Quinns Beach Long Term Coastal Management

Coastal Processes and Preliminary Options Assessment Report

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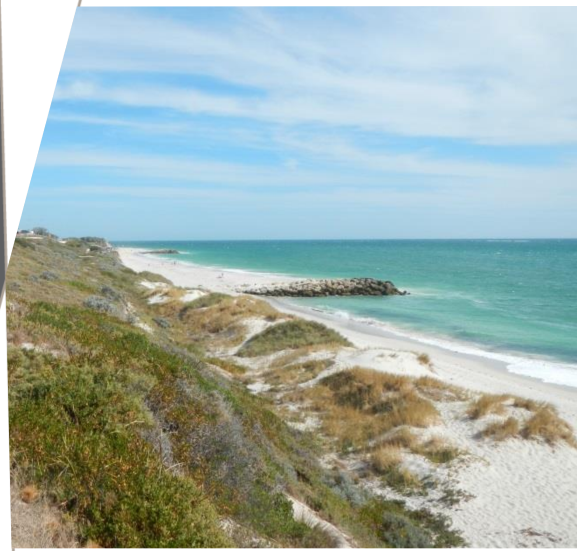

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Executive Summary

The Quinns Beach Long Term Coastal Management Study was established by the City of Wanneroo with the goal to assess potential coastal management options to mitigate the ongoing trend of erosion present at Quinns Beach. Erosion and coastal management has a long history at Quinns Beach; early anecdotal evidence suggests that Quinns Beach has been experiencing erosion since at least the 1940's.

Sediment transport at Quinns Beach has a complex response to the spatially variable nearshore wave climate. Waves arriving from offshore are modified considerably through processes including shoaling, breaking, refraction and diffraction across the system of three reefs. Wave shoaling and breaking results in wave set-up over the shallower reef areas, which forces complex nearshore circulation and drives sediment transport pathways within the reef system. At the beach face, the variation in nearshore wave angle caused by the reefs results in complex littoral drift to both the north and south.

These processes occur and interact over a range of nested temporal and spatial scales. A beneficial conceptual framework for understanding the geomorphological outcomes of the interactions involves coastal compartments (commonly referred to as sediment cells). Coastal compartments have been mapped in Western Australia at three scales: Primary, Secondary and Tertiary.

At the Primary Cell scale (100's kilometres, 1000's years) Quinns Beach is situated leeward of a number of remnant dune and reef ridges formed along temporary shorelines as sea levels rose and fell (Collins 1988). The present day Spearwood, Marmion and Staggie limestone reef ridges are the highly weathered remains of those dunes. Consequently, at the Secondary Cell scale the City of Wanneroo coast has numerous salients and cuspate forelands associated with prominent sections of reef. Quinns Beach is a cuspate foreland that has formed as a result of the presence of Quinns Rocks in combination with shallower sections of the Staggie and Marmion Reef Ridges. At the nearshore Tertiary Cell scale (the scale of an individual beach) Quinns Beach is bounded by cliffs and Mindarie Keys to the south, and a series of nearshore reefs and cliffs to the north.

Cardno has performed a variety of analyses on recently collected and historic data to inform a conceptual sediment transport model and sediment budget for the Quinns Beach system. Both cross-shore and longshore sediment transport is important at Quinns Beach. The typical summer season (from October through April) is characterised by frequent and strong south-westerly sea breezes that drive a persistent northward littoral drift. The typical winter season (from May through September) is characterised intermittently by strong storm fronts that approach from the northwest and cause significant transport of sediment southward and offshore. The sediment budget and transport pathways at longer time scales largely derive from inter-annual variations in the relative strengths of these two seasonal cycles.

Monthly beach surveys through 2014 demonstrated that there is a seasonal exchange in the cross-shore direction associated with storm and beach recovery cycles (approximately 40,000 m^3 per season along the 4km length of Quinns Beach). Numerical modelling has demonstrated that gross longshore transport along Quinns Beach is approximately 60,000 m^3 annually, but the direction is highly variable. The balance is an intermittent net northward drift of up to approximately 5,000 m^3 per year, however with significant inter-annual variability and periods of net southward drift. The presence of the cliffs and reefs to both the north and south means the littoral drift and longshore transport near the shoreline is limited. Through numerical modelling, sediment exchange between Quinns Beach and adjacent coastal cells has been identified to generally occur further offshore at deeper depths (between approximately -5 and -10m AHD), and therefore at much slower rates than is typical at the shoreface.

Analysis of survey data since the construction of three groynes in 2002-2004 indicates that the Quinns Beach system continues to have a deficit in sediment supply. On the basis of beach and dune survey data (since 2002) it is estimated that the sediment budget for Quinns Beach has a deficit of approximately 20,000 m^3 per year which has been balanced over the past 10 years by artificial sand nourishment and dune erosion, despite the significant coastal engineering works that have been undertaken.

To support the assessment of potential coastal management options, numerical models were developed and calibrated to available measurements. The SWAN wave model was calibrated to two wave measurement locations. A high degree of model skill was obtained for both the offshore and nearshore locations; however, with some uncertainty around the accuracy of the modelled results in the north of the study area away from the measured data location. Taking due consideration of this uncertainty in wave predictions, the SWAN model was used to force two storm erosion models (XBeach and Delft3D) and a long-term shoreline evolution model (LitPACK).

In order to test the ability of Delft3D and XBeach to model both longshore and cross-shore sediment transport processes during storm conditions the 8th September 2014 storm was simulated. Modelled and measured data highlighted the importance of wave and wind set-up on both Quinns Rocks and the Alkimos reef for driving nearshore circulation. There appears to be a southward-directed sediment transport pathway situated between Quinns Rocks and the shore that over successive storms delivers sediment to a large sand bank located to the west of Mindarie Keys. With respect to the morphological response of the beach to the storm, XBeach produced reasonable results whereas Delft3D performed poorly. The XBeach model was extended and improved with generally good prediction of the complex sediment transport that occurs during storms. LitPACK was validated against measured beach survey data for the period May 2008 to May 2009. This model demonstrated that there is significant variation in longshore transport, both in direction and magnitude, along Quinns Beach due to variation in coastal orientation and nearshore wave angle.

Whilst a good degree of calibration was achieved in the numerical models, some model limitation and additional areas of uncertainty were identified. Calibration of the wave model highlighted that nearshore wave conditions in the proximity of the Dog Beach are sensitive to the schematisation of wave dissipation across the offshore reefs. Additional data collection is recommended to resolve this. The presence of reef structures embedded within the active beach profile (just below mean sea level) are currently not schematised in the models due to insufficient information on their depths and extent. As a consequence, the storm erosion model currently underestimates the erosion around Queenscliff Park. The longshore transport model had difficulty resolving the morphological processes in the immediate vicinity of the artificial headland, due to its proximity to the shoreline. However the effectiveness of the model in predicting the seasonal evolution of the shoreline to the south of Groyne 1 highlights that, in its present configuration the artificial headland has minimal influence in controlling sediment exchange between Sections 1 and 2. Acknowledging that some uncertainty remains with respect to the numerical model outcomes, overall the performance and diversity of modelling approaches applied provide a valuable set of tools to evaluate coastal management options in subsequent stages of the project.

A number of potential management options have undergone a preliminary qualitative multi-criteria assessment with the four options being carried forward into the subsequent stage of assessment and implementation in the calibrated numerical model. The four options selected were:

> Option 3 – Carpark Small Headland & Shift Existing Headland ;

> Option 4 – Long Groynes & Offshore Breakwaters;

> Option 5 – Y-shaped Groynes & Offshore Breakwaters; and

> Option 6 - Long Groynes, Offshore Breakwaters & Artificial Headland.

It is noted that due to the ongoing sediment deficit at Quinns Beach all engineering interventions will require some level of ongoing monitoring, maintenance and sand nourishment. The outcomes of subsequent detailed multi-criteria and cost benefit analysis may indicate halting the erosion at Quinns Beach is impractical, in which case the best outcome is that which helps to isolate the issue to locations where it can most appropriately be accommodated and managed, whilst maintaining the values of Quinns Beach.

Longer term variations in wave climate, sea levels and their interaction with the complex reef system remain an area of uncertainty, and particular combinations of future climate and weather conditions will likely continue to place intermittent pressure on the performance of coastal structures at Quinns Beach.

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1 Introduction

Quinns Beach is an iconic region of the City of Wanneroo. Quinns Beach has a long history of beach-side culture with the public amenity and recreational value of Quinns Beach being a focal point for the community. In addition, the history of Quinns Beach is characterised by a key challenge facing coastal communities – erosion. Early reports of erosion date back to the 1940's and have continued through to present times. The ongoing erosion at Quinns Beach is a challenging issue that the tight-knit community wants resolved.

The Quinns Beach Long Term Coastal Management Study was established by the City of Wanneroo with the goal to assess potential coastal management options to mitigate the ongoing trend of erosion present at Quinns Beach. The study area extends from the southernmost section of Quinns Beach, approximately 1 km north of the Mindarie Keys marina entrance, to the northernmost rocky outcrop approximately 2.2 km northwest of Groyne 3. This study area essentially includes all sandy coastlines from Mindarie Keys to Alkimos Beach in the north, and includes several coastal protection structures, including the most recent works adjacent to Frederick Stubbs Park.

The overall study is split into five stages:

> Stage 1 – Undertake a detailed coastal processes assessment based on existing studies and recently collected data

> Stage 2 – Assess coastal management options and identify a preferred option based on a multi criteria analysis

> Stage 3 – Provide detailed design drawings and technical specifications (suitable for tendering purposes) for the preferred coastal management option

> Stage 4 – Provide technical advice during tendering and construction phases of the project

> Stage 5 – Provide technical advice and coastal engineering services post construction

The purpose of this Stage 1 report is to develop a foundation of coastal processes understanding to support the assessment of coastal management options at Quinns Beach. This is achieved through the analysis of available measured data and past reports, development of a conceptual sediment transport model and implementation of numerical models for waves, currents and sediment transport.

1.1 Scope of works

The scope of works and key objectives for this stage of the works are:

- Provide a succinct summary of all relevant key events and available studies conducted to date including historical information gathered from community representatives;
- Provide an update of the Cardno (2012) coastal processes assessment based on the extended study area and recently collected data (photographic monitoring, metocean data, beach profiles and hydrographic surveys);
- Develop calibrated numerical models to simulate wave conditions, hydrodynamics and sediment transport over the study area;
- Identify design criteria for detailed design;
- Obtain a detailed understanding of cross shore and longshore sediment transport during storm conditions and over typical summer and winter weather patterns; and
- Consider all potential coastal management options and identify a shortlist (minimum of 4 options) for concept design and further assessment.

1.2 Community consultation

A community consultation campaign was carried out by the City in conjunction with this study. This included the following components:

> **Quinns Beach Long Term Coastal Protection Community Reference Group**
  - A community reference group consisting of Community Representatives, Elected Members, City of Wanneroo Officers and Department of Transport Representatives was established in May 2014 in order to provide input into the development of long term coastal protection options for Quinns Beach. The Group meets on a quarterly basis (as a minimum) and/or at key stages of the Quinns Beach Long Term Coastal Management project (i.e. commencement of the consultancy study and completion of project stages).

> **Compilation of recent relevant correspondence**
  - All correspondence received directly by the community and suppliers with reference to potential coastal management options along the Quinns Rocks coastline were compiled and forwarded to Cardno for consideration in the options assessment. Options included artificial reefs, an ocean pool, a rock armoured seawall, dune rehabilitation and other coastal protection structures.

> **Comments received from January 2014 Community Information Session and Mail-Out**
  - A Community Information Session was held on 29 January 2014 regarding the need for a limestone retaining wall to provide a wider park area as part of the Quinns Beach Immediate Coastal Protection Works. At this meeting, community comments were received via a comments sheet and this sheet was also sent out via mail to the local Quinns Rocks community. A number of comments received were not relevant to the limestone retaining wall topic; however some of these did provide insight into potential coastal management options. These comments were compiled and sent through to Cardno for consideration in the options assessment.

> **Quinn Beach Community Reference Group - Community Questionnaire on Wave and Current Observations**
  - Community members from the Quinns Beach Community Reference Group developed a community questionnaire regarding observations of waves and currents along the Quinns Rocks coastline. Eight community responses were received providing insight into the observed weather conditions at the site. Some of these observations will be used to verify wave and current conditions determined through analysis of recorded data and calibrated numerical modelling.

> **Mail-Out to attendees at recent Quinns Beach Community Meetings**
  - A letter requesting details of potential options for consideration by Cardno in the options assessment was sent out in November 2014 to all community members who attended the two community information sessions in October 2013 and January 2014. Two formal responses were received in addition to the correspondence previously received.

> **Council Meeting Presentations**
  - Council meeting presentations are scheduled at the completion of all key stages of the project in order to ensure that elected members and the community are informed of the project progress and outcomes.

> **Community Information Sessions**
  - Two community information sessions are proposed at the completion of Stage 2 (Concept Options Assessment) and Stage 3 (Detailed Design). These sessions will be used to present the outcomes of the study and highlight the intentions of the City for coastal protection along the Quinns Rocks coastline, whilst gauging the views and perception of the local community towards the recommended solutions prior to the implementation stage.

> Project progress updates published on the City of Wanneroo website, social media and local newspapers.

1.3 Directional Convention

All directions quoted in this report use nautical conventions. That is, waves and winds are quoted as degrees coming from relative to true north. Currents are quoted as degrees heading to relative to true north.

2 Site investigation

Cardno carried out the site investigation at Quinns Beach on the 30th October 2014, accompanied by Caroline White, a representative from the Community Reference Group (CRG). The inspection started at 9:00 am, following a brief meeting with the City's Project Manager regarding safety procedures and the general site visit plan.

Mild meteorological conditions were noted on the day. The Perth weather station recorded a sea level standard atmospheric pressure of 101.4 kPA, with the absence of high or low pressure systems. It was partly cloudy with an average temperature of 20 °C throughout the duration of the inspection (9am to 12pm). Wind at an average speed of 15 km/h coming from the south southwest direction was recorded and a northward littoral drift was evident predominantly within 30m distance of the shoreline.

The tide receded from 0.55 m Chart Datum (CD), at 9 am to 0.50 m CD (mean higher low water) at 12 pm, indicating that the tide was undergoing the ebb stage. Offshore swell waves (H_s = 1.5m recorded at Rottnest Island), were seen breaking on the Staggie, Marmion and Spearwood reef ridges (**Figure 2-1**).

The study area was divided into 6 sections; depicted in **Figure 2-1**:

> Section 1: the 600m stretch of beach south of the artificial headland

> Section 2: the area from the artificial headland to Groyne 1

> Section 3: the area from Groyne 1 to Groyne 2, including the car park at Groyne 1.

> Section 4: the area from Groyne 2 to Groyne 3

> Section 5: the area 600 m northwest from Groyne 3, to the beach access from Queenscliffe Park

> Section 6: the area northwards from Queenscliffe to the northern extent of the study area.

The characteristics of these shoreline sections are described below.

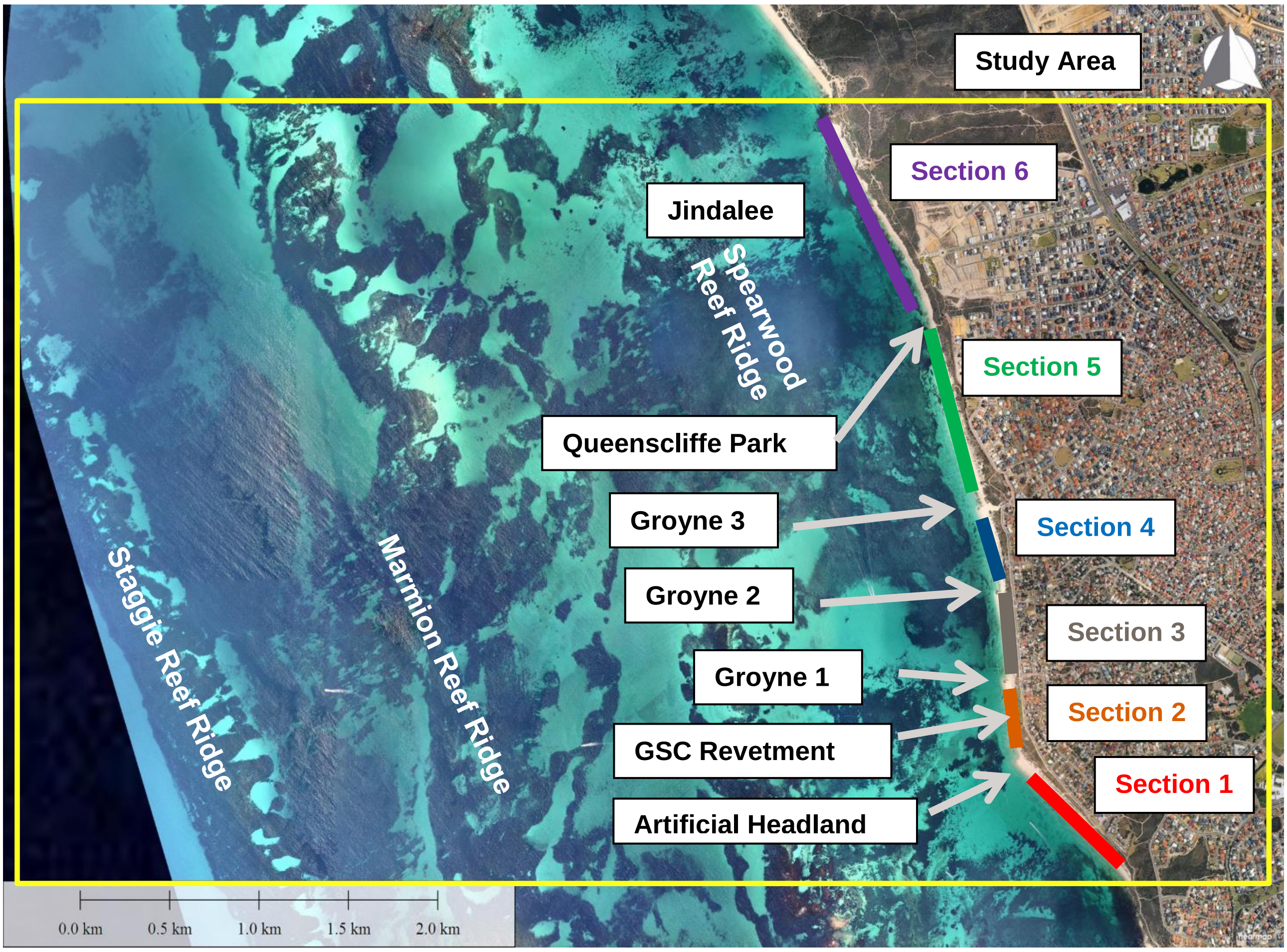

Figure 2-1 Study area compartmentalised during the site inspection

2.2 Section 1

The inspection at Section 1, outlined in red in **Figure 2-1**, included the identification of all features in the foreshore, backshore and dune systems which affect the coastal processes. The significant social value of this section to the City was demonstrated through the presence of public open space, a coastal path and the Quinns Mindarie Surf Life Saving Club.

The backshore was flat and wide, in comparison with the other sections (**Figure 2-2**). The presence of rocky cliffs to the south towards Mindarie Marina was noted. In addition the beach had significant cusps along its length in the swash zone. Since Cardno's site visit in December 2012 there had been additional growth and establishment of fore dune vegetation. Vegetation growth was encroaching on installed sand fencing, with overall evidence of fore dune growth and increased elevation since 2012 (**Figure 2-3**).

The back dune was well established with flourishing vegetation. The fore dune, the beach profile section that is more prone to growing, shrinking or moving in response to prevailing winds or erosion, was well vegetated and situated on a reasonably elevated berm; however, there were some areas with significant exposure to winds. Evidence of windblown, aeolian sand transport was shown through sediment accumulation on access paths (**Figure 2-4**)

The beach access from the Surf Life Saving Club consisted of staircases, two ramps, including disability chair access and four wheel drive access. The structures were in good condition, even though wind-transported sand had partially covered the stairs and ramps. The other secondary entrances to the beach from Quinns Road were also prone to sand accumulation, likely due to their southerly aspect (**Figure 2-5**).

Figure 2-2 View of Section 1 from the Surf Club. Good growth in vegetation was evident in this area since 2012.

Figure 2-3 Comparison of Section 1, looking south from the artificial headland, December 2012 (left) and October 2014 (right). Notice the elevation of dune vegetation and secondary species growth.

Figure 2-4 Accumulated sand on the beach access from the Surf Life Saving Club

Figure 2-5 A secondary access to the beach, from Quinns Road

2.3 Section 2

Section 2 (outlined in orange in **Figure 2-1**), from the artificial headland to Groyne 1 inclusive, was marked by the absence of a berm along the backshore. The beach width was significantly less than that in Section 1. Macro-algal wrack, as seen in **Figure 2-6**, reached up to the foot of the fore dune. Vehicle tracks were identified on the site.

The dune was at a higher elevation at the southern end of Section 2 in comparison to the dunes in Section 1 (**Figure 2-7**). The rehabilitation of vegetation on the dunes was still in progress, with fencing used for protection. No formal beach access was present north of the artificial headland.

The artificial headland, constructed in 1977 (City of Wanneroo 2014), was in poor condition, with some armour rocks having been displaced over time (**Figure 2-8**). In 2014 maintenance works were carried out on Groyne 1 and the condition of the groyne was good (**Figure 2-9**). The recently completed Geotextile Sand Container (GSC) revetment, built in 2014, was in excellent condition (**Figure 2-10**). There was evidence of aeolian sand transport accumulating on the southern end of the structure.

Figure 2-6 View from the middle of Section 2 ; the view to the south (left) and the north (right)

Figure 2-7 View of the fore dune adjacent to the artificial headland, to the south (left) and the north (right)

Figure 2-8 The artificial headland, with rocks partially displaced, covered with sand and low crest level

Figure 2-9 Groyne 1 after maintenance

Figure 2-10 The newly constructed GSC revetment and the recently maintained Groyne 1

2.4 Section 3

Section 3, the grey outline in **Figure 2-1**, stretched from Groyne 1 to Groyne 2, inclusively. The area was nourished with 20,000 m^3 of sand in May 2014 during construction works. The new beach profile, after artificial nourishment, is undergoing a stage of readjustment to a new equilibrium profile. The presence of an erosion step and berm at the south end of Section 3 was evidence of the ongoing readjustment (**Figure 2-11**). No dune system was present close to the car park to the south and evidence of aeolian transport was present due to sand accumulation on the car park (**Figure 2-12**). A narrow fore dune was present at the northern end of Section 3. A steep scarp was present north of the car park, with vegetation on the brink of collapse (**Figure 2-13**).

The car park from Robert Road to Terry Road provided the main form of beach access to Section 3 with the only other access being staircases closer to Groyne 2. Vehicle access through the northern end of the car park (**Figure 2-14**) was only present during the GSC revetment construction period. The access was blocked off after construction. The parking area had been damaged by storms in the past years; the limits of the car park have undergone considerable retreat and evidence of the original extents could be seen through the buried car park base a few metres from the current limit (**Figure 2-15**). A partial revetment, comprised of limestone boulders, had been installed since 2002 (City of Wanneroo 2014) in order to provide protection to the parking area. A stockpile of armour stone was present, with maintenance of Groyne 2 planned for completion in November 2014 (**Figure 2-16**).

Figure 2-11 The view from the middle of Section 3 to the south (left) and the north (right)

Figure 2-12 The view from the middle of the car park to the south (left) and the north (right)

Figure 2-13 The absence of a fore dune system along the beach just south of the car park

Figure 2-14 Vehicle access during the GSC revetment construction (left) and a path in the northern part of Section 3 (right)

Figure 2-15 Northern end of the car park with the limestone revetment

Figure 2-16 Groyne 2 before maintenance works planned for November 2014

2.5 Section 4

Section 4, outlined in blue in **Figure 2-1**, stretched from Groyne 2 to Groyne 3. The beach was wide, in comparison to Section 2. There were no steep scarps and the active beach face had prominent beach cusps. The dune elevation increased from Groyne 2 to Groyne 3. The southern part of Section 4 was moderately vegetated whereas vegetation on the dunes to the north was well established with fencing erected at the northern end (**Figure 2-17**).

Groyne 3 was already in a deteriorated state in 2012 during Cardno's previous site visit (Cardno 2013). The structure was due for maintenance works when Cardno carried out this inspection in 2014. Both sides of the groyne had lost armour rocks, which had fallen to the sides. Rocks, for rebuilding the primary armour layer, were stacked next to the groyne, indicating the extent of works required to bring the structure to a safe and functional condition (**Figure 2-18**).

Two car parks, at Mary Street and Coastal Rise, served the area. The concrete access ramp from Coastal Rise, leading to Groyne 3, was in good condition (**Figure 2-19**). Timber access stairs opposite Mary St allowed access down the steep dune face.

Figure 2-17 View to the North from Groyne 2 (left) and to the South from Groyne 3 (right)

Figure 2-18 Groyne 3 before maintenance works

Figure 2-19 Access from car park at Coastal Rise

2.6 Section 5

Section 5, shown in green in **Figure 2-1**, extended from Groyne 3 to the beach access at Queenscliffe Park. This area is locally known as the 'dog beach' with the area available for dog recreation.

Dune elevation continued to increase through this area, reaching up to approximately 15m AHD elevation, however, there were no fore dune present and an extensive erosion escarpment undermining vegetation was visible through the length of this section. The beach was narrow with a steep prominent berm along the southern end and flatter and lower towards the north (**Figure 2-20**).

Sea weed wrack deposition reached the toe of the steep sloped dune indicating recent potential erosion of the dune (right, **Figure 2-20**). There was clear evidence of vegetation collapsing along the dune. In contrast, the back dune had flourishing vegetation. The northern end of Section 5 included a limestone cliff outcrop within the dune system (**Figure 2-21**).

Figure 2-22 shows the start of a shallow near shore reef system that becomes more prominent to the north.

Recently constructed beach stairs from Queenscliffe Park provided the main access to the section. As seen in **Figure 2-23**, the structure was in good condition. In addition to the park, the area also included a coastal path that ran through the elevated back dune.

Figure 2-20 View to the North from Groyne 3 (left) and to the South from access to Queenscliffe Park (right)

Figure 2-21 Calcarenite limestone present in the dune complex at the northern end of Section 5

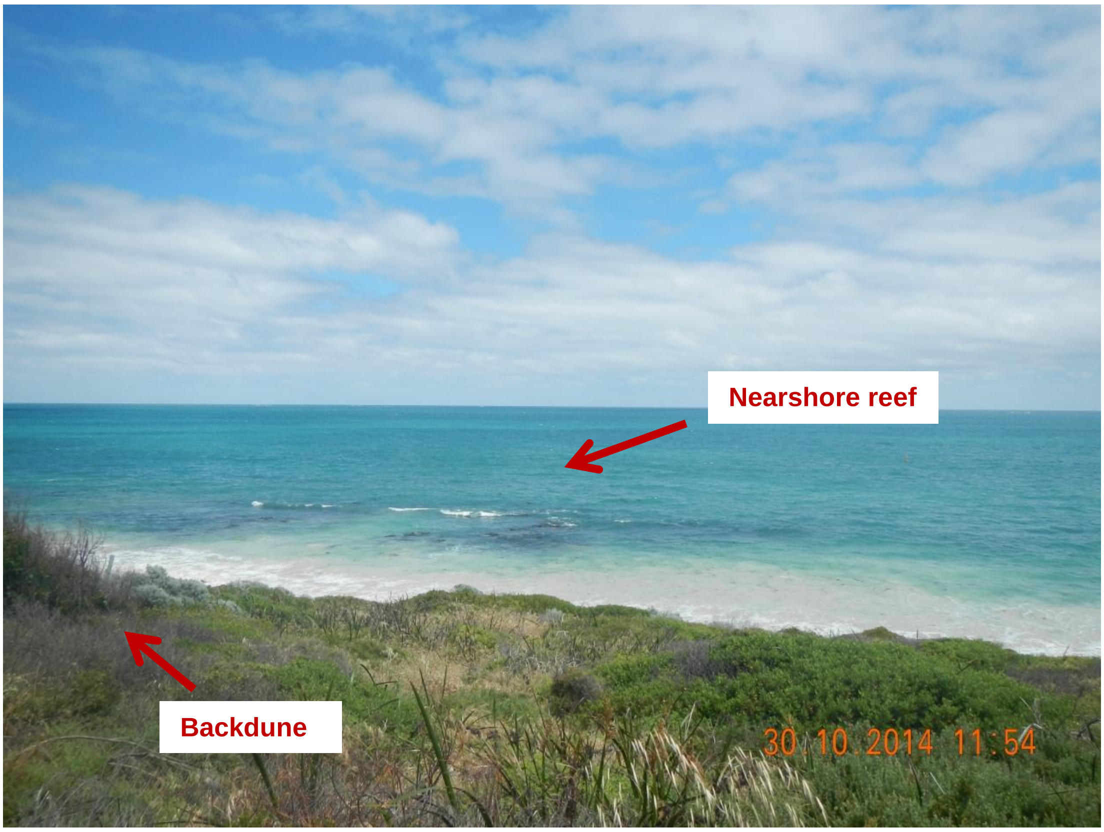

Figure 2-22 Small reef system along Section 5

Figure 2-23 Beach access from Queenscliffe Park

2.7 Section 6

Section 6, outlined in purple in **Figure 2-1**, stretched from the Queenscliffe Park access to the northern boundary of the study area, in Jindalee. The beach was flat and narrow, with no berm present. Wave run up reached the base of the dune (**Figure 2-24**). The eroding dunes were compartmentalised between outcrops of limestone. In comparison to Section 5, the outcrops were larger in size. There was no foredune but the backdune was well established. The nearshore reef system became more extensive and was visible through the length of the section (**Figure 2-25**). The northward littoral drift present throughout sections to south was considerably reduced through this section (**Figure 2-26**). The foreshore at Jindalee was mainly composed of rocks with a narrow beach perched on the reef (**Figure 2-27**).

A public open space with a cafe setback atop the large dunes and cliffs provided additional amenity to this area. Access from Waterland Point was in good condition; however the path terminated at the top of the dune with a steep climb up the dune face required. Three wooden stair cases provided access to the beach via a coastal path. The southernmost wooden access stairs, at Seashore Cove, were unusable after previous storms caused the loss of the base components of the structure (**Figure 2-28**).

This section of shoreline ended in a short region of near shore reefs fronting limestone cliffs prior to the commencement of Alkimos Beach extending to the north.

Figure 2-24 View to the South (left) and North (right) from the middle of Section 6

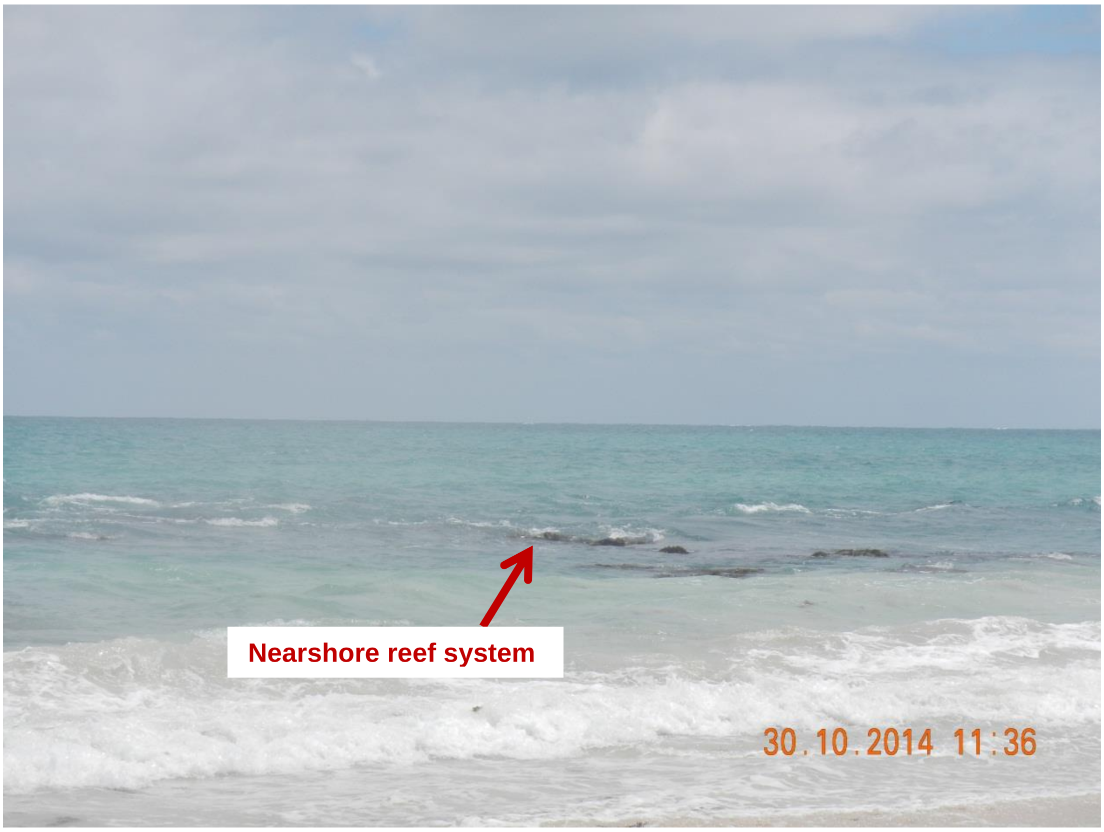

Figure 2-25 Reef visible along Section 6

Figure 2-26 Overview of the beach at Jindalee from atop the high dunes, notice the significantly reduced suspended sediment load and reduced littoral drift.

Figure 2-27 Wave run-up to limestone rocks

Figure 2-28 Storm damaged stairs

3 Coastal Geomorphology

Sediment transport at Quinns Beach has a complex response to the spatially variable nearshore wave climate. Waves arriving from offshore are modified considerably through processes including shoaling, breaking, refraction and diffraction across the system of three reefs. Wave shoaling and breaking results in wave set-up over the shallower reef areas, which forces complex nearshore circulation and drives sediment transport pathways within the reef system. At the beach face, the variation in nearshore wave angle caused by the reefs results in complex littoral drift to both the north and south.

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At the Primary Cell scale (100's kilometres, 1000's years) Quinns Beach is situated leeward of a number of remnant dune and reef ridges formed along temporary shorelines as sea levels rose and fell (Collins 1988). The present day Spearwood, Marmion and Staggie limestone reef ridges are the highly weathered remains of those dunes. Consequently, at the Secondary Cell scale (10’s kilometres, 100’s of years) the City of Wanneroo coast has numerous salients and cuspate forelands associated with prominent sections of reef. Quinns Beach is a cuspate foreland that has formed as a result of the presence of Quinns Rocks in combination with shallower sections of the Staggie and Marmion Reef Ridges. At the nearshore Tertiary Cell scale (the scale of an individual beach) Quinns Beach is bounded by cliffs and Mindarie Keys to the south, and a series of nearshore reefs and cliffs to the north.

3.1 Primary Sediment Cell Processes

Coastal geomorphology at the primary cell scale typically relates to the elevational range over which coastal processes have operated during the Quarternary period (from 2.6 million years ago through to present). During this time sea level fluctuated over 135m due to expansion and contraction of ice sheets and warming and cooling of the oceans (Masselink et al., 2011). The Quarternary period is divided up into the Pleistocene (between 2.3 million years ago and 10,000 years ago) and Holocene (10,000 years ago to present).

The coastline of south Western Australia is a submerged coastline. Submerged coastlines are formed when during periods of falling sea levels, there were periods of long still stands, followed by a marine transgression (where sea-level again rises relative to the land). These still stands are thought to be identified by sharp breaks of slope offshore. Prominent shelf breaks near to Perth are present at approximately 40m and 200m depth on the continental shelf. Fairbanks (1989) reconstructed a generalised sea level curve for the late Pleistocene and Holocene which is shown in **Figure 3-1** (reproduced from Masselink et al., 2011).

The beaches of northern Perth consist of shelly and calcareous material, which are developed due to the semi-arid climate resulting in minimal supply of terrestrial inorganic sand from few rivers, and where rocky sectors do not yield much sand (Bird, 2008). During Pleistocene times the calcareous beaches were a source of sand for dunes, resulting in the formation of dune calcarenites (dune rock) within their structure. During the Holocene marine transgression the dunes have eroded, leaving behind the calcarenite rock that is the basis of the Spearwood, Marmion and Staggie limestone reef ridges.

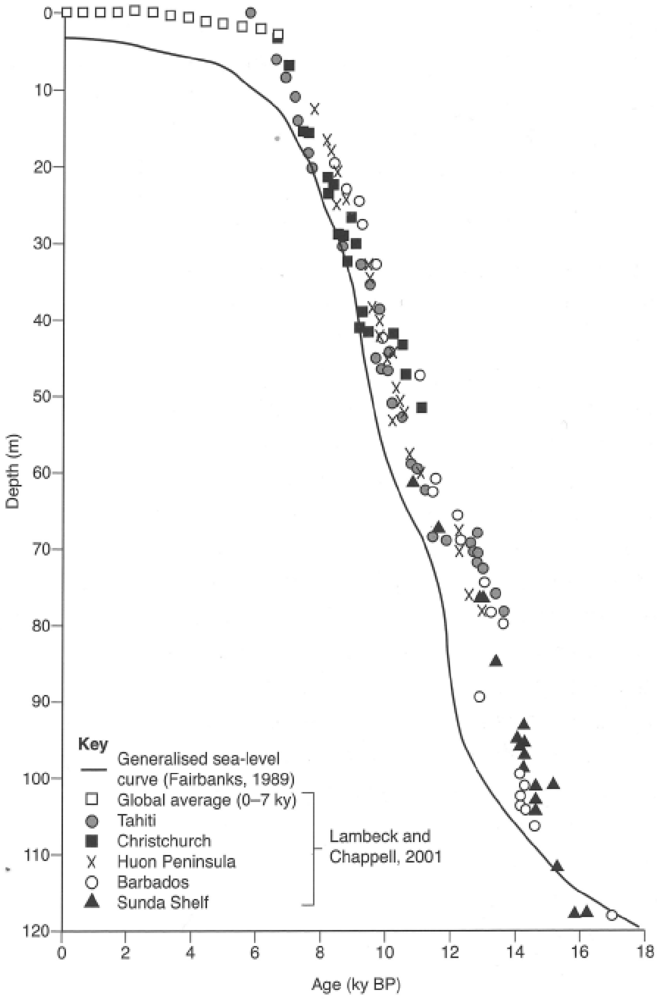

Figure 3-1 Late Pleistocene and Holocene sea-level curve according to Fairbanks (1989), reproduced from Masselink et al. (2011)

3.2 Secondary Sediment Cell Processes

The presence of the numerous reef systems, results in a highly modified wave environment at the beach face. As waves propagate across the reefs they shoal and break. The shoaling and breaking of waves on the reefs results in an elevation in water level over the reef crest (called wave setup) which drive complex currents and circulation patterns within the reef system. In addition, wind stress acting on the water surface, whose effect is enhanced in the shallow water inside the reef system forces currents in the lee of the reefs. These processes result in the redistribution of sediments throughout the reef system and exchange of sediment between the shoreface (area's shallower than approximately 5m depth) and deeper areas.

In addition to the shoaling and breaking process, in lee of the reefs the waves refract and diffract, resulting in changes in wave angle at the shoreface. Where waves arrive at the beach at an angle they drive a littoral drift which transports sand along the beach. When the reef is located close to the shore (such as Quinns Rocks) the littoral drift can be directed to both the north and the south, which in areas of convergence of sediment transport, results in the formation of salients and cuspate forelands (seaward protrusions in the shoreline). Quinns beach is an example of a cuspate foreland formed in the lee of Quinns Rocks. Cuspate forelands, depending on their formation, can be dynamic features (over several decades) that migrate alongshore in response to changes in the balance between northward and southward littoral drift and landward and seaward in response to changes in wave energy penetration. These changes can be due to inter-annual variability in the offshore wave climate (both in wave direction and height) and changes in mean sea level.

3.3 Tertiary Sediment Cell Processes

Tertiary sediment cell processes operate over the spatial scale of an individual beach at the shoreface and over timescales of days (individual storms) through years (seasonal processes). At the tertiary sediment cell scale, both cross shore and longshore sediment transport processes are important. Quinns Beach is afforded significant protection from the offshore swell due to the presence of the numerous reef systems. Due to this, the relative importance of locally generated sea is enhanced in its influence on longshore transport. As such, Quinns Beach experiences significant seasonal fluctuations in the magnitude and direction of longshore sediment transport associated with the southerly summer sea breeze cycle and northerly winter storm season. This process is evident in the seasonal rotation of the beach planform between the groynes constructed in 2002 – 2004. During summer, sand accumulates on the southern side of the groynes, whilst in winter sand accumulates on the northern side of the groynes.

Similarly in the cross shore direction, there is an annual seasonal cycle of erosion and progradation of the beach. During storms and periods of elevated wave conditions, sand is eroded from the beach berm and transported to a nearshore bar. This erosion and flattening of the beach is a natural response that assists in dissipating the incoming wave energy through wave shoaling and breaking on the developing nearshore bar. Subsequently, during calmer periods the shoaling of longer period swell transports sand from the nearshore bar back onto the beach berm, resulting in building and recovery of the beach.

Typically these processes are not steady processes that take place continuously over each season, but rather are intermittent processes with short periods of rapid change (due to severe storms or several days of strong southerly winds) punctuating the more gradual beach building and recovery process.

It is through the interaction of processes operating at different scales that the location and severity of erosion is realised. Dune erosion during storms occurs when there is insufficient volume of sand in the beach berm profile to protect the dune from direct wave attack. This deficiency may be due to a series of severe storms or due to longshore gradients in littoral drift and sand supply. Sand supply can be limited due to the presence of man-made structures, or due to climatic fluctuations in the magnitude and timing of strong littoral drift events.

The presence of structures (such as groynes) that block littoral drift can introduce susceptibility to erosion in different areas at different stages of the seasonal cycle and due to inter-annual variations in the strength of the seasonal cycle. This is seen by the susceptibility of the shoreline immediately north of a groyne to erosion due to an early winter storm (such as occurs north of groyne 1 adjacent to the car park) and to the south of groyne 1 in late winter (as occurred in September 2013).

4 Measured Data

This section summarises the data available for the study area that was utilised in the modelling and reporting for this investigation. It also presents a summary of notable historic events for the area concerning the active coastal zone. Significant gaps in the data or analysis of the study area, along with any suggested methods to close said gaps, are discussed at the end of the section.

4.1 Metocean Data

Data Type	Source	Location & Description
Tides	NTC	Tidal constituents for Hillary's and Two Rocks Marinas.
Water Level	DoT & BoM	Measured water level data from the DoT's gauges at Fremantle (1992-2014) and Two Rocks (1994-2014), and from the BoM's gauge at Hillary's Marina (1992-2014).
Waves	DoT	Measured wave data from the DoT's wave rider buoys off Rottnest Island (1994-2014) and Cottesloe (1994-2007).
Wind	BoM	Complete measured wind data records from the BoM's sites at Bunbury, Garden Island, Lancelin, Mandurah, Ocean Reef, Rottnest Island, and Swanbourne.
Waves and Currents	CoW	Inshore and Offshore data from Summer and Winter AWAC deployments during 2014 off Quinns Beach including temperature, current, water level and directional wave data.
Waves and Currents	Cardno	Data from a single ADCP deployment by Cardno (for another project) off Alkimos (2008-2009) including current, water level and directional wave data.

Note: additional met-ocean data was available but was not required for the purpose of this study

4.2 Spatial Data

Data Type	Source	Location & Description
Aerial Imagery	DoT	Aerial imagery of the study area from 1949 to 2012, including high resolution georeferenced aerials from 2000 onwards.
Aerial Imagery	NearMap	Aerial imagery of the study area from 2007-2014.
Beach Surveys	CoW	Monthly beach surveys from the City's intensive monitoring program at Quinns Beach during 2014.
Beach Surveys	DoT	Beach Surveys (1997-2014)
Hydrographic Surveys	DoT	Detailed hydrographic surveys of the nearshore ocean floor along Quinns Beach (1974-2014).
Shoreline Movements	DoT	Plotted data of the historical vegetation and shoreline positions (1954-1996).
Sediment Cells	DoT	Locations of the Primary, Tertiary, and Secondary sediment cells developed by the DoT (Stul et al 2012).

4.3 Water levels

4.3.1 Astronomical tide

Astronomical tides refer to water movement caused by the gravitational effect of the moon and the sun, and their movements relative to the earth. It is these movements which are predicted in standard tide tables and tidal predictions in the press.

The predicted tide levels for nearby Two Rocks Marina for December 2014 are shown in Figure 4-1. Quinns Beach is located in a diurnal tide zone, generally having one high and one low tide level per day. The difference in tide levels also cycles over roughly a two week period or half a lunar month, as can be seen clearly in Figure 4-1.

The astronomical tidal planes at Two Rocks have been included in Table 4-1. The tidal range is quite small at 1.2 m.

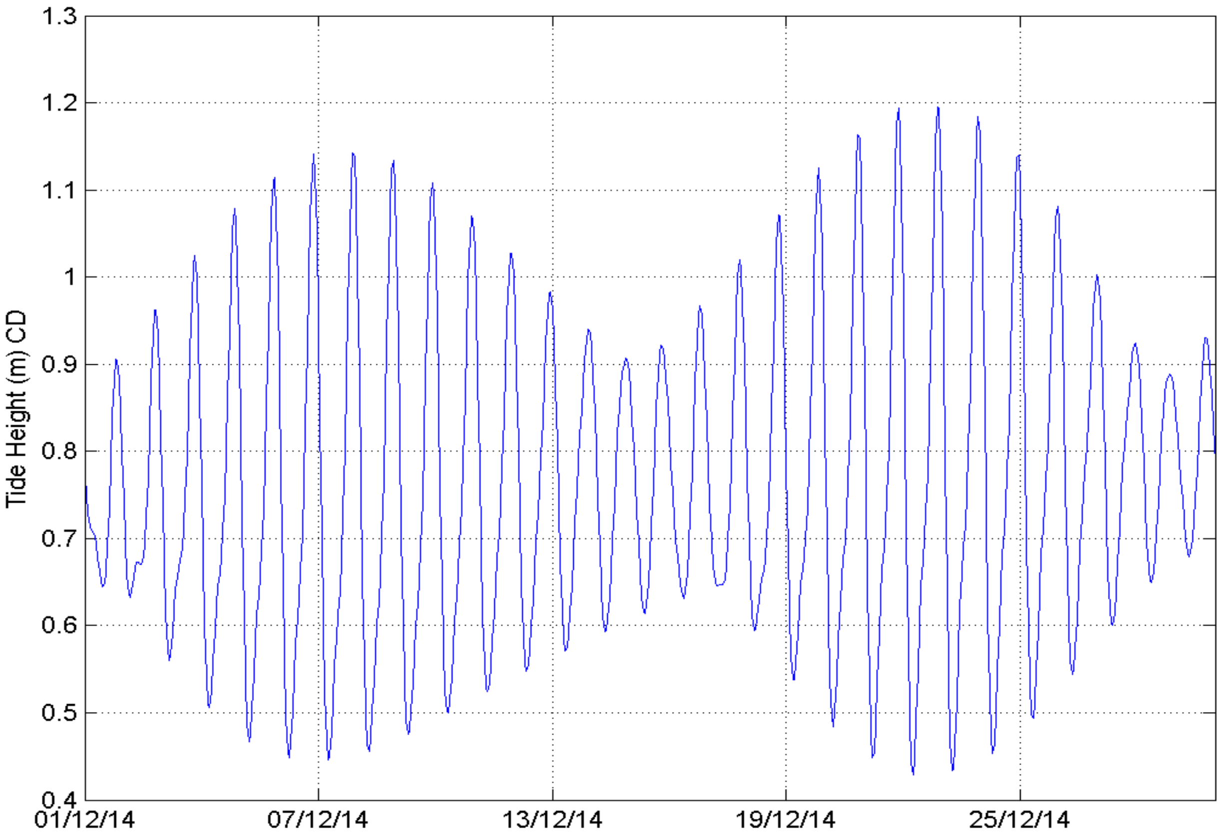

Figure 4-1 Predicted tide levels for Two Rocks Marina during December 2014

Table 4-1 Two Rocks tide levels (NTC 2014)

AHD (metres)	Tide	Chart Datum (metres)
0.6	Highest Astronomical Tide (HAT)	1.4
0.3	Mean Higher High Water (MHHW)	1.1
0.2	Mean Lower High Water (MLHW)	1.0
0	Australian Height Datum	0.8
-0.3	Mean Higher Low Water (MHLW)	0.5
-0.4	Mean Lower Low Water (MLLW)	0.4
-0.6	Lowest Astronomical Tide (LAT)	0.2

4.3.2 Sea Level

Water-level data was obtained from the Department of Transport (DoT) at Two Rocks from 1994 to 2014 inclusive and also the National Tide Centre for Hillarys from 1992 to 2014 inclusive. For each year, the 0.05, 0.1, 0.5, 1, 5, 10, 20 and 50% exceedence levels were calculated. To clarify, the 1% exceedence level for 1992 is the value exceeded by 1% of the data for that year. Figure 4-2 shows the exceedence levels plotted for each year at Hillarys, while Figure 4-3 shows the exceedence levels for Two Rocks. The National Tidal Centre conducts an annual review of the sea level rise around Australia. The rate calculated for Hillarys in the most recent study is 10 mm/year, based on data spanning 1992-2014 (BoM 2014).

