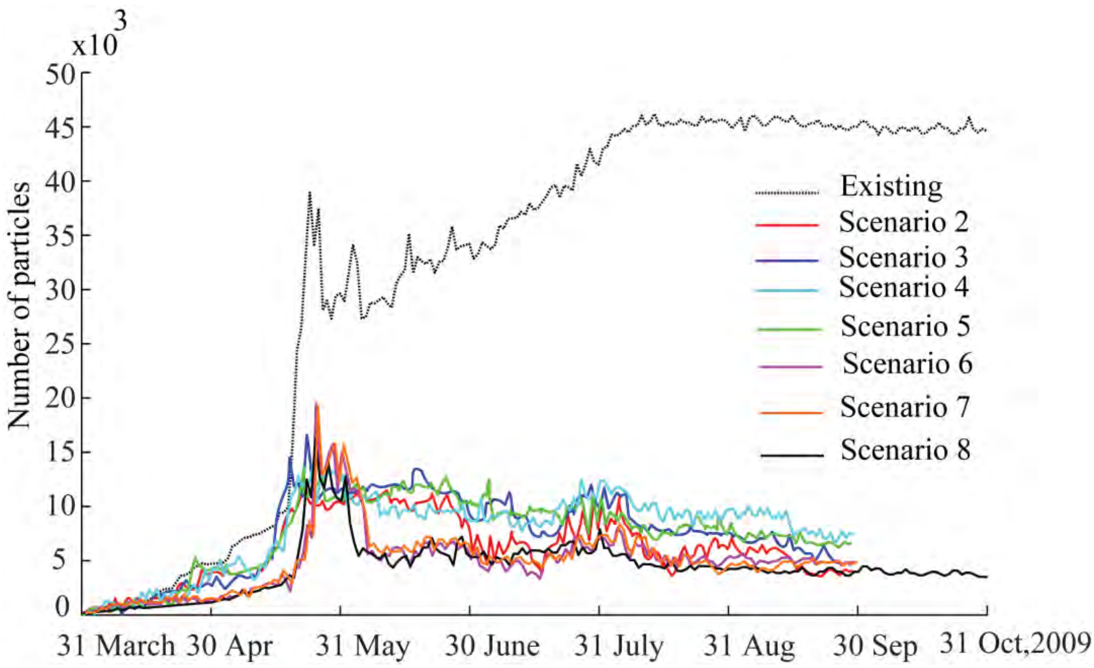


Figure 4.106 Comparison predicted cumulative number of particles (seagrass wrack) at the western beach, Port Geographe for 2009 for the different layouts (Scenarios 1- 8)

A comparison of the sand and seagrass particle transport modelling for the different scenarios indicated that the layout represented by Scenario 8 was the optimal configuration for improved management of both sediment and seagrass wrack around Port Geographe. Schematic of material transport process (sand and seagrass wrack) in the vicinity of Port Geographe under easterly currents and typical wave conditions with existing configuration and preferred layout (Scenario 8) are shown in Figures 4.107 and 4.108, respectively.