It should be noted that the Two Rocks Marina tide gauge is prone to blockages. Data during partial blockages has been included in the data supplied by the DoT.

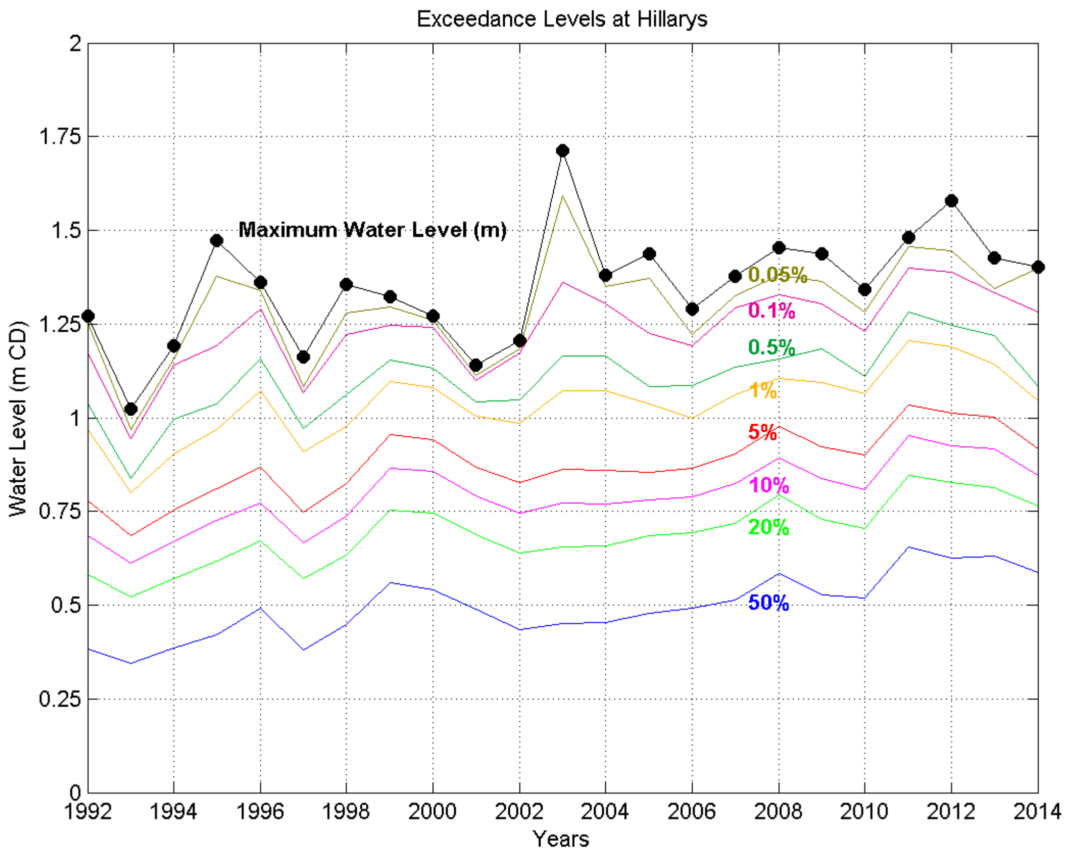

Figure 4-2 Exceedence levels at Hillarys 1992 - 2014

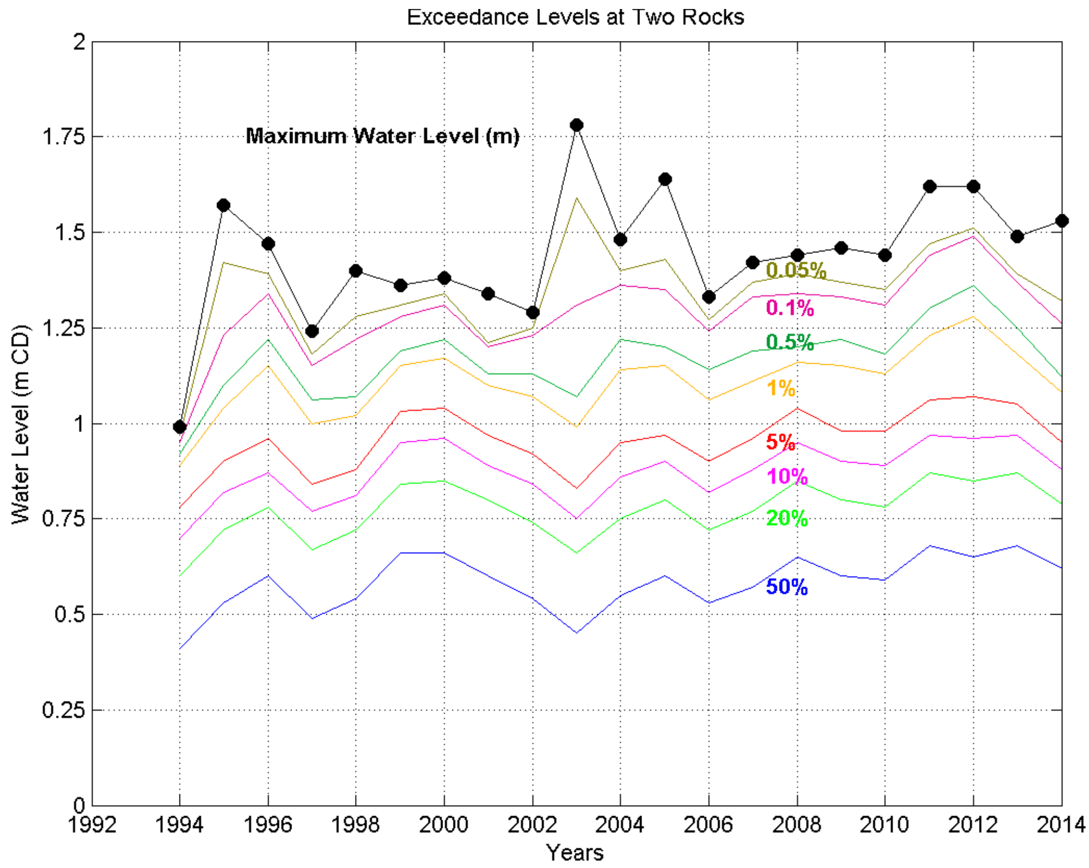

Figure 4-3 Exceedence levels at Two Rocks 1994 – 2014

4.3.3 Storm Surge Events

Variations in water level are caused not only by the astronomical tides, but also by phenomena such as wind and atmospheric pressure. The action of the wind blowing over the surface of the water causes a change in level with, for example, water "piling up" against the coast towards which the wind is blowing. Atmospheric pressure leads to changes in sea level with high pressure lowering the sea level and low pressure resulting in an increase in sea level. This is called the inverse barometric effect. These changes in level can cause very long-period waves to move across the ocean and, in particular, along the edge of continents where they interact with the continental shelf to form "shelf waves". There are a number of types and propagation modes for such waves and all involve a variation in sea level at the coast. Since all these mechanisms combine to make up the water-level variations other than the astronomical tides, they have been grouped under the term storm surge in this report since their combined effect will be greatest during a storm event.

The changes in sea level caused by these phenomena have a time scale similar to those of meteorological systems, which is a number of days. Tidal levels at Two Rocks and Hillarys from 1992/1994 to 2014 were analysed to determine the top 20 highest water levels or storm surge events. The times and heights of these events have been included in Table 4-2. Heights are given relative to Chart Datum. An individual event has been taken as a 5 day period; that is the maximum water level occurring within the 5 days has been utilised.

In the Perth region the majority of storm surge will arise in relation to strong winter storms moving out of the Southern Ocean. Significant summer storms and tropical cyclones, while possible (BOM 2013), are very rare, as shown by the timing of the top 20 storm surge events in Table 4-2. Only two of the top events in the last 20 years have occurred outside of the May to July period. One of these, the equal fifth largest storm surge event (at Hillarys), was tropical cyclone (TC) Bianca (highlighted in yellow), which crossed the coast near Perth as a tropical low on the 30th of January 2011 (ABC 2011).

Table 4-2 Top 20 storm surge events for Hillarys and Two Rocks

Hillarys (1992-2014)	Height (m CD)	Two Rocks (1994-2014)	Height (m CD)
16-May-2003 01:00	1.71	16-May-2003 07:45	1.78
10-Jun-2012 06:00	1.58	07-Jun-2005 07:15	1.64
28-Nov-2012 13:00	1.52	20-May-2011 09:15	1.62
20-May-2011 01:00	1.48	10-Jun-2012 12:55	1.62
30-Jan-2011 10:00 **TC Bianca**	1.48	28-Nov-2012 22:05	1.61
12-Jul-1995 00:00	1.47	12-Jul-1995 08:30	1.57
18-Jul-2008 03:00	1.46	13-Jun-2012 18:45	1.55
07-Jun-2005 00:00	1.44	07-Jun-2012 01:10	1.54
21-May-2009 22:00	1.44	17-Jun-2014 05:25	1.53
08-May-2013 01:00	1.43	30-Jan-2011 18:10 **TC Bianca**	1.51
17-Jun-2014 05:00	1.40	08-May-2013 01:20	1.49
05-Jan-2011 14:00	1.39	09-May-2004 11:10	1.48
09-May-2004 04:00	1.38	16-Jul-1996 09:15	1.47
21-Jul-2004 03:00	1.38	28-Jul-2011 08:20	1.47
02-Jul-2007 02:00	1.38	21-Jul-2004 11:00	1.46
24-Jun-2009 02:00	1.36	22-May-2009 06:30	1.46
28-Jul-2011 00:00	1.36	19-Jun-2012 09:45	1.46
25-Jun-2003 23:00	1.36	23-Jun-2005 09:30	1.45
16-Jul-1996 01:00	1.36	14-Jun-2011 07:25	1.45
08-Jun-1998 00:00	1.36	02-Jul-2004 10:20	1.44

4.4 Sediment Sampling

Cardno conducted sediment sampling within Sections 1 through 5 on 20th November 2013, prior to the inclusion of Section 6 in the study area. Five sediment samples were taken from each of the five distinct sections along Quinns Beach. Roughly in the middle of each section, three samples were taken from around the mean high water (MHW) level across one of the natural beach cusp formations. At each section a fourth sample was taken from the beach berm approximately halfway between the first three samples and the toe of the dune. The final sample for each section was taken from just above the toe of the dune.

Due to the significant amount of historical renourishments that have occurred at Quinns Beach, it is expected that many of the samples are a mix of natural and borrow sand. The dune sample for each section is expected to be predominantly natural sand, with the exception of Section 2, which was likely primarily borrow sand due to recent renourishment and slope stabilisation earthworks undertaken along the erosion escarpment south of Groyne 1 in response to severe storms in September 2013.

Figure 4-4 through **Figure 4-8** below shows the approximate sampling locations for each of the five sections. Each sample location is colour coded to represent the median particle size as per the colour bar on the right. Actual median particles diameters are listed in **Table 4-3**.

It should be noted that field notes and sketches made on the day of the sampling indicates that the GPS readings in **Figure 4-7** (for Section 4) are incorrect. In reality the sample points were all closer to the water, as they are presented in the other figures. Also, sample point 118 should be located between the front three sample points (115-117) and the dune sample point (119). The layout and position relative to the water line in **Figure 4-7** should look similar to **Figure 4-5.**

From the figures listed above some general observations were noted with regards to the sediment distribution along Quinns Beach:

> Section 1 contains generally finer particles than other sections

> In Sections 3, 4, and 5 the natural sand taken from the dune was generally finer than on the beach

The newly imported (near to the car park) and reworked sand found on the dune face of Section 2 was much coarser than the existing beach sand. Likely due to the sorting associated with the earthworks.

Due to the long history of renourishment work at Quinns Beach it is difficult to draw specific conclusions on the natural sediment characteristics from the results presented. It is likely that all of the sediment samples taken along the MHW line, and also on the berm, contain a mix of natural and imported sand.

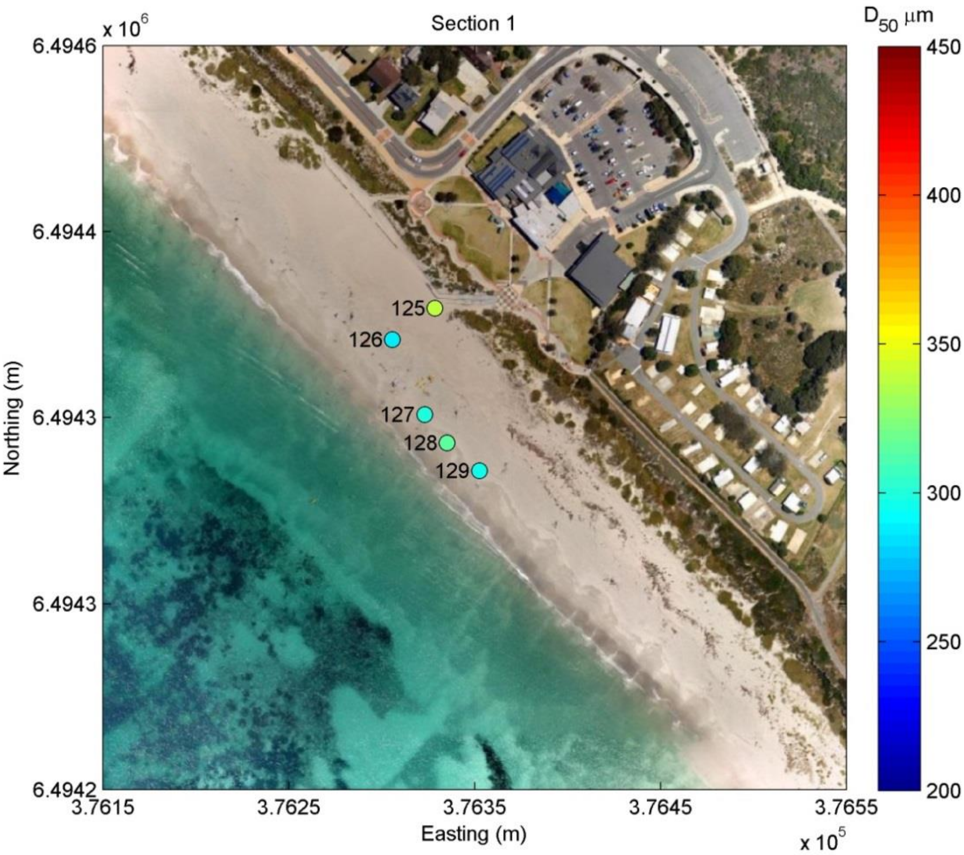

Figure 4-4 Sediment Samples from Section 1

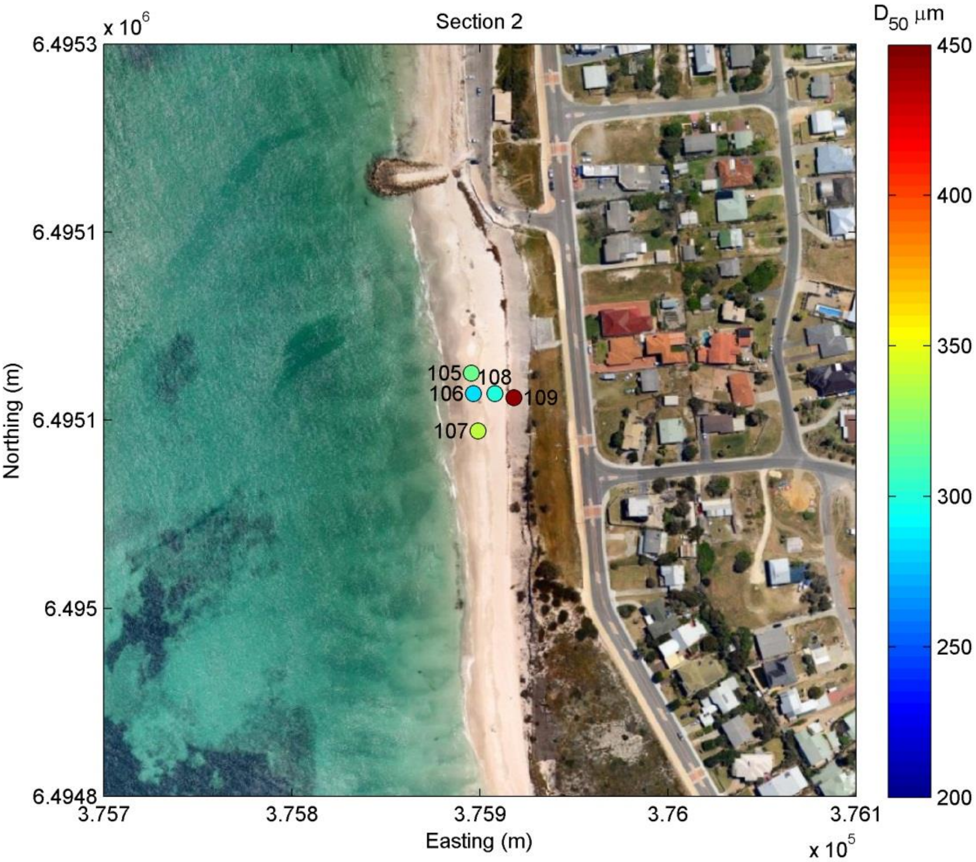

Figure 4-5 Sediment Samples from Section 2

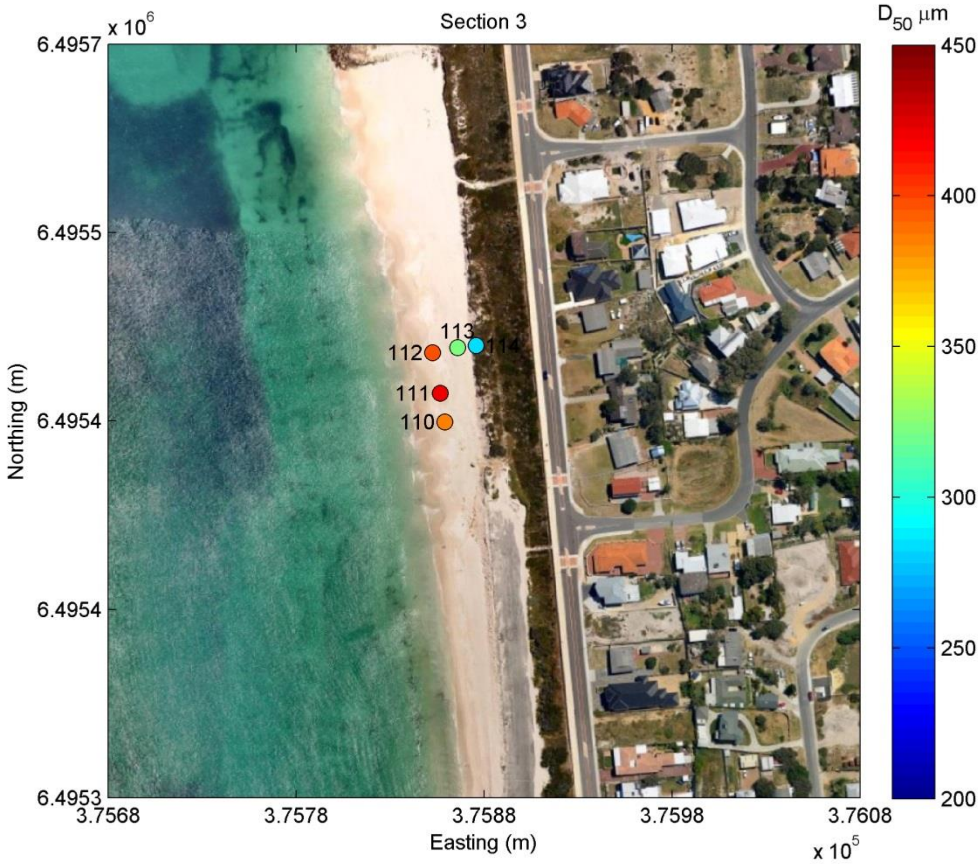

Figure 4-6 Sediment Samples from Section 3

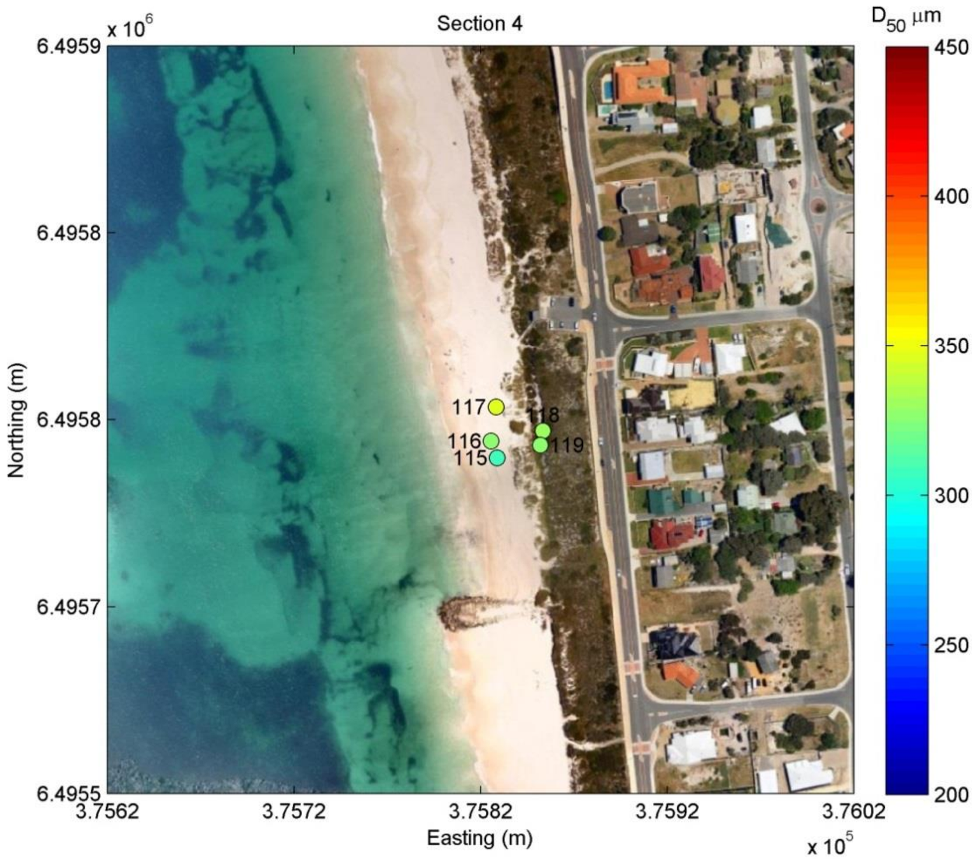

Figure 4-7 Sediment Samples from Section 4. Note: GPS accuracy was low for these sample points, with the actual spread alignment of samples nearer the water line, very similar in appearance to Section 2 (Figure 4-5) and Section 5 (Figure 4-8).

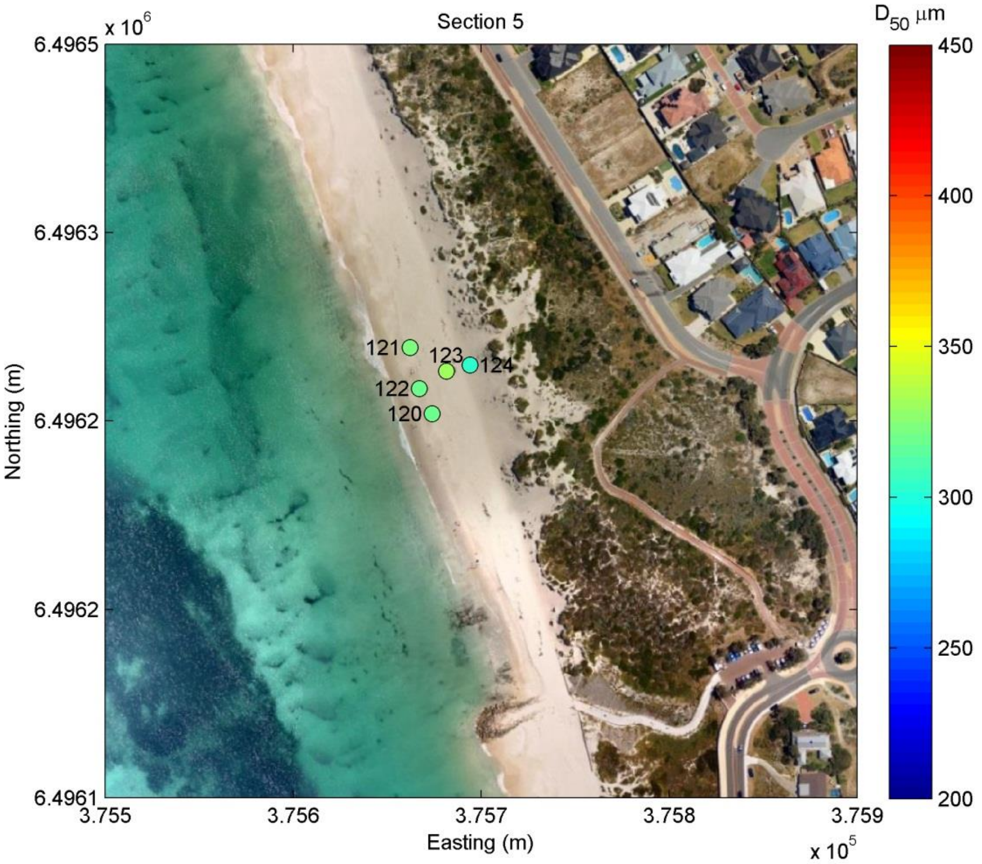

Figure 4-8 Sediment Samples from Section 5

Table 4-3 Cardno November 2013 sediment sample PSD results by percentage passing sieve

Section	Sample Point	D_{50} (µm)	+75µm	+150µm	+300µm	+425µm	+600µm	+1180µm	+2.36mm
Section 1	**125**	**338**	100	99	64	21	4	0	0
	126	**289**	100	99	46	12	2	0	0
	127	**300**	100	99	50	16	3	0	0
	128	**314**	100	98	54	21	5	0	0
	129	**294**	100	99	48	15	3	0	0
Section 2	**105**	**320**	99	98	56	21	5	0	0
	106	**283**	100	98	44	14	3	0	0
	107	**338**	100	99	62	26	9	3	0
	108	**300**	100	98	50	19	6	0	0
	109	**444**	100	99	78	54	19	2	0
Section 3	**110**	**386**	100	100	74	40	14	1	0
	111	**419**	100	100	75	49	24	2	0
	112	**397**	100	100	73	44	18	0	0
	113	**324**	100	100	57	20	6	0	0
	114	**284**	100	99	44	12	2	0	0
Section 4	**115**	**307**	100	99	52	19	6	0	0
	116	**327**	100	99	57	29	12	1	0
	117	**346**	100	100	64	26	8	1	0
	118	**329**	100	100	60	15	2	0	0
	119	**328**	100	99	60	18	2	0	0
Section 5	**120**	**318**	100	100	55	20	6	0	0
	121	**322**	100	100	56	20	5	0	0
	122	**320**	100	100	55	23	7	0	0
	123	**332**	99	99	60	19	3	0	0
	124	**304**	99	99	51	14	1	0	0

The comprehensive sediment sampling revealed that sand present at Quinns Beach has a D_{50} ranging from 283 µm to 444 µm. The dune toe sediment samples (excluding Section 2) had a mean D_{50} of 305 µm while the MHW sediment samples for the four northern sections had a mean D_{50} of 340 µm. This may be due to sediment sorting on the beach face due to waves, resulting in removal of fines. In addition it is likely that wind driven transport and deposition of fines at the dune toe is responsible for the smaller D_{50} at the dune toe. The dune toe sediment sample for Section 2 (sample 109) was taken from recently placed sand nourishment work following the September erosion event. The borrow sand was clearly of a different colour and grain size to the existing beach sand. Hence, sample 109 was not used in the following statistical calculations.

The mean D_{50} of each section is as follows:

- Section 1 = 307 µm
- Section 2 = 310 µm (excluding sample 109)
- Section 3 = 362 µm
- Section 4 = 327 µm
- Section 5 = 319 µm

The sediment sampling results are generally in agreement with previous sediment samples taken at Quinns Beach (Cardno 2013, MRA 2005).

Given the long history of nourishment work at Quinns Beach (if possible) the future use of borrow sand that is coarser may assist in reducing the rate at which imported sand is lost from the beach face. A minimum D_{50} of 360µm is recommended for future nourishment work; note that the D_{50} at Jindalee was reported to have a D_{50} of 370 µm in MRA (2005).

4.5 Photo Monitoring

The City of Wanneroo implemented a monthly photo monitoring plan in November 2013 with additional monitoring performed around significant metocean events in winter (Cardno, 2014b). The photo monitoring dataset includes photographs taken from consistent locations and bearings to allow for a chronology of visual changes in the beach system to be recorded. This provides context and informs further detailed analysis of measured data and modelling results.

4.6 Historical Works & Renourishment

Cardno has compiled a list of significant events relevant to the study area based on literature and the City's records (**Table 4-4**). Detailed recording of renourishment quantities were only available from 2002 onwards, and these are presented in (**Table 4-5**).

Table 4-4 Important historical dates for Quinns Beach

Date	Event
1973	First report of coastal erosion at Quinns Beach (Section 1)
1977	Artificial headland constructed
1984-1988	Erosion reported to the north of headland
1988-1989	Construction of Mindarie Keys south of Quinns Beach
1996-2001*	'Substantial' renourishment by the City, several investigations into coastal processes
2002	Emergency coastal protection works; limestone boulder seawall placed in front of car park
2002-2004	Staged construction of 3 groynes and combined renourishment (~260,000 tonnes)
2006	Further renourishment (30,000 tonnes)
2008	Emergency coastal protection works; repair of limestone seawall. Maintenance of Groynes 1, 2 and 3.
2012	Damage to car park during November storm; Ad-hoc repair of limestone boulder seawall
Sept 2013	3 successive storm events lead to an estimated loss of 19,000 m^3 from the dune system immediately south of Groyne 1, Frederick Stubbs Park is closed and play equipment removed
2014	Construction of geotextile sand container revetment south of Groyne 1, 20,000 m^3 sand nourishment placed in Section 3

*In 2001 a substantial amount of sand was placed in front of the car park.

Table 4-5 Quinns Beach Renourishment 2002-2014

Date	Event
11/02 – 03/03	36,000 m^3 placed in Section 2
11/02 – 03/03	36,000 m^3 placed in Section 3
11/03 – 02/04	12,400 m^3 placed in Section 2
11/03 – 02/04	23,400 m^3 placed in Section 3
11/03 – 02/04	35,900 m^3 placed in Section 4
11/04 – 01/05	15,200 m^3 placed in Section 2
11/04 – 01/05	24,100 m^3 placed in Section 3
10/06 – 12/06	20,700 m^3 placed in Section 2
04/14 – 05/14	20,000 m^3 placed in Section 3
04/14 – 10/14	15,000 m^3 dune sand reworked from bunds during construction of revetment (approximate, not imported)

4.7 Measured metocean data analysis (2014)

The City of Wanneroo contracted WorleyParsons to obtain measured wave and current data at two locations in the proximity of Quinns Beach (WorleyParsons 2014a, 2014b – see **Appendix G**). The 'Offshore' instrument was located approximately 3.4km west of Section 3 at a depth of approximately 14 mAHD between the Staggie Reef Ridge and Marmion Reef Ridge. The 'Inshore' instrument was located approximately 650m west of Section 2 at a depth of approximately 5.5 mAHD midway between Quinns Rocks and the shore (**Figure 4-9**). The instruments were deployed for a summer period (22 January 2014 – 30 April 2014) and a winter period (28 June 2014 – 16 October 2014).

Appendix A presents the measured wave and current data at the offshore and inshore location plotted with relevant forcing parameters: wind data from Ocean Reef, water level data from Fremantle and offshore wave height data from Rottnest for the summer deployment.

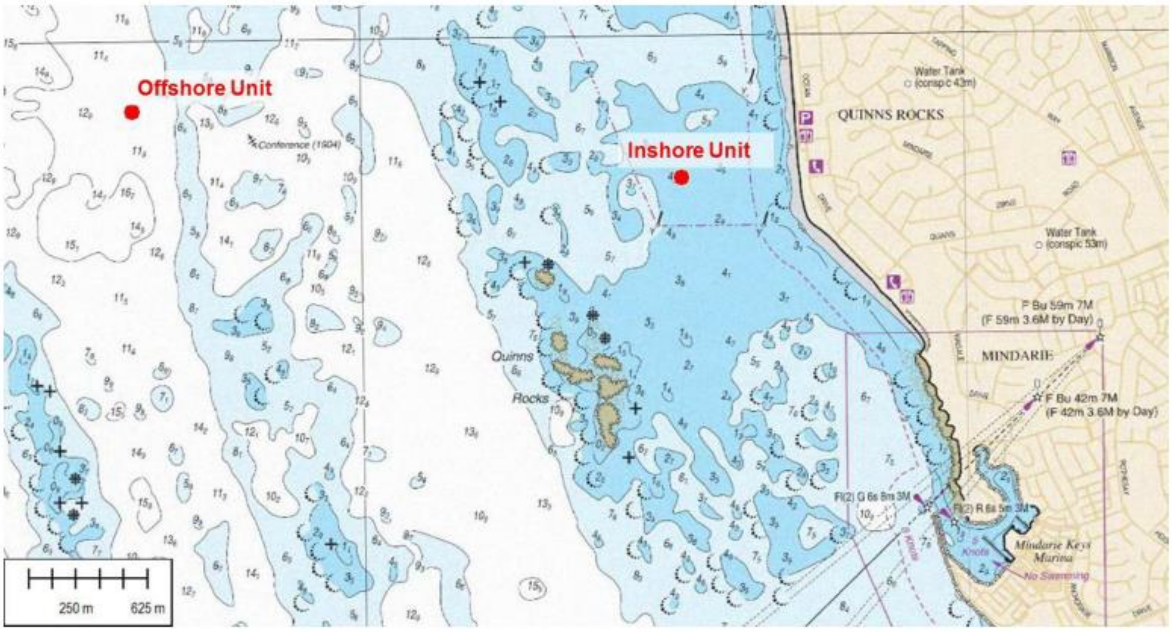

Figure 4-9 Metocean data collection locations for summer and winter 2014.

4.7.2 <u>Currents</u>

Depth averaged current rose plots for the summer deployment are presented in **Figure 4-10**. Surface current rose plots for the summer deployment are presented in **Figure 4-11**. Bottom current rose plots for the summer deployment are presented in **Figure 4-12**.

Depth averaged currents in summer are typically less than 0.2 m/s and generally northward during summer at both the Offshore and Inshore locations. The strongest currents (exceeding 0.2 m/s) were observed during strong southerly winds, with currents at the Inshore location generally stronger than at the Offshore location. Southward reversals in currents (with a magnitude generally < 0.1 m/s) did occur during easterly winds possibly due to wave setup on the reef systems or wind driven surface currents that are steered by the reefs. Current direction at each location is consistent throughout the summer period suggesting that currents may be forced by regional scale processes in summer.

Depth averaged current rose plots for the winter deployment are presented in **Figure 4-13**. Surface current rose plots for the winter deployment are presented in **Figure 4-14**. Bottom current rose plots for the winter deployment are presented in **Figure 4-15**.

Currents in winter were observed to reach 0.4 m/s at the Offshore location and 0.3 m/s at the Inshore location. Currents were southward the majority of the time at the Inshore location. The strongest currents were observed during storms and large swell events which frequently resulted in a circulation with southward flowing currents at the Inshore location and northward flowing currents at the Offshore location, particularly during periods of sustained westerly winds. This is clearly observed during the storms of 7 – 9 September 2014. This suggests some complex circulation patterns during storms.

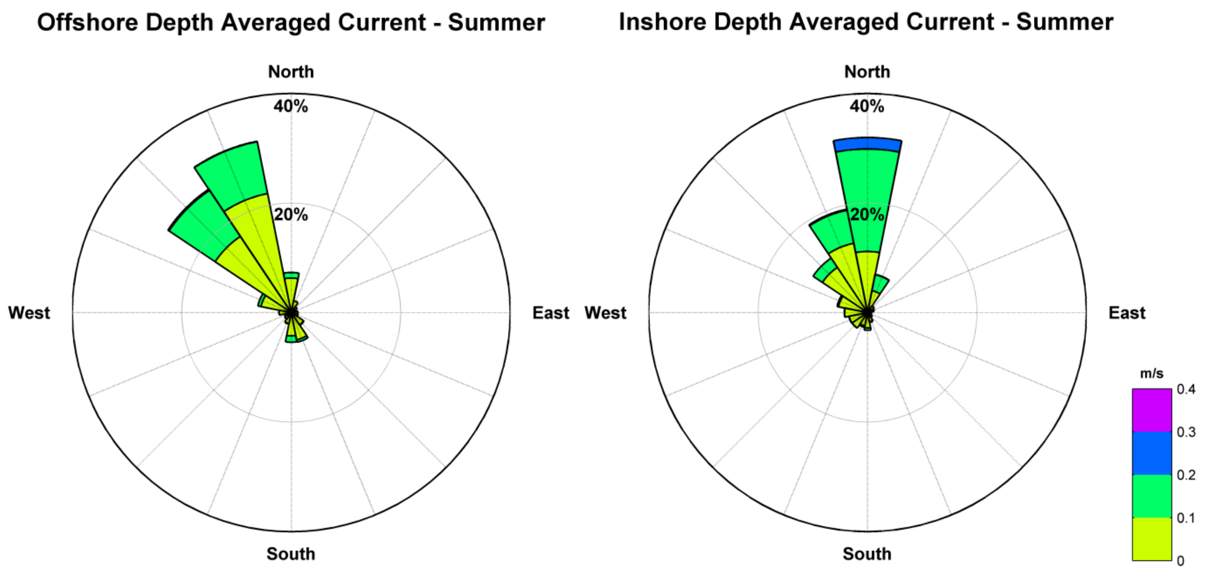

Figure 4-10 Summer depth averaged current roses for the Offshore and Inshore

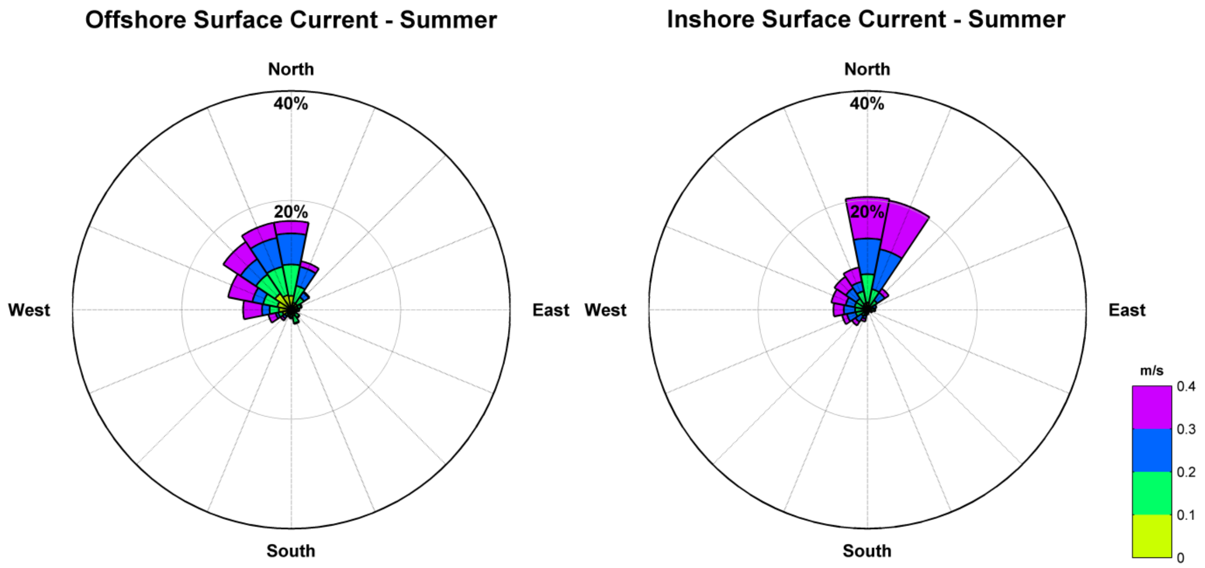

Figure 4-11 Summer surface current roses for the Offshore and Inshore location

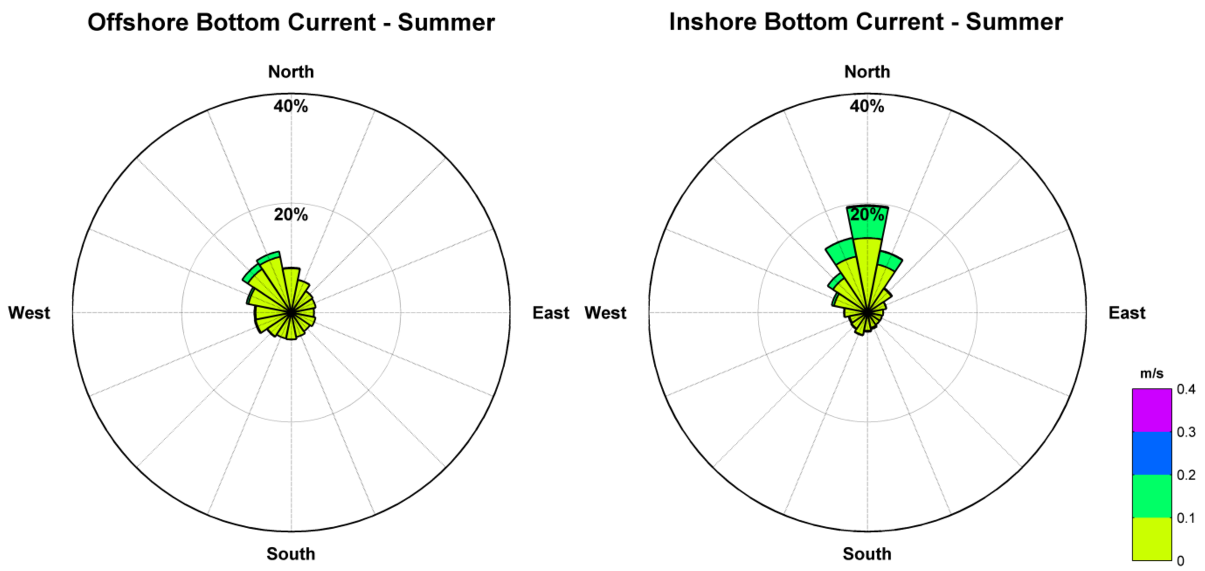

Figure 4-12 Summer bottom current roses for the Offshore and Inshore location

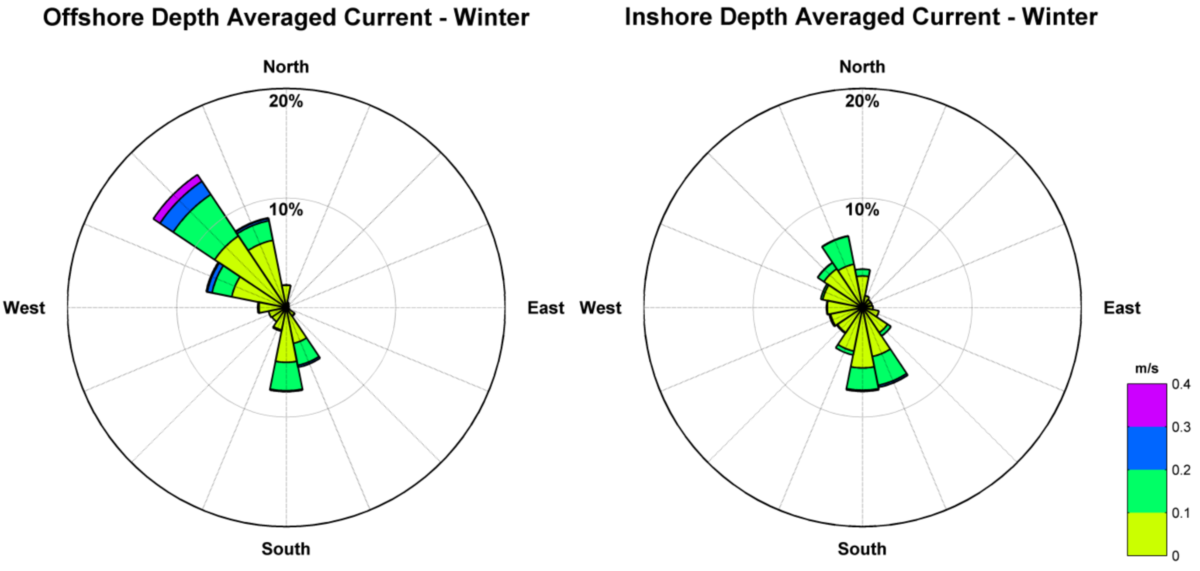

Figure 4-13 Winter depth averaged current roses for the Offshore and Inshore locations

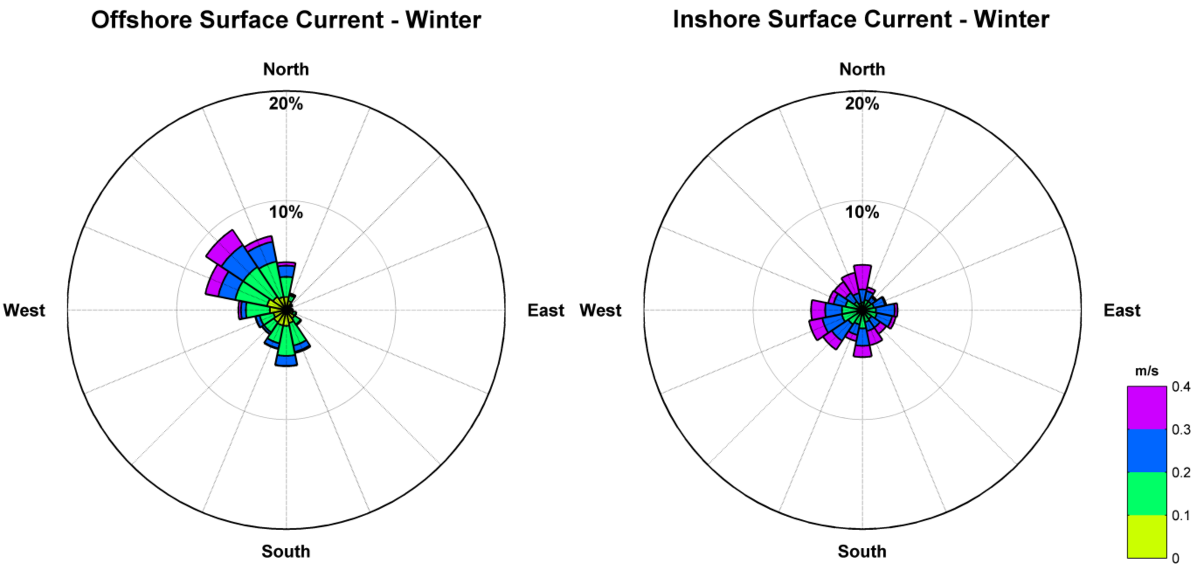

Figure 4-14 Winter surface current roses for the Offshore and Inshore locations

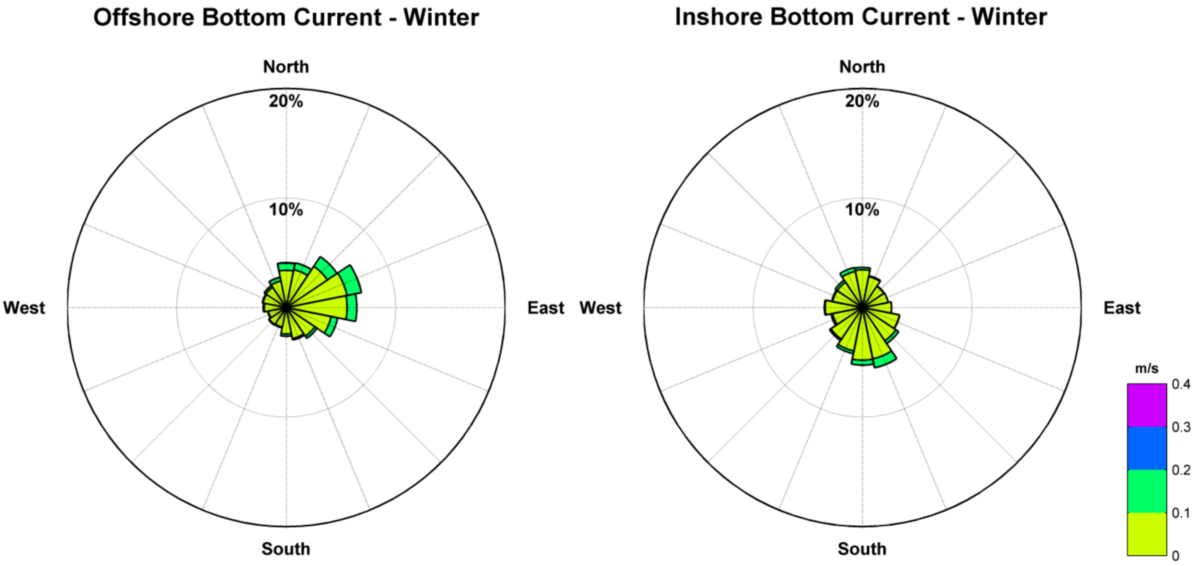

Figure 4-15 Winter bottom current roses for the Offshore and Inshore locations

4.7.3 Waves

Significant wave heights are generally below 2 metres at the Offshore location and below 1 metre at the Inshore location during summer. Significant wave heights are generally below 3m at the offshore and 2m at the inshore location during winter. Rottnest wave heights are reduced by over 50% across the continental shelf and by the Staggie Reef Ridge before reaching the Offshore instrument location and approximately 50% again by the Inshore location.