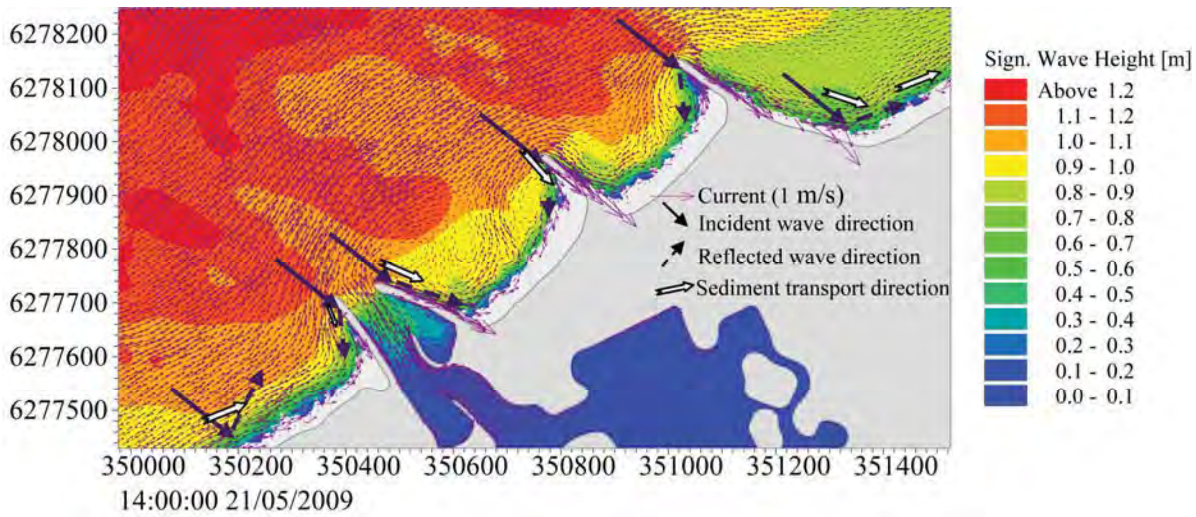


Figure 4.107 Schematic of typical wave conditions, easterly currents during storm conditions on 21st May 2009 for existing configuration.

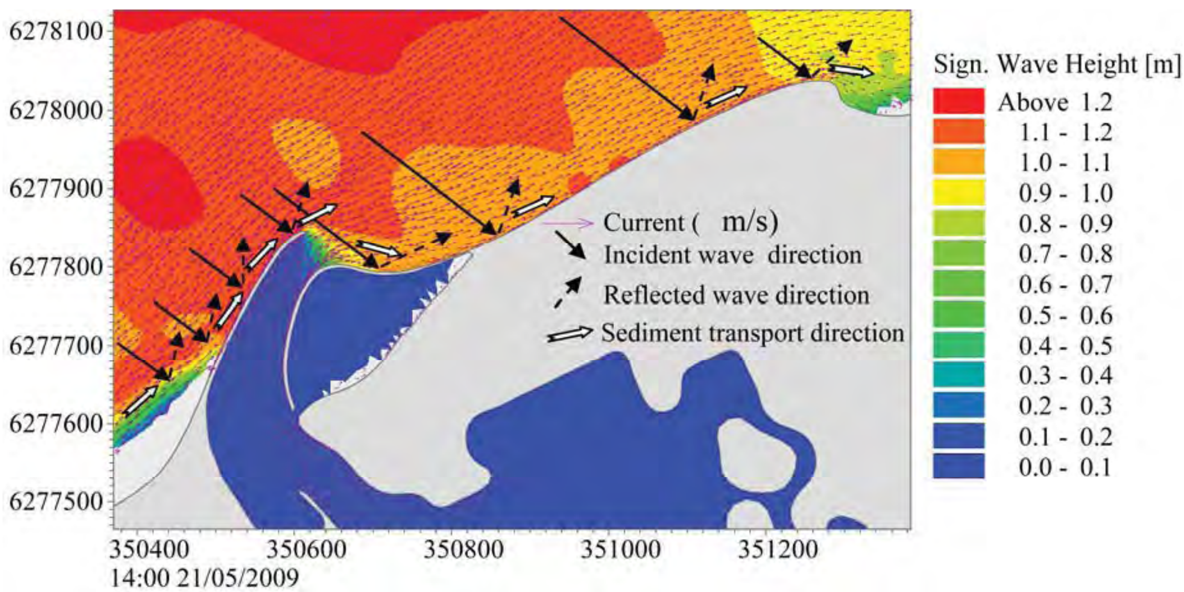


Figure 4.108 Schematic of typical wave condition, easterly currents during storm conditions on 21st May 2009 for Scenario 8.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study has examined and refined a number of scenarios leading to the development of an optimal layout for the coastal configuration of Port Geographe coastal structures with respect to natural sand and seagrass wrack bypass using numerical model simulation. This was achieved by modifying the coastal structures associated with the Port Geographe development such that:

- enhanced natural movement of seagrass wrack along the shoreline with limited trapping within the coastal structures;
- naturally bypassed sediment supply to Wonnerup beaches;
- limited harbour entrance channel sedimentation; and
- limited influence on water quality within the canal segments (predicted by changes to the tidal regime).