Mean wave direction is generally from the WSW at both the Offshore and Inshore locations during summer and winter, with winter storm waves propagating from the WNW at these locations. Some uncertainty is present in the measured wave directions, with the difference in wave direction between the Offshore and Inshore locations changing markedly between instrument deployments (25 March 2014 and 12 August 2014). Whilst no specific reason for these differences could be identified, it was possibly related to magnetic fields induced by the instrument batteries or anchoring arrangement (pers. comm. WorleyParsons, 09-02-2015). This has implications for the wave model calibration discussed in greater detail in **Section 6.3.3**.

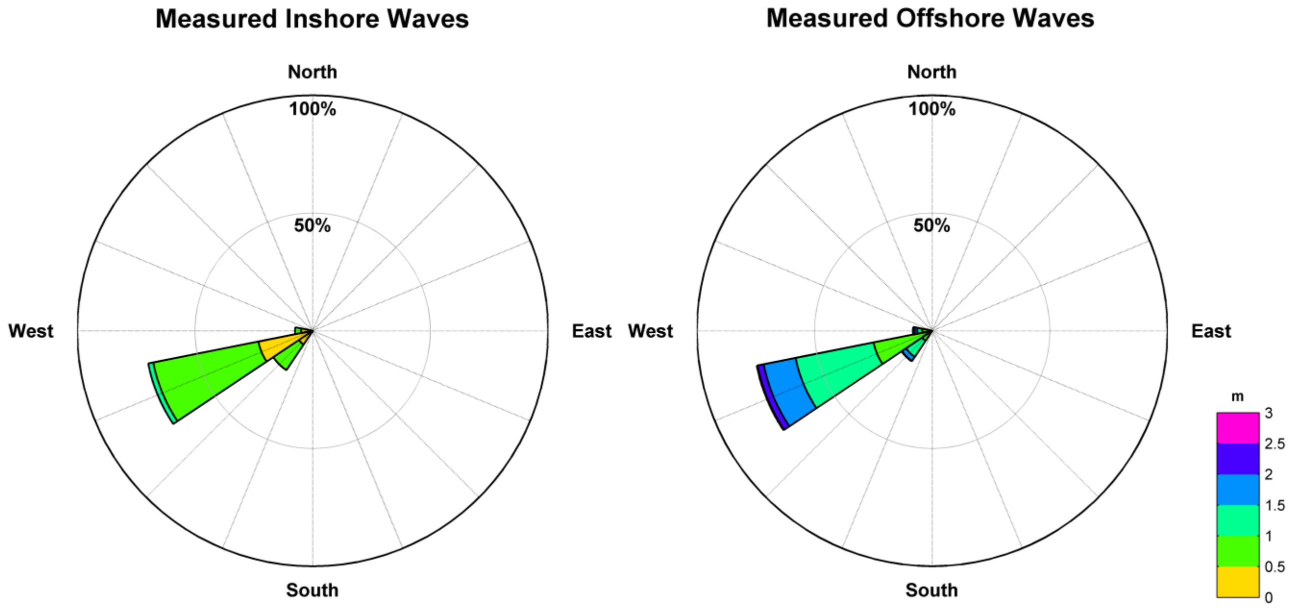

Figure 4-16 Wave rose plots of the measured wave height (in metres) and wave direction for the summer data collection period at the Inshore and Offshore AWAC locations

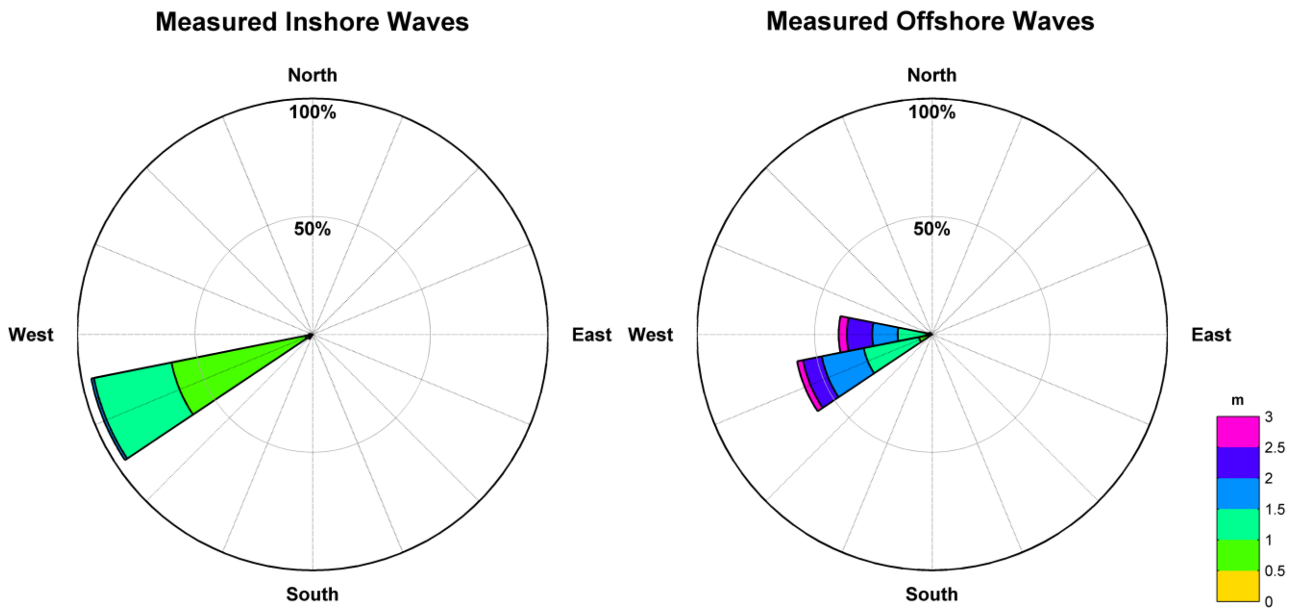

Figure 4-17 Wave rose plots of the measured wave height (in metres) and wave direction for the winter data collection period at the Inshore and Offshore AWAC locations

4.8 Longshore wind stress

The Swanbourne wind data was analysed for longshore wind stress for the full data record, December 1993 to October 2014. The record consists of half-hourly wind speed and direction measurements with relatively few gaps. Wind stress is traditionally calculated using the formula shown below (Resio et al, 2003):

$$\tau = C_{Dz} \frac{\rho_a}{\rho_w} U_z^2 \qquad \text{Equation 1}$$

Where τ is the wind stress, ρ_a is the density of air, ρ_w is the density of water, C_{Dz} is the coefficient of drag for winds measured at level z and U_z is the wind speed measured at level z.

The drag coefficient depends on the wind speed itself, as well as the air-sea temperature differences. As the behavioural trends were required for analysis, rather than the accurate quantification of the wind stress, the monthly trends in the wind speed squared have been analysed. The wind speed was decomposed into alongshore and cross shore components based on the general orientation of the coast through the northern region of Perth. The elected orientation was positive towards 352° N, i.e.: positive for wind moving towards the north-northwest on a heading of 352° N.

Figure 4-18 shows the mean of the monthly averages for the entire 21 year dataset, i.e.: the mean of 21 January averages, and 21 February averages, etc., drawn in black with bars indicating 1 standard deviation plus and minus for each month. A northward wind is positive and southward wind negative.

The figure highlights the strong seasonal trend in local wind forcing experienced at the study area, with the winter season lasting from May through to September in a typical year. The figure also indicates that the net wind stress is towards the north, which is consistent with the trends in wave direction and general northward sediment transport along the beaches of northern Perth.

Figure 4-18 also shows the monthly average wind speed squared for 2013 in blue and 2014 (Jan-Oct) in green. The summer of 2013 demonstrated a significantly lower than average northward wind stress (due to reduced southerly sea breezes) followed by a mild winter and an unusually stormy September. It is possibly these antecedent conditions that lead to the severe erosion in Section 2 south of Groyne 1 in September 2013.

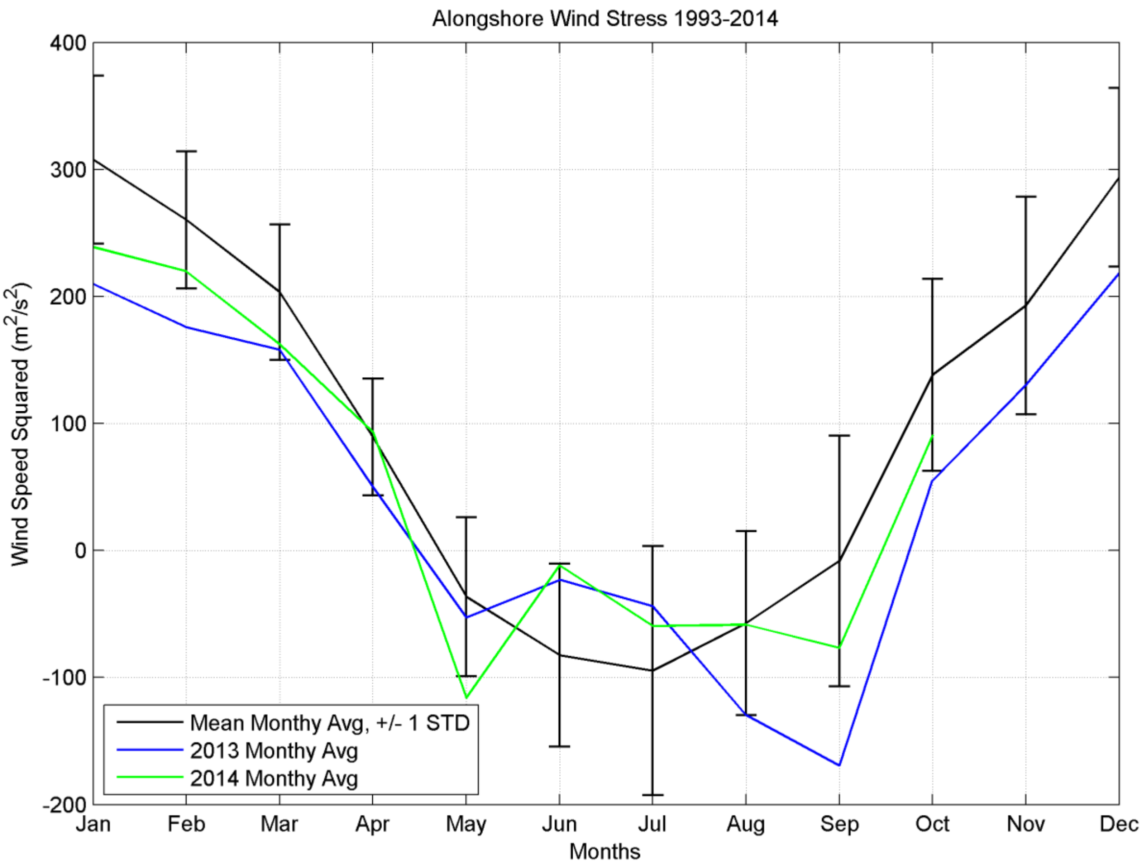

Figure 4-18 Monthly alongshore wind stress

4.9 Beach survey analysis (2014)

A total of eleven beach surveys were completed between February and November 2014. Beach widths were calculated as the distance between the 0m AHD contour and an arbitrary landward baseline drawn parallel to the shore. The data is presented separately for each section defined in **Figure 2-1**. For each beach survey profile a chainage was defined as the distance along the beach from the southern end of the section.

An overview of the measured data is presented in **Figure 4-19,** which shows a time-series of beach width for each section. The colour shows the individual survey beach widths relative to the mean beach width for that chainage across all surveys (i.e. the 'width' is defined relative to the annual mean 0m AHD contour – a value greater than 0 indicates a seaward movement of the beach profile, while a value less than 0 indicates a landward movement). This highlights any seasonal process that may be present in the shoreline position. The black dots are measured data points, with the colours derived from linear interpolation between these points. The gap in Section 2 between June and October 2014 is due to construction activities taking place on site. In addition, various other gaps are present due to incomplete survey, or changes in the scope of defined survey area.

Figure 4-19 quantifies the seasonal rotation of the shoreline, shown by a change from red to blue. **Table 4-6** presents the estimated change in beach volume between each consecutive survey for each section based on the measured beach profile surveys. The change in beach volume is estimated using Equation 2:

$$V = \Delta.B.C \qquad \text{Equation 2}$$

Where V is the change in the aerial (above mean sea level) beach volume, Δ is the change in beach width between the two surveys, B is the estimated berm height and C is the chainage between each beach survey. Cardno (2014b) estimated a berm height of between 1.5 and 1.7m above mean sea level (AHD), this agrees well with visual inspection of the surveyed beach profiles, and a value of 1.6m was used.

In addition to the changes between surveys the gross change over winter between April 2014 and October 2014 is shown in the second last column and the recovery of the system post the 8 September 2014 storm shown in the last column. **Table 4-6** demonstrates the significant seasonal fluctuation in the volume of sand stored in the various beach compartments. Section 1 and Section 5 increased in volume by approximately 10,000 m^3 between April and October, whilst Section 2 and Section 6 reduced in volume by 15,000 and 6,000 m^3 respectively. The storm that occurred on 8 September 2014 removed 26,000 m^3 over the course of 1 week. Subsequently it took approximately 2 months to recover this volume, noting that there were two less severe storms towards the end of September. All Sections exhibited recovery by October except Section 2 and Section 6. This suggests that, whilst some beach recovery is exhibited in the cross shore direction (demonstrated by the mostly closed Sections 3 and 4), transport in the longshore direction is important for post storm recovery in some areas of Quinns Beach (Sections 2 and Section 6). It is important to note that cross shore recovery in these sections is possibly limited by the proximity of nearshore reefs.

In addition the data demonstrates that the artificial headland between Sections 1 and 2 is 'saturated', suggesting there is significant exchange of sediment between Sections 1 and 2 seasonally. This connectivity means that Section 2 is sensitive to the alongshore supply of sediment from Section 1 in summer. If there is reduced supply due to climatic variability in northward transport (i.e. the summer of 2012-2013) Section 2 will be vulnerable in the subsequent winter. Similarly Section 5 suffers from the same effect in summer with supply from the south limited by the groyne field, which makes this area susceptible after mild winters.

It is important to consider that the winter 2014 season included 20,000 m^3 of sand nourishment in Section 3 from 2 April through 14 May and approximately 15,000 m^3 of 'nourishment' due to construction activities (sand lost from bunds and excess sand from dune reshaping) in April through October. The effect of the sand is likely demonstrated in the June survey where a net increase in beach volume of 12,000 m^3 was observed.

Including the sand nourishment inputs, it is estimated that a total of approximately 40,000 – 50,000 m^3 of sand was lost from the overall beach study area over the winter of 2014. Up to 4 November 2014 approximately 30,000 m^3 had returned to the beach after the last significant storm in September. It would be informative to obtain a beach survey in April 2015 to examine the full sediment budget for both seasons. At present there are no historical beach surveys that span a summer period to obtain an estimate of the onshore transport in summer.

Appendix B presents a plan view of the 0m AHD contour lines for Sections 1 to 6 respectively. Sections 1 through 5 demonstrate the significant seasonal rotation, due to their proximity to coastal structures and natural hard points.

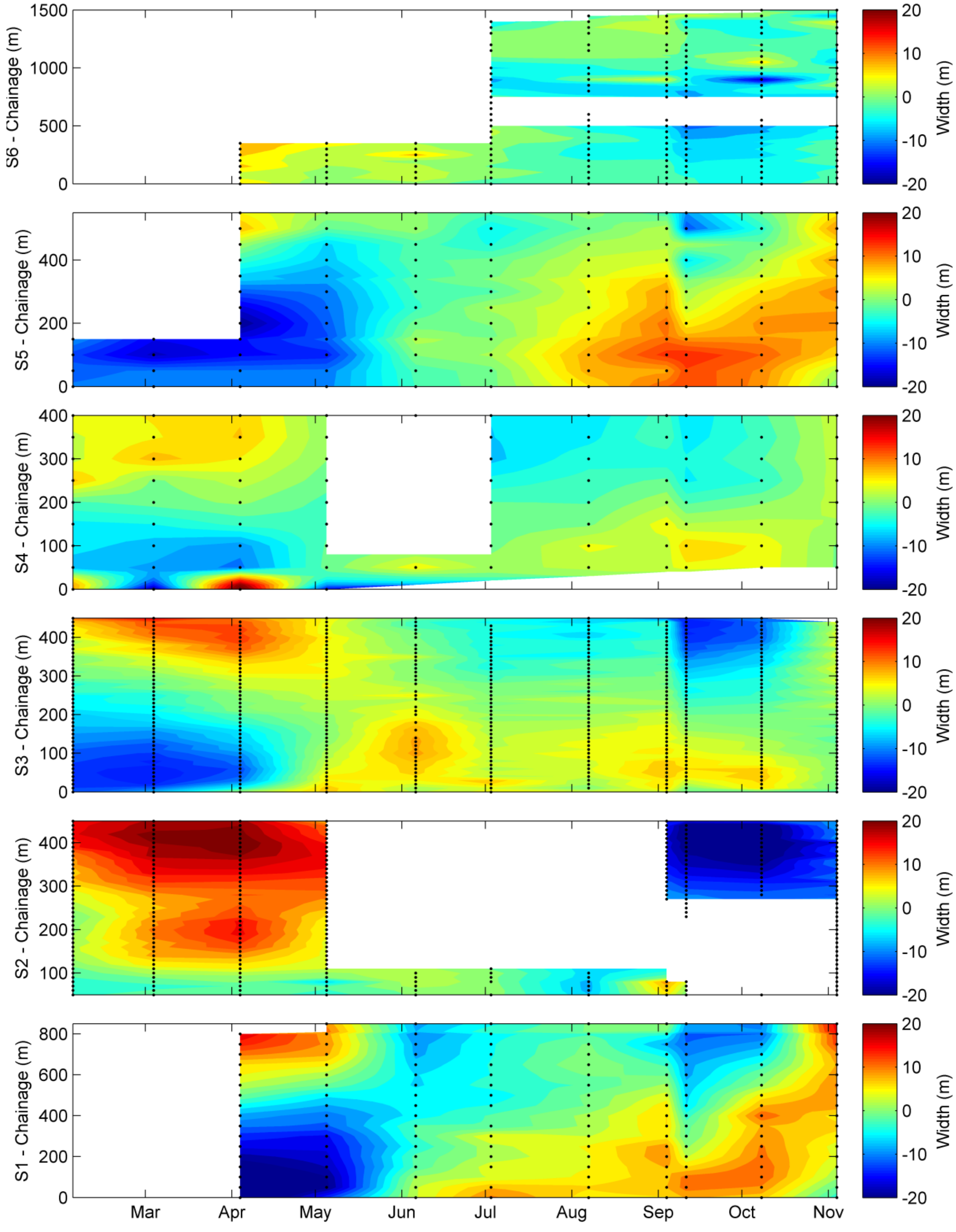

Figure 4-19 Timeseries of relative beach width for each section of Quinns Beach derived from beach survey data. The vertical axis shows distance (chainage) along the section, from south to north. The colour shows the beach width (distance of the 0m AHD) relative to the mean width at that chainage across all the surveys. The black dots indicate measured data points, all other areas are interpolated data.

Table 4-6 Estimated volume changes over 2014. Estimates in italics are poor due to missing or low quality data.

	Beach Volume Change (m^3)	03-Feb-14 to 04-Mar-14	04-Mar-14 to 04-Apr-14	04-Apr-14 to 05-May-14	05-May-14 to 06-Jun-14	06-Jun-14 to 03-Jul-14	03-Jul-14 to 07-Aug-14	07-Aug-14 to 04-Sep-14	04-Sep-14 to 11-Sep-14	11-Sep-14 to 08-Oct-14	08-Oct-14 to 04-Nov-14		04-Apr-14 to 08-Oct-14	11-Sep-14 to 04-Nov-14
Section 1		*N/A*	*N/A*	-2,038	1,812	4,737	3,360	2,115	-8,222	8,496	5,679		10,259	14,175
Section 2		3,888	954	-3,231	*N/A*	*N/A*	*N/A*	*N/A*	-2,252	-681	2,431		-15,465	1,748
Section 3		1,023	2,441	2,139	123	-2,543	59	1,153	-3,599	868	2,523		-1,800	3,391
Section 4		-55	270	-440	4,442	*-6,053*	1,038	1,719	-1,530	858	1,178		31	2,035
Section 5		-840	271	-618	6,207	-55	4,380	2,340	-5,072	3,599	2,163		10,781	5,762
Section 6		*N/A*	*N/A*	*-2,154*	*351*	*-1,673*	-187	754	-5,570	-2,957	5,127		-6,425	2,170
Total		4,017	3,936	-6,343	12,934	-5,588	8,650	8,082	-26,246	10,182	19,101		-2,620	29,283

4.10 Vegetation line analysis

Cardno undertook a thorough analysis of the identified location of the vegetation line as part of Stage 1 of the Review of Coastal Management study in 2012 and 2013 (Cardno, 2013a). This analysis involved review of the DoT provided vegetation lines including adjustments if necessary. It also involved a significant amount of vegetation line tracing where appropriate data was not available. The final analysis utilised a total of 18 points in time based on aerial photographs from 1969 to 2014.

Vegetation recession between each aerial photograph was measured on 22 transects along the study area's coastline. Each section contains 4 equally spaced transects designed to assess long term shoreline evolution, with the exception of Section 6, which only contains 2 transects where vegetation line changes were assessed. This is due to the nature of the coastline in the far north of the study area, where cliffs and rocky bluffs limit vegetation line analysis for much of the section.

Figure 4-20 presents the monthly mean wave height at Rottnest Island, the alongshore wind stress (as defined in **Section 4.8**) and the average movement in the vegetation line for transects in each section along the study area. This average section movement has been plotted cumulatively from 1969 to November 2014. This figure demonstrates well the inter-annual variability in natural processes relevant for morphological change at Quinns Beach.

All Sections experienced significant vegetation line recession between 1994 and 1997, likely due to the very severe winter of 1996 which had the largest monthly mean wave heights and southward wind stress of the record. The greatest change was experienced in Sections 3 and 4, north of the cuspate foreland with some 20m of recession over that time.

Reports of historical erosion during the 1970's south of the cusp are clearly visible (Section 1). This coincides with progradation of the sections north of the cusp. The construction of the artificial headland in 1977 appears to have stabilised the vegetation line in Section 1 until 2010, where a persistent trend of progradation occurs. This may be associated with a lagged response to the construction of the three groynes in 2002-2004, or due to the lower than average northward wind stress over the period 2012 through 2014.

The groyne construction was staged over three years, with groynes 1 and 2 constructed in 2002/03 (City of Wanneroo, 2002) and groyne 3 constructed in 2003/2004 (City of Wanneroo, 2003). The recession of the vegetation line between 2003 and 2005 in Sections 4 and 5 is likely an initial response to the reduction in sediment supply introduced by the groynes, with Section 4 showing subsequent recovery back to its previous position between 2005 and 2012.

From 2007 till the present the vegetation line behaviour along the study area is varied. Sections 1 and 4 both exhibit a strong accretionary trend, suggesting a link between the works of 2002 – 2006 and their recovery to approximately their 1969 locations (on average). This is consistent with first hand reports and site visits where it was noted that these were the only locations where a significant and vegetated foredune was present. 'Hotspot' Sections 2 and 5 have experienced significant recession since groyne field construction, and Section 3 appears to have stabilised. It should be noted that vegetation has not been present seaward of the southern end of the car park since 2004, resulting in 0m vegetation movement for the southernmost transect in Section 3. By 2013 vegetation had been removed from the entire seaward edge of the car park, resulting in a 0m vegetation recession for the two southernmost transects in Section 3. This has the effect of artificially reducing the average vegetation line movement and it is noted that frequent and costly emergency works and sand nourishment have taken place to prevent further loss of the car park.

There has been a succession of summers from 2012 through to 2014 where the northward wind stress has been lower than all previous summers in this record and may be a contributing factor to the reduction in sediment supply to Section 2. This is supported by longshore sediment transport modelling, which indicates a net northward drift in Section 1 from 2005 through 2012 with a (albeit reduced) net southward drift from 2012 through October 2014 (**Section 6.5.4**). This coincides with progradation of the vegetation line in Section 1 over the 2012 through 2014 period.

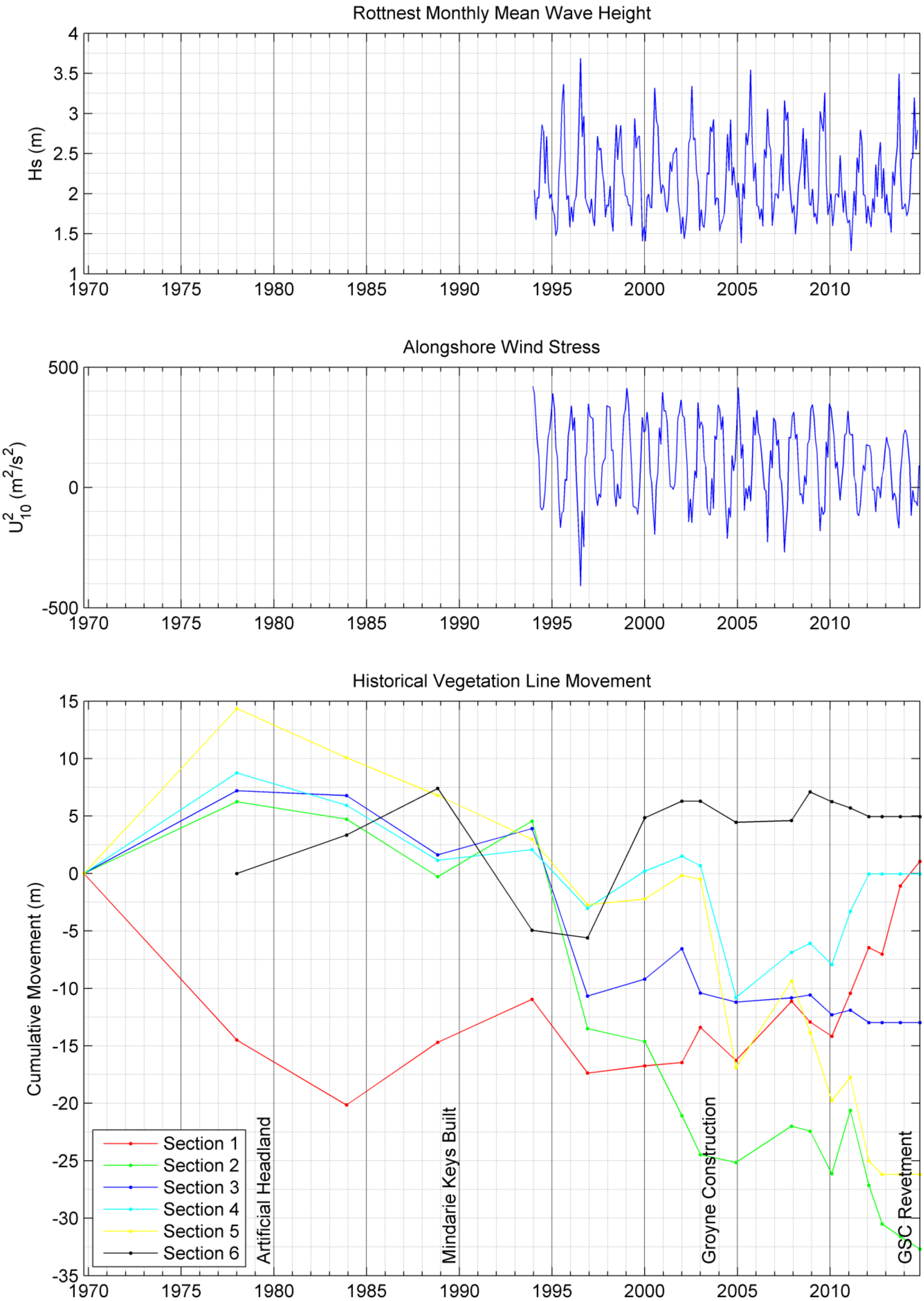

Figure 4-20 Each sections averaged vegetation line movement along the study area, plotted cumulatively from 1969 to November 2014

4.11 Dune erosion estimate

The loss of sediment from the dune system was estimated using the measured vegetation line movements and the approximate height of the dune system at each transect, multiplied by the length between each transect. Dune height was estimated as the approximate level of the present vegetation line (estimated from LiDAR and beach surveys) minus the level of the beach. **Table 4-7** shows the approximate annual volume rate of change for the dune system along the study area. The figures were calculated using the vegetation line movements between December 2004 and November 2014 to provide an indicative estimate of the sediment budget with the present configuration of coastal structures.

Sections 1 and 4 have experienced a net gain in dune volume due to the stability of the beach in these compartments, with subsequent aeolian transport of sediment inland and the reclamation of a foredune by vegetation, as is evident from **Figure 4-20**. Sections 3 and 6 have remained roughly stable since 2004, whilst Sections 2 and 5 have experienced significant fluxes of sediment into the active coastal zone from the dunes. Section 2 and Section 5 are effectively down drift of the groyne field for winter and summer respectively making these areas susceptible to erosion. These figures have been employed in the development of the conceptual sediment transport model and sediment budget in **Section 4**.

Table 4-7 Approximate annual volume exchange of dune sediment

	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Annual Sediment Exchange (m^3/year)	**2000**	**-3500**	**-500**	**2000**	**-6000**	**500**

4.12 Literature

The relevant literature available for this project area consists mainly of previous reports prepared by Cardno and others who have investigated coastal processes and suggested solutions to mitigate erosion issues. These reports provided a strong base of coastal processes knowledge that this study has reviewed and built upon.

> Eliot, I. (1988). Beach Erosion at Quinns Rocks. Report to the Investigations and Surveys Branch, Department of Marine and Harbours, Western Australia.

> Tremarfon Pty Ltd (1997). Quinns Coastal Processes Study. Prepared for the City of Wanneroo.

> Department of Transport (1998). Quinns Seawall Proposal Preliminary Investigation.

> Mick Rogers Associates (1999). Quinns Beach Coastal Protection Works Stage 1 Report. Prepared for the Shire of Wanneroo.

> Mick Rogers Associates (2002). Quinns Beach Protection Re-evaluation of Options. Prepared for the City of Wanneroo.

> Cardno (2013-14). Quinns Beach Review of Coastal Management (Stages 1 to 3). Prepared for the City of Wanneroo.

4.13 Other data

The City has completed several structural condition reports for the three rock groynes located in the study area. These reports provided an indication of the performance of the structures during severe weather events, helped to determine their safety with regards to public access and flagged any requirements for maintenance. It should be noted that since construction the groynes have required maintenance approximately every 5 years.

4.14 Knowledge gaps

Significant improvements in the understanding of coastal processes occurring at Quinns Beach have been obtained through the data collection performed throughout 2014 and analysed in this study. However the following short-comings are present:

- Lack of beach surveys spanning summer to obtain an estimate of the summer sediment budget

- Beach profile data does not extend to approximate closure depths, only allowing for a sediment budget (based on measured data) for the beach at a level greater than 0 mAHD
- Beach morphological changes are based on a single year of data that included considerable man-made disturbance resulting in extensive gaps in the beach profile data and should not be considered representative of long term trends
- Improved understanding of the influence of inter-annual variability in environmental forcing on the location and severity of erosion will assist in developing improved management

5 Conceptual Sediment Transport Model

One of the key objectives of this study was to develop a quantified conceptual sediment transport model that describes the prevailing sedimentary processes and pathways for the study area. The purpose of the sedimentary conceptual model is to provide a visual representation of the complex coastal processes in a simple and easy to understand way, presented on a plan or diagram, together with some ‘high level’ estimates of transport rates and directions.

Conceptual models can be a key element in communicating an understanding of complex physical and environmental processes. They integrate present understanding of system dynamics, identify important processes and facilitate communication of complex physical interactions. The intention of a conceptual model is generally to:

> Formalise present understanding of system processes and dynamics;

> Identify linkages of processes across system boundaries; and

> Identify the bounds and scope of the system of interest.

Quinns Beach, like many others in the Perth area, is predominantly a sandy coastline with intermittent limestone cliff features and a complex system of offshore and near shore reefs that reduce wave energy from the ocean, but at the same time makes near shore wave directions and related shoreline features complex. The study area experiences highly seasonal sediment transport, due to the seasonal wave climate, with persistent southerly sea breeze conditions during summer and severe north westerly storm events during winter.

The Conceptual Model is primarily focussed on shoreline-related sediment movements and their interaction with the near shore reef systems. However, it is also necessary to consider the sediment movements into and out of larger primary and secondary sediment cells over longer timeframes. Given the significant seasonal differences expected between the sediment transport conditions for summer and winter, the model will investigate both seasons.

Figure 5-1 shows the sediment cell developed by the Department of Transport (Stul et al 2012). The study site is part of Primary Cell G, Secondary Cell 29 and extends the length of Tertiary Cell 29b. Tertiary Cell 29b is bounded by a series of cliffs and small pocket beaches to the south, with minimal littoral drift from the south. Similarly to the north the cell is bounded by cliffs and pocket beaches, however these are less extensive as compared to the south. The tertiary cell is characterised by the presence of Quinns Rocks (part of the Spearwood Ridge) which is responsible for the cuspate foreland commonly known as Quinns Beach.

5.1 Sediment Budget Components

A coastline such as the Perth area typically has a number of sediment sources and sinks that supply or accumulate sediment at varying rates and spatial variability. The components of long-term sediment budgets include (Woodroffe, 2012):

> Littoral supply (or loss)

> Offshore/Onshore transport

> In situ net sediment production (i.e. by seagrass or macroalgal epiphytes or weathering of the limestone headlands and reefs)

> Coastal sand nourishment, mining, or land reclamation

> Sand losses to dunes and adjacent coast

> Sand exchanges with the inner continental shelf

> Exchanges with inlets (not applicable in the study area)

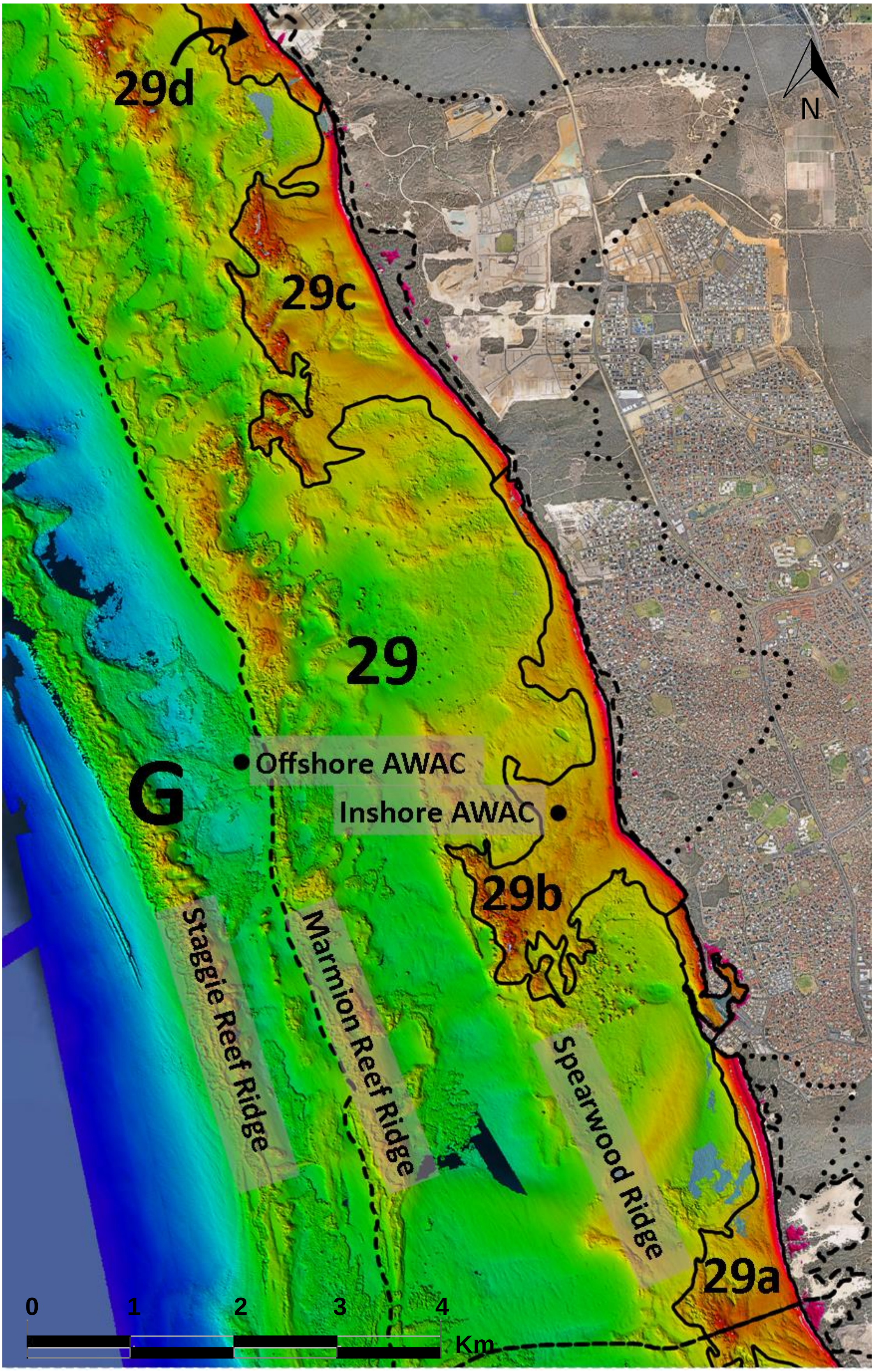

Figure 5-1 Sediment cells developed by the Department of Transport (Stul et al 2012). The study area extends the length of tertiary cell 29b. Locations of measured data are indicated and reef ridges

5.2 Annual Sediment Budget

A sediment budget has been estimated for the aerial beach at the tertiary sediment cell scale. The potential links to adjacent sediment cells and to the secondary sediment cell scale are estimated in order to later inform assessment of potential implications of coastal management at Quinns Beach on the adjacent beaches.

This section presents the estimates of the different components of the sediment budget, and explores the reasoning for these estimates based on the information presented above. It should be noted that the quantification of sediment budgets for dynamic coastal regions is exceedingly difficult and has significant uncertainty, particularly given the scarcity and quality of available historical data. In addition this budget is estimated for the period of approximately 2004 – 2014, which is subsequent to the construction of the three groynes.

The principal sediment transport mechanisms for the study area are:

- Longshore sediment transport
- Cross-shore sediment transport
- Aeolian sediment transport and dune erosion
- Onshore/offshore sediment exchange (between adjacent tertiary cells with in the secondary sediment cell).

Cardno (2012) analysed data from 2002 through to 2012 to obtain estimates of erosion and accretion of sections of Quinns Beach, shown below in **Table 5-1**. This suggests that the Quinns Beach system has an annual supply deficit of approximately 20,000 m^3.

Table 5-1 Estimated net sediment budget for Quinns Beach over the period 2002 through 2012

	Artificial nourishment (m^3)	Net Change: Nov 02 to Apr 12 (m^3)	Rate of change (m^3/yr)
Section 1	0	48,600	5,200
Section 2	84,300	-82,500	-8,800
Section 3	83,600	-78,300	-8,300
Section 4	35,900	-32,400	-3,400
Section 5	0	-47,800	-5,100
All Sections	203,800	-192,400	-20,400

5.3 Sediment Transport at Quinns Beach

The pattern of sediment transport at Quinns Beach is a critical process that can affect the success of coastal works dramatically. There have been several investigations into coastal processes, sediment transport, and sediment composition at Quinns Beach. Sediment transport can be due to waves, currents or winds – noting that waves breaking obliquely on a beach will cause a longshore current.

5.3.1 Sediment Description

An initial investigation by Cardno (2012) determined the sediment to be mostly medium sand. In 2013, another more comprehensive sediment sampling program (see **Section 4.3**) revealed that the sand present has a D_{50} ranging from 283 µm to 444 µm. The samples from the dune toe had a mean D_{50} of 305 µm while the mean D_{50} for the northern sections at the high water line was 340 µm. The sampling investigation concluded that a significant proportion of fines is transported away from the beach as the dune face is eroded.

Visual inspection of the LiDAR data, hydrographic surveys and aerial photography suggests that there is limited sediment availability beyond approximately -5m AHD, the seaward extent of the tertiary sediment cell utilised by Stul et al (2012), with the substrate being primarily reef flats, macro algae or seagrass. The presence of significant seagrass in the proximity of Quinns Beach is evidenced by the annual accumulation of seagrass wrack along the beach in late September/October each year. It is likely that there is also some production of skeletal carbonate within the reef systems.

5.3.2 Wind Induced Transport

Wind induced transport occurs when sand is moved through the air or along the beach surface by wind. The sediment at Quinns Beach is small enough to be transported by moderate winds and there is evidence of this during the site visits, where sediment has been transported onto access paths, particularly in Section 1.

Wind must reach a critical speed in order to overcome gravity and friction and move sand along and across a beach. This depends on factors such as the density of the sand and most importantly the grain size. The Shore Protection Manual (SPM, 1984) provides guidelines on calculating the threshold wind speed required for wind induced transport of a given grain size. Using the wind data acquired from BoM it was calculated that this threshold is reached 27% (Swanbourne) to 39% (Ocean Reef) of the time. If the beach sand is wet, transport by the wind is inhibited, therefore, generally a beach berm must first develop before sand will be transported from the beach and impounded in dunes. As such, during winter and in locations where the beach profile is in poor condition due to a lack of longshore supply, the transport of sediment by wind is limited. Therefore wind transport will be most important in summer, resulting in a generally north and westward direction of transport; this is likely the case for the dune growth exhibited in Section 1.

MRA (1999a) noted that afternoon summer southerlies produce windborne sediment transport to the north. The report also notes that the summer sea breeze (in combination with the summer sea and swell) produce a net onshore movement of sand while the strong winter storms and resulting sea produce a net offshore movement of sand.

5.3.3 Current Induced Transport

The measured near bed currents presented in **Section 4.7.2** rarely exceed 0.2 m/s. Whilst currents of this magnitude alone are not considered sufficient to suspend sediment, the wave induced turbulence, particularly through interaction with the shallow reefs can result in significant suspension of sediment, outside of the littoral zone, that can then be transported by currents. This is likely the primary transport mechanism by which sediment is transported throughout the secondary sediment cell.

5.3.4 Longshore sediment transport

As with many open coast beaches in the Perth area, longshore sediment transport is an important component of sediment transport in the Quinns coastal region. The predominant driver of this transport is waves arriving obliquely to the coast. When wave direction differs from shore-normal the result will be a net longshore drift of sediments. This wave induced action moves sand outside the surf zone, inside the surf zone, and along the beach face, but most significantly in the breaker zone.

Longshore sediment transport is dominated by seasonal processes which produce a steady northwards transport during summer and strong, but intermittent transport to the south during winter storm events.

An investigation into coastal management strategies by the then Coastal Management Maritime Division (now Department of Transport) in 1998 found that since the artificial headland's construction, the beach south of the cusp had accreted around 80,000 m^3 of sand (1977-1997). The report also states that the northern flank of Quinns Beach had undergone substantial erosion. Similarly since the construction of the artificial headland, the northern cusp had lost approximately 170,000 m^3 of sand due to a lack of sediment supply. The report said that "coastal protection works conducted at Quinns Cusp in the late 1970's may have contributed to erosion by trapping sediment (in Section 1) which would have previously returned to the northern beaches". The report suggested that the possible influence of the headland must be considered when analysing processes in the area. The more recent analysis of vegetation lines suggest that whilst there was some recovery of the shoreline up to 1997, the construction of the groynes has resulted in the persistent progradation of the shoreline in Section 1, highlighting the connectivity that remained between the northern and southern flanks of the cuspate foreland post construction of the artificial headland. The investigation of the Coastal Management Maritime Division suggests a loss of 8,500 m^3 per year 'north of the headland'.

MRA 1999a concluded that the net sediment transport direction was to the north, but with transport occurring in both directions depending on the time of year. Furthermore, MRA (2002) employed the GENESIS model, which estimated the seasonal fluxes to be in the order of 80,000 m^3 (each way to the north and south) with a net movement of about 7,000 m^3 to the north (1995-1999). No indication of the spatial variation in longshore transport is provided in MRA (2002). MRA (2002) conclude that the installation of the artificial headland led to the net annual sediment transport in Section 1 changing from an annual deficit of approximately 3,000 m^3 to a positive influx of approximately 4,000 m^3 per year.