A series of different layouts were tested using a fully integrated hydrodynamic, wave, sediment and seagrass particle model as described in Section 2. The different layout performances with respect to physical processes were described in Section 4.

5.2 Numerical Model

A coupled, fully integrated 2D numerical model for waves, currents and sediment transport (DHI MIKE 21 Flow Modelling Tools) incorporating a particle transport model has been developed for Geographe Bay. The physical structures and land/water boundaries were accurately represented in the model using fine triangle meshes near the vicinity of Port Geographe. Recently acquired (end of 2008) coastal LIDAR survey data was used to generate the initial model bathymetry, such that model allowed the examination of seagrass and sediment transport processes in 2009. The hydrodynamic model forcing data (open boundary and meteorological) were constructed using measured time series of sea levels, wave climate, and wind data from Geographe Bay in 2009. Model validation was been undertaken in terms of hydrodynamics, wave climate, sediment and seagrass transport for 2009. Sediment transport and bed evolution modelling also provided qualitative and quantitative prediction on sediment transport rate and erosion and accretion in the area. A particle transport model was qualitatively evaluated based on seagrass wrack accretion on the beaches and accumulation pattern. Then model simulations were undertaken to examine the processes controlling seagrass and sediment transport processes in the vicinity of Port Geographe.

5.3 Existing condition

The sediment transport model simulations showed that net littoral drift was from west to east in the Port Geographe area. The processes involved in sediment transport, accumulation and erosion in the vicinity of Port Geographe were found to be most dominant during winter months. The model result depicted a complete trapping of sediment and seagrass wrack on the western side of Port Geographe in 2009. The cumulative volume of sand trapped on the western side of the Port Geographe development was estimated to be ~70,000 m^3 in 2009 and by the end of 2009 the western trap area of Port Geographe was close to full saturation. The analysis of historic storm conditions revealed that 2009 was a comparatively stormy year.

In the absence of a physical sand bypass program from the western side of the Port Geographe development, sediment transport morphological modelling indicated that the western side beach would fully saturate within a year or two, depending on wave climate and storm conditions. The extended model runs into 2010 for the existing structural arrangement (without a physical sand bypass being conducted) revealed that there would be development of a sand shoal at the harbour entrance and high sedimentation rates within the harbour entrance channel. Subsequently, the majority of naturally transported seagrass wrack would become trapped within the harbour entrance channel and within the eastern groyne fields or compartment beaches. The model also confirmed that beaches to the east of the development would continue to erode under the conditions present in 2009 and 2010. Thus without a continuation of the current bypass arrangements the existing structural arrangement (Scenario 1) would rapidly lead to higher rates of maintenance dredging of both seagrass and sand, poorer water quality for the harbour development, greater need for beach nourishment and increased environmental problems to Port Geographe.

5.4 Alternative layouts tested

In total, eight different physical layouts for Port Geographe were tested to find an effective solution for the seagrass and sediment management problem. The layouts have been developed with regard to the results of the earlier seagrass modelling study and the principles of natural material bypass within the littoral coastal zone. The main physical features for the tested model layouts are described below:

- Curved breakwater concepts were developed for the western side of Port Geographe as replacements to the existing breakwater, which is perpendicular to the shoreline.
- Removal of all groynes associated with the compartment (pocket) beaches.
- The establishment of a foreshore seawall to eastern side of the harbour entrance.

The alignment and extent of the curved western breakwater, the channel entrance, the geometry and the angle of the eastern side seawall are all critical parameters, which were optimised through numerous model experiments. The rationale behind the various scenarios developed was presented in Section 4 of this report and the associated stepwise approach to their development is summarized below:

- Tuning of the alignment, shape and extent of the curved western breakwater for Port Geographe took place until an efficient bypass of both seagrass and sand was achieved from west to east across the harbour entrance.
- The harbour entrance channel configuration was modified until a minimum rate of sedimentation and seagrass wrack accumulation was demonstrated within the entrance channel.
- The eastern side seawall was altered in both its extent from shoreline and its alignment until an efficient transport of sand and seagrass was achieved along the seawall towards Wonnerup Beach.
- Scenarios were tested with the inclusion of a small lagoon between the seawall and shoreline as a possible alternative to an area of reclamation.
- A short promontory or spur was added to the end of eastern side seawall to improve protection to the western corner of Wonnerup beach.