Given the presence of the extensive cliffs to the south of Quinns, in conjunction with Mindarie Keys, longshore sediment supply from the south is likely limited and highly variable from year to year. It should be noted that supply of sediment to Quinns from the south was limited prior to the construction of Mindarie Keys due to the cliffs and pocket beaches already present at the site. Likewise the presence of cliffs and reefs to the north of Quinns Beach likely limits the exchange of sediment between Quinns Beach and Jindalee.

Where there are rocky headlands, such as the artificial headland or the three groynes in the study area, there is a disruption to the littoral drift and therefore a change in the alignment of the coast. Sediment transport along the coast is blocked by the headland or groyne and sand will be deposited until the beach builds out to the end of the headland/groyne (impoundment) and sand is then able to pass along the coast and past/around the headland. Examples of this process occurring at Quinns Beach are shown in **Figure 5-2**. Some bypassing can occur much earlier and also depends on water level and wave heights. That is, a lower water level allows longshore transport to occur further offshore (for given incident wave heights) and higher incident waves have a deeper closure depth that may also allow partial bypassing before the beach width extends to the end of the structures. Although the local structure of wave kinematics varies near headlands and groynes, they both cause some reduction in longshore transport until engulfed by sand.

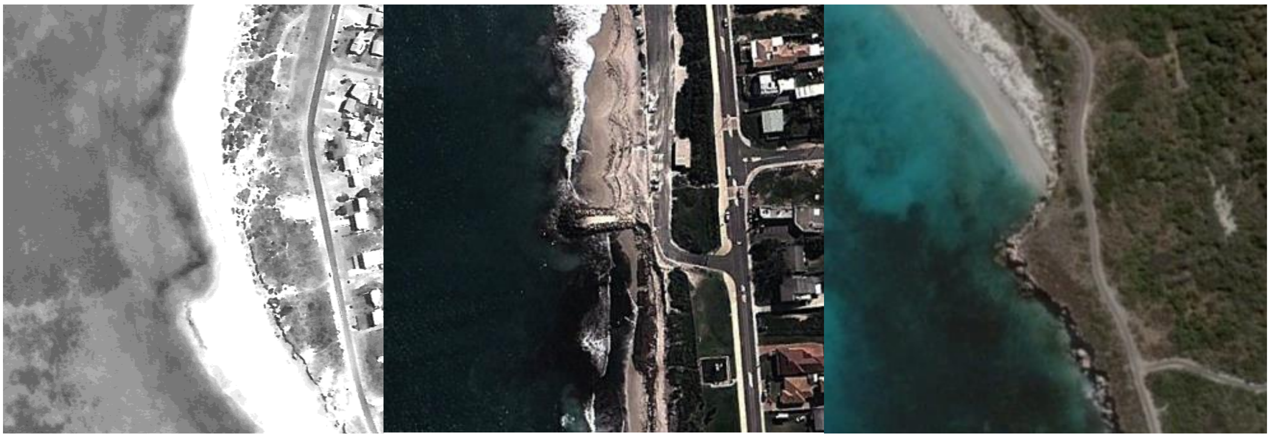

Figure 5-2 Examples of beach morphological response at Quinns due to blocking of the littoral drift by man-made and natural coastal structures. The Quinns Beach artificial headland in 1978 (left), Groyne 1 at the end of winter 2012 and the headland at the southern end of Section 1 at the end of summer 2014.

The structures in place at Quinns Beach are intended to interrupt longshore transport and hold the beach in place. However, this reduces the sediment supply on the down-drift side of the structures. Section 5 and Section 2 suffer most strongly from this in the summer and winter periods respectively. In each of these locations sand is blocked by the groyne with no down drift structure able to prevent the net loss of sediment.

Beaches between two hard points will not only recede and accrete, but also “rotate” depending on the dominant wave climate and prevailing conditions, and on up drift sediment supply. This will occur seasonally and in the long term. This phenomenon applies to Sections 1 to 5, but in particular Sections 1 and 2. MRA 1999b noted that a small change in the angle of the beach can lead to a significant change in net annual movements.

Calibration of the longshore transport model in this study indicates that longshore transport is highly variable in direction and magnitude along Quinns Beach with gross transport up to 60,000 m^3 per year (**Figure 6-33**) and an average net northward transport of between 2,000 – 5,000 m^3 per year for sections one through five (**Table 6-7**). This is notably less than previous assessment in MRA (2002), likely due to the improved estimation of nearshore wave conditions. In addition the longshore transport model suggests that littoral supply from the south is minimal. Gross sediment transport through the north of Section 6 is modelled to be approximately 20,000 m^3 per year with net supply from Quinns Beach to the north (on average) suggested to be minimal but highly variable (up to +/- 4,000 m^3 per year). It should be noted that the model has limited representation of the reefs and cliffs at the north of the study area. Therefore if the volume of sand that can be impounded on the southern flank of these reefs and cliffs is smaller than the estimated budget, bypassing to the north in late summer is possible, however this is intermittent from year to year. Further discussion is provided in **Section 6.5.4**.

5.3.5 Cross shore transport

Across the beach in an offshore direction, the beach profiles evolve towards a dynamic equilibrium which is a function of the incoming wave energy and the sediment grain size as well as reef structures. During calm periods, sand is transported up onto the beach face building up a berm, a flat area at the top of the swash zone, the highest point wave run-up reaches during ambient conditions. During storms, this berm is eroded and the whole profile lowered. Sand is moved offshore to form an offshore bar, and also may be transported alongshore (Masselink et al., 2011). In severe storms, waves can undercut the base of the dune resulting in a loss of the dune that can take several years or decades to recover.

Cross shore exchange of sediment takes place year round, it is primarily offshore in winter due to the action of storms and onshore in summer. In winter sediment is transported offshore and southward, with ambient periods of beach recovery between storms bringing sediment back onshore.

Analysis of pre and post beach survey data from a storm in September 2014 showed the cross shore exchange of sediment (from the aerial beach) during that single event was approximately 30,000 m^3 for the 5km study area. Analysis of survey data between April 2014 and October 2014 indicates that whilst there was minimal net change in beach volume, over the same period approximately 35,000 m^3 was added to the aerial beach through nourishment. This suggests that approximately 40,000 m^3 was taken from the beach over the 2014 winter (**Table 5-2**). Subsequently, between October and November the beach recovered 20,000 m^3 (**Table 4-6**). Assuming that this rate slows throughout summer as the offshore bar is brought back onshore into the berm, the seasonal cross shore exchange is estimated at approximately 40,000 m^3.

Table 5-2 Sediment budget for the aerial beach for winter 2014

	Surveyed Beach Volume Change April to October 2014 (m^3)	Nourishment/Input (m^3)
Section 1	10,259	0
Section 2	-15,465	15,000
Section 3	-1,800	20,000
Section 4	31	0
Section 5	10,781	0
Section 6	-6,425	0
Total	**-2,620**	**35,000**
Lost to nearshore/south, ignoring potential supply from the north		*-37,620*

5.3.6 Dune Erosion

Changes due to impoundment of sediment in the dunes and input of sediment into the active beach due to erosion of dunes were estimated for each section of Quinns Beach in **Section 3.7** (see **Table 5-3** reproduced here). Averaged over the period 2004 through to 2014, dune erosion was on average 10,000 m^3 per year and impoundment on average 4,500 m^3 per year, resulting in a net supply of 5,500 m^3 per year into the active beach from the dunes.

Table 5-3 Approximate annual volume exchange of dune sediment

	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Annual Sediment Exchange (m^3/year)	**2000**	**-3500**	**-500**	**2000**	**-6000**	**500**

5.3.7 Annual sediment budget

An annual sediment budget has been estimated based on the data analysis and numerical modelling results presented in this study.

Numerical modelling of storm erosion undertaken in this study identified that there is likely a sediment transport pathway driven by strong wave setup currents during storms from the north of Quinns Beach into deeper water adjacent to the reefs and cliffs present at the northern end of Section 6 into the deeper water. This current is driven by wave setup on the reefs at Alkimos and likely transports sand offshore to depths below 5m AHD adjacent to the Dog Beach (see **Section 6.4.7**).

In addition, there may be an additional offshore sediment pathway from the south of Section 1 during storm, transporting sediment to a large sand bank feature offshore of Mindarie. This offshore transport, separate from the seasonal cross-shore processes occurring at the shoreface is quantified separately as “loss to nearshore”.

The analysis performed in Cardno (2012) suggests a long term sediment deficit (over the period 2002 to 2012) of 20,000 m^3 per year. Including this in conjunction with the longshore, cross shore and dune exchange components of the tertiary sediment cell budget developed throughout this chapter, the exchange of sediment from the tertiary cell to the adjacent nearshore tertiary cell is estimated to be 25,500 m^3 per year (**Table 5-4**) – that is, a loss of sand. This deficit would represent a combination of offshore transport to deeper water in winter, via offshore transport pathways and intermittent loss of sand to the north during years of strong northward transport. Equally, there is likely intermittent onshore transport from the sand bank adjacent to Mindarie Keys. This highlights the importance of improving an understanding of the interaction between the Quinns Beach tertiary sediment cell and the adjacent offshore tertiary sediment cells.

At current market rates for nourishment sand (approximately \$35/m^2), the 20,000 m^3 deficit equates to a loss of approximately \$700,000 per annum. This presents a significant engineering and management challenge, as exemplified by the limited success of the groynes to stabilise the shoreline without significant ongoing sand nourishment.

Figure 5-3 presents an overview of the conceptual sediment transport pathways for the tertiary and secondary sediment cells adjacent to Quinns Beach. The dark blue lines represent the dominant summer pathways and the light blue lines the dominant winter pathways. The relevant quantities derived in the annual sediment budget for the aerial beach are also indicated.

Table 5-4 Estimated annual sediment budget for the aerial beach between 2004 and 2014

	Inputs (m^3/yr)	Outputs (m^3/yr)
Net longshore (from south/to north)	0	0
Dune exchange (erosion/impoundment)	10,000	4,500
Loss to nearshore		25,500
Seasonal cross shore exchange - Summer/Winter	40,000	40,000
Total	50,000	70,000
Net annual sediment budget		**-20,000**

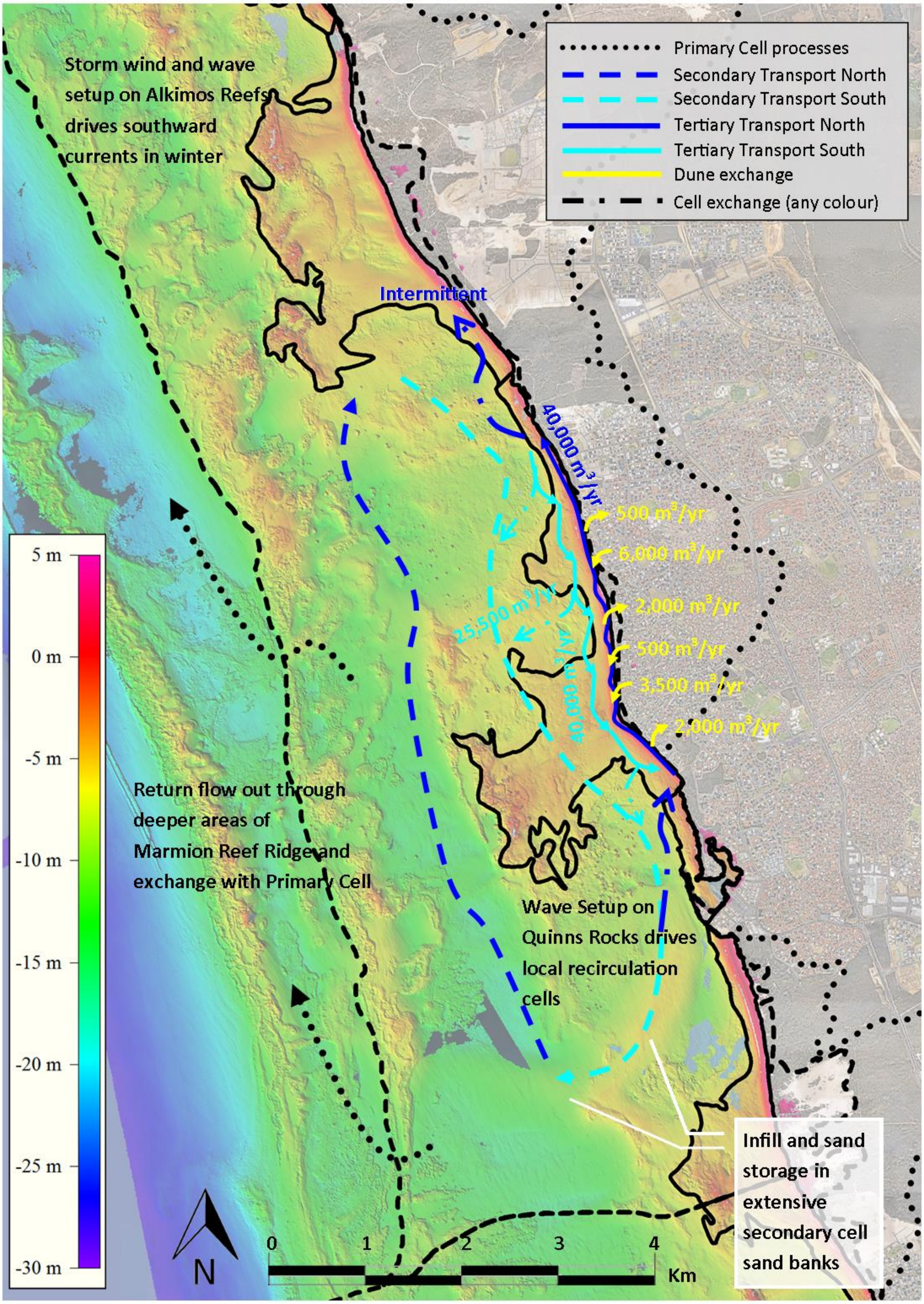

Figure 5-3 Conceptual sediment transport model, sediment transport pathways and annual sediment budget for Quinns Beach.

6 Numerical modelling

6.1 Methodology

Sediment transport and beach morphology are a result of complex interactions between site characteristics, available sediments, waves, currents and water levels. The presence of numerous shallow near shore reefs further increases the complexity of the physical processes governing sediment transport due to the dependence of wave breaking and refraction on local water depth , seabed slopes and possible seiching between the shoreline and reefs. Due to the small tidal range present at the site, storm surge can significantly increase the penetration of wave energy across the reefs to the beach. In addition to storm events, inter-annual climate variability (i.e. latitude of low pressure systems (Bosserelle et al., 2012) and decadal sea level cycles (Pattiaratchi, 2011)) can also have a significant influence on the wave processes acting at the beach face.

The methodology applied in this investigation primarily involves the hindcast of near shore wave conditions for a 10 year period. From this hindcast, nearshore spatially variable design wave criteria were established for the extent of the study site; the location of the proposed coastal management options would then determine which design wave data to apply.

The modelled wave conditions are then applied to process based models to examine both short term (storm) and long term sediment transport. Due to the complex nature of the wave field and observed importance of both longshore and cross shore sediment transport, an assessment of two 2D numerical models (Delft3D/XBeach) was performed to assess their capacity to simulate the interaction between waves and currents and their effect on sediment transport during storm conditions. The results of this assessment are presented in **Appendix C**. On the basis of this assessment the XBeach model was selected due to its ability to better predict observed shoreline bed level changes and measured currents.

In order to assess the long term evolution of the shoreline, the results from the nearshore wave model were used to drive a longshore sediment transport and shoreline evolution model (LitPACK).

6.2 Bathymetry

The following bathymetric data were used in the wave and sediment transport models:

> Lancelin to Cape Peron Navigational Chart (AUS0754)
  - Source: Department for Planning and Infrastructure
> Bouvard Navigational Chart (AUS0755)
  - Source: Department for Planning and Infrastructure
> Two Rocks to Cape Naturaliste LiDAR data
  - Source: Department of Transport
  - Survey date: April 2009 to May 2009
> Quinns Beach Dynascan Survey
  - Source: Department of Transport
  - Survey date: October 2014
> Quinns Hydrographic Survey
  - Source: Department of Transport
  - Survey date: October 2014
> Pre-September-Storm Beach Survey
  - Source: Cardno
  - Survey date: September 2014

The navigational charts were used for the coarse wave modelling grid, in the offshore area where LiDAR data was not available. The LiDAR data was used in the finer model domains, from the +5m AHD contour line to the offshore boundaries.

Cardno's Pre-September-Storm Survey was complemented by the Dynascan Survey for the beach area of the model domains. Cardno's Post-September-Storm Survey was subsequently used to validate the sediment transport models. The hydrographic survey, carried out in October 2014, best described the nearshore bed morphology corresponding to when the Pre-September-Storm Beach Survey was taken.

Bathymetric data used in the wave and sediment transport models are shown in **Figure 6-2** and **Figure 6-16**.

6.3 Nearshore wave modelling

6.3.1 Model description

The wave model system applied in this investigation was the SWAN (**S**imulating **WA**ves **N**earshore) model developed at the Delft University of Technology (Booij et al., 1999). The model can provide third generation full spectral solutions and includes wind input, refraction, diffraction, shoaling, bed friction, white capping, wave breaking, the effect of currents and non-linear wave-wave interaction.

It can be applied as a steady-state model for local sea, developed from spatially and temporally variable winds which provides a very reliable basis for generating local sea. The model has been well verified by its authors and is considered to be one of the most reliable systems available at present.

6.3.2 Model setup

6.3.2.1 Model grid

A nested grid approach was adopted in order to enable the transition from ocean scales to coastal scales. A coarse grid, with 1000m x 1000m grid cells, extended from Lancelin to Preston Beach and from the coastline out to the -50m AHD contour line, with the offshore boundary located co-incident with the Rottnest Waverider buoy. This coarse grid allowed remotely generated, measured swell waves to be applied at the offshore boundary using time-series data from this instrument – height, period and direction.

An intermediate grid (medium grid), with 200m grid cells, extended from Two Rocks to Hillarys and from the coastline out to the -30m AHD contour line. This medium grid used boundary conditions that were generated by the coarse grid model area. A fine grid area, with 40m grid cells, extended from 2 kilometres north to 4 kilometres south of the study area and from the coastline out to the -26m AHD contour line. The resolution of the fine grid was sufficient to resolve the complex series of barrier reefs present at Quinns Beach. **Figure 6-1** and **Figure 6-2** depict the grid nesting set up and bathymetry of the fine grid, respectively.

6.3.2.2 Simulation period

The simulation started on 01 October 2004 and ended on 30 September 2014. This simulation period encompassed the wave calibration periods in summer and winter 2014, when metocean data collection was undertaken at two near shore locations, namely Offshore and Inshore. The result from the 10 year simulation was used to model the long term shore line evolution and the near shore wave design criteria. The calibration of the short term erosion models (XBeach and Delft3D) involved the use of wave results during the storm that affected Quinns Beach on 08 September 2014.

6.3.2.3 Boundary conditions

The offshore open boundary of the coarse grid was forced with measured directional swell data obtained from the Rottnest Waverider buoy between 2004 and 2014 and modelled with a JONSWAP spectral shape on the boundary.

Measured water levels from the Fremantle tide gauge were applied to the model to ensure that combined tide and storm surge water levels were represented in the model.

Wind forcing was applied to the model in order to reproduce the sea waves generated within the model domain. Temporally and spatially varying wind maps were generated for the model area from measured wind data recorded around the Perth region.

Wind data from the Bureau of Meteorology's (BoM) stations at Swanbourne, Ocean Reef, Rottnest Island, Garden Island, Mandurah, Bunbury and Lancelin were interpolated onto the coarse grid using an inverse-square weighting approach, whereby the wind u and v components at any given point is the weighted mean of the measured winds. The weights are inversely proportional to the square of the distance from each station. All wind data was 10 minute averages 10 m above ground level.

6.3.2.4 Bed roughness

Experiments carried out on the Kaneohe Bay barrier reef (Oahu, Hawaii) showed that bed friction accounts for the majority of the wave energy dissipation in complex reef environments (Lowe 2005). The Madsen spectral wave friction model was determined to be most applicable to the turbulent wave boundary layer dissipation caused by the hydraulically rough reef systems. The Madsen model was found to have good agreement with the rates of frictional dissipation measured over the reef flats of coral reefs (Lowe, 2005).

Sensitivity testing of the depth dependant breaking coefficient and bed roughness established that the observed wave transformations present in the measured data were primarily the result of bed friction rather than the depth dependant wave breaking coefficient. A depth dependant wave breaking coefficient of 0.73 was utilised in the model. Through the calibration stage, a constant Madsen roughness length scale of 0.42m was developed for the fine grid. JONSWAP friction model with constant roughness coefficient of 0.067 m^2/s^3 was used for the medium and coarse grids. Directional spread specification at the offshore boundary at Rottnest was found to be unimportant.

Through the model calibration process an alternative spatially variable roughness map was developed in order to represent the increased roughness of the shallow limestone reefs. A comparison between the two models is provided in **Appendix D**.

6.3.2.5 Other model parameters

The Westhuysen whitecapping formulation (Westhuysen et al. 2007) was applied to all three domains of the wave model. It is based on the apparent relationship between wave groups and whitecapping dissipation and is deemed to be most appropriate for mixed sea-swell conditions (common during storms) and for shallow water.

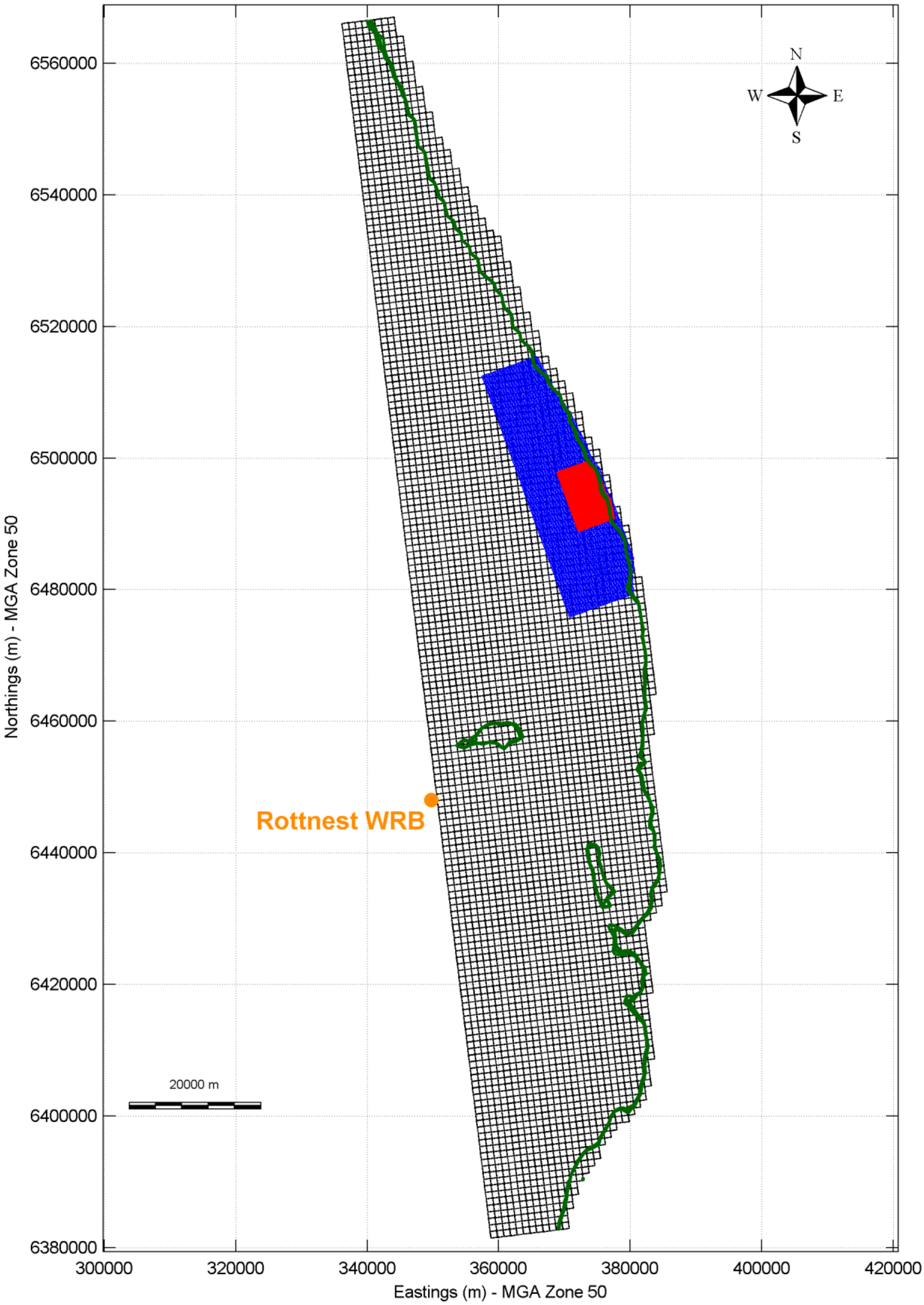

Figure 6-1 Nesting of SWAN grids: Coarse Grid (black), Medium Grid (blue), Fine Grid (red)

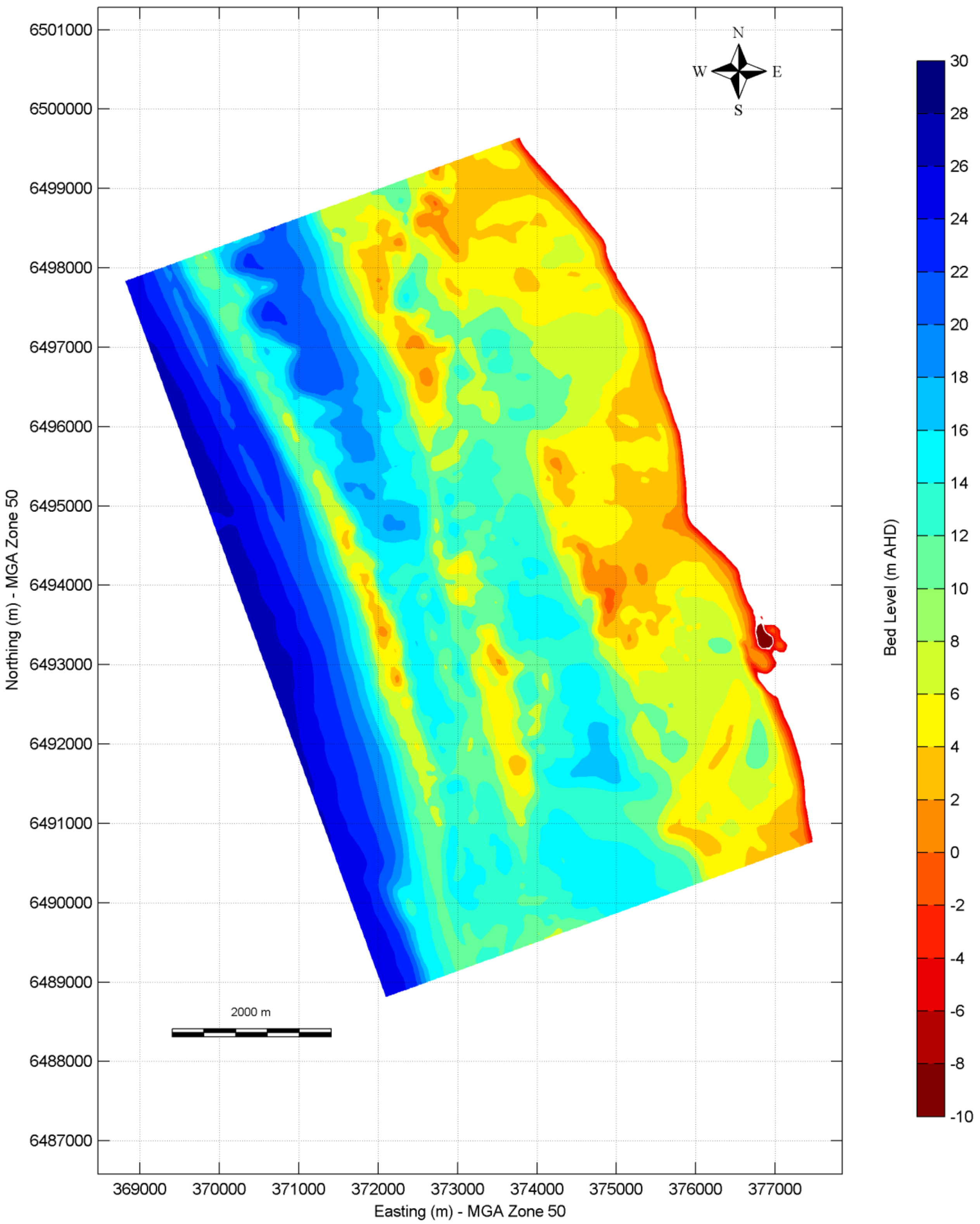

Figure 6-2 Bathymetry used in the nearshore wave model; LiDAR was used from the +5mAHD bed level to the offshore boundary, October 2014 Hydrographic survey was used in the nearshore area and Cardno's Pre-September-Storm Survey complemented by the Dynascan Survey was used for the beach area

6.3.3 Model calibration and validation

The model was calibrated and validated through comparison with wave data recorded at two locations at Quinns Rocks, namely Offshore and Inshore.

Table 6-1 Offshore data collection

Instrument	Longitude	Latitude	Deployment Period	Depth range (mCD)
ADCP	115.6540° E	31.6700° S	22/01/2014 – 24/03/2014 (Summer)	Surface – 12.7
AWAC	115.6552° E	31.6697° S	24/03/2014 – 30/04/2014 (Summer)	Surface – 13.9
AWAC	115.6556 ° E	31.6697 ° S	27/06/2014 – 16/10/2014 (Winter)	Surface – 13.9

Table 6-2 Inshore data collection

Instrument	Longitude	Latitude	Deployment Period	Depth range (mCD)
AWAC	115.6843° E	31.6734° S	22/01/2014 – 18/03/2014 (Summer)	Surface – 5.4
AWAC	115.6846° E	31.6729° S	18/03/2014 – 30/04/2014 (Summer)	Surface – 5.1
AWAC	115.6840° E	31.6731° S	27/06/2014 – 16/10/2014 (Winter)	Surface – 5.2

Model calibration was assessed using the Root Mean Square Error (RMSE) and Model Skill, given by the **Equations 3 and 4**, respectively.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{meas,i} - X_{model,i})^2}{n}} \qquad \text{Equation 3}$$

$$Model\ Skill = 1 - \left[\frac{\sum_{i=1}^{n}(X_{model,i} - X_{meas,i})^2}{\sum_{i=1}^{n}[(X_{model,i} - \overline{X_{meas,i}}) + (X_{meas,i} - \overline{X_{meas,i}})]^2}\right] \qquad \text{Equation 4}$$

For **Equations 3 and 4** X_{meas} is the measured value and X_{model} is the model output. The value for n is the size of the sample data.

Figure 6-3 and **Figure 6-4** show the comparison of the model wave heights with the measured wave heights at the Inshore and Offshore measurement locations for the summer and winter seasons, respectively. The model slightly over-estimates the measured summer wave heights at the Inshore and reproduces the Offshore summer measured wave height well. The winter wave height has a positive bias with increasing wave height (over-estimate) at the Offshore location. At the Inshore location wave heights tended to be slightly underestimated in winter, particularly for the largest wave events where wave heights were under estimated by approximately 0.2 m (up to approximately 15% of the measured wave height).

Table 6-3 presents a summary of model skill assessment statistics. At the Inshore location the model demonstrated a good degree of skill for both summer and winter with a model skill of 0.93 and 0.90 respectively. The root mean squared error of the model at the Inshore location was 0.1 m and 0.15 m for summer and winter respectively. The model at the Offshore location showed a good degree of model skill at the Offshore location of 0.93 for summer and winter, with root mean squared error of 0.22m and 0.29m, respectively.

Table 6-3 Skill assessment statistics for wave height data

	Model Skill	RMSE
Summer Nearshore	0.93	0.10
Winter Nearshore	0.90	0.15
Summer Offshore	0.93	0.22
Winter Offshore	0.93	0.29

The wave model performance was further analysed through time series and wave rose plots. **Figure 6-5** and **Figure 6-6** present modelled versus measured time series comparisons for the summer and winter calibration periods (February and September) at the Offshore location. The model reproduces the summer measured wave height, direction and period very well. The modelled winter wave direction at the Offshore location is more northerly than the measured data and mean wave period somewhat longer from time to time. **Figure 6-7** and **Figure 6-8** present comparison wave rose plots, for the complete summer and winter data collection periods at the Offshore location. The distribution of the measured wave directions was reasonably well replicated in the model for the Offshore location in summer. In winter the model predicted an increased proportion of large waves from the west. As noted in **Section 4.7.3**, there is some doubt around the accuracy of the measured wave direction. The second winter deployment, which commenced on 12 August 2014, included an approximate 20^{o} southward shift in mean wave direction, which covered the September period which recorded the largest waves. To further validate the numerical model, a comparison was made between the numerical model and some wave rider buoy data collected by Cardno at Alkimos in 2010 approximately the same distance offshore (**Figure 6-9**). It is seen that the agreement in wave direction is improved when compared to the wave rider buoy.

Figure 6-10 and **Figure 6-11** present a modelled versus measured time series comparison for the summer and winter calibration periods (February and September) at the Inshore location. The model overestimates the summer measured wave height (by approximately 20%), predicts somewhat more southerly wave direction and reproduces the wave period well at the Inshore location. The model has no overall bias in the winter measured wave height, predicts somewhat more northerly wave direction and mean wave period somewhat longer from time to time. **Figure 6-12** and **Figure 6-13** present comparison wave rose plots, for the complete summer and winter data collection periods at the Inshore location. The model results are somewhat more southerly compared to the measured data at the inshore location in summer and somewhat more northerly in winter.

Given the uncertainty and variability present in both the measured and modelled data, the wave model is considered to adequately reproduce the wave conditions at Quinns Beach. The modelled wave conditions play a critical role in driving the sediment transport processes and the outputs of the wave model are used as boundary conditions to the storm erosion and shoreline evolution models presented in **Section 6.4** and **Section 6.5**.

Through the model calibration process an alternative spatially variable wave roughness description was investigated as a mechanism to represent the increased roughness of the reef areas. Whilst model calibration metrics were broadly comparable at the two calibration locations, each schematisation produced significantly different peak storm wave heights in the nearshore adjacent to Sections 5 and 6 of the study area. To establish which schematisation is best overall would require additional wave data or direct estimates of the wave roughness across the various bed types in the study area. Additional details are provided in **Appendix D**.

Whilst significant effort has been taken to ensure the modelled wave conditions are as accurate as possible, the limitations of the wave model and measured data uncertainty can affect the accuracy of wave design criteria and modelled sediment transport rates. Whilst inaccuracies in the wave model are somewhat corrected through the subsequent sediment transport model calibration, the outcomes of the study must make due consideration to the inherent uncertainty associated with modelling complex nearshore processes.

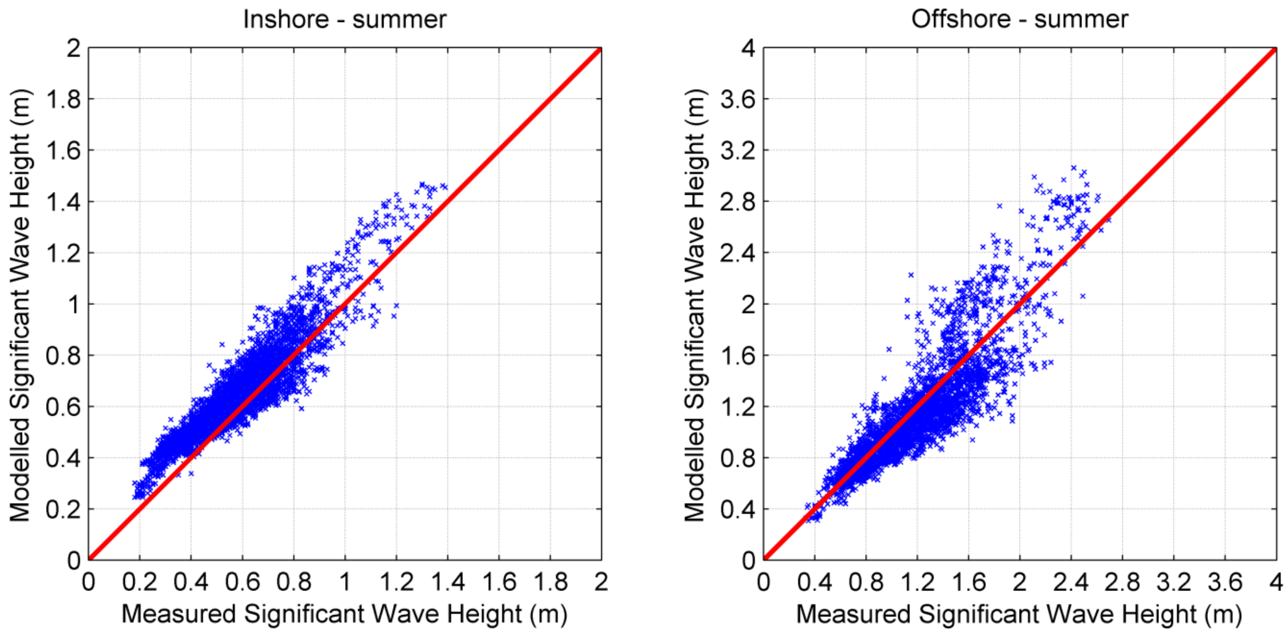

Figure 6-3 Comparison between modelled and measured wave heights for the summer period

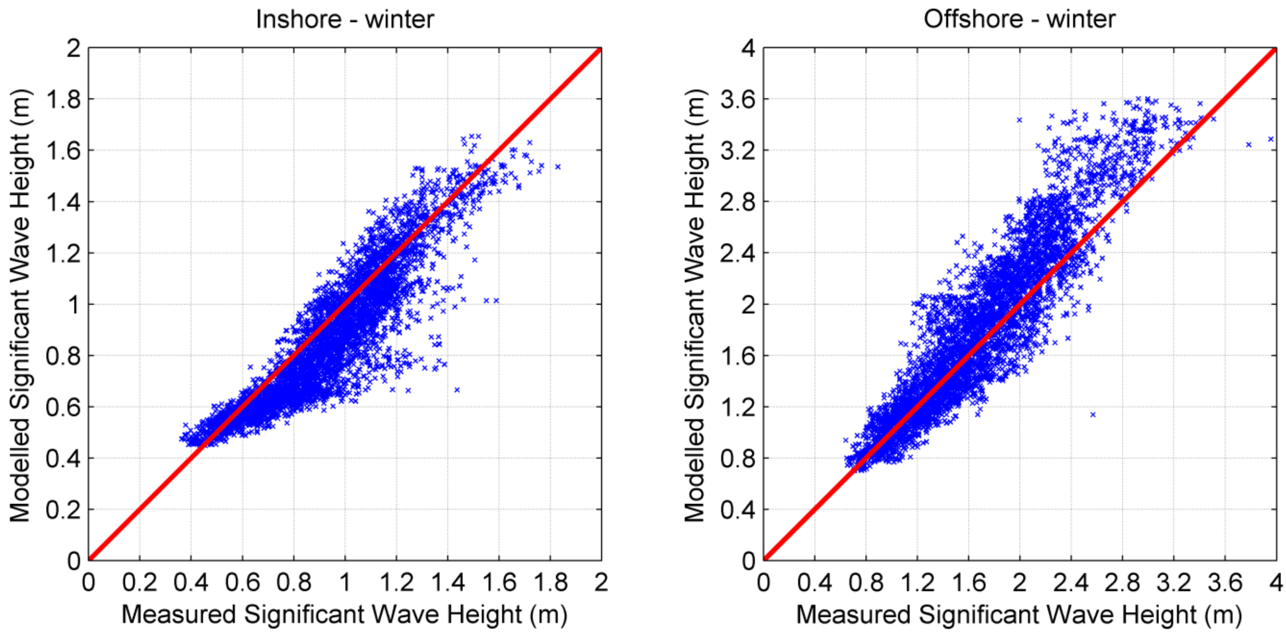

Figure 6-4 Comparison between modelled and measured wave heights for the winter period

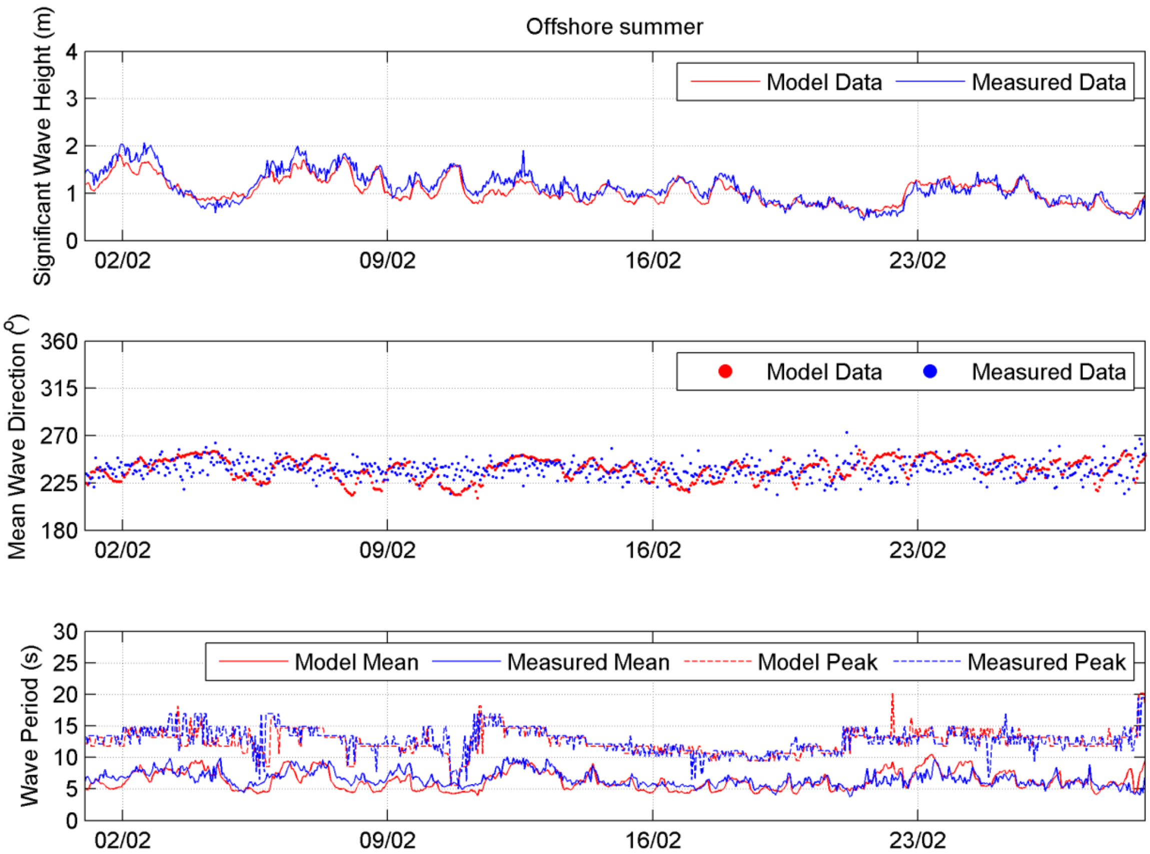

Figure 6-5 Timeseries plot of the modelled and measured wave data at the offshore ADCP location for the February 2014 period

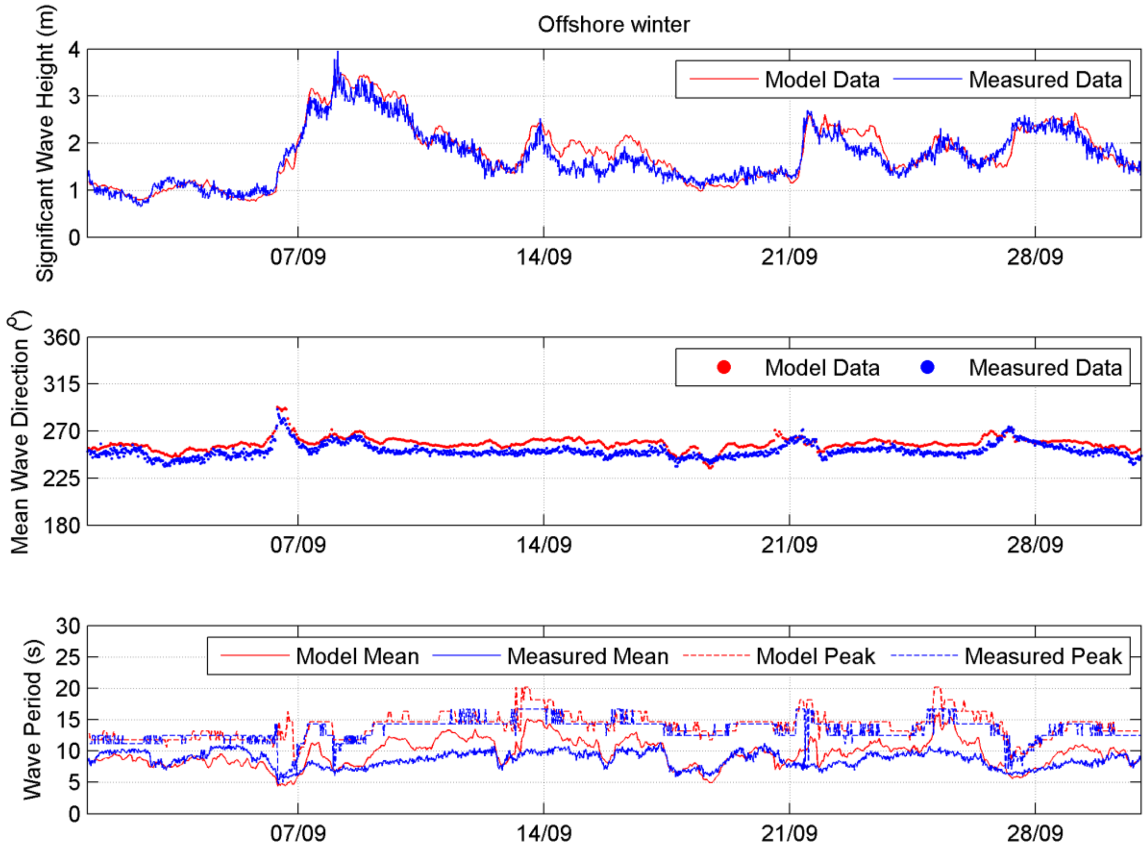

Figure 6-6 Timeseries plot of the modelled and measured wave data at the Offshore AWAC location for the September 2014 period

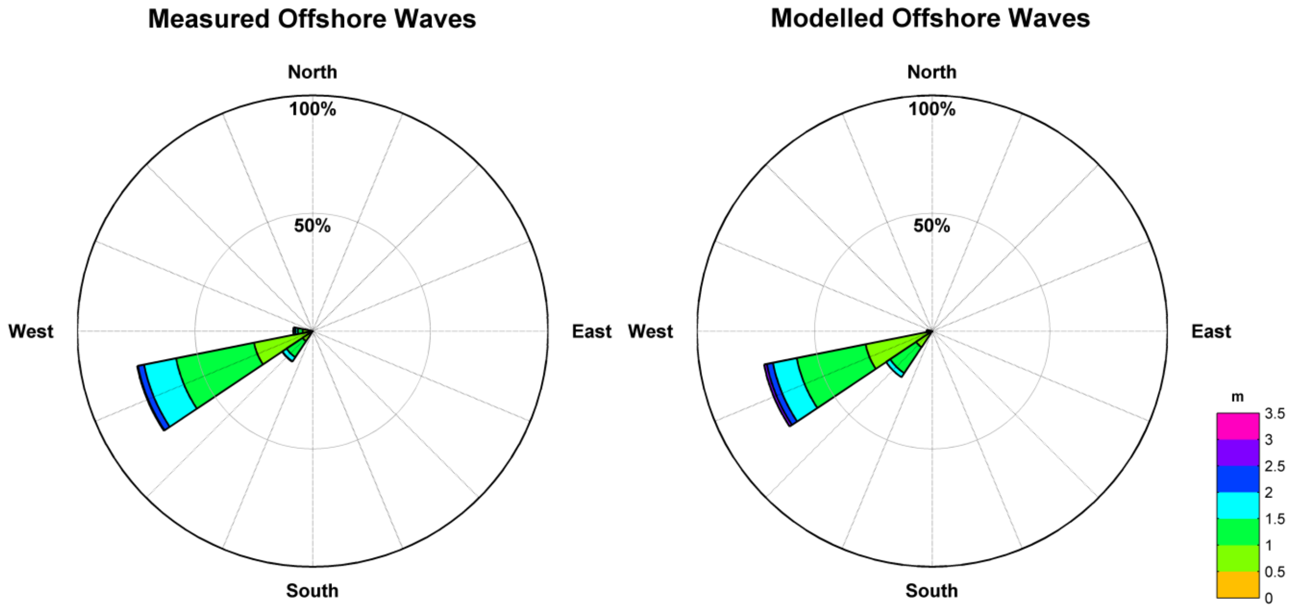

Figure 6-7 Wave rose plots of the measured and modelled wave height (in metres) and wave direction for the summer data collection period at the Offshore AWAC location

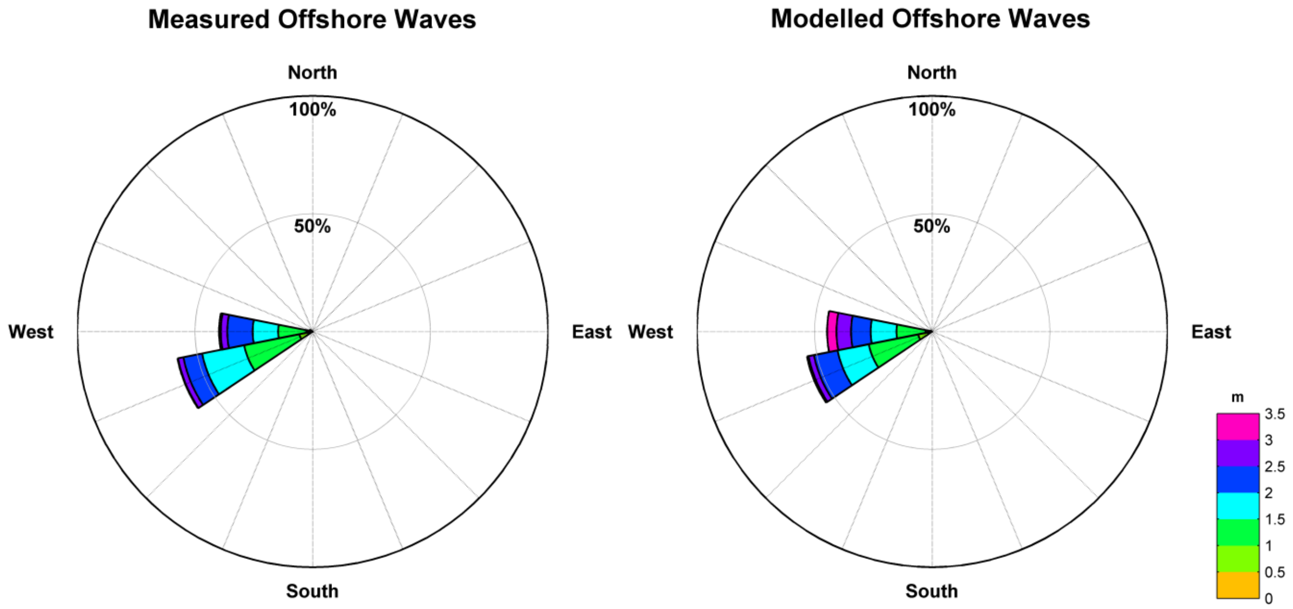

Figure 6-8 Wave rose plots of the measured and modelled wave height (in metres) and wave direction for the winter data collection period at the Offshore AWAC location

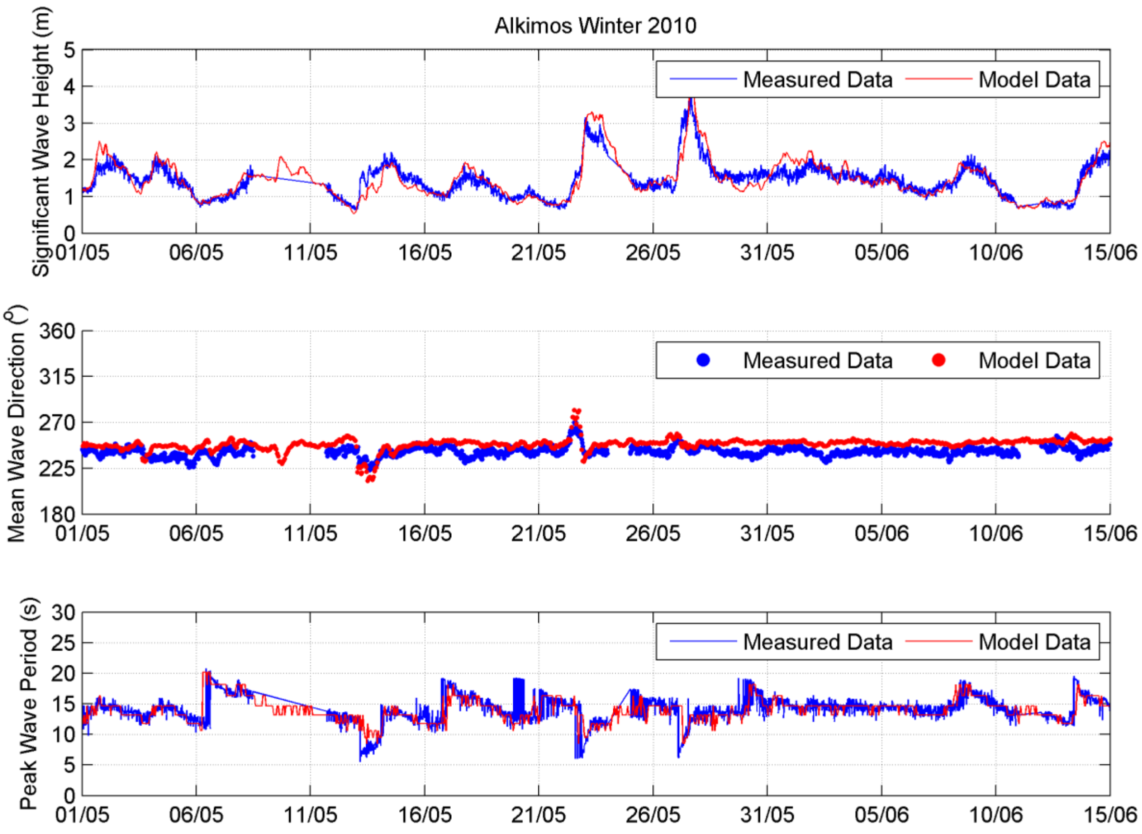

Figure 6-9 Timeseries plot of modelled and measured wave data at the Alkimos wave rider buoy in winter 2010

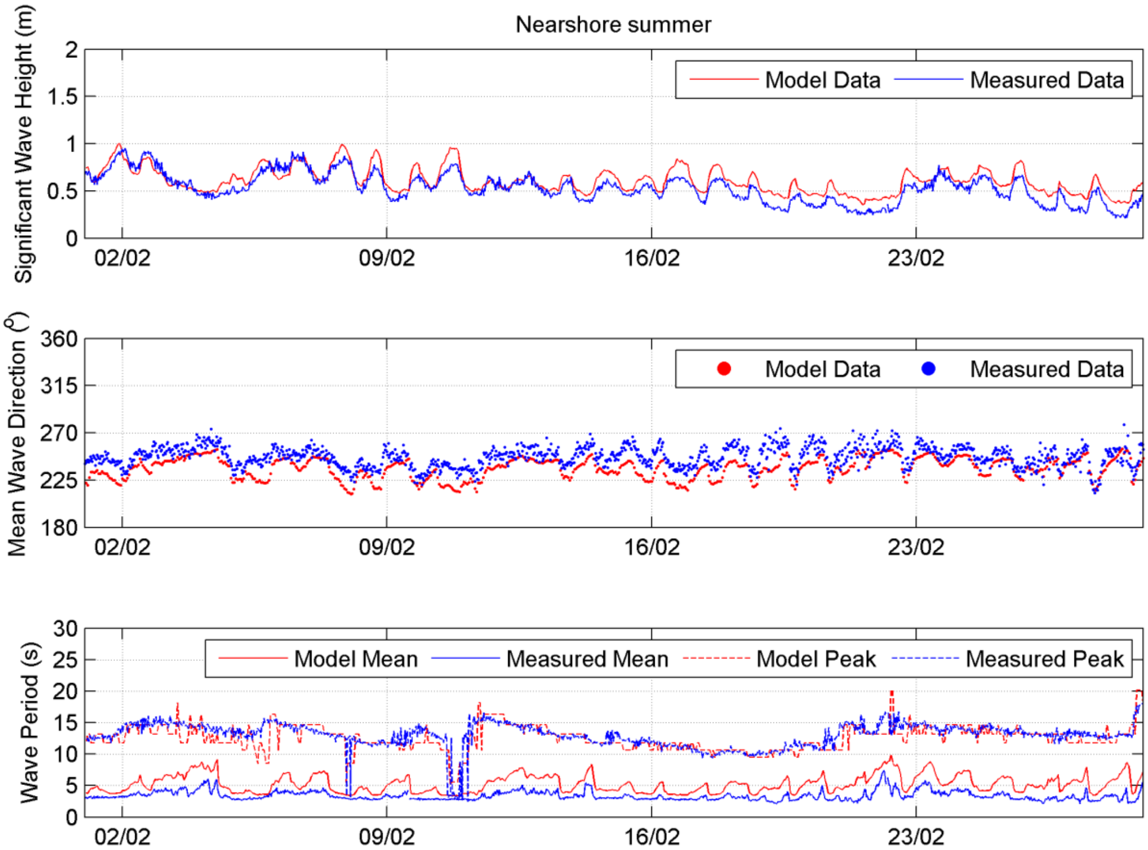

Figure 6-10 Timeseries plot of modelled and measured wave data at the Inshore AWAC location for the February 2014 period

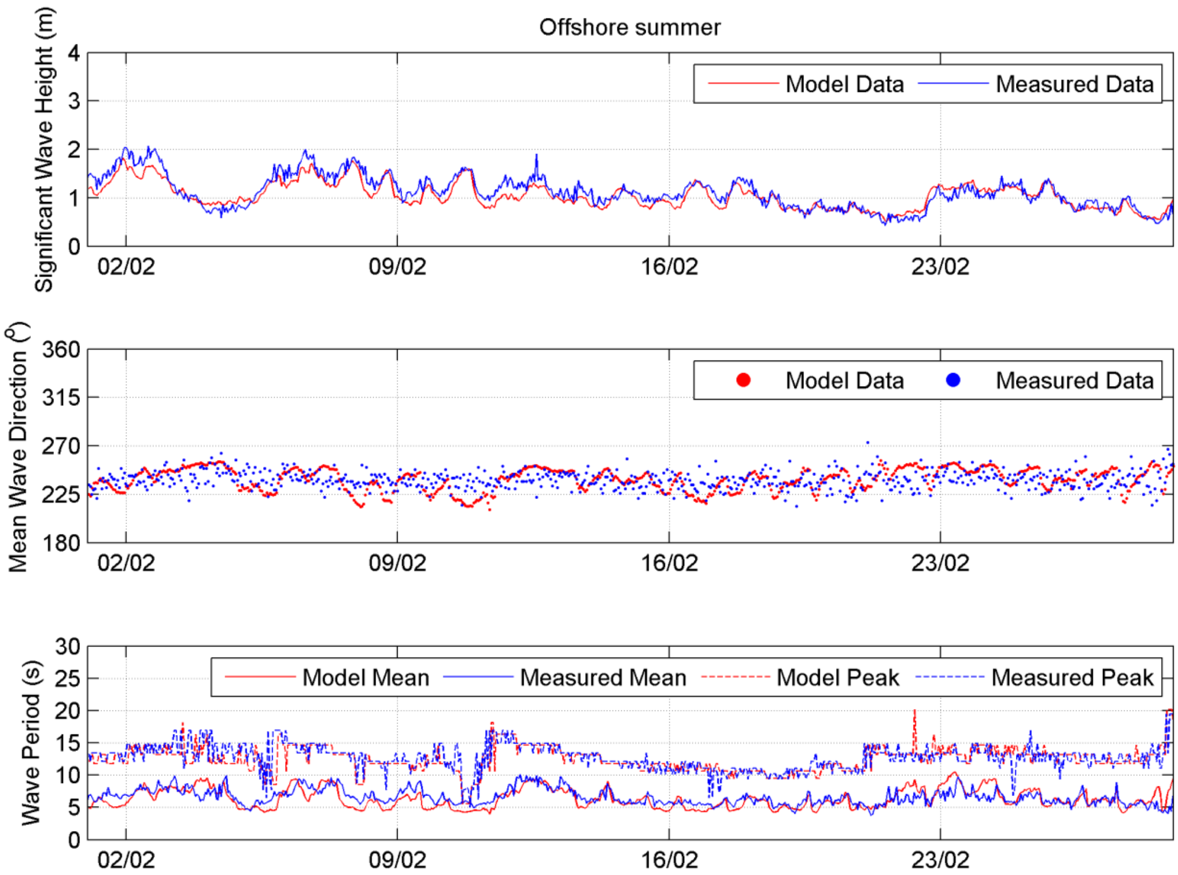

Figure 6-11 Timeseries plot of the modelled and measured wave data at the Inshore AWAC location for the September 2014 period

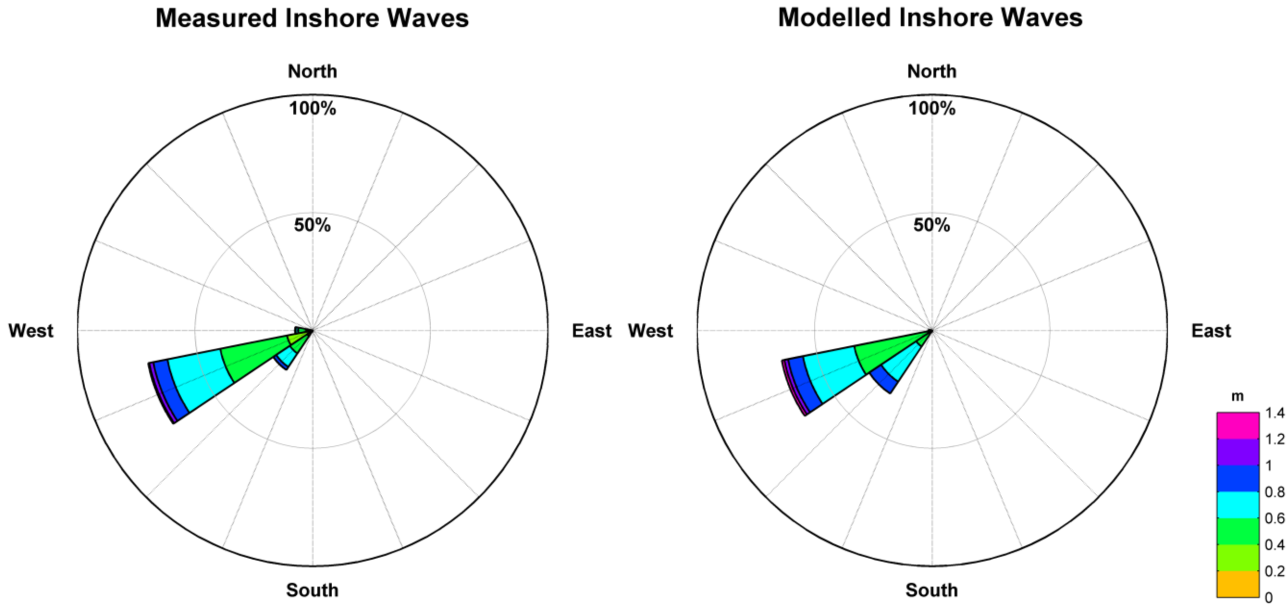

Figure 6-12 Wave rose plots of the measured and modelled wave height (in metres) and wave direction for the summer data collection period at the Inshore AWAC location

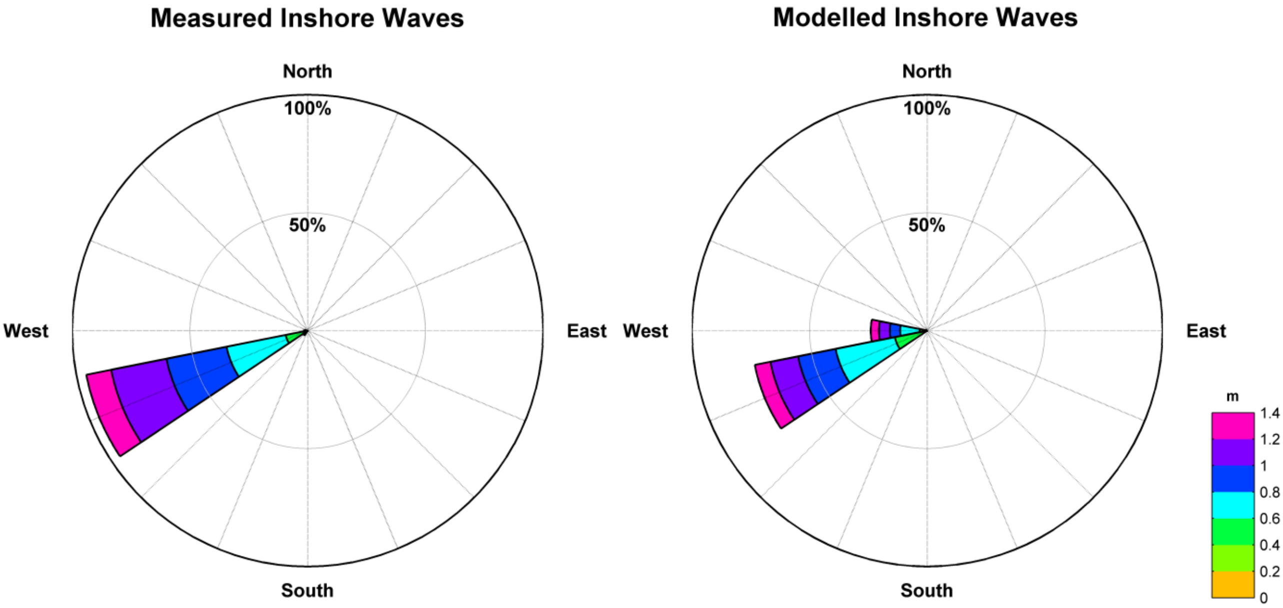

Figure 6-13 Wave rose plots of the measured and modelled wave height (in metres) and wave direction for the winter data collection period at the Inshore AWAC location

6.3.4 Near shore design wave conditions

Consistent with the scope of works for this phase of the study, an estimate of the nearshore design wave conditions has been obtained from the 10 year wave hindcast. The energy weighted mean wave direction was calculated from the wave hindcast model results at 15 locations for summer and winter over the whole data record. This data is plotted in **Figure 6-14**. The seasonal variation in direction varies throughout the study area. As expected, the waves have a greater southerly component for the summer and a northerly component for the winter – waves coming from. The greatest deviation in seasonal mean weighted wave direction occurs in the proximity of the cuspate foreland, however it should be noted that the SWAN model does not reproduce the diffraction of wave energy around reefs well.

The depth of closure was calculated using the method of Hallermeier (1980) and is presented alongside the energy weighted mean wave direction in **Table 6-4.** The wave height exceeded for 12 hours per year was calculated and the average period for these waves used to calculate the closure depth. Various other statistical methods for calculating closure depth were also investigated with similar (albeit slightly shallower) results. It should be noted that the closure depth is a statistical estimate of the nominal limit of the shoreface, it does not suggest that wave driven sediment transport does not occur below this depth. Visual inspection of measured bathymetry in conjunction with aerial photography demonstrates that -3 m AHD is the approximate level where the bottom form changes from sand to either reef or seagrass/macro algae.

The 5, 10, 20, 50 and 100-years nearshore design wave criteria are presented in **Table 6-5.** Design wave heights are estimated by fitting the top 30 independent wave events at each location to the Weibull Distribution using a maximum likelihood method (Goda, 2000). A peak over threshold approach was tested for a range of thresholds, with goodness of fit measures and number of events varying significantly between locations due to variability in the near shore wave climates. Visual inspection of the Rottnest deep water wave buoy data suggested that rate of occurrence of potential design events is 3 per year on average. This corresponds to a peak over threshold of approximately 0.8.

It is likely that ten years of data is of insufficient record length to extrapolate to the 100 years condition. However it should be noted that the influence of wave breaking and dissipation over the reefs is significant, resulting in limited increases in nearshore wave height with increasing offshore wave height. It is recommended during detailed design that design wave criteria for Rottnest are assessed and applied to the calibrated wave model to confirm nearshore design wave criteria for ARI greater than 20 years.

In addition during model calibration, significant sensitivity in the modelled nearshore wave heights was demonstrated for sites 9 through 12, with the current model setup potentially underestimating nearshore wave heights by up to 50% depending on how wave dissipation over the reefs is schematised (with equally good calibration at the existing measured data locations). Additional data collection is recommended in this area.

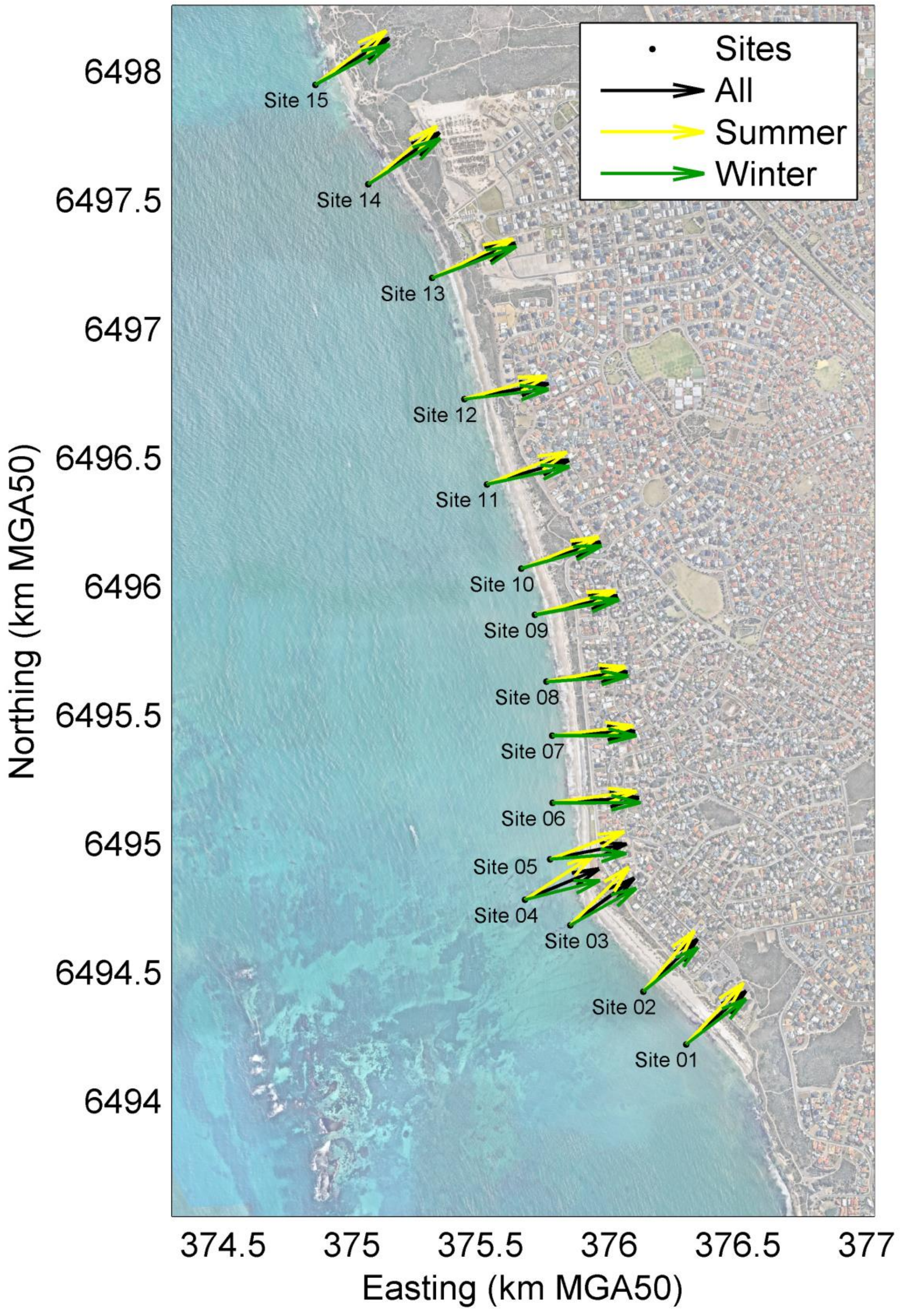

Figure 6-14 The 15 SWAN model output locations and the modelled mean weighted wave direction for summer, winter, and annual conditions

Table 6-4 Mean weighted wave direction from the 2004-2014 hindcast and the statistical closure depth (based on Hallermeier, 1980) in metres below AHD

Model Output Locations	Summer Mean Weighted Wave Direction (°)	Winter Mean Weighted Wave Direction (°)	Annual Mean Weighted Wave Direction (°)	Depth of Closure (m)
1	223.0	232.6	228.1	2.3
2	220.1	231.1	225.9	2.1
3	225.2	240.6	233.6	2.4
4	236.9	255.6	247.3	2.4
5	249.7	265.7	258.8	2.5
6	262.1	269.8	266.6	3.0
7	263.1	270.0	267.1	2.9
8	259.4	266.1	263.2	2.7
9	253.4	259.7	257.0	2.9
10	247.7	254.1	251.3	2.7
11	248.3	257.7	253.6	2.7
12	254.6	263.3	259.6	2.7
13	244.0	249.5	247.2	2.9
14	229.6	237.4	233.9	2.7
15	232.6	241.4	237.5	2.6

Table 6-5 Near shore design wave heights and upper 95% confidence limits (in brackets)

Model Output Locations	Location Bed Level	Design Significant Wave Height (m) per ARI (years)				
	(m AHD)	5	10	20	50	100
1	4.0	1.4 (1.5)	1.5 (1.5)	1.5 (1.6)	1.6 (1.6)	1.6 (1.7)
2	3.8	1.5 (1.6)	1.6 (1.6)	1.6 (1.7)	1.7 (1.8)	1.7 (1.8)
3	3.6	1.5 (1.6)	1.6 (1.6)	1.6 (1.7)	1.7 (1.8)	1.7 (1.8)
4	3.7	1.6 (1.6)	1.6 (1.7)	1.7 (1.7)	1.7 (1.8)	1.8 (1.9)
5	3.6	1.5 (1.6)	1.5 (1.6)	1.6 (1.6)	1.6 (1.7)	1.7 (1.8)
6	3.3	1.5 (1.5)	1.5 (1.6)	1.5 (1.6)	1.6 (1.7)	1.6 (1.7)
7	3.1	1.3 (1.4)	1.4 (1.4)	1.4 (1.5)	1.5 (1.5)	1.5 (1.6)
8	3.2	1.3 (1.4)	1.4 (1.4)	1.4 (1.5)	1.5 (1.5)	1.5 (1.6)
9*	3.5	1.2 (1.3)	1.3 (1.3)	1.3 (1.4)	1.4 (1.4)	1.4 (1.5)
10*	2.9	1.3 (1.4)	1.4 (1.4)	1.4 (1.5)	1.5 (1.5)	1.5 (1.6)
11*	3.6	1.4 (1.4)	1.4 (1.5)	1.5 (1.5)	1.5 (1.6)	1.6 (1.7)
12*	3.4	1.4 (1.5)	1.4 (1.5)	1.5 (1.6)	1.5 (1.6)	1.6 (1.7)
13	3.3	1.6 (1.7)	1.7 (1.7)	1.7 (1.8)	1.8 (1.8)	1.8 (1.9)
14	4.1	1.5 (1.6)	1.6 (1.7)	1.6 (1.7)	1.7 (1.8)	1.7 (1.8)
15	3.6	1.5 (1.5)	1.5 (1.6)	1.6 (1.6)	1.6 (1.7)	1.7 (1.8)

*Note Model displays significant sensitivity to schematisation of wave dissipation at these locations. Design wave heights may vary by up to 50%

6.4 Storm erosion modelling

6.4.1 Summary of model selection process

Cardno modelled the short term changes due to a storm using the Delft3D and XBeach models. The performance of each model was assessed in order to determine which model was most suited for subsequent stages of the project. Each model was setup to simulate the observed beach morphological changes that occurred between 4 September 2014 and 11 September 2014 due to a storm that impacted the study area on 8 September 2014.

Equivalent wave, water level and wind boundary conditions were applied to each of the model systems for the week long simulation and the modelled currents and beach morphological changes compared to the measured data.

Overall the XBeach model reproduced the beach morphological changes considerably better, both qualitatively and quantitatively compared to the Delft3D model and the XBeach model was selected for further investigations. Additional details can be found in **Appendix C**.

6.4.2 Model description

XBeach is a 2D morphological model developed specifically to assess the time varying response of coastlines to storm and tropical cyclone conditions. It has specific formulations for dune erosion, overwash and breaching. Differing to Delft3D, XBeach does not model the short waves directly, rather it uses the results of SWAN to calculate and apply a non-stationary (time varying) long wave boundary condition to the model and then solves the propagation of the short wave envelope, non-stationary shallow water equations, sediment transport and morphology (Roelvink et al, 2009). Avalanching is used to model dune erosion and cross-shore transport is calculated specifically from a balance of onshore transport by wave skewness and asymmetry and offshore transport by return flow. Whilst XBeach includes the influence of wind on the hydrodynamics, it does not include the processes associated with wave growth within the model domain.

6.4.3 Model setup

6.4.3.1 Model grid and bathymetry

A curvilinear grid was designed to follow the coastline, with local grid refinement through the study area and adjacent to the shoreline. The grid extended offshore to a depth of -27 m AHD approximately 6km offshore. The grid covered approximately 13 kilometres in the longshore direction with the model domain extended 3.8 kilometres north and 4.8 kilometres south of the study area.

The grid had a fine resolution along the beach and within the nearshore area in order to resolve the morphological processes along the beaches in the study area. The grid resolution of 4 metre cross-shore and 15 metres alongshore enabled a reasonable representation of the non-erodible structures which impact on the sediment transport: the groynes, the revetment, the headland and the limestone cliffs. Resolution gradually diminished to approximately 140 metres at the model boundaries.

Model bathymetry was developed from the following datasets: LiDAR was used from the 5mAHD depth to the offshore boundary, October 2014 Hydrographic survey was used in the nearshore area and Cardno's Pre-September-Storm Survey complemented by the Dynascan Survey was used for the beach area.

6.4.3.2 Simulation period and timestep

The simulation period started on 04 September 2014 and ended on 11 September 2014. The period, which involved a storm, that affected Quinns Beach on 08 September 2014, would enable short term erosion changes to be observed in the study area. Cardno carried out beach surveys before and after the storm. The measured changes due to the storm have been used to calibrate and validate the numerical models.

The time step in XBeach is determined automatically based on a Courant number criterion. For all XBeach simulations a Courant Number of 0.7 was specified. The Courant Number is given by the following equation (Deltares 2011):

$$\text{Courant Number} = (\Delta t \sqrt{gH})/(\{\Delta x,\Delta y\}) \qquad \text{Equation 5}$$

Where Δt is the time step, g is the acceleration of gravity, H is the water depth and $\{\Delta x, \Delta y\}$ is the minimal value of the grid spacing in either direction.

6.4.3.3 Boundary conditions

Flow Boundary Conditions

The model was bound by 3 open boundaries: West, North and South boundary.

The West offshore boundary consisted of time series of measured water level data from the Fremantle tide gauge. A Neumann boundary condition was applied on the North and South boundaries. This boundary condition allows the specification of a 'zero gradient' boundary condition, allowing wind and wave driven currents to flow freely into or out of the domain.

Wave Boundary Conditions

Spatially and temporally varying 2D spectral boundary conditions from the SWAN model were applied to the XBeach model at the model boundaries (offshore and lateral).

Wind Boundary conditions

Spatially constant and temporally varying wind data was applied to the XBeach model (**Figure 6-15**). The wind data at the study area was interpolated using the measured wind data at Swanbourne, Ocean Reef, Rottnest Island, Garden Island, Mandurah, Bunbury and Lancelin as described in **Section 6.3.2.3**.

6.4.3.4 Flow bed friction

The bed friction was defined by the constant Chezy coefficient of 55 $m^{1/2}/s$.

6.4.3.5 Wave breaking and dissipation

The wave breaking model of Roelvink, (1993) (*break=roelvink1*) was utilised in the model with a gamma factor of 0.55. Wave dissipation by bottom friction is modelled using a friction coefficient and model calibration resulted in a friction coefficient of 0.15.

6.4.3.6 Sediment description

The Van Thiel-Van Rijn sediment transport equations were applied in XBeach (van Rijn, 2007; van Thiel de Vries, 2009). The XBeach model used an initial sediment thickness map shown in **Figure 6-17**. No initial sediment was applied offshore of approximately the -5 mAHD contour level. Sediment transport in the offshore region is not relevant at the time scale of an individual storm; the sediment transport models were therefore limited to changes on the beach and out to the depth of closure. The non-erodible limestone cliffs along Sections 5 and 6, the groynes, the headland, the GSC revetment and the Mindarie Marina did not contribute to the sediment budget and therefore had zero metres of sediment. For the area from the beach to the closure depth (about -5mAHD), a constant thickness of 5 metres was added to the bed level so as to mimic the equilibrium beach profile; there was no sediment at closure depth (-5mAHD + 5 metres) while the beach, at an elevation of 3mAHD for example, had 8 metres of sediment. It should be noted that the nearshore reefs of Sections 5 and 6 were not schematised in the model. That is whilst the bed level included the reefs, their spatial description in the sediment thickness map was not able to be included due to limited detailed information on their location, extent and depth above (and below) the seabed.

A D_{50} grain size of 340 µm and D_{90} grain size of 500 µm was used in the XBeach model. This is based on sediment sampling detailed in **Section 4.4**.

6.4.3.7 Morphological parameter sensitivity analysis

A sensitivity analysis was performed on numerous parameters in the XBeach model that control the sediment transport and morphology. The greatest sensitivity was demonstrated by the facSk and facAs parameters which are calibration parameters that control the magnitude of onshore transport due to wave skewness and asymmetry respectively. Whilst these parameters can be adjusted independently in this study both were adjusted simultaneously with a final value of 0.3 selected for each. A summary of model parameters adjusted from their default values are:

- Onshore transport due to wave skewness (facSk) = 0.3
- Onshore transport due to wave asymmetry (facAs) = 0.3
- Wet area critical slope for avalanching (wetslp) = 0.2
- Wave bed friction coefficient (fw) = 0.15

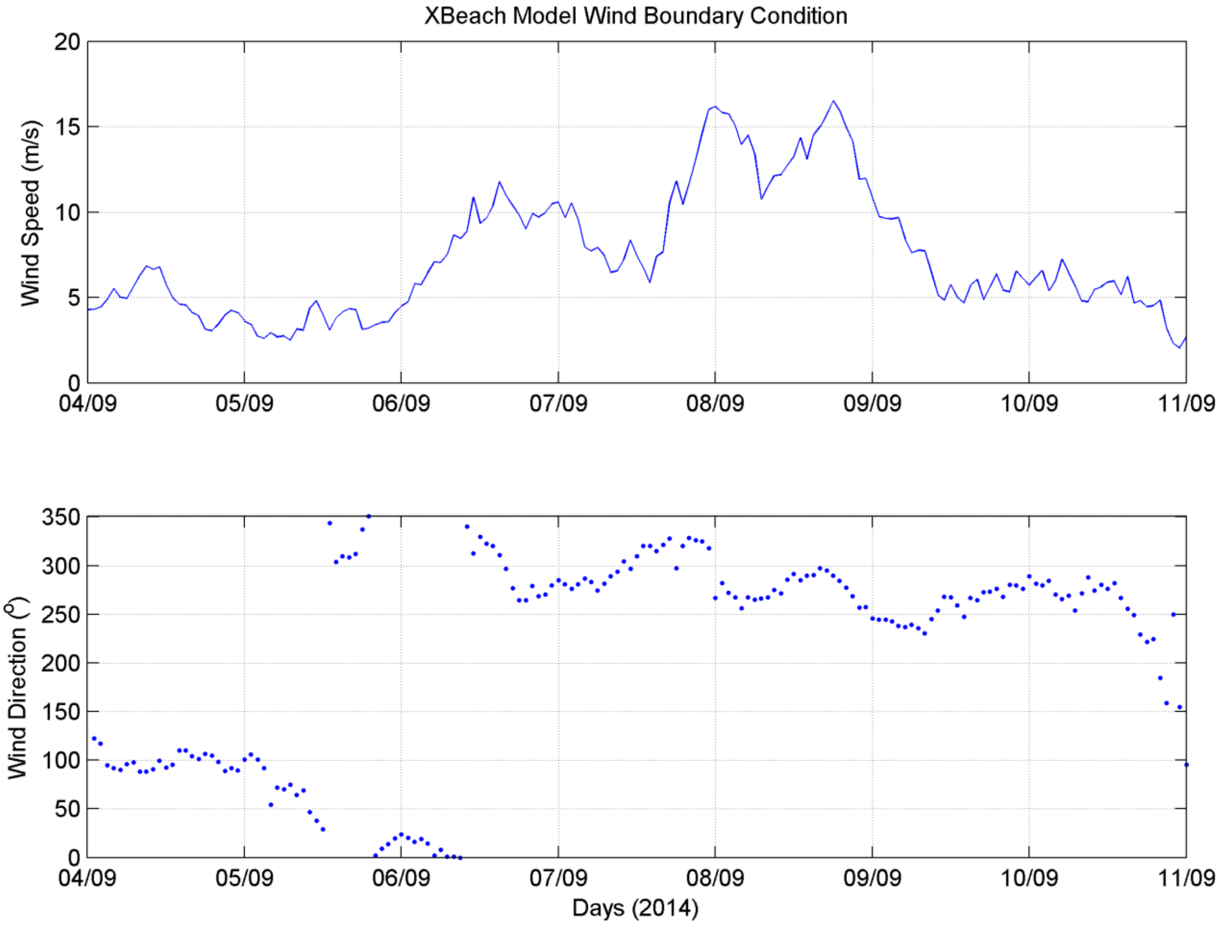

Figure 6-15 Wind boundary condition applied to the XBeach model for the storm on 8 September 2014.

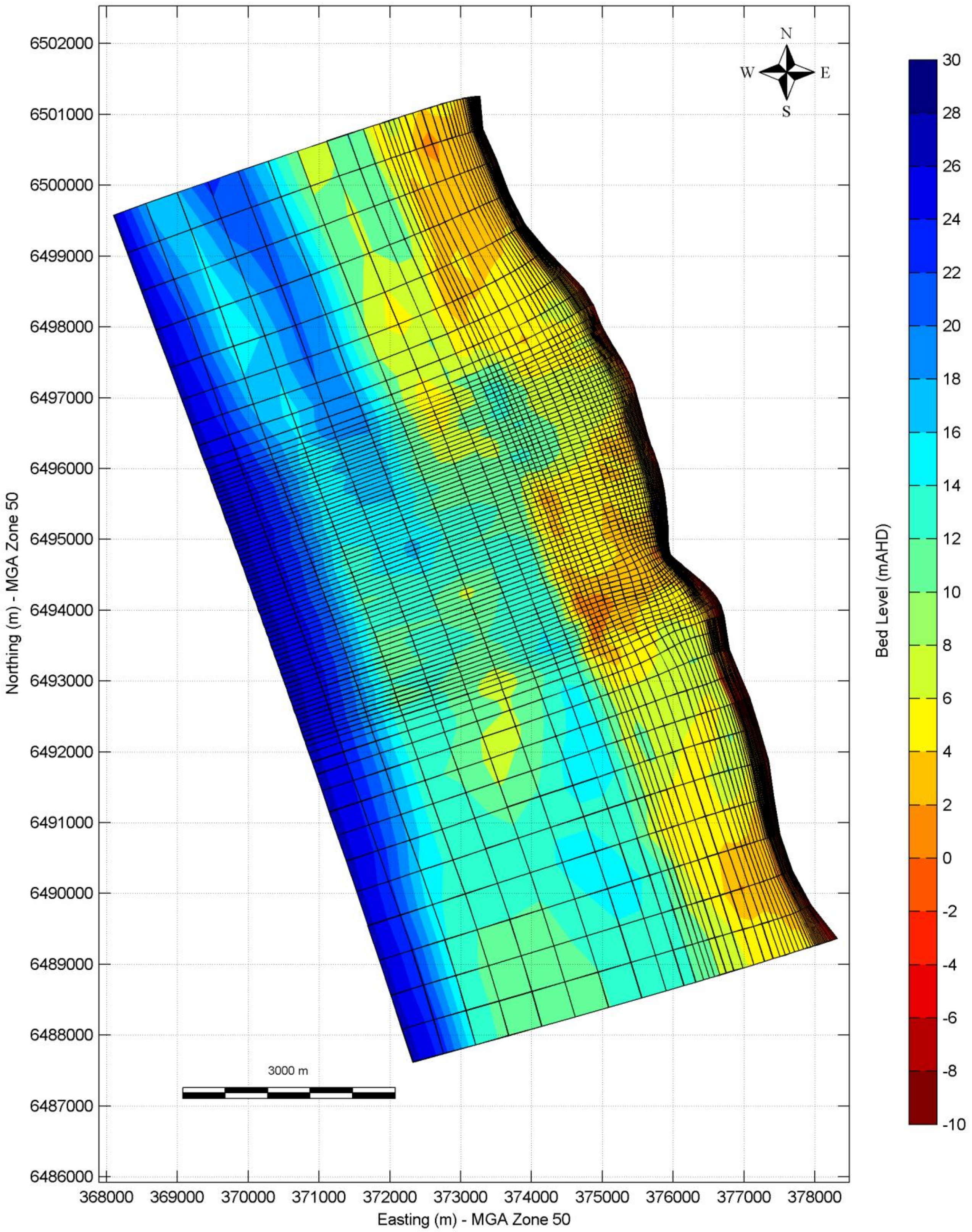

Figure 6-16 The grid set up and bathymetry used in the XBeach model. Note that for display purposes the grid has been de-refined by a factor of 4, i.e. 4 grid cells are represented by 1 grid cell.

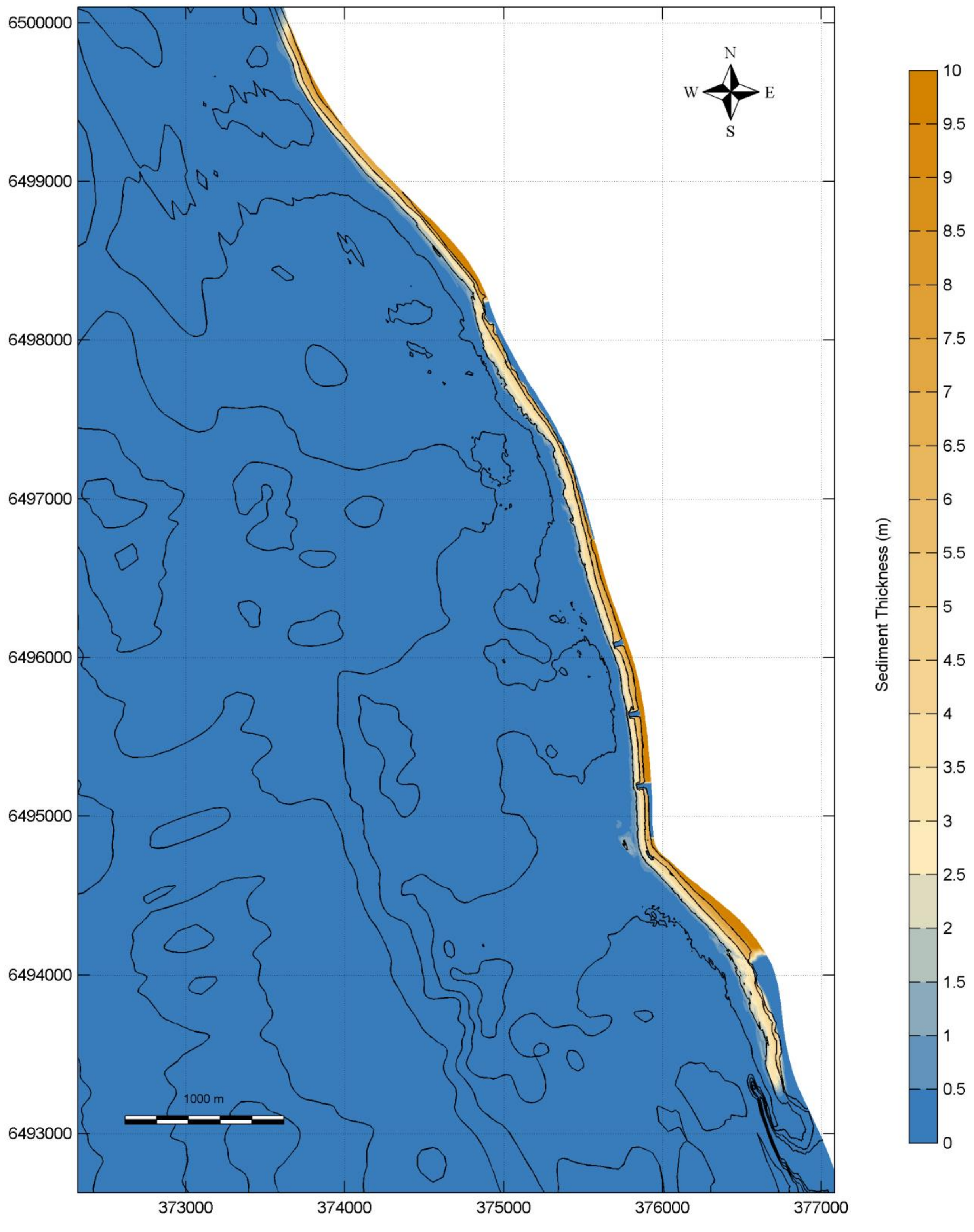

Figure 6-17 Initial sediment thickness used in the XBeach model.

6.4.4 Modelled Waves

Figure 6-18 presents the measured and modelled wave heights for the Inshore (top) and Offshore (bottom) measurement locations. The calibrated XBeach model reproduces the observed wave heights during the storm well.