The coupled model (sediment and seagrass) was applied to each layout with the same (forcing) conditions as based on the 2009 data. The model experiments confirmed that both natural seagrass and sand bypass across the Port Geographe entrance can be achieved by providing a curved breakwater to the western side of the harbour entrance. However, critical to the model performance was the early achievement of an equilibrium shoreline to the beach on the western side of Port Geographe. The saturation of the western beach with sand for the scenarios with a curved western breakwater (Scenarios 2–8) established that equilibrium was reached relatively quickly in comparison with the existing condition, which has its breakwater perpendicular to the beach. The simulations also indicated that the coastal erosion to the eastern beaches can be improved with a curved western breakwater assisting with sediment transport. For Scenario 2, a bypass shoal developed close to the harbour entrance, which in turn was observed to be a feed permitting rapid sedimentation into the harbour entrance channel. Subsequent scenarios including Scenarios 3, 4, 5 and 6 were developed in an attempt to address this problem. Scenario 6 was found to provide the optimal configuration for both the management of sedimentation and seagrass wrack deposition with regard to the performance of the harbour entrance channel. A small lagoon was also trialled at the eastern side of the harbour entrance in Scenario 7. This was considered as an alternative option in relation to beach amenity for the community but otherwise had no substantial impact on the hydrodynamics of the waterway or the performance of seagrass and sediment transport. The lagoon itself was observed not to be impacted by sediment or seagrass movements. Scenario 8 was developed with regard to all the critical elements above and the optimisation of results from Scenarios 1 to 7.

5.5 The Preferred layout (Scenario 8)

The preferred layout (Scenario 8) would prevent seagrass trapping on the western side of the Port Geographe development and sediment would effectively bypass to the eastern side beaches. The innovative elements of the proposed layout are the combination of the curved breakwater combined with a streamlined seawall on the eastern side of the Port Geographe entrance, a streamlined entrance channel, a concave bulge on the eastern side of the harbour entrance, and extended tip or promontory at the Wonnerup end of the seawall. The layout dimensions for Scenario 8 are given in Table 5.1. The performance of this scenario is dependent on the early establishment of shoreline equilibrium to the beach on the western side of the Port Geographe development.

5.5.1 Sedimentation and erosion for Scenario 8

- Under Scenario 8, sand transport along the beach (parallel to the shoreline) is driven by alongshore currents and/or waves approaching obliquely to the shoreline. Thus, when the beach to the western side of Port Geographe becomes saturated, the predominant west to east movement of sand a natural bypass of seagrass and sand can occur.
- Oblique wave reflection to the edge of the curved breakwater and a streamlining of the nearshore currents would also act to accelerate the sand and seagrass wrack transport process.
- The bulge depicted to the eastern side of the harbour entrance has been shown to assist in preventing bypassing sediment from entering into the harbour entrance channel, particularly during times of westerly winds and related eddies.
- The seawall established along the foreshore is close to being parallel with the present shoreline on each side of the development, thus oblique waves from northwest and easterly currents have a similar ability to transport sediment eastward along the seawall to Wonnerup.
- The extended tip or promontory to the eastern end of the seawall has been shown to improve conditions that currently cause erosion to the corner at the western end of Wonnerup beach.
- In conclusion, the preferred configuration for Port Geographe has demonstrated that once an equilibrium beach is established through the saturation of sand at the western beach, sedimentation of the harbour entrance channel is minimised and sand transport to Wonnerup Beach is achieved. This outcome reflects that close to zero net cumulative volume differences can be achieved for sediment transfer from west to east.

5.5.2 Seagrass wrack trapping and bypass for Scenario 8

- The inclusion of the curved western breakwater at Port Geographe as modeled in Scenario 8 would not act as a barrier to seagrass wrack movement across the Port Geographe development.
- The smoother profile of the proposed coastal structures leads to a removal of eddies that currently exist near to shore. This reduces the potential for wrack aggregation and together with improved shoreline currents achieves an enhancement to seagrass transport capacity.