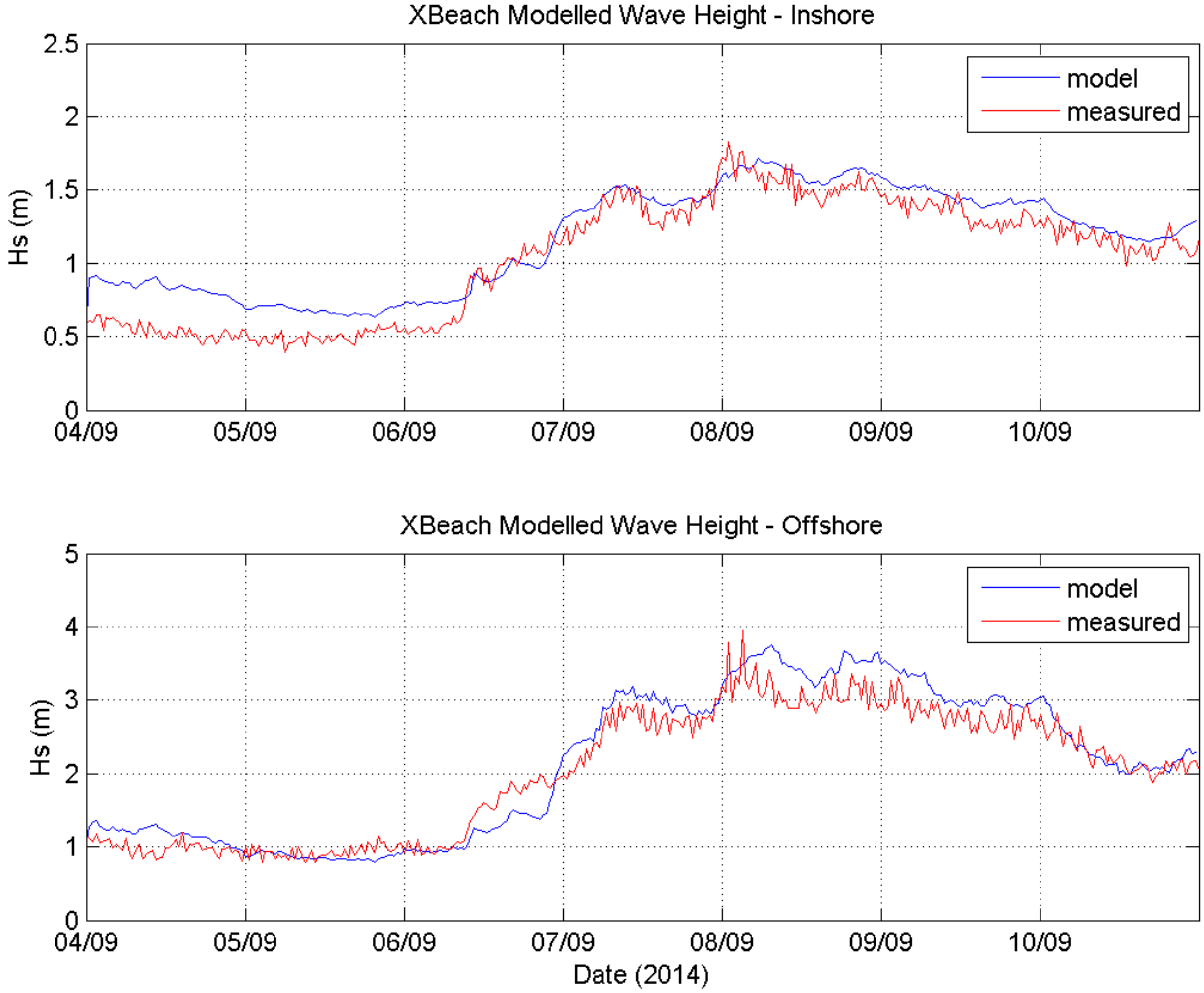

Figure 6-18 Measured and modelled significant wave height at the Inshore (top) and Offshore (bottom) measurement locations

6.4.5 Modelled Currents

Figure 6-19 and **Figure 6-20** present the time series plots of the modelled and measured current at the Inshore and Offshore AWAC locations respectively. The XBeach model is able to reproduce the measured currents at the Inshore location reasonably well. It appears to take approximately 18 hours for the model to warm up with modelled and measured agreement commencing around midday on 5th September 2014. The XBeach model reproduces the measured currents across the peak of the storm at the Inshore location very well through until 9 September 2014, which coincides with a reduction in applied wind speed. Throughout the simulation the strong currents driven by wave setup on Quinns Rocks are directed south of the cuspate foreland, however when the southward winds stress is reduced a component is deflected north which is not present in the measured data. Similarly the XBeach model reproduces the measured currents at the offshore location well through until 8 September 2014. The Offshore location is sensitive to a 'jet' like region of offshore flow in a gap in the Marmion Reef Ridge, if the modelled location of this jet is offset the measured currents at the Offshore location can vary significantly (**Figure 6-21**). The magnitude of the currents within the jet agrees well with the measured current magnitude. Overall the measured currents are reproduced very well by the XBeach model. **Figure 6-22** presents example vector fields of the depth averaged mean littoral drift current at 3:00 AM on 8 September 2014 for a relatively straight area of Section 5 and around Groyne 1. This demonstrates the resolution of the model and its ability to model shoreface currents and the effects of coastal structures on the current field. In addition the modelled currents agree well with anecdotal evidence provided through community consultation.

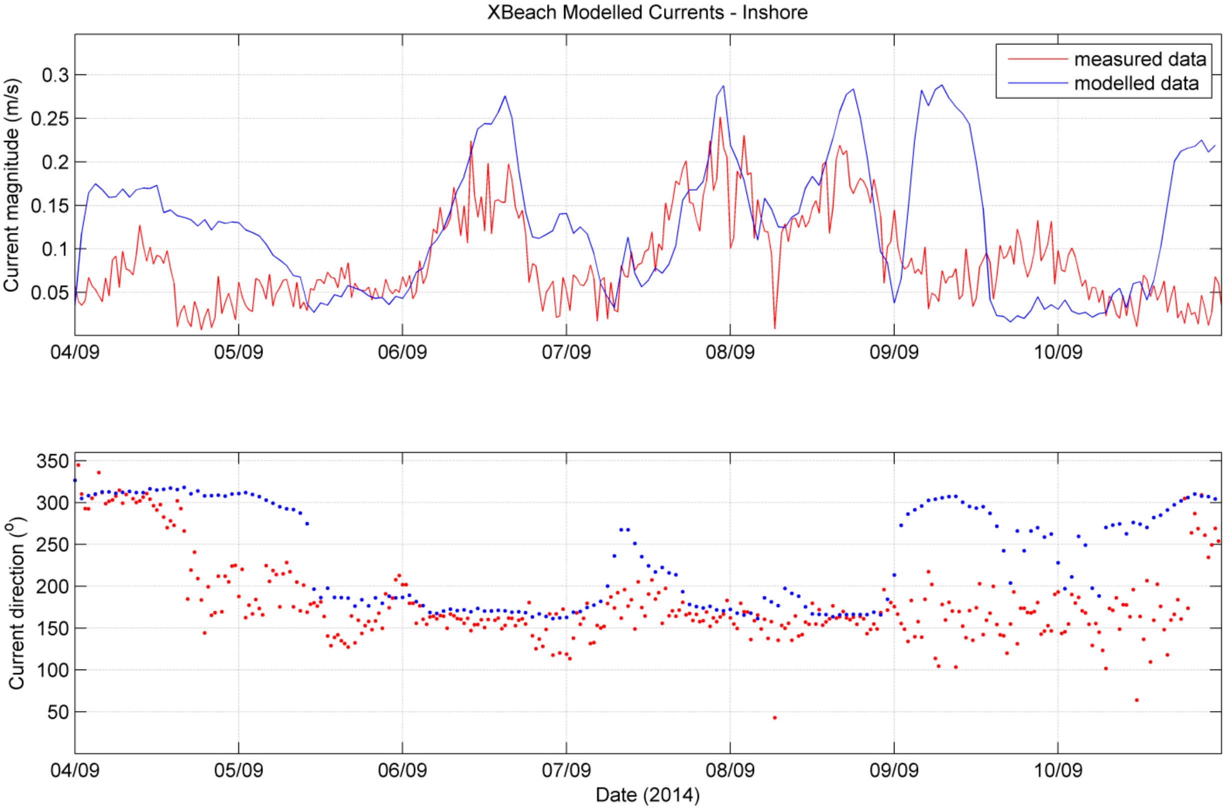

Figure 6-19 Measured and modelled depth average current data at the Inshore AWAC location

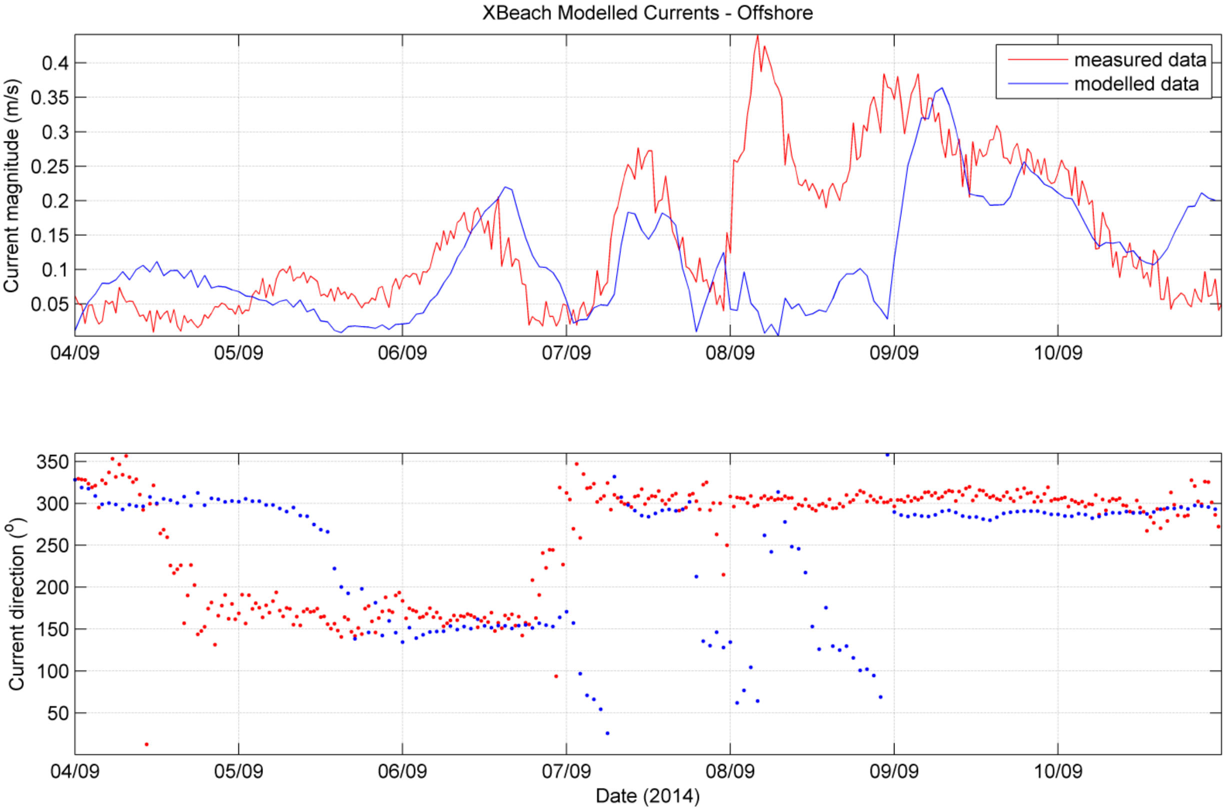

Figure 6-20 Measured and modelled depth average current data at the Offshore AWAC location

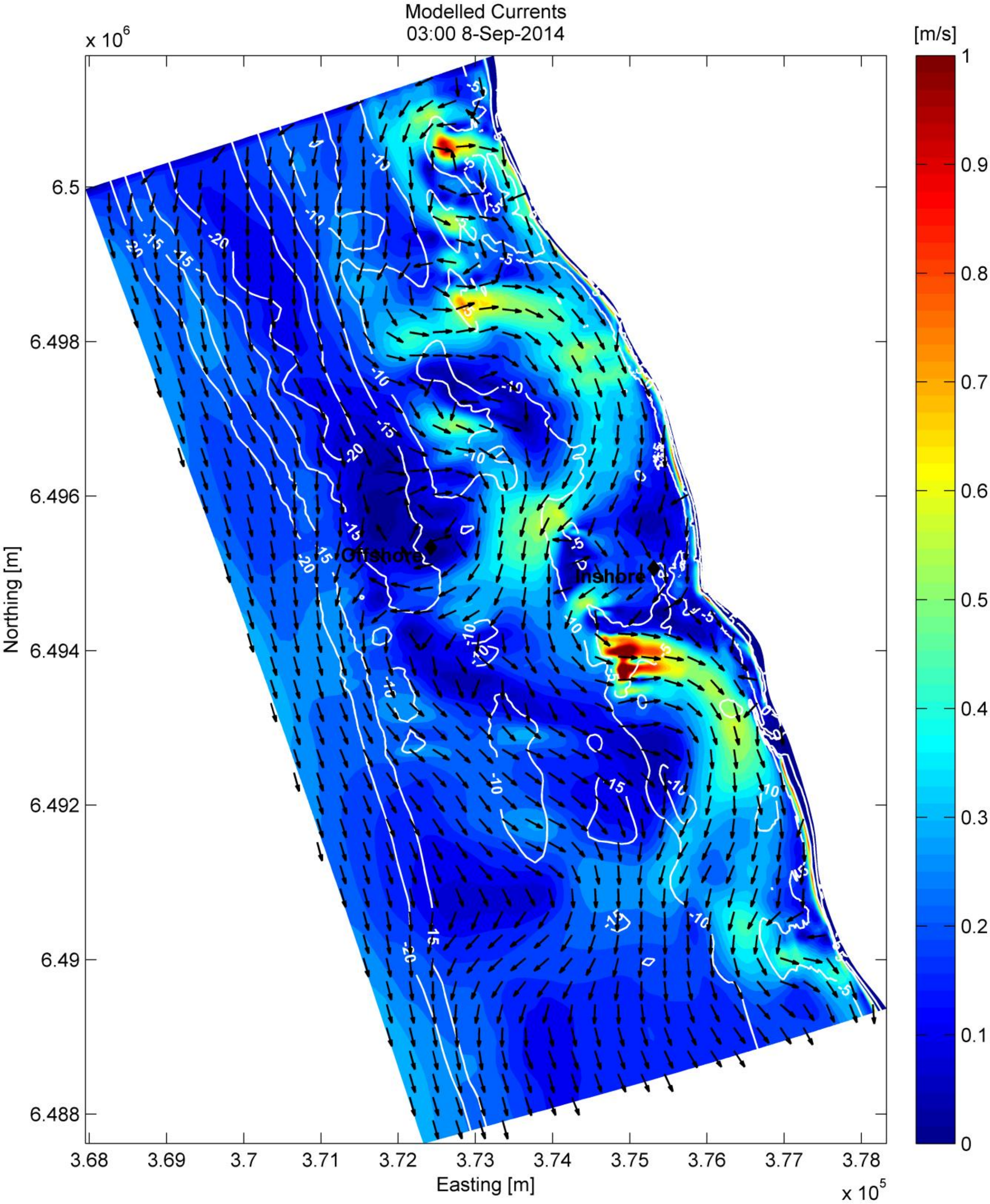

Figure 6-21 XBeach modelled depth average current map at 3:00AM 8 September 2014. Note vector field had been thinned to a 300 m interval.

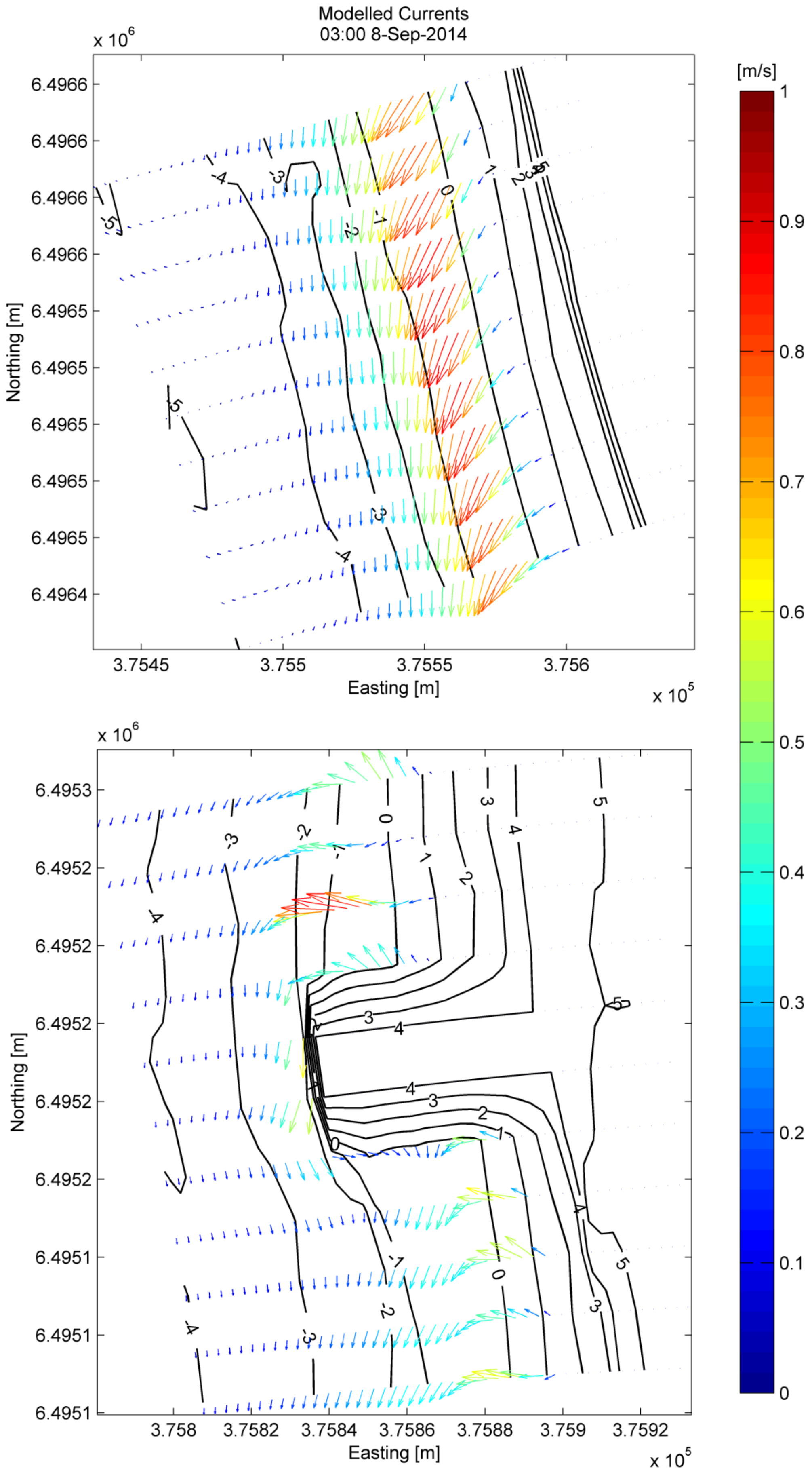

Figure 6-22 XBeach modelled depth average wave driven littoral drift currents at 3:00AM 8 September 2014 for a straight area of Section 5 (top) and around Groyne 1 (bottom).

6.4.6 Morphological Changes

The morphological changes predicted by the XBeach model were compared to the measured changes along 119 shore-normal transects across the study area, the full details of which are presented in **Appendix E**.

The Brier Skill Score (BSS) was used to assess the performance of each model (**Equation 6**).

$$BSS = 1 - \left(\frac{\langle |x_m - x_p|^2 \rangle}{\langle |x_p - x_b|^2 \rangle}\right) \qquad \text{Equation 6}$$

Where x_m is the modelled post-storm profile, x_b is the measured pre-storm profile and x_p is the measured post-storm profile.

The Cardno beach survey profiles on 04 September 2014 and 11 September 2014 were used as the measured pre-storm profiles and the measured post-storm profiles respectively. Profiles from each section (1 to 6) were used in determining the BSS. The significance of the BSS is given by the following: BSS< 0 bad, 0-0.3 poor, 0.3-0.6 reasonable/fair, 0.6-0.8 good and 0.8-1 excellent (van Rijn et al., 2003).

Significant variability in the BSS was exhibited with a minimum score of -26 and a maximum score of 0.98. Profiles where only a small change was measured often exhibited negative BSS scores due to the small numerator in **Equation 6**. **Table 6-6** presents a summary of the information presented in **Appendix E**. This table presented the average BSS for each section, the sum of the measured and modelled profile volume changes for each section and a weighted BSS. To reduce the bias in the average BSS score by profiles that had minimal change in volume a weighted mean BSS was calculated with each profile weighted by the volume change of the profile. In this way profiles with a small volume change have reduced weight.

The XBeach model reproduced the profile with reasonable skill in Sections 1, 3 and 4 with excellent reproduction of the observed volume changes. The majority of Section 2 is quite poor (except for good results within 50 m south of groyne 1), and likely suffers due to the 200 m gap in the measured beach profile data and due to construction activities taking place on the beach. It is understood the several bunds were present close to the shoreline to protect the construction site from wave attack. The model also failed to reproduce the observed changes in the northern end of Section 5 (around 450m chainage) which may due to the limited schematisation (due to limited information) of a nearshore reef embedded in the shoreface adjacent to Queenscliff Park, or due to differences between the modelled and actual wave conditions in this area. Section 6 exhibited variable skill, with reasonable skill for chainage 50 m through 350 m and excellent skill between 750 m and 1000 m chainage.

During sensitivity testing an alternative model configuration with reduced onshore transport calibration parameters (facSk and facAs = 0.2) exhibited somewhat improved model skill through the northern end of Section 5, suggesting that offshore transport due to wave asymmetry and skewness may be increased in this part of the study area compared to areas further south.

Table 6-6 Assessment of the XBeach model using the Brier Skill Score and modelled profile volume change.

Section	Average Brier Skill Score	Measured Profile Volume Change (m^3/m)	Modelled Profile Volume Change (m^3/m)	Weighted Brier Skill Score
1	0.23	-40	-43	0.48
2*	-4.28	-60	-17	-5.45
3	0.10	-213	-196	0.54
4	0.21	-59	-47	0.64
5+	-0.07	-24	27	0.10
6	0.00	-83	-33	0.46

* The pre-storm bathymetry in Section 2 was poorly represented due to construction activities on the site preventing survey of 200m of beach
+ Section 5 had limited representation of shallow reefs embedded within the shoreface. In addition this area is sensitive to the wave and morphological parameter calibration.

Figure 6-23 presents a comparison of the measured and modelled beach profile volume change (top) and BSS for the study area. Note that the vertical scale on the BSS plot is linear between 1 and -1 and transformed (by a power of 1/5) for values < -1. The black vertical lines identify the different beach sections, with Section 1 commencing at 0 m chainage. The grey shaded areas represent gaps in the measured beach profile data where the pre storm beach profile had to be estimated. Overall the general trends in beach morphological change are reproduced very well spatially through the study area, including in Sections 2 and Section 5, albeit with overall net differences. In particular the XBeach model performs very well in the proximity of the coastal structures, providing confidence that the model is appropriate for assessment of coastal management options.

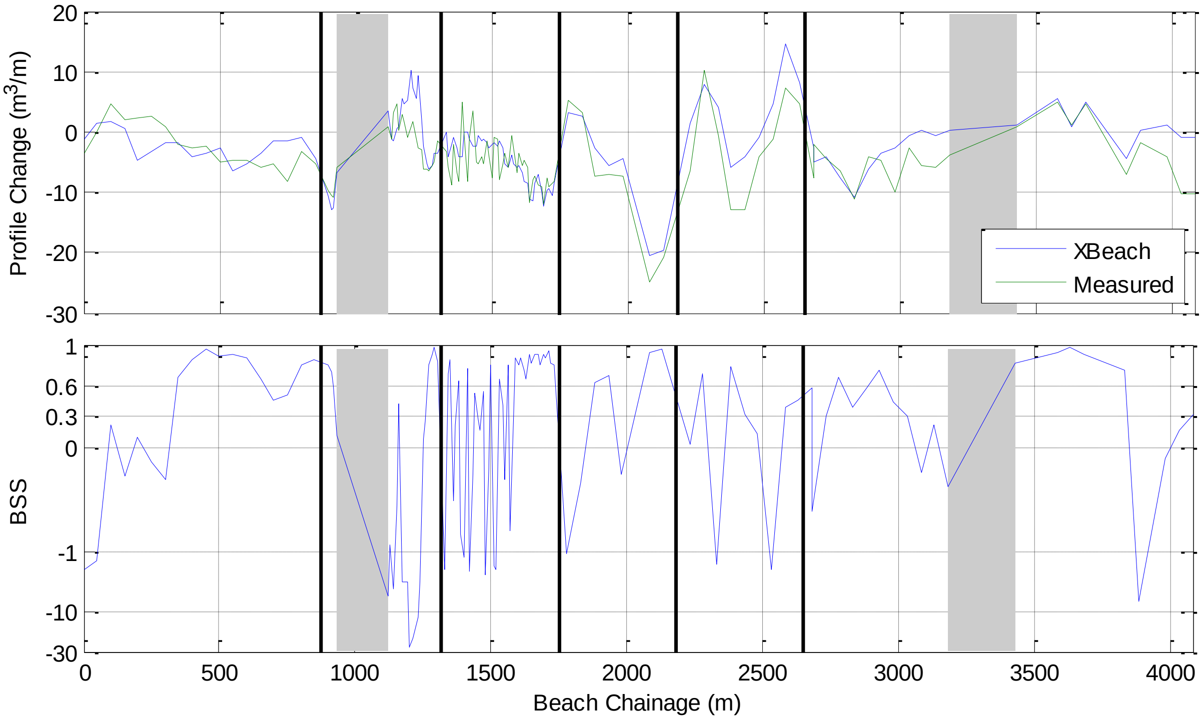

Figure 6-23 Comparison of the modelled versus measured beach profile volume change (top) and Brier Skill Score (bottom) from the XBeach model along the extent of the study area.

6.4.7 Modelled Bed Shear Stress

Figure 6-24 presents a maps of the average bed shear stress magnitude and direction over the duration of the storm (06:00 6/9/2014 through to 23:30 10/9/2014), plotted with an estimate of the threshold shear stress for the initiation of motion for sand with D_{50} = 340 µm based on the Shields Criterion. In addition the -3 mAHD contour line is shown to provide context relative to the closure depth (**Table 6-4**). The left panel shows an expanded view that extends to Alkimos in the north and Mindarie Keys in the south. During this north westerly storm there is an active transport pathway from Alkimos/Jindalee where sand is transported offshore from the southern end of Jindalee and offshore into deeper water, rather than along the beach to provide a supply of sand to the north of Quinns during storm conditions. Wave setup on Quinns Rocks similarly drives a potential transport pathway towards Mindarie Keys with sufficient strength to transport sand, at least as bedload, to the south of Quinns Beach, rather than towards the cuspate foreland. There is further evidence that this pathway is well established and persistent through the presence of a large sand bank that is present offshore of Mindarie Keys as shown in **Figure 5-3**.

Bed shear stress at the shoreface is highest throughout Section 5 and the southern end of Section 6. The right hand panel of **Figure 6-24** shows a zoomed view of the beach areas and demonstrates that on average for this storm the mobility of 340 µm sand extends to approximately the -3 m AHD contour. The depth of sediment mobility is increased in Sections 5 and 6 where wave conditions are larger due to the gaps in the Spearwood and Marmion Reef Ridges (**Figure 5-1**). The bed shear stress map also indicates that transport is occurring past the ends of the three groynes during this storm, which is supported by inspection of the sedimentation and erosion maps which indicate sedimentation around the ends of the groynes (**Figure 6-25**). The southward transport pathway along the beach is directed offshore in the proximity of Groyne 1. Acknowledging that conclusions from only a single modelled storm introduces significant uncertainty, the model results suggest that due to the dynamics of the system the northern end of Quinns Beach may allow some transport from Quinns to Jindalee during summer, but the equivalent reverse pathway in winter during southward littoral drift events does not exist. In addition the sediment transport pathway from Quinns Rocks similarly does not appear to supply sand to Quinns Beach during storm conditions.

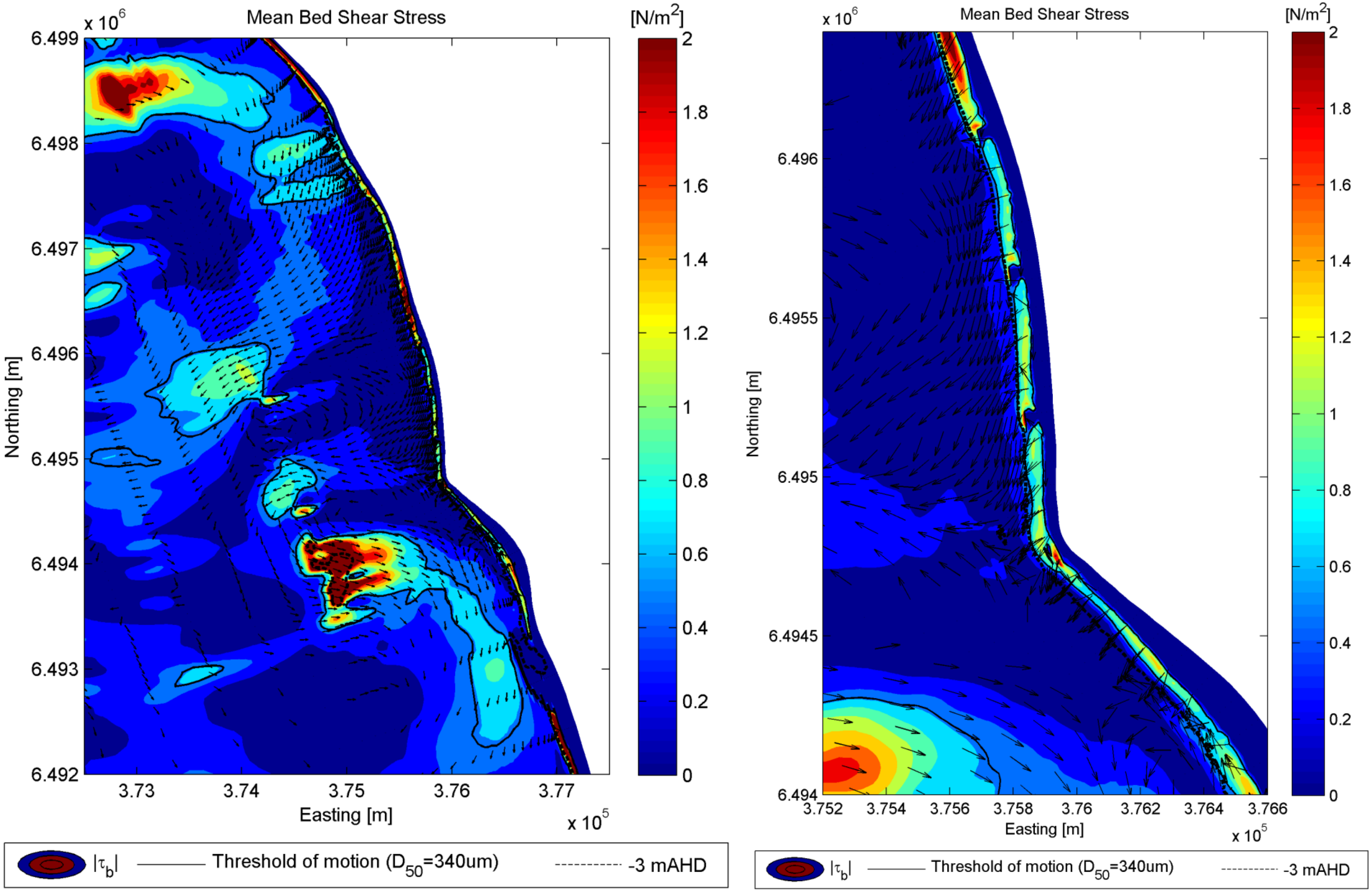

Figure 6-24 XBeach average bed shear stress over the duration of the storm (06:00 6/9/2014 through to 23:30 10/9/2014). Left: expanded view showing the complete study area. Right: zoomed view showing bed stress in the proximity of the existing coastal structure.

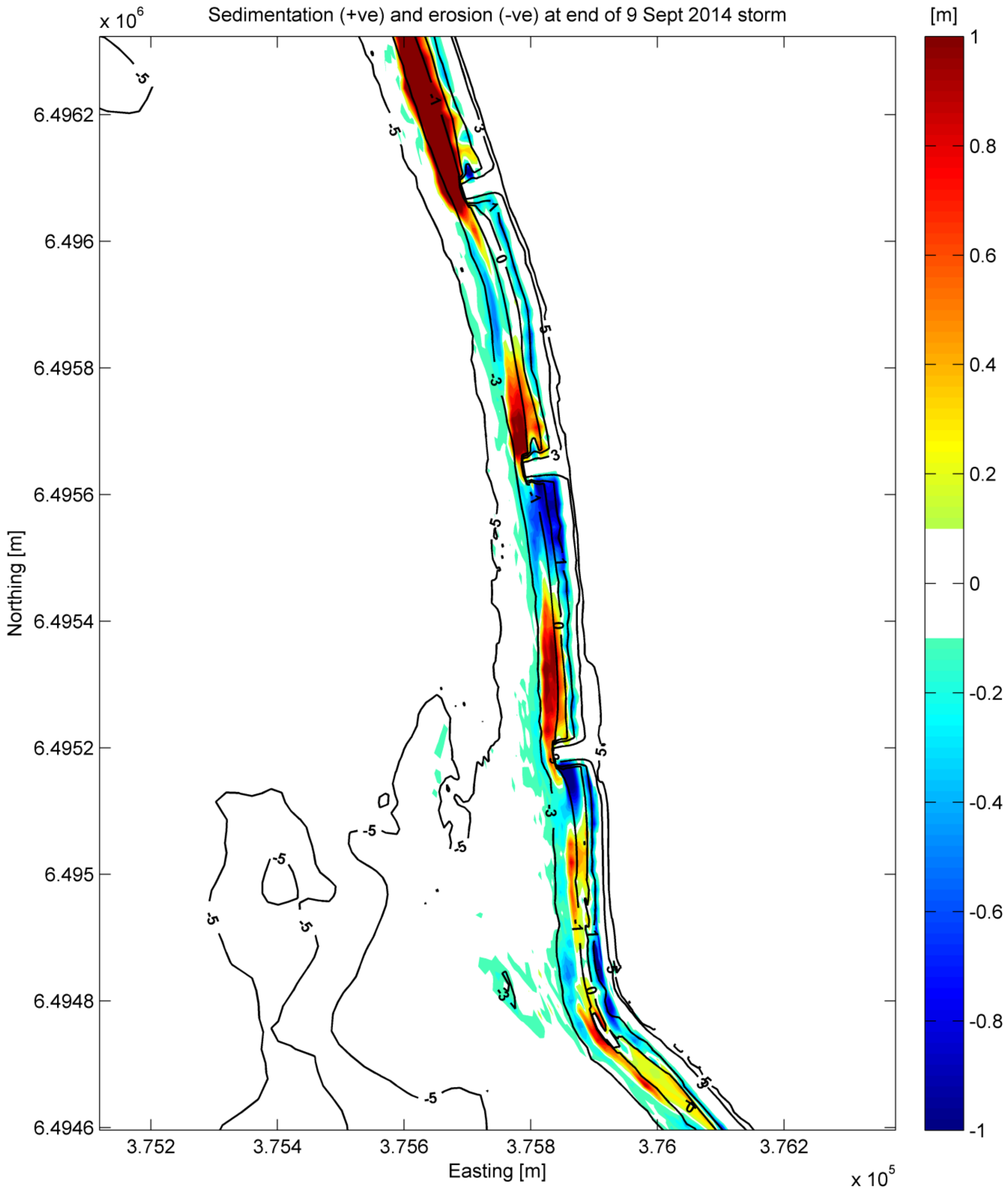

Figure 6-25 Cumulative sedimentation and erosion map at the end of the XBeach simulation (shaded) overlain on contours of the initial model bathymetry in the proximity of the coastal structures present at Quinns.

6.5 Shoreline evolution modelling

6.5.1 Model description

Investigations of shoreline evolution within the study area required a modelling system capable of describing time and space varying incident wave energy, a range of shoreline structures and layouts, beach nourishment options and be able to undertake medium term simulations within a realistic time-frame. Because of the complex near shore reef systems in the Perth metropolitan area, near shore incident wave heights and, importantly, directions vary markedly over short distances causing complex salient plan beach forms in the lees of major reef systems. This region is too complex to apply basic principles alone; though understanding them is important to interpreting model results. Hence the LITPACK coastal modelling system was applied to these investigations.

This modelling system has been developed by the Danish Hydraulics Institute. It is used internationally for assessment of coastal processes investigations, planning and concept design of shoreline beach rehabilitation works. Cardno have some decades of experience in LITPACK based investigations and applied the most recent version to this study.

LITPACK includes a number of modules. One of these, LITDRIFT, computes longshore sediment transport time-series from a time-series of wave parameters. Natural beach profiles, graded sediments, currents, wind and local roughness can be included. Generally the highest transport rate occurs in the breaking wave zone. The model includes the Shields' criterion for initiation of sediment movement. Many other sediment transport systems do not.

LITDRIFT allows the use of real, shore normal profiles that are based on survey, irregular, directionally spread waves and a description of the shore normal variation of longshore transport, to be undertaken. This is an important aspect where there is a closure depth and groynes, for example, where a structure may intercept all or some of the sand transported alongshore. The degree of interception depends on the location of the shoreline, defined to be 0m AHD, along the groyne. Beach width may be different on the two sides of a groyne because of up-drift accretion and down-drift erosion. Wave conditions in the lee of the groyne are affected by diffraction (height and direction), and LITPACK includes that process. LITDRIFT can be used to calculate up to several decades of longshore sediment transport rates at the time interval of available wave and water level data.

LITLINE is another module of LITPACK and is used to determine changes to a shoreline over a period of time using spatially and temporally varying wave conditions and longshore transport. It includes coastal structures such as groynes and revetments (seawalls). In this case the existing headland and groynes, together with proposed groynes and renourishment options, were included in models of the Quinns Beach shoreline. Note that groynes in LITLINE can be specified to have an apparent length; that is, sand bypassing can commence before sand builds-up fully on the up-drift side to the full length of a groyne. This process is important because it more closely describes what happens naturally than the alternative of delayed bypassing. The extent of bypassing depends on this apparent length and the shore normal profile of longshore sediment transport in different wave conditions – transport occurs further offshore in bigger waves. The length of a groyne is also dynamic in terms of the shore normal profile and reduces as a beach builds-out against the updrift side of a groyne. LITLINE includes an active depth and dune height in computation of shoreline changes. All five shore normal profiles, and hence the shore normal grid lines that use those profiles for transport rate calculation, extend sufficiently far seaward to ensure no transport occurs beyond their seaward depths.

LITDRIFT and LITLINE use the basic Engelund and Fredsoe (1976) transport formulation which includes combined wave and current motion, which may be in different directions, as well as bed and suspended sediment loads. It takes account of the threshold shear stress for initiation of sediment transport through the Shields Parameter. However, LITLINE includes the change in plan alignment of the shoreline, in terms of its effect on the relative incident wave direction, as erosion and accretion progress, whereas LITDRIFT does not.

LITDRIFT and LITLINE were applied to analyses of annual longshore transport variation along Quinns Beach from the southern end of Section 1 to the northern end of Section 6, as shown in **Figure 2-1**. LITLINE was applied as one method of analysing the long term shoreline effects of groyne construction – in the order of decades depending on available suitable data, about 10 years to be applied in this case.

6.5.2 Model setup

LITLINE was setup for these investigations using a base line parallel with the general alignment of the coastline in the study area. A grid size of 10m along this base-line was adopted and the survey of May 2008 used to determine the location of the shoreline (0m AHD contour) defining the initial plan alignment of the shoreline for the selected calibration period – May 2008 to May 2009. Although surveys were available only at the start and end of this period, this period was not affected by beach nourishment or construction activities that would confuse the physical processes description. In the shore normal direction grid size was set at 2.5m in order to define the profile shape at five profile locations – LITPACK allows five profile shapes. The along base line grid points were then banded about each of these five profile shapes. Note that the 10m grid lines of alongshore computational points positioned along the base-line are not computationally these profile shapes. The number of grid points at 2.5m spacing on each shore normal computational line varies from one computational line to another. The shore normal shapes of these computational lines are based on the five surveyed and adopted profile shapes, the selection of profile shape assigned to a shore normal computational line was assigned by the model user as part of the model set-up process.

A sediment particle size (D_{50}) of 0.34mm was adopted, based on available sediment data. A bed roughness (Nikuradse Number) of 0.004 was adopted based on experience on previous sandy shoreline investigations (Cardno, 2011a, Cardno, 2011b). This parameter affects the magnitude of the long shore current generated by the waves.

A closure depth of 5m and height of wave run-up of 3m were adopted; summing 8m. This parameter is used to define the height of active beach used in the beach-width change calculation of the one-line beach processes model. This occurs in each alongshore 10m computational cell; wherein the change in sediment volume each time step (3 hours), is used to compute change in shoreline location. Sediment porosity of 40% was adopted.

Figure 6-26 describes the model layout and **Figure 6-27** describes the five profiles adopted to describe the beach shape. This setup includes the three existing groynes and 'offshore' headland structure, but not the new geotextile sand container revetment, which was constructed in 2014. In order to provide realistic computational times, LITLINE provides a routine to pre-calculate sediment transport rates – look-up tables, at each of the five specified profiles for a range of wave heights, water levels, wave direction relative to the shore normal direction and breaking wave indices – over the range of incident wave parameters. LITLINE then uses interpolative routines to determine rates at each shoreline grid point at each time step. Modelled longshore transport rates can be output at every grid point along the baseline – 10m intervals. This grid resolution allows the description of localised changes in sediment transport at structures.

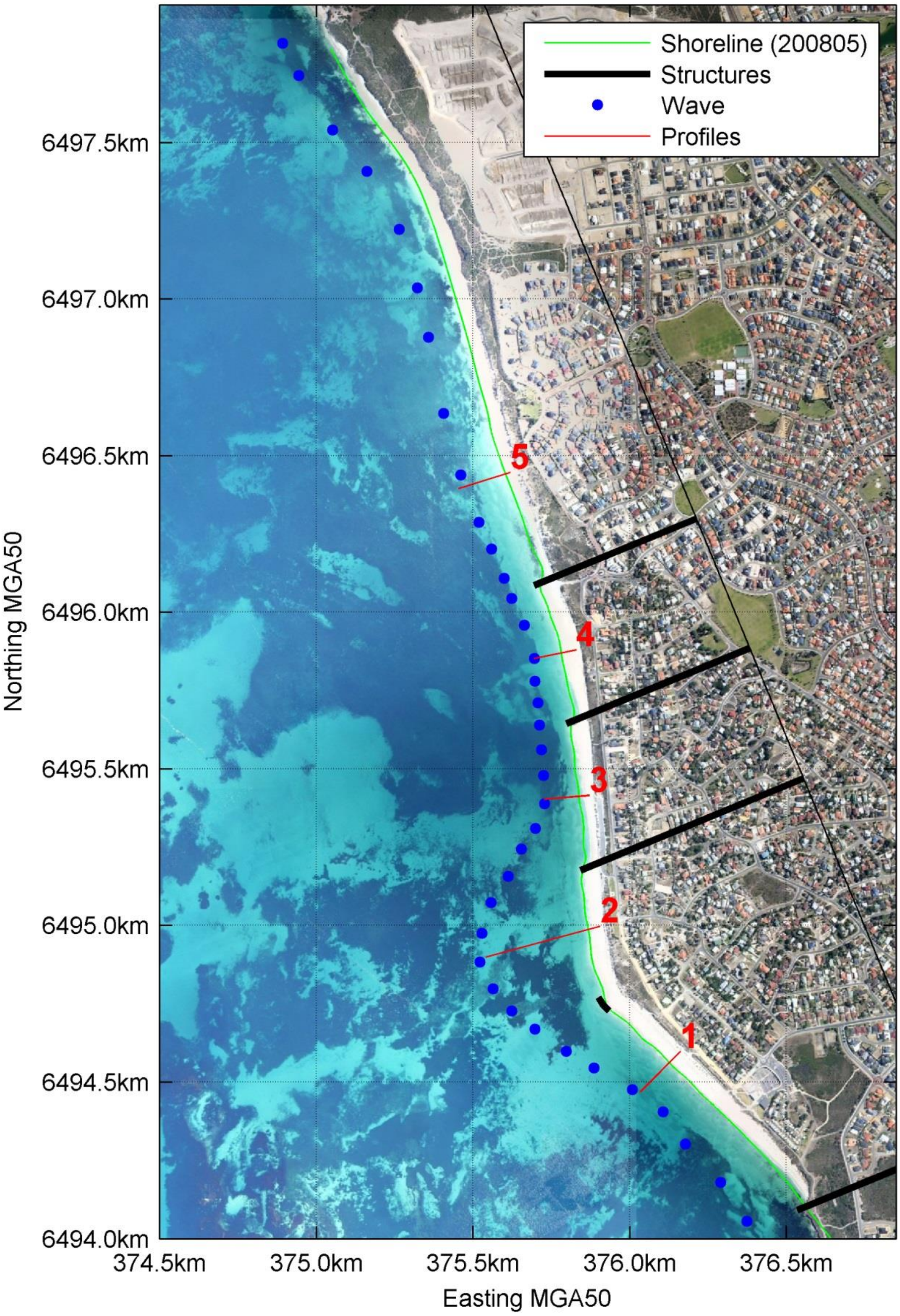

Figure 6-26 LITPACK Model Layout

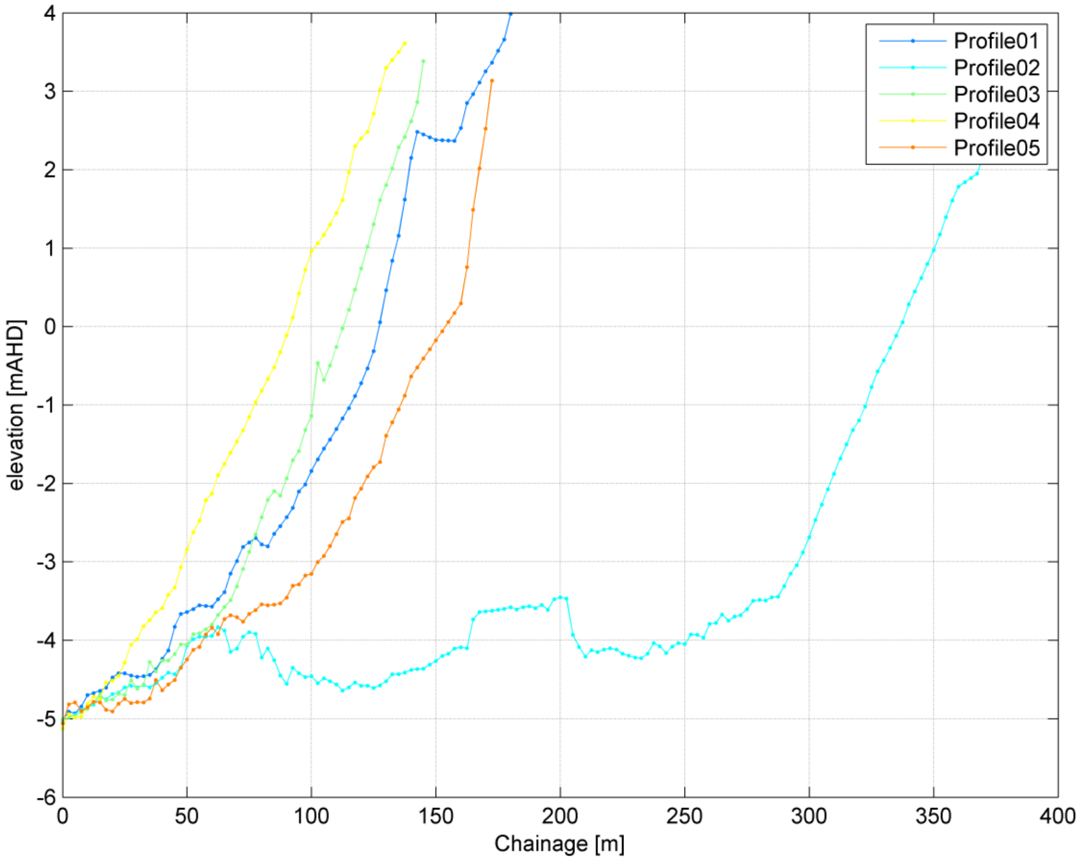

Figure 6-27 Modelled Profiles

6.5.3 Model validation

As described above, the first stage of model application was to validate the model in order to ensure that the seasonal sediment transport characteristics were replicated and that transport rates were realistic in terms of spatial and temporal variation. Note that the geotextile sand container revetment was not included for the 2008 to 2009 validation period – not constructed. LITDRIFT and LITLINE results are presented in terms sediment transport rate time-series at the five selected profile locations in **Figure 6-28** to **Figure 6-32**. These figures are not intended to provide numerical detail, but rather to describe the trends. These results are examples only and output is available at all grid points along the baseline and within the study area. One can see that transport rates vary from one profile (location along the shoreline, see **Figure 6-26**) to another quite markedly. A positive value of longshore transport discharge indicates that the sand is moving towards the north in the model. One can then observe that the seasonal change is mainly driven by the change in wave direction. The energy weighted mean wave direction and the associated modelled longshore transport calculations show the sand moving towards the south in winter and towards the north in summer, which results in a seasonal change of beach orientation. It is then important to notice that although LITDRIFT can give a good indication of the longshore transport, it is limited by the fact that the shore-normal profile direction remains constant. Hence the LITLINE results are the more realistic and show the seasonal changes in sediment transport and plan alignment expected.