5.5.3 Water quality: Scenario 8

Water quality within the Port Geographe harbour development with regard to the Scenario 8 was evaluated in terms of tidal choking and cumulative volume fluxes at canal entrance. The cumulative volume flux is the main parameter, which determines flushing times within the system. The tidal choking and volume fluxes for the proposed layout achieved the same order of magnitude as that of the existing structural configuration and therefore represent neither an improvement nor deterioration in the flushing characteristics of the harbour and canal waterways.

Concluding it appears that there are no major environmental impacts due to an adoption of the proposed layout (Scenario 8) from the viewpoint of hydrodynamics.

- The change of harbour entrance configuration does not change tidal process within the harbour and canal waterway and thus tidally induced water exchange between canal waters and Geographe Bay.
- The proposed structures do not change the overall pattern of the current flows and wave patterns in Geographe Bay.
- The harbour entrance channel is well protected from the larger northwest waves.
- A pattern of lesser eddy circulation is achieved across the nearshore waters of Port Geographe.

5.6 Recommendations

Based on the extensive modelling studies undertaken as part of this study, it is recommended that the Department of Transport and the Shire of Busselton note that, Scenario 8 presents the optimum solution to the coastal management problems currently experienced at Port Geographe. This recommendation has regard to guidance from the steering committee, The Department of Transport, The Shire of Busselton, and to the Port Geographe Sediment and Seagrass Reference Group workshops. This recommendation is supported by the following study outcomes for Scenario 8:

Scenario 8 demonstrated that:

- Unnatural seagrass wrack accumulation on the western beach is reduced to the maximum extent considered possible, with this option delivering the best or equal best outcome of any option considered in the course of this extensive study. Seagrass wrack accumulation is a natural seasonal phenomenon in Geographe Bay. The beaches adjacent to the Port Geographe development will remain subject to those seasonal impacts. Occasional trapping of small quantities of seagrass wrack may occur from time to time across the development.

- Siltation to the Port Geographe harbour entrance channel is minimised to the greatest extent considered possible, with this option delivering the best or equal best outcome of any option considered over the study period. The resultant channel maintenance requirements are likely to be altered from the existing situation and this will need to be considered as part of a new coastal maintenance program.

- The modelling of the recommended groyne reconfiguration demonstrates that once shoreline equilibrium is established on the western beach, improved natural sediment transport from the western beach to Wonnerup can be achieved. Erosion at Wonnerup Beach can be transformed from a typically eroding beach to a stable and accreting beach. The model indicates an increase in beach width of between 10 and 20 m in comparison to the current situation will result from the increased sediment delivery to Wonnerup, representing substantial improvement to the current condition and the provision of a beach consistent with the widths of other nearby natural beaches.

5.7 Study Observations

5.7.1 The Western Beach

The performance of the recommended Scenario (8) will not be optimised until shoreline equilibrium has been established on the western beach. This equilibrium is achieved by either the natural or artificial sediment saturation of the western beach to achieve a modified shoreline conducive to natural bypass. Should Scenario 8 be implemented then a decision on how the shoreline equilibrium state can be most effectively achieved will be required and this is expected to relate to nourishment rates, costs, timing and regard for the existing beach condition.

5.7.2 Wonnerup Beach

Environmental Condition 4.1 from EPA Statement 391 was subject to a review in September 2006, which defined a modified beach alignment for Wonnerup. The modelled scenarios were developed and examined with regard to that Statement. It should be noted that none of the model options trialled demonstrated an ability to achieve full compliance with the proposed beach alignment approved by the review in September 2006. The modelling results indicate that the beach alignment submitted and subsequently reviewed by the EPA in September 2006 remains unachievable under all reasonable scenarios. It is recommended that this issue be re-visited with the environmental authorities. Winter storms will, from time to time, cause erosion at Wonnerup Beach as a normal and natural process. If future mechanical sediment bypass is required, such as from the entrance channel, then the beach at Wonnerup remains a viable deposition area.

5.7.3 Water Quality

The recommended option is to retain the existing channel entrance width and design depths, and hydrodynamically smoother channel alignment may represent a general improvement to water exchange between the marina, canals and Geographe Bay. In addition, the curved entrance is expected to perform better than the existing configuration with regard to excluding seagrass wrack from within the entrance channel. Seagrass wrack within the entrance and canal system has proven to be a navigation hazard in the past and is a known source of nutrients, which can be a cause of poor water quality.

5.7.4 The Development of the Foreshore

The recommended option includes the requirement for a seawall between the harbour entrance channel and Wonnerup Beach resulting in the loss of two artificial pocket beaches (Moonlight Bay). Modelled options revealed no viable alternative. Waters in front of the seawall are expected to remain shallow, however, beach formation in front of the seawall is considered unlikely. This issue could be revisited by the authorities once the overall performance of the modified structure has been established and actual data has been collected.

5.7.5 The Lagoon

The inclusion of a lagoon in the recommended option, as opposed to a reclaimed area of land, adjacent to the harbour entrance has evolved as a result of community engagement and feedback. The lagoon has no impact on the performance of seagrass wrack and sediment management and therefore remains an optional inclusion. Whilst not specifically modelled, the shallow nature of the lagoon, its close proximity to the harbour entrance and its protection from the influences of sediment and seagrass wrack suggest that water quality concerns with its inclusion are unlikely. Should the lagoon proposal be advanced through to the detailed design then it are recommended further environmental studies be undertaken.

5.7.6 Future Coastal Maintenance

The implementation of the recommended option will result in an altered requirement for coastal management with emphasis shifting from the bypass and management of seagrass wrack and sediment on the western beach, to some increase in sediment management at the harbour entrance. Overall the recommended concept effectively deals with the environmental and social impacts together with an expected reduction in the ongoing coastal management costs.

6. REFERENCES

Brøker I., Zyserman J., Madsen E.O., Mangor K., and Jensen J. (2007). Morphological Modelling: A Tool for Optimisation of Coastal Structures, *Journal of Coastal Research, 23*(5), 1148–1158.

Interstruct Holdings Pty Ltd. (1990). Port Geographe: Environmental monitoring and management Program. Appendix 3: Sand bypassing and coastal management Report J219/R326.

Fahrner C. and Pattiaratchi C.B. (1994). Review of physical oceanography of Geographe Bay. Report prepared for the Water Authority of Western Australia (WA). CWR report no. WP 898 CP, Centre for Water Research, the University of Western Australia, Perth.

M J Paul and Associates Pty Ltd (2005). Port Geographe Coastal Management Study – an independent review of coastal aspects of the Port Geographe Marina Project. Report No. SW330-3301-056. Report prepared for Seaport Pty Ltd.

Oldham C.E., Lavery P.S., McMahon K., Pattiaratchi C., and Chiffings T. (2010). Seagrass wrack dynamics in Geographe Bay, Western Australia. Report to WA Department of Transport.

Pariwono, J., Bye J., and Lennon G. (1986)., Long-period variations of sea-level in Australasia, *Geophysical Journal International*, *87*(1), 43–54.

Pattiaratchi, C., and Buchan S. (1991). Implications of long-term climate change for the Leeuwin current, *Journal of the Royal Society of Western Australia*, *74*, 133–140

Ruessink, B. G., Wijnberg, K. M., Holman, R. A., Kuriyama, Y. and Van Enckevort, I. M. J., (2003). Intersite comparison of interannual nearshore bar behaviour, *Journal of Geophysical Research*, 108(C8), 3249, doi:10.1029/2002JC001505.

SHORE COASTAL (2010). Dept. of Transport and Shire of Busselton 2009/10 Port Geographe Bypassing Works – Close Out Report Contract DOT400510. July 2010.

Willmott C.J. (1984) On the evaluation of model performance in physical geography. In: G.L. Gaile and C.J. Willmott, Editors, *Spatial Statistics and Models*, Reidel, Dordrecht, Netherlands, pp. 443–460.