LITLINE is able to change the shore normal direction of the shoreline by moving sand along the coastline causing changes in plan alignment of the beach. LITLINE results are displayed as plan views of beach position in **Appendix F** as it changes over the one-year of calibration, respectively in sections 1 to 6 from South to North. The coastline evolution model starts in May 2008 and ends in May 2009 for which measured surveys are available and respectively shown in black and pink. The assessment of the model is then made by comparing the measured shoreline in pink and the modelled shoreline in dark red. The seasonal evolution of the shoreline is shown in the figures in **Appendix F** with a colour scale starting in blue (May 2008) towards light green (October 2008) and finishing in dark red (May 2009). Although there is no monthly survey data, these monthly results describe the character of the progressive seasonal shoreline changes. The seasonal change of shoreline orientation in each compartment, between groynes, for example, is well represented in the model and can be observed by comparing the light green line (October 2008) with the alignment in May. The influence of the groynes on the shoreline is also well represented by the model.

The model results demonstrate good agreement with the measured shoreline annual changes in most places, however, it has some difficulty in describing all shoreline changes in a localised area landward of the artificial reef. LITLINE does not have a model structure that is totally similar to this headland when sand has accumulated in its lee area, that is, it is not an offshore breakwater.

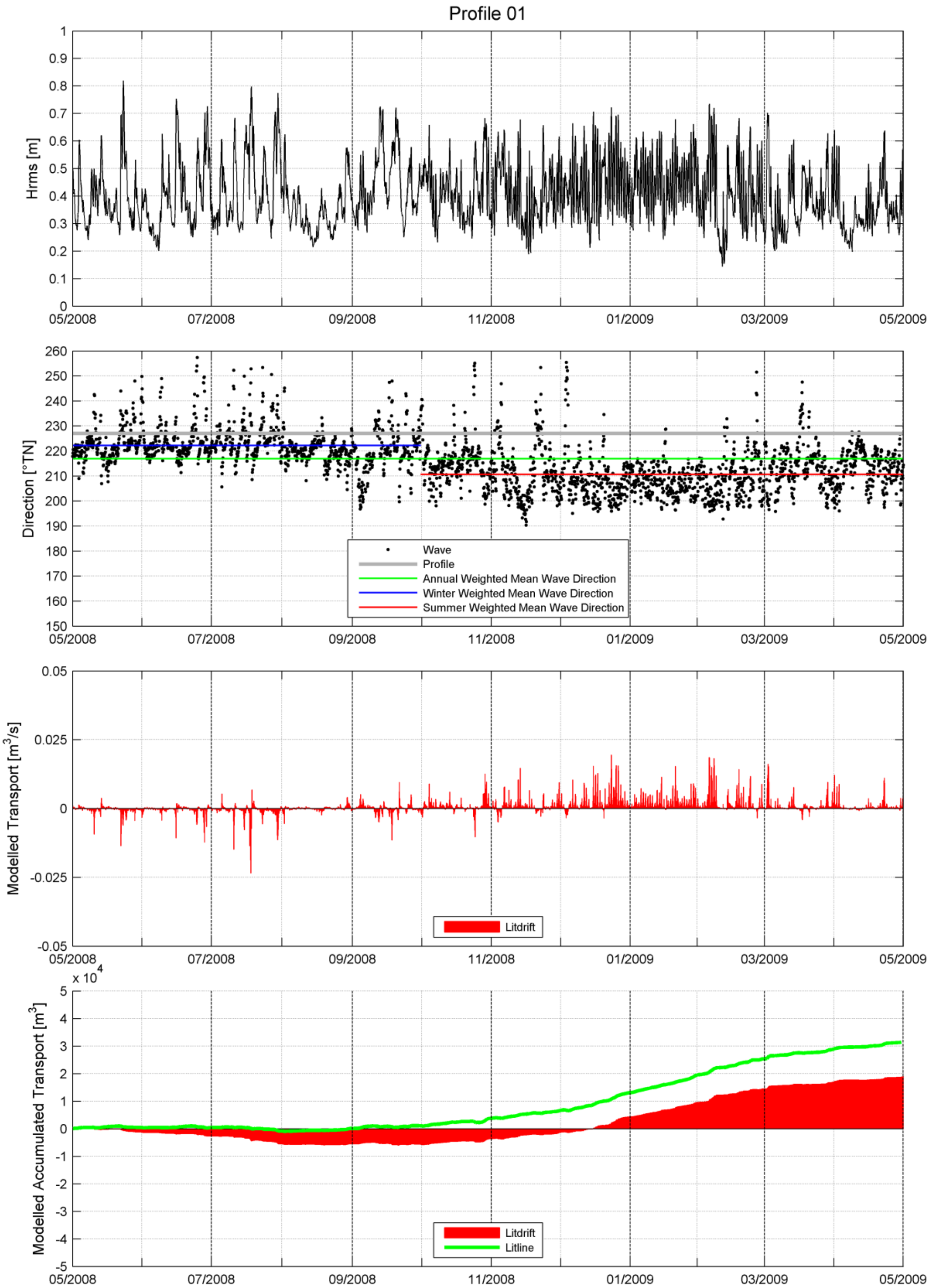

Figure 6-28 Modelling of Longshore Transport with Litdrift (May 2008 – May 2009) for Profile 1

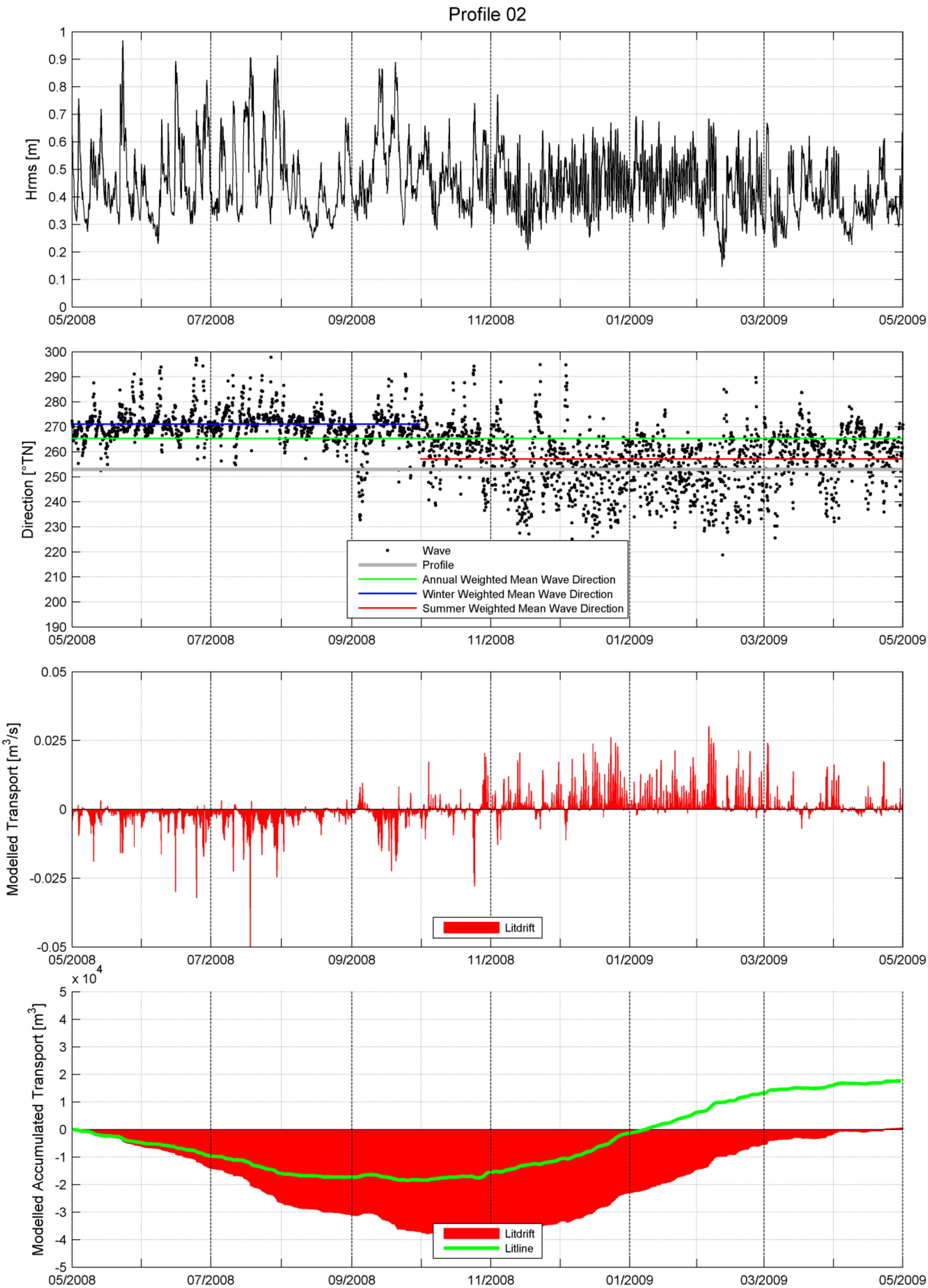

Figure 6-29 Modelling of Longshore Transport with Litdrift (May 2008 – May 2009) for Profile 2

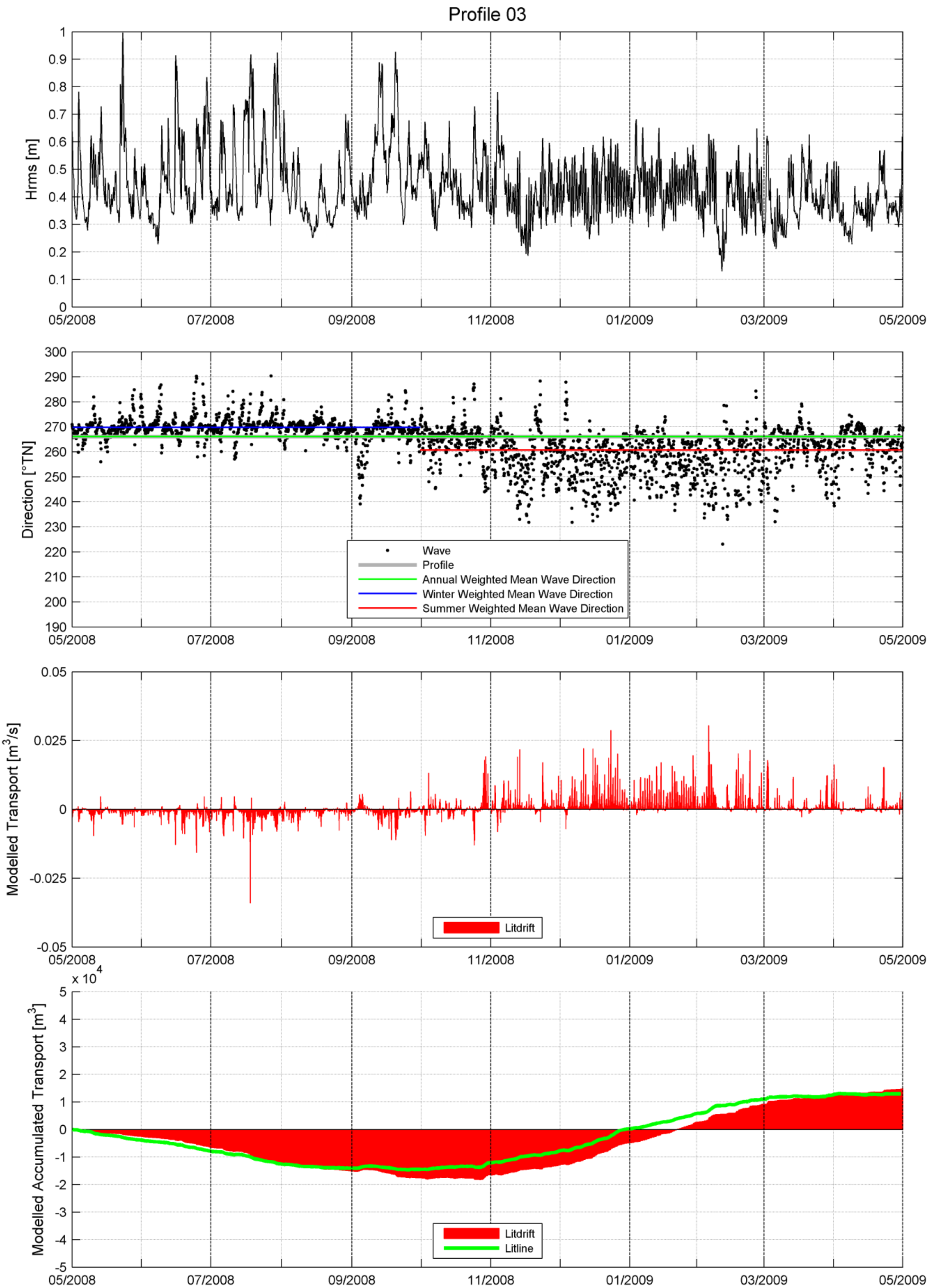

Figure 6-30 Modelling of Longshore Transport with Litdrift (May 2008 – May 2009) for Profile 3

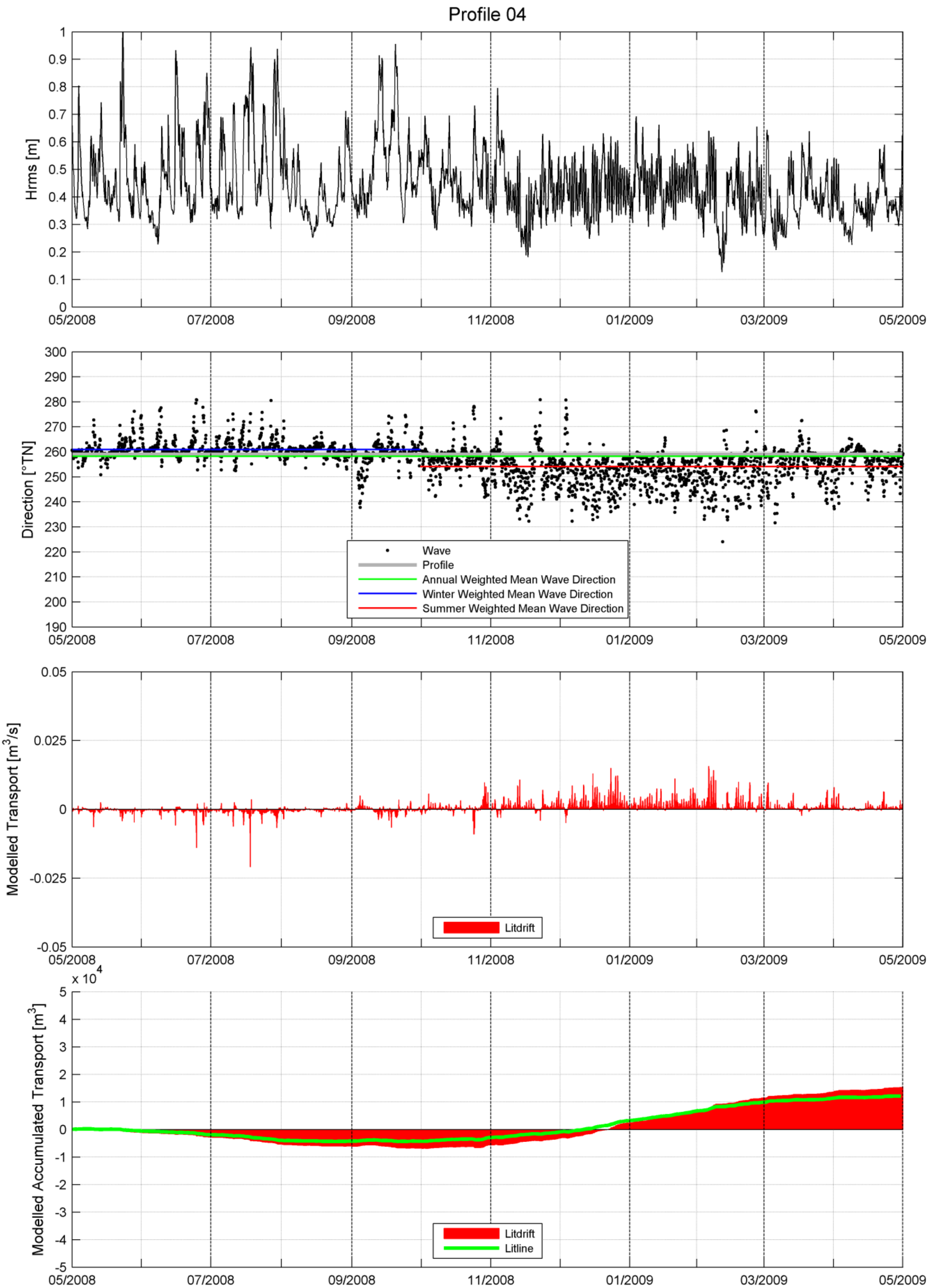

Figure 6-31 Modelling of Longshore Transport with Litdrift (May 2008 – May 2009) for Profile 4

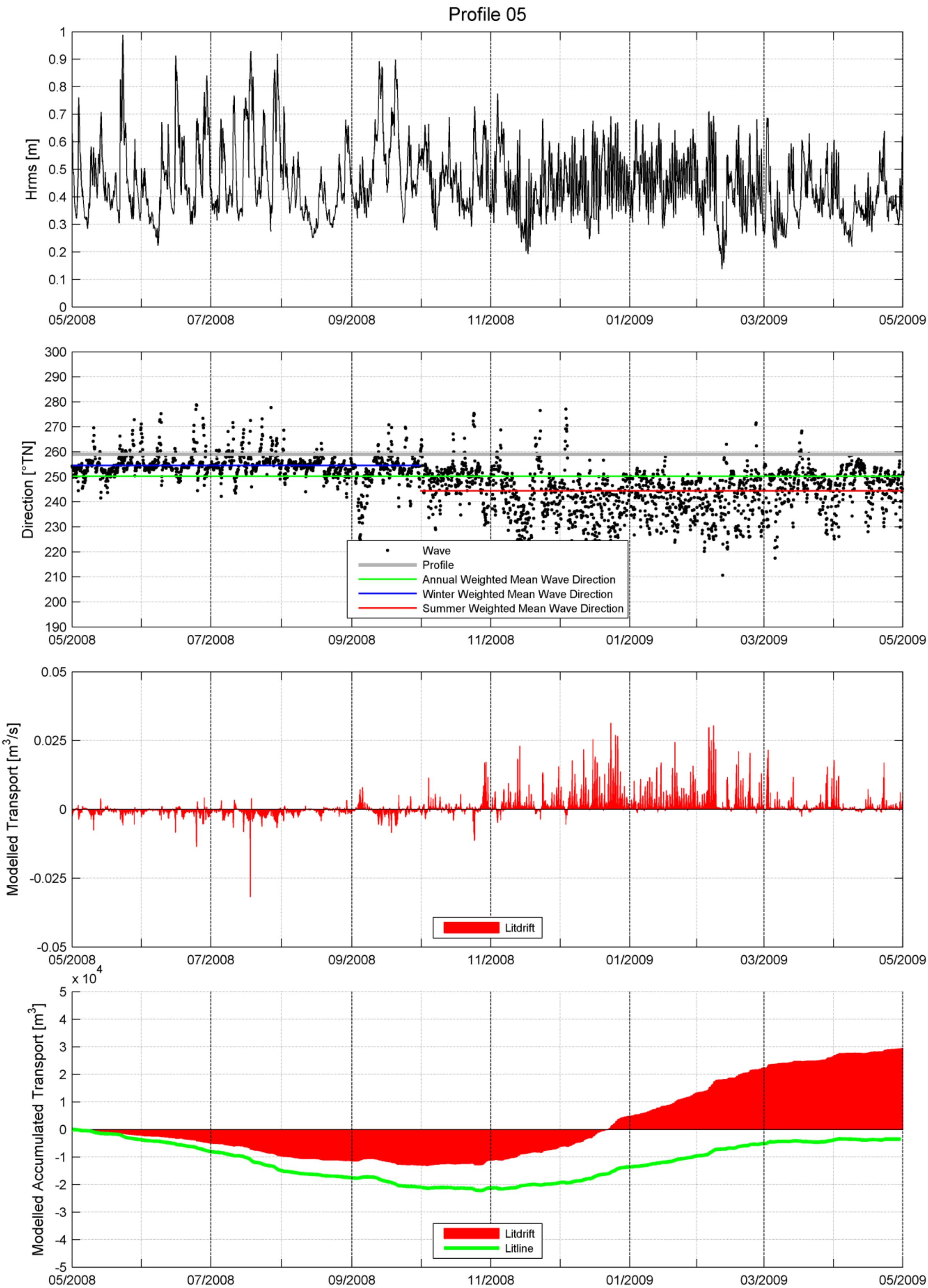

Figure 6-32 Modelling of Longshore Transport with Litdrift (May 2008 – May 2009) for Profile 5

6.5.4 Ten year simulation

The calibrated LITLINE model was executed for the 10 year period of the wave hindcast to examine the spatial and inter-annual variability in longshore transport present at Quinns Beach. In interpreting these results it is important to consider that the shoreline used to start the simulation was the surveyed shoreline that was present in May 2008. As such the model undergoes an initial period of readjustment. In addition the longshore transport model neglects cross-shore transport and no sand nourishment has been included.

Figure 6-33 presents a time series plot of the integrated drift over 10 years (from September 2005 through October 2014) at six locations along Quinns Beach. Profiles 1 through 5 are consistent with those presented in **Figure 6-26**. The sixth location is aligned approximately with the northern end of the study area. Considerable variability in the magnitude and direction of longshore transport is present at Quinns Beach. Sediment is transported northward generally from October to March/April and southward from April through September. The model suggests that there has been overall a modest net northward drift along Quinns Beach from 2005 through to 2015. Exceptional years are 2007 and 2009 which exhibited strong southward transport during winter, and the slight southward trend that has established over the period 2012 through 2015. These observations are in good agreement with the longshore wind stress presented in **Figure 4-20**.

Gross longshore transport can be up to 60,000 m^3 in a given year, with the largest fluctuations in longshore transport occurring past Profile 2. **Table 6-7** presents the average annual net drift at six locations along Quinns Beach. In addition the 95% confidence interval of the mean net drift is shown in the second and third columns. This highlights the year to year variability in magnitude and direction that is present at Quinns Beach. Section 1 exhibits a predominantly northward drift of approximately 5,000 m^3 per year. Sections 2 and 5 have highly variable longshore drift with years of both southward and northward drift and an overall mean of approximately 2,000 m^3 per year. Sections 3 and 4 have generally northward drift with an average net northward longshore transport of 3,000 m^3 per year. Longshore transport through the northern end of the study area is highly variable with years both to the north and south, however with minimal net transport over the 10 year simulation. Inspection of aerial photos showing the pocket beaches to the north of the study area supports the conclusion of highly variable longshore transport in this area. The impoundment of sand against these reefs and cliffs plays an important role in both ensuring sufficient supply to the south in the subsequent winter. In years of particularly strong northward transport this may be a pathway for sand to be transported to the north and out of the Quinns Beach system.

Figure 6-34 presents the net longshore drift for each year of the 10 year simulation. The LITLINE model predicts that, on average, over the 10 year simulation approximately 4,000 m^3 is bypassed northward around groyne one, 5,000 m^3 around groyne two and 3,000 m^3 around groyne three. This suggests that Section 4 has a net influx of sediment, which is consistent with the recovery of the vegetation line in this Section compared to others. These results demonstrate that the LITLINE model can be utilised to comparatively assess the performance of different coastal management measures at Quinns Beach.

The end of summer and end of winter shoreline alignments over the 10 year period are presented in **Appendix F**. The model reproduces the seasonal shoreline rotation well and demonstrates the variability in this process. Erosion 'hotspots' in Section 2 and Section 5 are reproduced reasonably well in years when erosion occurred. Sections 3 and 4 are generally stable, however the late summer erosion at the southern end of Section 3 (adjacent to the car park) is not as prominent as observed.

Table 6-7 Annual net drift and 95% confidence interval of the mean net drift calculated from 10 years of data at six locations. Positive values indicate northward drift.

	Mean Annual Net Drift [m^3/yr]		
Location	Mean	95% Confidence Interval	
Profile1 (Section1)	4909	-936	10754
Profile2 (Section2)	2206	-3836	8249
Profile3 (Section3)	3395	487	6304
Profile4 (Section4)	3381	1006	5757
Profile5 (Section5)	1714	-3125	6553
North of Section 6	-137	-4117	3844

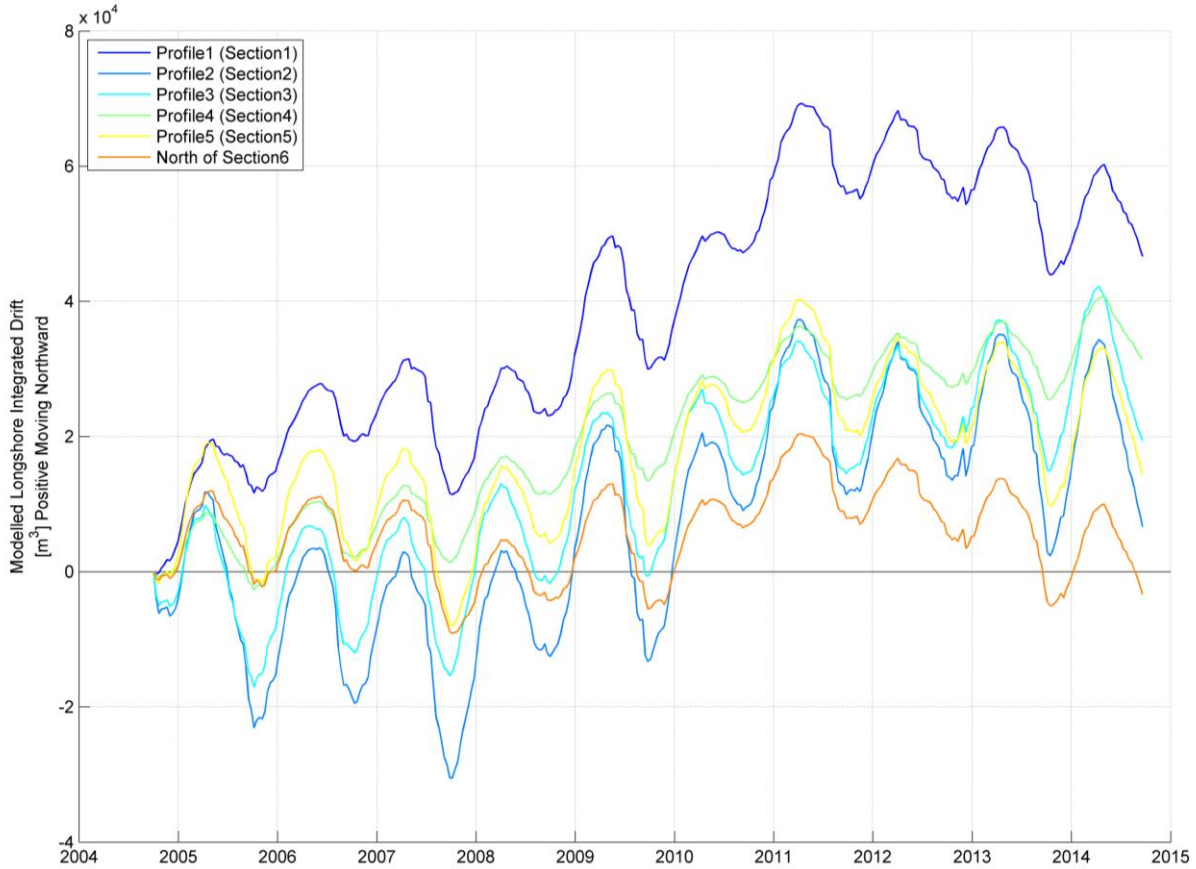

Figure 6-33 Timeseries plot of the integrated drift over 10 years at six locations along Quinns Beach

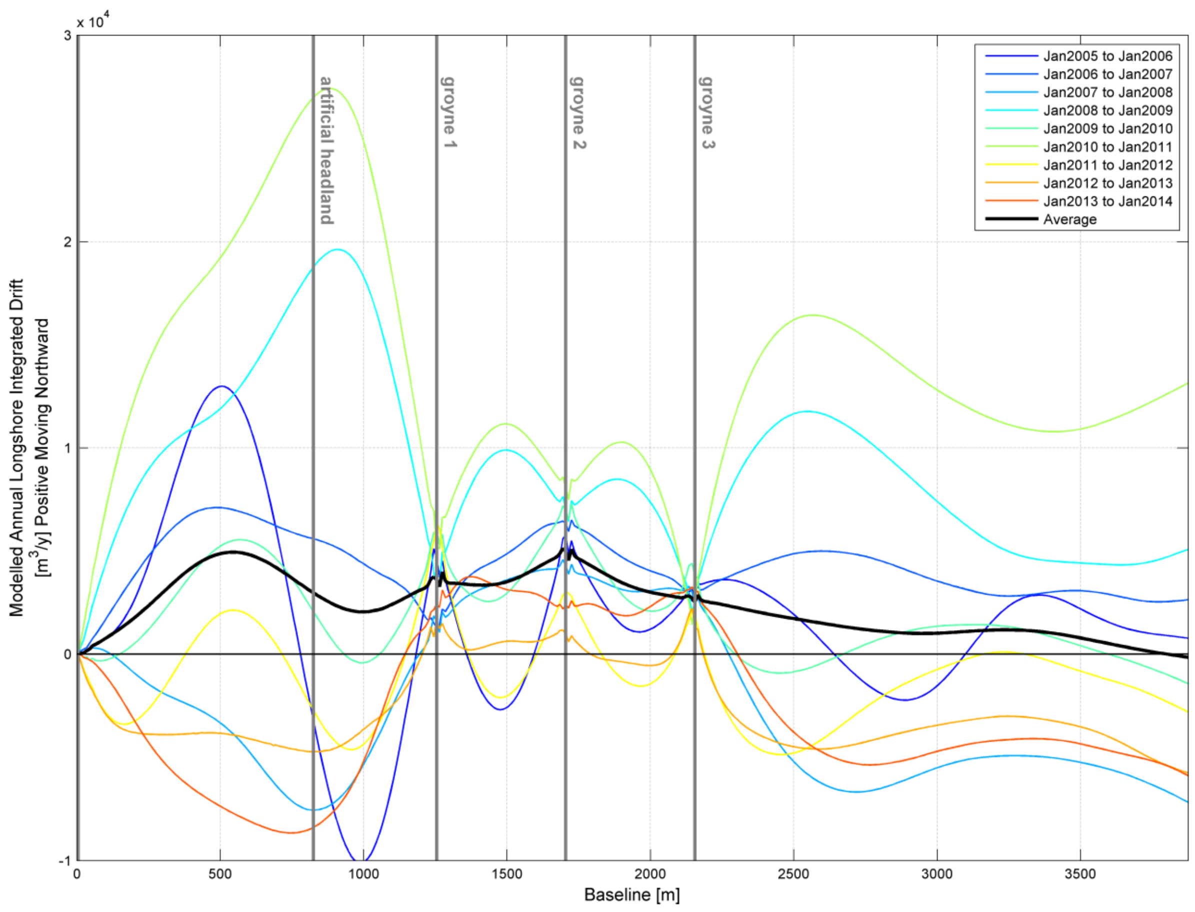

Figure 6-34 Modelled annual longshore drift along Quinns Beach between 2005 and 2014

6.6 Summary of model outcomes

A SWAN wave model was developed and calibrated to measured wave conditions at two measurement locations near to Quinns Beach. Wave dissipation by bottom friction was found to be the critical parameter for the calibration of wave heights. Two alternative descriptions of the bottom friction and associated wave dissipation (constant and spatially variable) were investigated, with nominally similar calibration metrics, however with significant variation in modelled wave heights through the northern extent of the study area, away from the measurement locations. It is recommended that additional wave data collection is undertaken in the proximity of Queenscliff Park to improve confidence in the modelled wave conditions for use in design of potential coastal structures in this area. For the purposes of this study, the constant bottom friction schematisation was utilised due to the somewhat improved results at the Offshore location.

A fatal flaw model comparison was made between the XBeach and Delft3D models and on the basis of comparison with measured morphological changes over a storm XBeach was selected for further investigation. The XBeach model was able to reproduce the measured currents very well and had good agreement with anecdotal evidence provided by the community. XBeach was able to reproduce the observed morphological changes over the storm, both qualitatively and quantitatively over broad extents of the study shoreline with a reasonable degree of skill. An incomplete description of the pre-storm shoreline and GSC construction activities taking place in Section 2 limited the model's skill in this area. In addition the model performance was poor in areas of Section 5 and Section 6 where the nearshore reefs were not schematised in the sediment availability map (due to limited information) and potentially due to uncertainty associated with the modelled wave conditions in this area.

The LitPACK model was developed for the extent of the study area and calibrated to observed shoreline changes over the period of May 2008 to May 2009 where survey data was available. The calibrated model was able to reproduce the seasonal changes in littoral drift and shoreline rotation well. LitPACK was not able to represent the artificial headland structure located at the apex of the cuspate foreland as it does not have a schematisation for an offshore breakwater structure that is fully engulfed by sand. The anecdotal evidence of sand bypassing the groynes was reproduced by the model, including the accumulation with in Section 4. The longshore transport was found to vary both in space and in time associated with changes in the incident wave direction. A 10 year simulation demonstrated significant inter-annual variations in longshore transport, however with a long term net mean of approximately 3,000 – 5,000 m^3 to the north within the study area, with limited exchange with longshore tertiary sediment cells.

The numerical modelling suggests that both longshore and cross shore sediment transport play an important role at Quinns Beach. It has demonstrated that the present groynes allow sand to bypass to both the north in summer associated with persistent northward transport and to the south in winter associated with larger storm waves from the northwest.

The two calibrated model systems can subsequently be used to assess the coastal management options at Quinns Beach. The LitPACK model will be used to estimate the long term changes (over 10 years) in shoreline alignment due to different coastal management measures. Following this the estimated long term shorelines will be assessed under storm conditions to assess the resilience of the coastal management option to a sequence of storms.

6.6.1 Model limitations and uncertainty

Whilst a good degree of calibration was achieved in the numerical models, some model limitation and additional areas of uncertainty were identified. Calibration of the wave model highlighted that nearshore wave conditions in the proximity of the Dog Beach (Section 5) are sensitive to the schematisation of wave dissipation across the offshore reefs. Additional data collection is recommended to resolve this. The presence of reef structures embedded within the active beach profile (just below mean sea level) are currently not schematised in the models due to insufficient information on their depths and extent. As a consequence, the storm erosion model (XBeach) currently underestimates the erosion around Queenscliff Park.

The longshore transport model had difficulty resolving the morphological processes in the immediate vicinity of the artificial headland, due to its proximity to the shoreline. However the effectiveness of the model in predicting the seasonal evolution of the shoreline to the south of Groyne 1 highlights that, in its present configuration the artificial headland has minimal influence in controlling sediment exchange between Sections 1 and 2. The LitPACK model only resolves longshore transport, however is calibrated to the observed changes in shoreline position and seasonal rotation which includes a cross shore component. Due to the computational cost of resolving both cross shore and longshore components of sediment transport it is currently not practical to model 10 years of shoreline evolution in a model such as XBeach, and to do so requires a number of alternative assumptions associated with long term water level and wave climate. As such Cardno has developed multiple models to assist in the assessment of potential management options, and appropriate consideration of the model limitations is required when assessing the model predictions.

Acknowledging that some uncertainty remains with respect to the numerical model outcomes, overall the performance and diversity of modelling approaches applied provide a valuable set of tools to evaluate coastal management options in subsequent stages of the project.

7 Conceptual Review of Coastal Management Options

The knowledge gained through the assessment of coastal processes has allowed the development of six conceptual coastal management options. These options have been rationalised to include a number of key design measures based on both the coastal processes analysis and past performance of the existing structures. They have been designed with further analysis in mind to assess performance and optimisation of structure location, length, spacing, crest level and other design parameters.

As discussed throughout this report, both cross shore and longshore sediment transport are important sediment transport mechanisms at the site. Storm-induced erosion is transported alongshore as it is removed from the beach face, and lost to adjacent beach compartments due to the present compartments being ‘open’. Most of the conceptual solutions developed for further analysis aim to hold sediment within each compartment, that is, to create ‘closed’ compartments. This will be achieved by extension of the groynes to the closure depth, and with the addition of offshore structures to assist in both protection from storm-induced erosion, and in trapping sediment. It is also noted that numerical modelling suggests that there is limited exchange between Quinns Beach and the adjacent tertiary sediment cells to the south and north through littoral drift; rather exchange occurs at deeper depths and at slower rates, predominantly during storm conditions.

Engineering structures (groynes, headlands, seawalls) can defend the land at the expenses of beach loss, severe erosion at other locations, and potentially significant ongoing maintenance expenditure (through structure maintenance or sand nourishment). The present best estimate is that Quinns Beach experiences an annual deficit of sediment in the order of 20,000 m^3 which is difficult to overcome with engineering structures alone, and will likely require ongoing sand nourishment to maintain the shoreline in its present position, particularly if medium-term down drift impacts are to be minimised. Given the likely ongoing sand nourishment requirements it is recommended that cost effective options for the supply and placement of sand are investigated; these should include the potential use of the extensive sand bank offshore of Mindarie as a source, however it is noted there would be significant environmental approval requirements.

When developing the options, Cardno consulted with the City to confirm their plans and priorities for protecting the coastline. This included examination of the City’s Coastal Management Plan Part 1 (City of Wanneroo, 2012). The following assumptions were applied when developing the options:

> Section 1 (Surf club beach): This beach has been performing reasonably; no modifications are recommended in this section

> Section 2 (South of Groyne 1): The installation of the GSC revetment has provided protection to the shoreline; additional beach width in winter would provide additional amenity, however lower priority than the remaining threatened area.

> Section 3 (Between Groynes 1 and 2): Protection of car park considered a high priority

> Section 4 (Between Groynes 2 and 3): This compartment has been reasonably stable, though still experiencing some erosion. The priority for protecting this section is less than Sections 3 and 5.

> Section 5 (North of groyne 3): High priority to mitigate erosion of the dog beach

> Section 6: Potential sacrificial beach commences from approximately 1 km north of Groyne 3, consistent with the commencement of nearshore reef and dunes interspersed with limestone cliffs. However, the coastal node at Jindalee should not be threatened.

Working together with the City to prioritise options such as allowing some sections to undergo a managed retreat approach ensures that the management option selected is in line with SPP2.6 and the corresponding Coastal Hazard Risk Management and Adaption Planning (CHRMAP) principles.

The options assessment considered a number of criteria in a comparative manner in order to narrow down the number of options to be assessed in the next phase. This was undertaken by using an evaluation matrix (Section 7.8 below) that assessed the options’ effectiveness, as well as other criteria such as cost and impacts to the community. The highest ranking four options from the evaluation matrix were then examined in terms of advantages and disadvantages that can be explored in the next phase of the project through modelling (**Section 7.9**).

Options 1 to 3 described below are as previously presented in the earlier Cardno reports (Cardno 2013 & 2014). Options 4 to 6 explore slightly different combinations to determine the individual effects of each component, in order to determine the optimal protection solution. The options are named by the key component that differentiates them from the other options for ease of discussion.

In addition to the six options presented below, there is also a list of optional extras that may be included in the analysis during the next phase of work (**Section 7.7**). It is envisaged that these will be included in the analysis if the option selected alone does not provide the required level of protection. All options put forward by the community have been included within this section for consideration.

7.1 Option 1 - Groyne 1A

Option 1 is presented in **Figure 7-1a**. This is the same as Option 1 in the previous study undertaken by Cardno (Cardno 2013 & 2014). The aim of Option 1 is to recreate the historical stable beach plan and profile as much as possible in order to limit the level of maintenance required, and therefore reduce long-term costs.

This option involves moving the artificial headland approximately 75 m to the northwest. The new headland location is designed to minimise any change to the beach in Section 1, by moving the structure in line with the existing shoreline to the south. To minimise the downdrift effect of this movement and ‘fill’ the headland, renourishment is required between the new and old positions.

In conjunction with this, Groynes 1 and 2 are to be removed from their present locations and combined into a new groyne, Groyne 1A, immediately north of the car park. Using materials from both groynes, as well as extra materials as needed, the new groyne is designed to extend approximately 80 m seaward of the vegetation line, approximately 20-30 m further than the existing groynes. A recommended higher crest level aims to reduce the level of damage due to overtopping that the existing groynes have experienced since their construction. In the long term this will reduce maintenance requirements and provide a safer, more effective coastal structure. Cardno notes that the crest level of the existing groyne designs were lowered during community consultation, rather than during initial coastal engineering design (pers comm 2013, City of Wanneroo). Renourishment through Sections 2 and 3 up to the new groyne is required to ‘fill’ the new beach compartment and again prevent down drift erosion issues to the north.

The final component of Option 1 is the construction of a new groyne (Groyne 4) 475 m north of Groyne 3. Groyne 4 will extend approximately 55 -80 m offshore. A significant amount of renourishment is again required to fill the resulting beach compartment. The addition of a fourth groyne has been included to halt the significant erosion and vegetation recession that has occurred directly north of Groyne 3 before and after its construction. The location of Groyne 4 was selected to be in line with the larger setback area near the Queens Park amphitheatre, as well as the presence of hard points visible within the dune that may halt or limit recession in lee of the new groyne. Sand stabilisation and associated revegetation would also be included in this option as required.

7.2 Option 2 – Managed Retreat

Selecting a managed retreat option involves the planned removal or loss of assets at risk in the area as coastal processes are allowed to continue without significant additional human interference. With this option, there will be no modification to the existing groyne length and crest level. Erosion during storms will lead to the necessary retreat of the car park in the next few years without constant renourishment.

Cardno (2014) presented vegetation line analysis to predict the likely loss in the next 25 years, based on historic erosion. This indicated that the southern half of the car park will be severely damaged over the next 10 years, and likely to be lost completely in 10-15 years. This cursory inspection did not utilise the WAPC’s guidelines for erosion prediction. If managed retreat was employed further investigation into the recommended coastal foreshore reserve would be required.

This prediction puts Ocean Drive and residential houses at high risk, and forecasts the majority of protective dune system to be removed. It is anticipated that the extent of retreat will reach an equilibrium in the next few years. However, the predicted increase in water levels due to the impacts of climate change may then lead to further retreat.

Selection of a managed retreat option and the resulting loss of the car park and dune vegetation will ultimately reduce the amenity, and thus the worth, of the beach itself. It is noted that construction of structures will also have an impact on the beach amenity.

7.3 Option 3 – Carpark Small Headland & Shift Existing Headland

Option 3 is presented in **Figure 7-1b**. Similarly to Option 1, Option 3 aims to create a stable beach profile. This option also involves shifting the existing headland to the northwest and constructing a fourth groyne in Section 5. However, for Option 3 the existing groynes are upgraded and left in their original location. This option involves the refurbishment of all three groynes in order for them to be functional without the need for regular significant repairs. This will involve the installation of a secondary armour layer to reduce permeability and raise the crest level, as well as repairs to the primary armour layer if required.

To protect the car park, a new artificial headland would be constructed in the middle of Section 3, as shown in **Figure 7-1b**. The additional headland proposed is similar to the existing one at the cusp of Quinns Beach. It is intended to protect the car park and hold renourishment in between Groyne 1 and itself, providing protection for the existing infrastructure currently under threat. It is directly offshore from the northern extent of the car park, placed at a depth of -1 m to -2 m AHD. It is recommended to be constructed with only primary armour. A main benefit of this option is the cost, as the rocks are simply placed in the desired location without the need for core, secondary armour, geotextiles or complicated construction techniques.

As with Option 1, this option has a substantial renourishment, sand stabilisation and revegetation plan. Approximate longitudinal renourishment extents are shown in **Figure 7-1b**.

7.4 Option 4 – Long Groynes & Offshore Breakwaters

Option 4, presented in **Figure 7-1c**, includes the construction of a fourth groyne in Section 5 and the upgrade of groynes 1 to 3 as described in Option 3. This option however proposes to lengthen the groynes out to the closure depth such that the beach compartment between each groyne is essentially closed. Preliminary calculations using the Hallermeier method of the closure depth (Hallermeier, 1980) indicate this varies between -2 and -3 mAHD within the study area. The groynes presented in **Figure 7-1c** are drawn out to the -3 m AHD contour.

Offshore breakwaters would be constructed in Sections 3 and 5 to protect the car park and dog beach respectively. It is likely that multiple structures would be required; lengths and spacing would be examined in subsequent phases of work. The length and spacing on the figures assumes an initial length of 50 m. Preliminary calculations using the method employed in Silvester & Hsu (1999) indicates spacing of 55 m with this length and distance offshore.

As with Options 1 and 3, this option has an associated substantial renourishment, sand stabilisation and revegetation plan. Approximate longitudinal renourishment extents are shown in **Figure 7-1c**.

7.5 Option 5 – Y-shaped Groynes & Offshore Breakwaters

Option 5 is the same as Option 4, but instead of lengthening the groynes, Y or T-shaped nibs would be added to Groynes 1 to 3 such that the overall distance extending offshore matches the length achieved in Option 4. Silvester & Hsu (1999) report that addition of a nib creates a headland that shifts the control point of the groyne out to the ‘headland’ rather than back near the base of the groyne. Two figures from Silvester & Hsu (1999) are presented below; **Figure 7-3** presents the different shapes available to use as nibs, while **Figure 7-4** shows the change in location of the control point.

Again, renourishment is required to “fill” the new beach compartments, as well as associated sand stabilisation and dune revegetation. Approximate longitudinal renourishment extents are shown in **Figure 7-2a**.

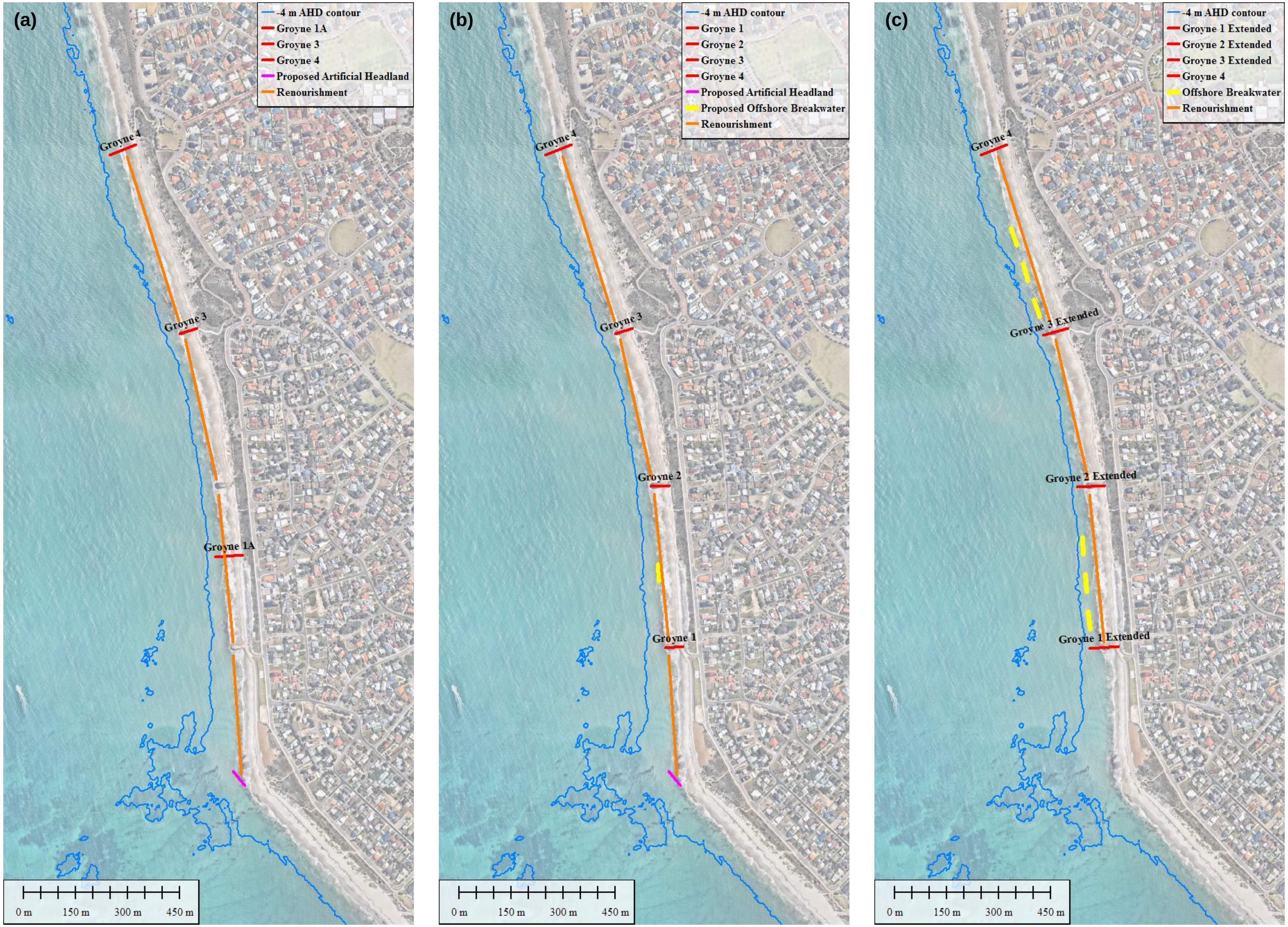

Figure 7-1 Conceptual Option Layouts: (a) Option 1 (b) Option 3 (c) Option 4. Note renourishment lines are indicative only; structures not labelled are removed for that option

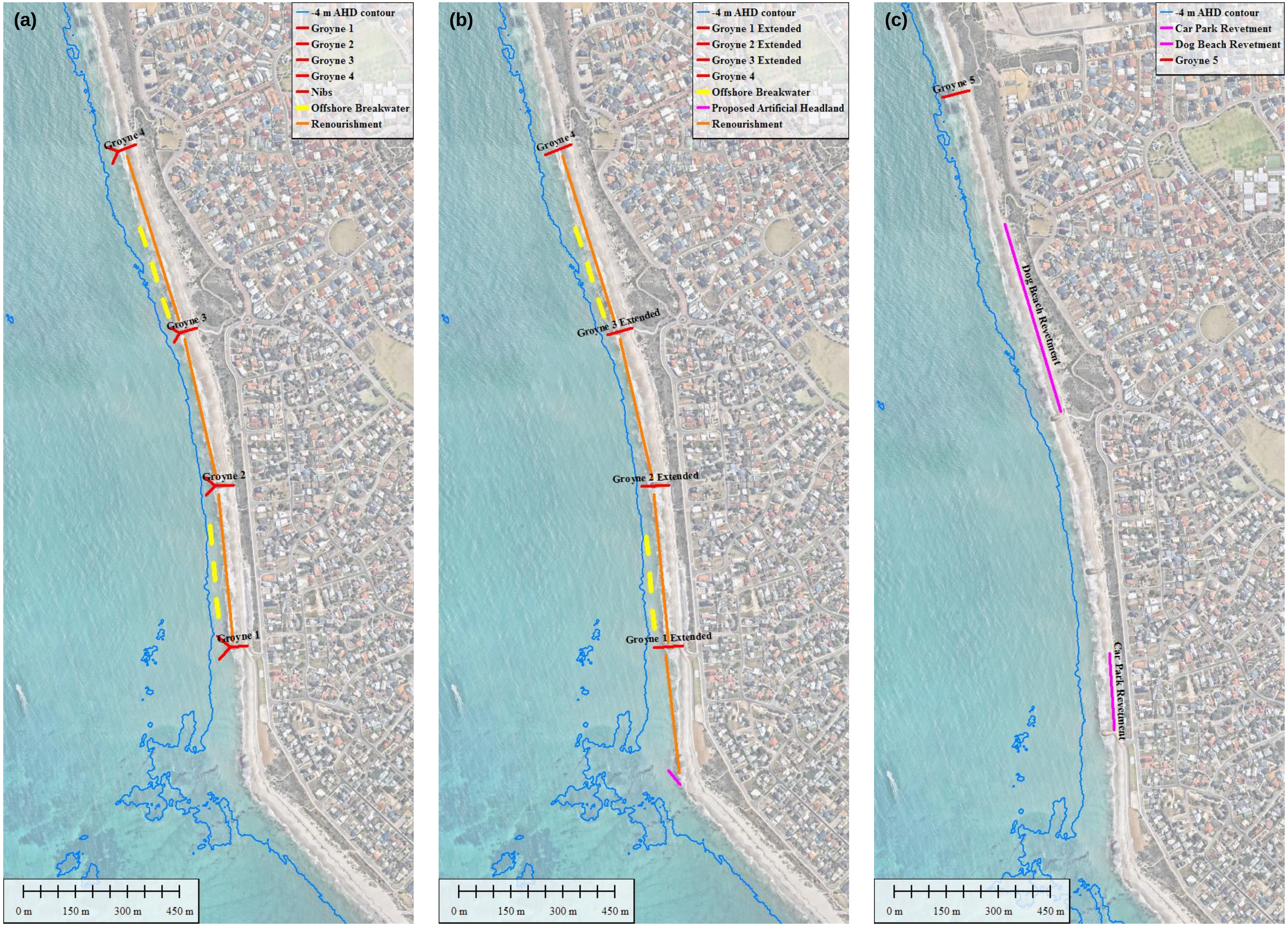

Figure 7-2 Conceptual Option Layouts: (a) Option 5 (b) Option 6 (c) Optional Extras: Groyne 5 and Revetments at Dog Beach and Car Park. Note renourishment lines are indicative only

7.6 Option 6 - Long Groynes, Offshore Breakwaters & Artificial Headland

Option 6 is the same as Option 4, but with the addition of the suggested artificial headland shift and associated renourishment in Section 2. This option will allow the effect of shifting the artificial headland to be clearly observed during the modelling of the next phase, and thus an assessment as to its suitability can be made.

Approximate longitudinal renourishment extents required to "fill" the new beach compartments are shown in **Figure 7-2b**.

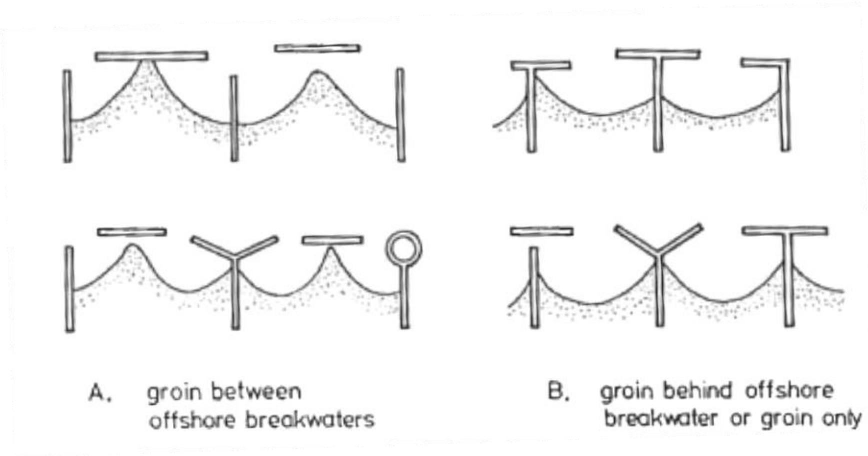

Figure 7-3 General layouts of offshore breakwaters and groynes used in creation of artificial beaches (Silvester & Hsu, 1999)

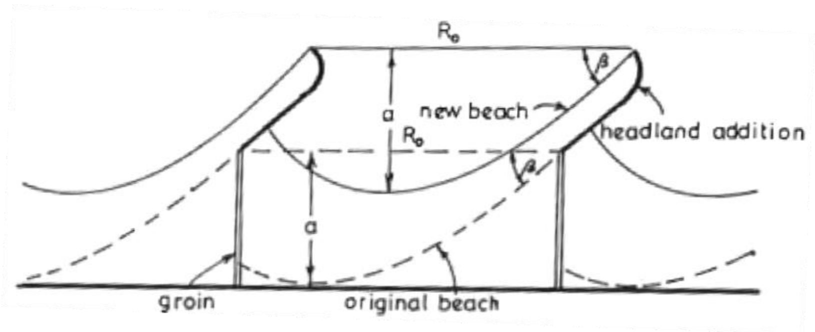

Figure 7-4 Converting groyne to headland to promote stable bay shape formation (Silvester & Hsu, 1999

7.7 Optional Extras

7.7.1 <u>Additional groyne - Groyne 5</u>

It is anticipated construction of the selected coastal management solution will be conducted using a staged approach. If the modelling conducted during the next phase indicates erosion to the north of the suggested groyne 4, there is the option of including Groyne 5, an additional groyne to the north. If the modelling indicates this assists with the coastal management, it may be suggested to be constructed at some time following the initial construction of the management option. The approximate location for Groyne 5 is presented in **Figure 7-2c**. It is located at a beach access point, with relatively wide dune vegetation in its lee to minimise the risk to coastal infrastructure. The limestone at the northern limit of the tertiary cell is approximately 400m to the north.

7.7.2 Car Park Revetment

If the modelling of the four options selected for further analysis indicates erosion seaward of the car park will be too great, there is the option of constructing a revetment seaward of the car park (also displayed in Figure 7-2c: Car Park Revetment). This has not been included in the base options above as it is considered a last resort option due to the potential for loss of beach seaward of the revetment. This is in line with the coastal management recommendations in SPP2.6 (WAPC, 2013).

7.7.3 Dog Beach Revetment

If the modelling of the four options selected for further analysis indicates erosion will be too great along the dog beach in Section 5, there is the option of constructing a revetment seaward of the dune (also displayed in Figure 7-2c: Dog Beach Revetment). This has not been included in the base options above as it is considered a last resort option due to the potential for loss of beach seaward of the revetment. This is in line with the coastal management recommendations in SPP2.6 (WAPC, 2013).

7.7.4 Artificial Reef

A community suggestion, also noted in the City's Coastal Management Plan Part 1 (City of Wanneroo, 2012), was the construction of an artificial reef offshore to assist in storm erosion protection and improve surfing conditions. Studies have shown that construction of artificial reefs give mixed results, varying considerably between sites. From a surfing perspective the considerable attenuation of wave energy that occurs over the two outer reefs will significantly limit the number of surfable days, with most of the long period swell waves most favourable for surfing breaking further offshore. A study by Mariani et al (2013) suggests that the success rate of artificial reefs (in meeting their specified objective is approximately 50%. Their protection during storms is limited due to the presence of storm surge – the waves will 'feel' the structures less and provide minimal protection. Offshore breakwaters provide a similar function, which are included in the above assessment. As such, this option is not considered any further.

7.7.5 Ocean Pool

A community suggestion, also noted in the City's Coastal Management Plan Part 1 (City of Wanneroo, 2012), was to construct an ocean pool at the southern end of Section 1, using existing cliffs as a southern bounding edge. Whilst this option would provide beach amenity, it is not a protection measure so is not considered any further for this study.

7.7.6 Submerged Wave Power Devices

A community suggestion was to construct Bombora wave power devices on the sea bed at intervals along the study area to act as submerged breakwaters and attenuate incident wave energy. Due to the extensive reefs present at Quinns which dissipate a considerable amount of wave energy it is unlikely that these devices could be placed sufficiently close to the shore to provide a somewhat predictable shoreline response, whilst still being efficient as an energy conversion device. In addition at present insufficient published information on their influence on the wave field is available to parameterise in the current modelling systems to facilitate coastal engineering design objectives. As such this is not considered further.

7.7.7 Submerged Barrier Structure

An offshore submerged artificial bar structure was put forward as an option by one of the members at the Community Reference Group meeting. It was envisaged this would have an elevation of approximately 1 m above the seabed, and be located such that it would catch the sediment driven offshore by the jet system of currents. Unfortunately this would have to be extremely large in order to cover the area where the jet occurs. In addition, the dominance of the longshore transport, as opposed to crosshore transport, is such that this would not be appropriate in the study area. A solution of this type would be best suited to a small pocket beach.

7.7.8 Sand Trap Devices

Another community suggestion was to use a sand trap device developed by Green SAB Technology. An example showing the implementation of these devices is shown in **Figure 7-5**. The company website indicates these have been successful in a number of locations in India. They aim to interrupt the suspension of sediment during wave breaking, resulting in settlement of sediment around the structure as the wave breaks or washes over it.

These are not considered further for the following reasons:

> These are unlikely to allow for the seasonal nature of the longshore sediment transport; they are more suited to cross-shore dominant sediment transport processes. Even if sediment completely covers the structures as is shown in **Figure 7-5**, they would likely be exposed again following the next big winter storm event as sand is moved offshore.

> Structures on the beach are not very aesthetically pleasing which is anticipated to be poorly perceived by the public.

> If beach accretion occurs, but doesn't completely cover the structures, they could create a trip hazard to beach users.

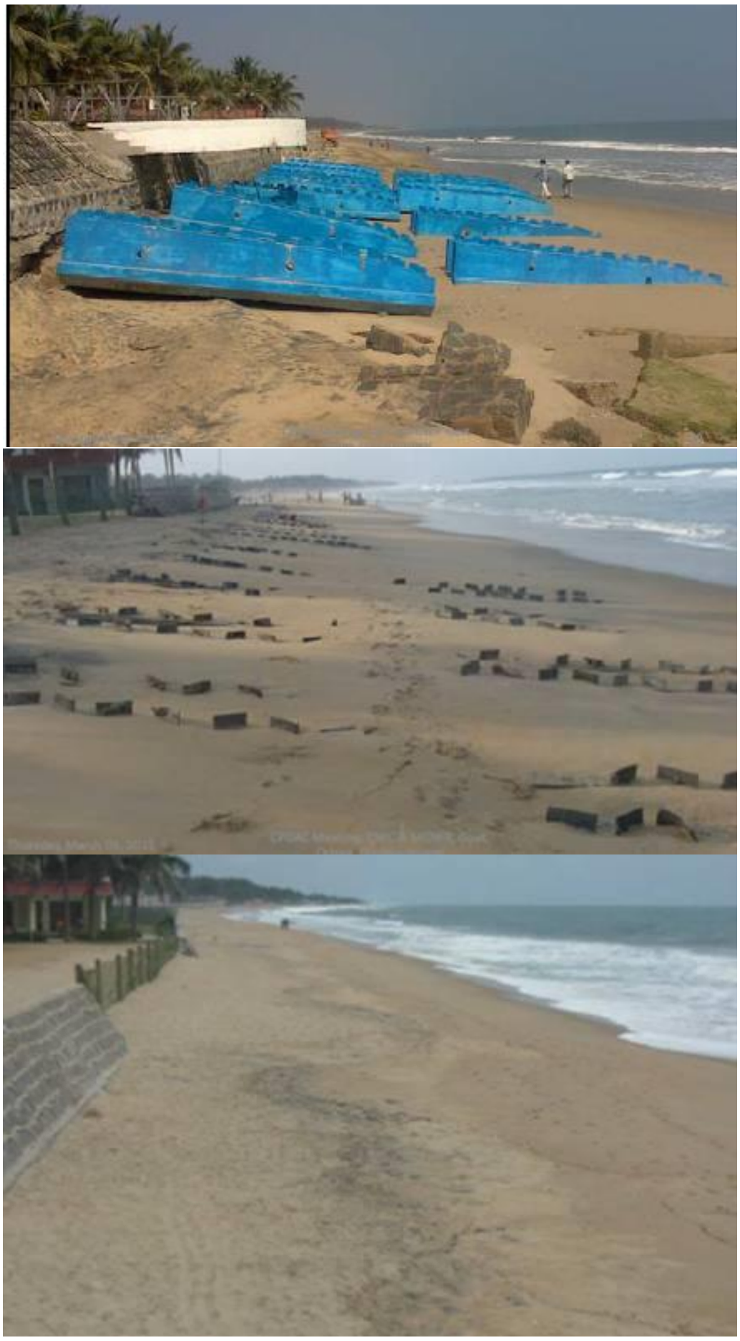

Figure 7-5 Example of sand trap device implementation – pre and post installation

7.8 Options Evaluation

Each option discussed above was evaluated according to the following criteria:

> Public perception
> Environmental impacts / impact on adjacent coastline
> Likely effectiveness
> Capital cost
> Maintenance cost
> Safety

Each criterion was given a score out of 5, as described in **Table 7-1**. Effectiveness was given a double weighting as if an option is not effective in mitigating the coastal hazards, the cost and other criteria were considered less relevant.

Table 7-1 Evaluation rating criteria

Impacts, Capital & Maintenance Cost		Public Perception, Effectiveness, Safety	
Rating	**Description**	**Rating**	**Description**
1	Very High	1	Very low
2	High	2	Low
3	Moderate	3	Moderate
4	Low	4	High
5	Very Low	5	Very High

Table 7-2 below presents the evaluation matrix for the options. Options 1 and 2 score the lowest. Option 1 received a low public perception score as Cardno understood from discussions with the City that the removal of Groyne 1 would not be well received by the community. In addition, the City has just spent considerable funding repairing Groyne 1 as part of the 2014 immediate coastal protection works. The increased knowledge regarding the coastal processes in the study area indicates that this option would not be suitably effective for the study area.

Option 2, managed retreat, was also given a low score for public perception due to the community's desire to maintain a useable beach for as long as possible. The costs of beach and infrastructure loss would be high, even though the initial capital cost would be low for this option. The resulting coastline would be unsafe for the public.

Options 3 to 6 received similar scores. They differed purely in estimates of relative capital cost. Modelling is required to differentiate the effectiveness of the option. All solutions include multiple structures so the public perception is considered to be fairly similar. The lower safety scores for Options 4 to 6 are due to the potential for rip currents landward of the offshore breakwaters which are a danger to swimmers. It should be noted that it is possible for rip currents to be associated with groynes also.

Table 7-2 Evaluation matrix

Solution Option	Protection Solution						
	Public Perception	Impacts	Effectiveness	Capital Cost	Maintenance cost	Safety	Total
1	1	3	2	3	3	2	16
2	1	2	1	5	1	1	12
3	3	4	3	3	3	2	21
4	3	3	4	2	3	2	21
5	3	4	4	2	3	2	22
6	3	3	4	2	3	2	21

7.9 Analysis

Further to the description and evaluation presented above, in Table 7-3 below is a summary of advantages and disadvantages for the top 4 evaluated options. The disadvantages listed are greater in number than the advantages purely to highlight potential issues that must be considered during the analysis in the next phase of the project.

Table 7-3 Option advantages & disadvantages

Solution Option	Advantages	Disadvantages
3	-Lower capital cost than Options 4 to 6. -Shift of artificial headland may recreate historical beach planform, and thus reduce pressure on Section 2. -Groyne 4 may assist in holding sediment in Section 5. -Protection of car park due to presence of small additional artificial headland in Section 3	-Existing groynes are too short to hold the required sediment within each compartment given their present spacing. -Shift of artificial headland may lead to erosion immediately to the north, and in Section 1. -Possibility of a new pinch spot forming north of new Groyne 4. As the dune retreats the existing hard points may make access along the beach difficult. -Small additional headland may not be sufficient to protect the car park.
4	-Increased groyne length will form closed compartments to retain sediment within the system during extreme events. -Offshore breakwaters retain sediment to form a wider beach. -Groyne 4 may assist in holding sediment in Section 5.	-Community concern over larger groynes. -Potential for rip currents to occur in lee of the offshore breakwaters. This could be a potential danger to swimmers. -Possibility of a new pinch spot forming north of new Groyne 4. As the dune retreats the existing hard points may make access along the beach difficult. -Less natural sand bypassing due to longer length of groynes
5	-Increased groyne length will form closed compartments to retain sediment within the system during extreme events. -Offshore breakwaters retain sediment to form a wider beach. -Presence of nibs may assist in erosion pinch spots adjacent to groynes, by shifting the control point out to the base of the nib. -Groyne 4 may assist in holding sediment in Section 5.	-Community concern over higher groynes. -Construction of Y-shaped nibs is more expensive than lengthening the groynes. -Possibility of a new pinch spot forming north of new Groyne 4. As the dune retreats the existing hard points may make access along the beach difficult. -Potential for rip currents to occur in lee of the offshore breakwaters. This could be a potential danger to swimmers. Less natural sand bypassing due to longer length of groynes.
6	-Shift of artificial headland may re-establish historical beach planform, and thus reduce pressure on Section 2. -Increased groyne length will form closed compartments to retain sediment within the system during extreme events. -Offshore breakwaters retain sediment to form a wider beach. -Groyne 4 may assist in holding sediment in Section 5.	-Community concern over higher groynes. -Possibility of a new pinch spot forming north of new Groyne 4. As the dune retreats the existing hard points may make access along the beach difficult. -Shift of artificial headland may lead to erosion immediately to the north, and in Section 1. -Less natural sand bypassing due to longer length of groynes.

8 Conclusion

Sediment transport at Quinns Beach forms a complex system resulting from the spatially variable nearshore wave climate. Waves propagating from offshore shoal, break, refract and diffract across the reefs. The wave shoaling and breaking results in wave setup over the shallower reef areas which drive complex circulations and sediment transport pathways within the reef system.

The SWAN wave model was calibrated for the Quinns Beach system and a 10 year hindcast of nearshore wave conditions developed for the extent of the study area. The highly modified nearshore wave field consequently results in significant along coast variations in sediment transport in the cross shore and longshore directions. The cross shore and longshore sediment transport present at Quinns Beach shows significant seasonal variability, with sediment transported off the beach and to the south in winter and onto the beach and to the north in summer. The littoral drift due to the oblique waves is interrupted by the presence of several coastal structures which create strong local gradients in sediment supply, the result of which are erosion ‘hotspots’ at several locations within the study area. Due to the seasonal reversals in sediment transport direction, these locations are particularly sensitive to longer term climatic fluctuations in updrift sediment supply, meaning that erosion events are often associated with a long period of antecedent conditions that lead to additional vulnerability of that section of coast.

A long term shoreline evolution model (LitPACK) was developed and validated against measured beach survey data and demonstrated that significant variation in longshore transport is present throughout the study area due to variation in coastal orientation and nearshore wave angle with significant inter-annual fluctuations.

Hydrodynamic modelling of a storm event, in conjunction with data analysis, has identified the important role that the near shore reefs play in establishing sediment transport pathways that carry sediment away from the active beach zone during successive storm events. Some of this sediment is then progressively, over a number of years, transported into large sand banks to the south west of Mindarie for example which act as sediment sinks.

Survey data analysis since the most recent construction of three groynes indicates that the Quinns Beach system continues to have a deficit in sediment supply, with ongoing erosion of dunes and beach nourishment balancing the loss of sediment offshore.

On the basis of the measured data analysis and numerical modelling a sediment budget has been developed for Quinns Beach. The key features of the sediment budget are:

- Up to 60,000 m^3/yr (gross) of longshore transport annually with a net northward drift of approximately 3,000 – 5,000 m^3 to the north, but with significant inter-annual variability in direction and magnitude.
- Approximately 80,000 m^3/yr (gross) of cross shore sediment transport at the beachface, offshore in winter and back onshore in summer (40,000 m^3 per season)
- Approximately 25,500 m^3 per year lost to offshore sediment sinks within the reef system
- Dune erosion has supplied (on average) 5,500 m^3/yr into the beach system over the past 10 years.
- Limited littoral drift connectivity between Quinns Beach and the adjacent alongshore tertiary sediment cells to the north and south.

The analysis and models developed through this stage of the work will be utilised for additional assessment of potential options to mitigate the erosion experienced at Quinns Beach. A conceptual review of coastal management options has been performed with various options proposed by the community and in previous studies assessed though a qualitative multi-criteria assessment. On the basis of this assessment, Options 3 through 6 are recommended for further assessment. These options include a range of potential layouts of coastal structures which will be assessed using the calibrated numerical models. The components of each option that are found to be effective in improving the resilience of the shoreline to erosion and minimising sand nourishment requirements will then be carried forward to detailed design and optimisation in a later stage.

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APPENDIX A

METEOROLOGICAL AND METOCEAN DATA TIMESERIES (2014)

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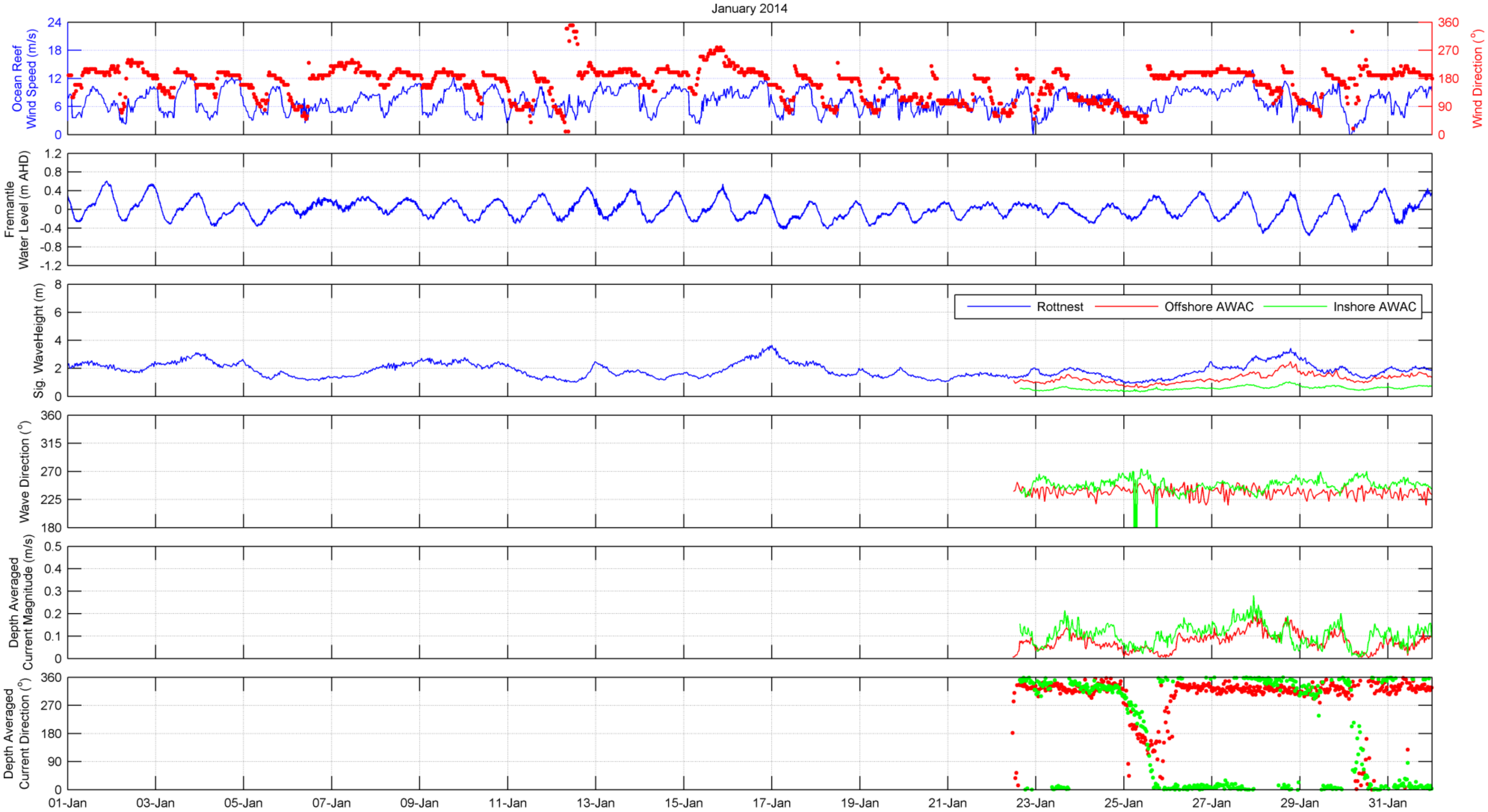

Figure A-1 Plot of measured metocean data during January 2014.

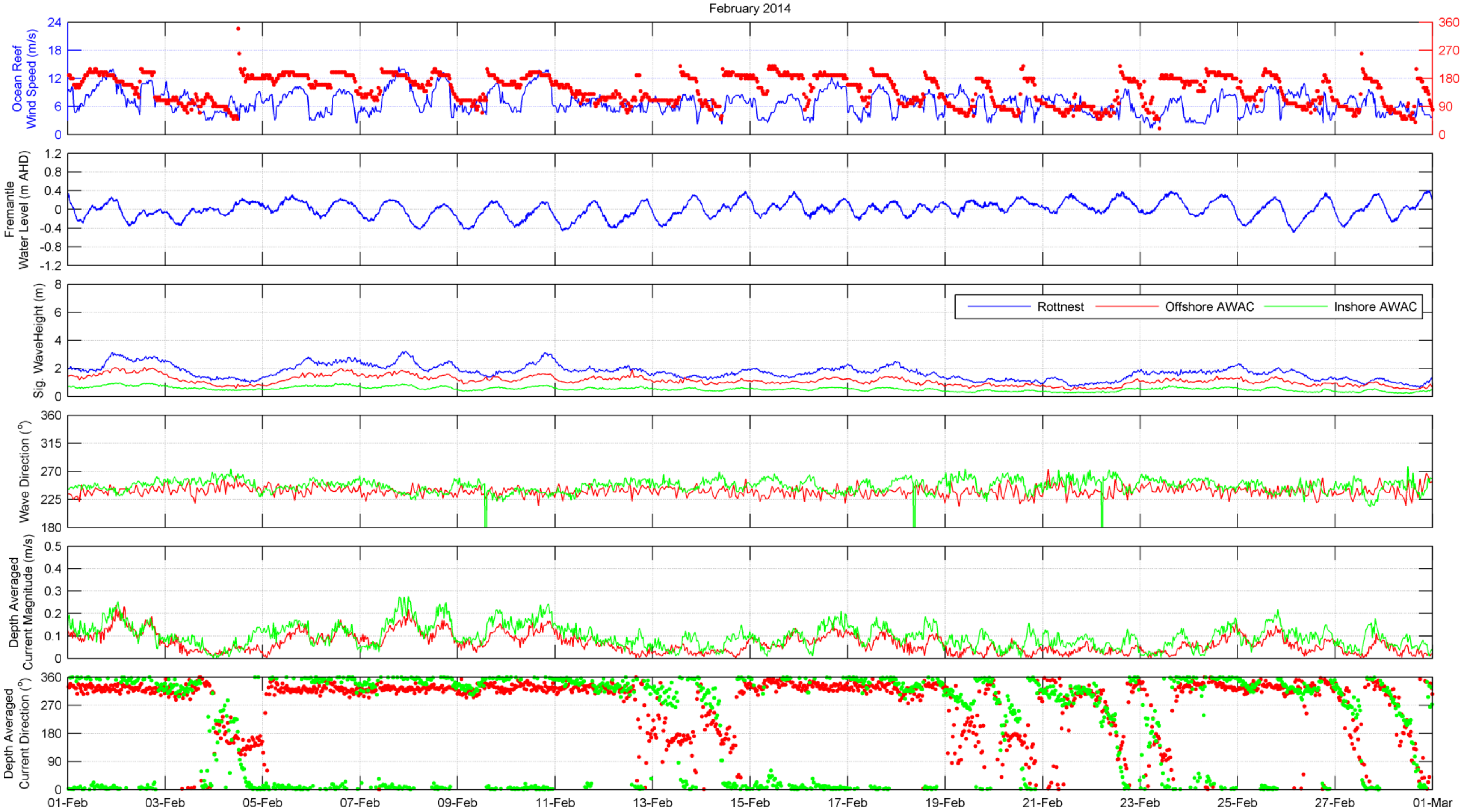

Figure A-2 Plot of measured metocean data during February 2014.

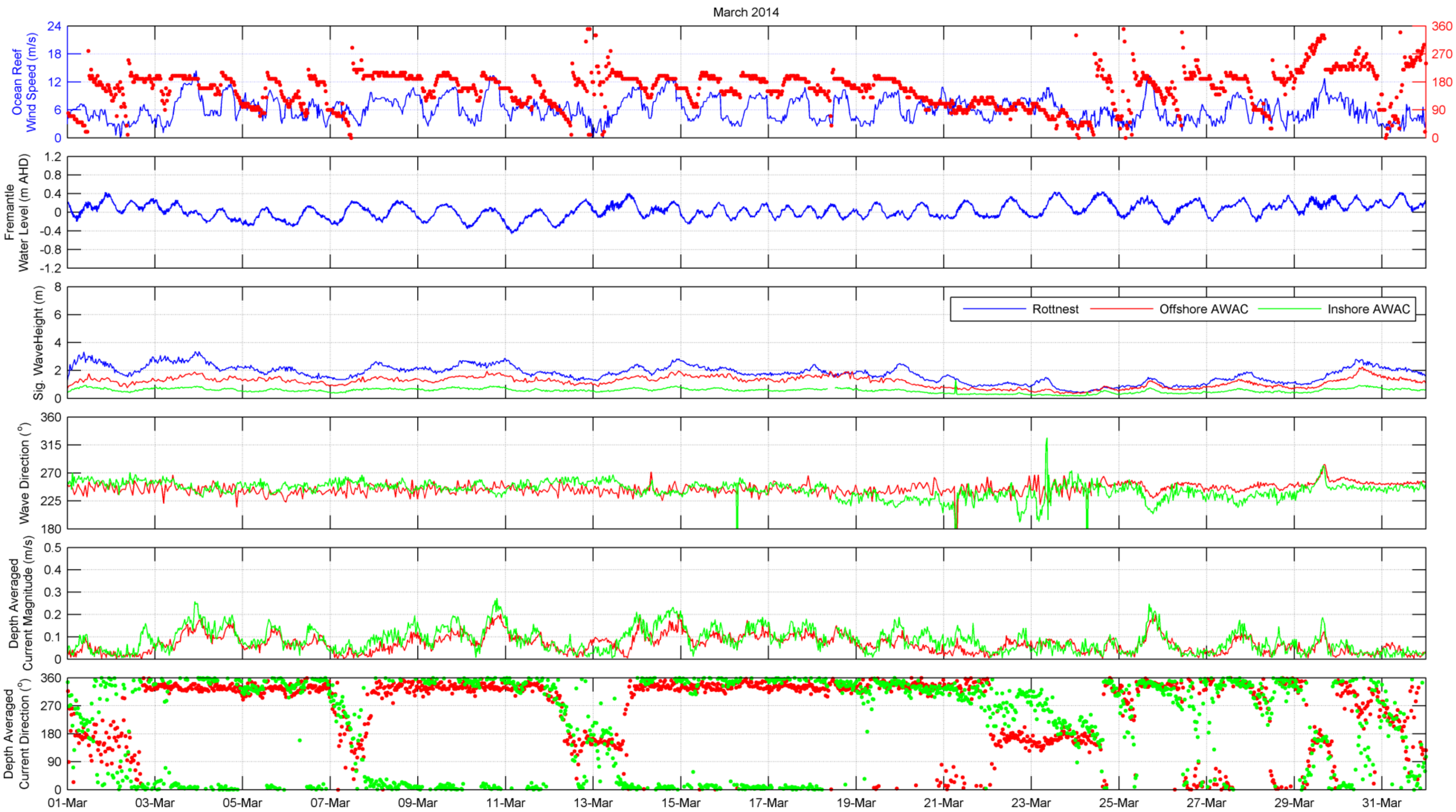

Figure A-3 Plot of measured metocean data during March 2014.

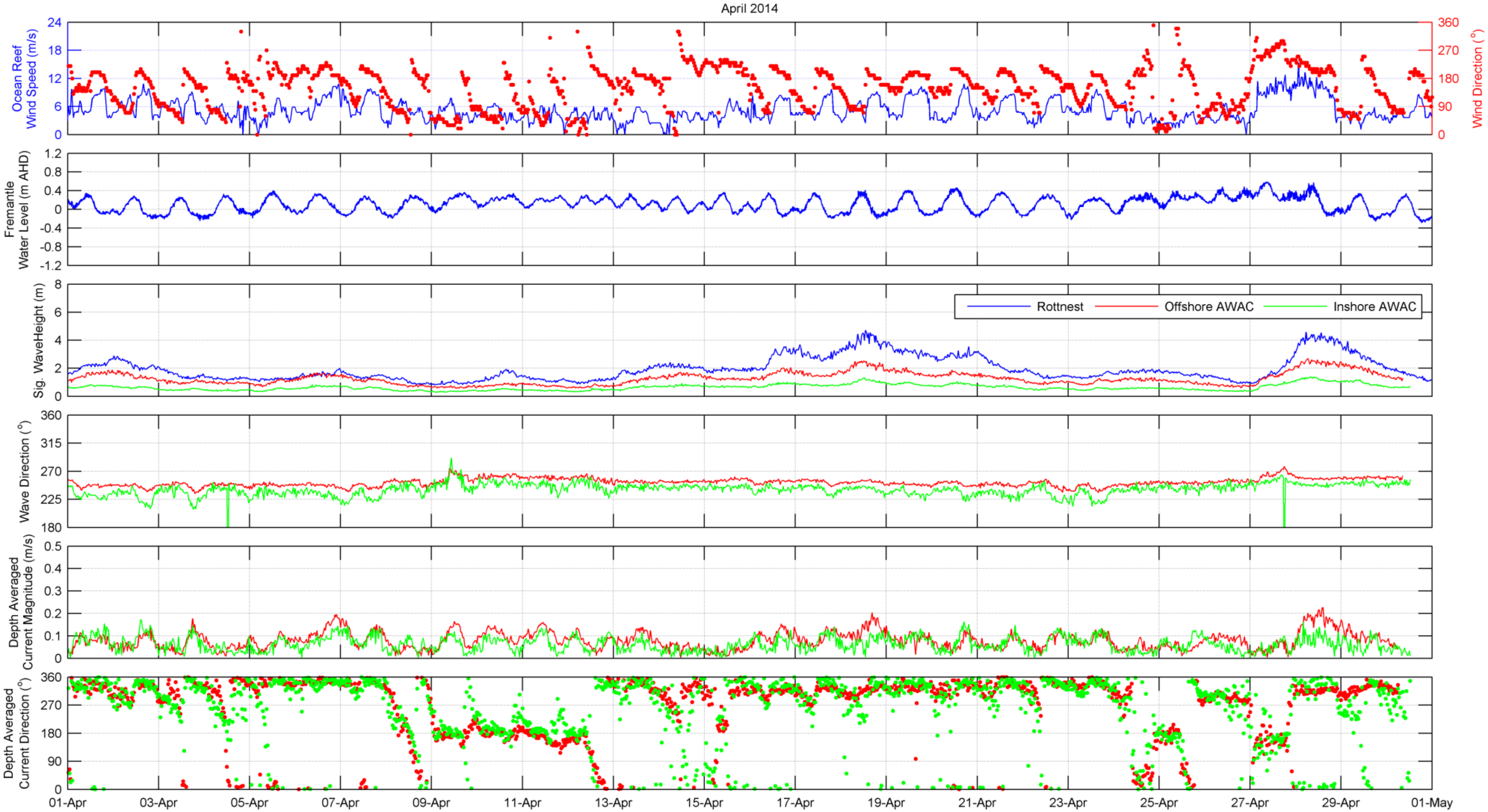

Figure A-4 Plot of measured metocean data during April 2014.

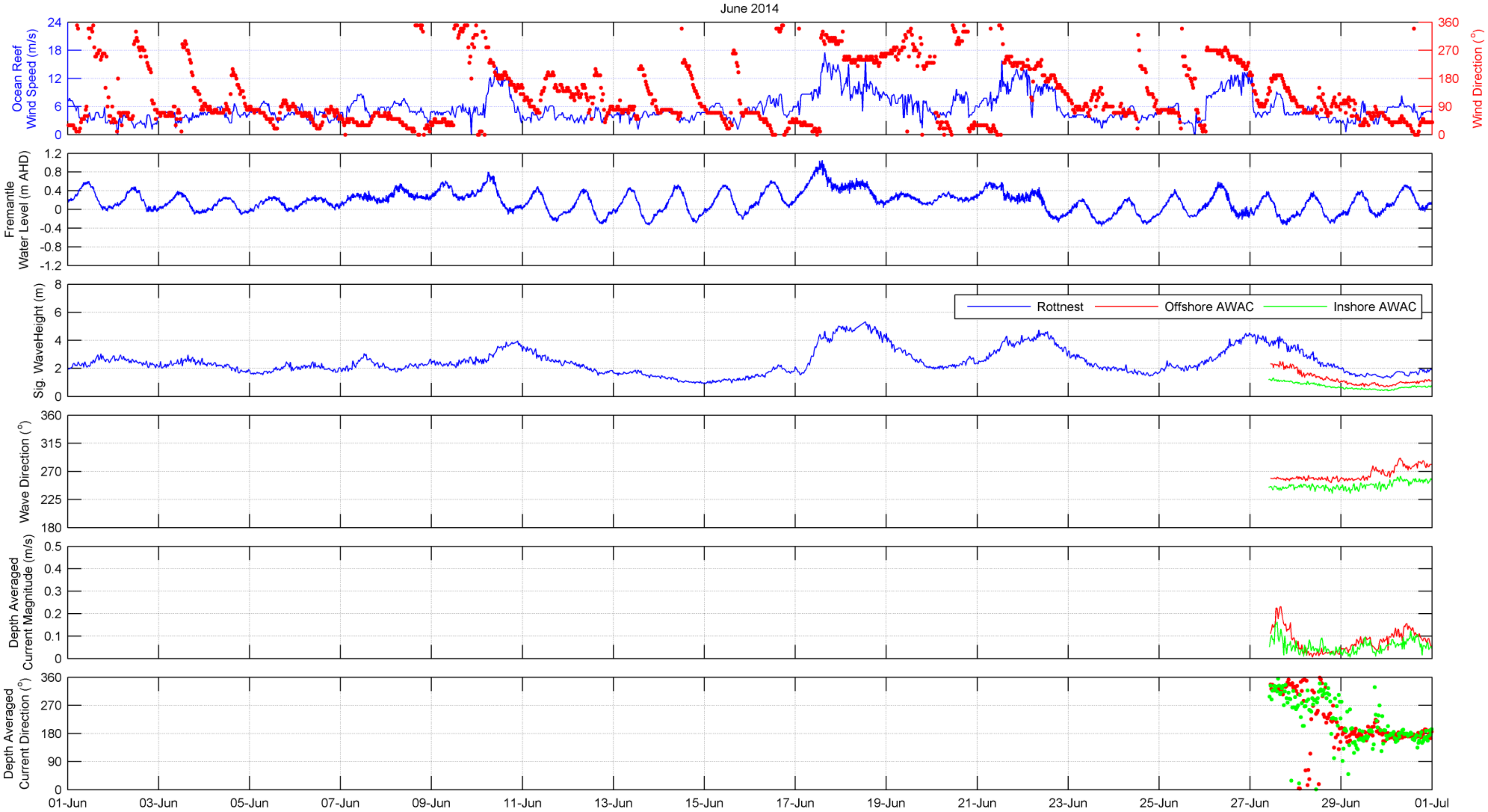

Figure A-5 Plot of measured metocean data during June 2014.

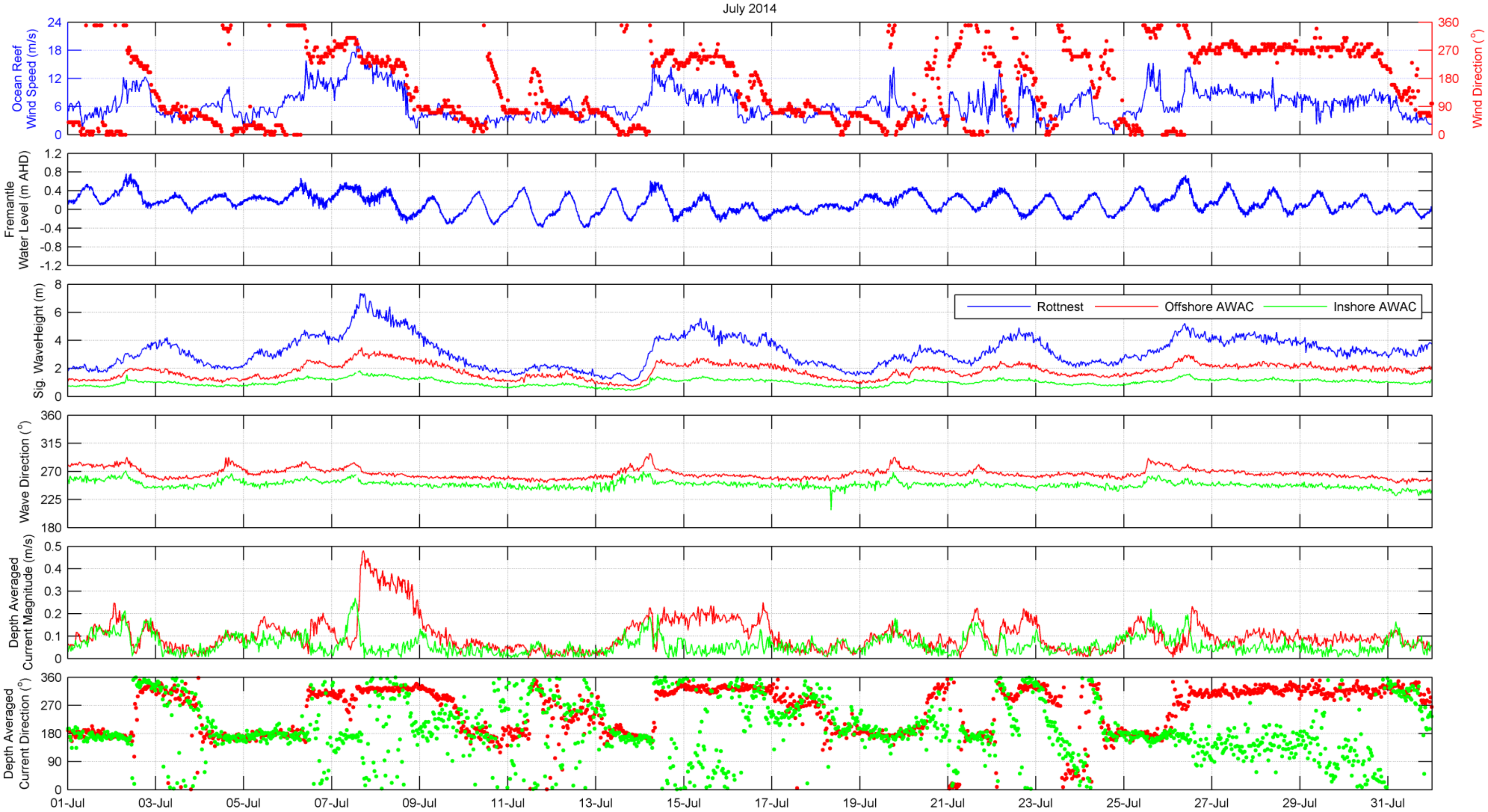

Figure A-6 Plot of measured metocean data during July 2014.

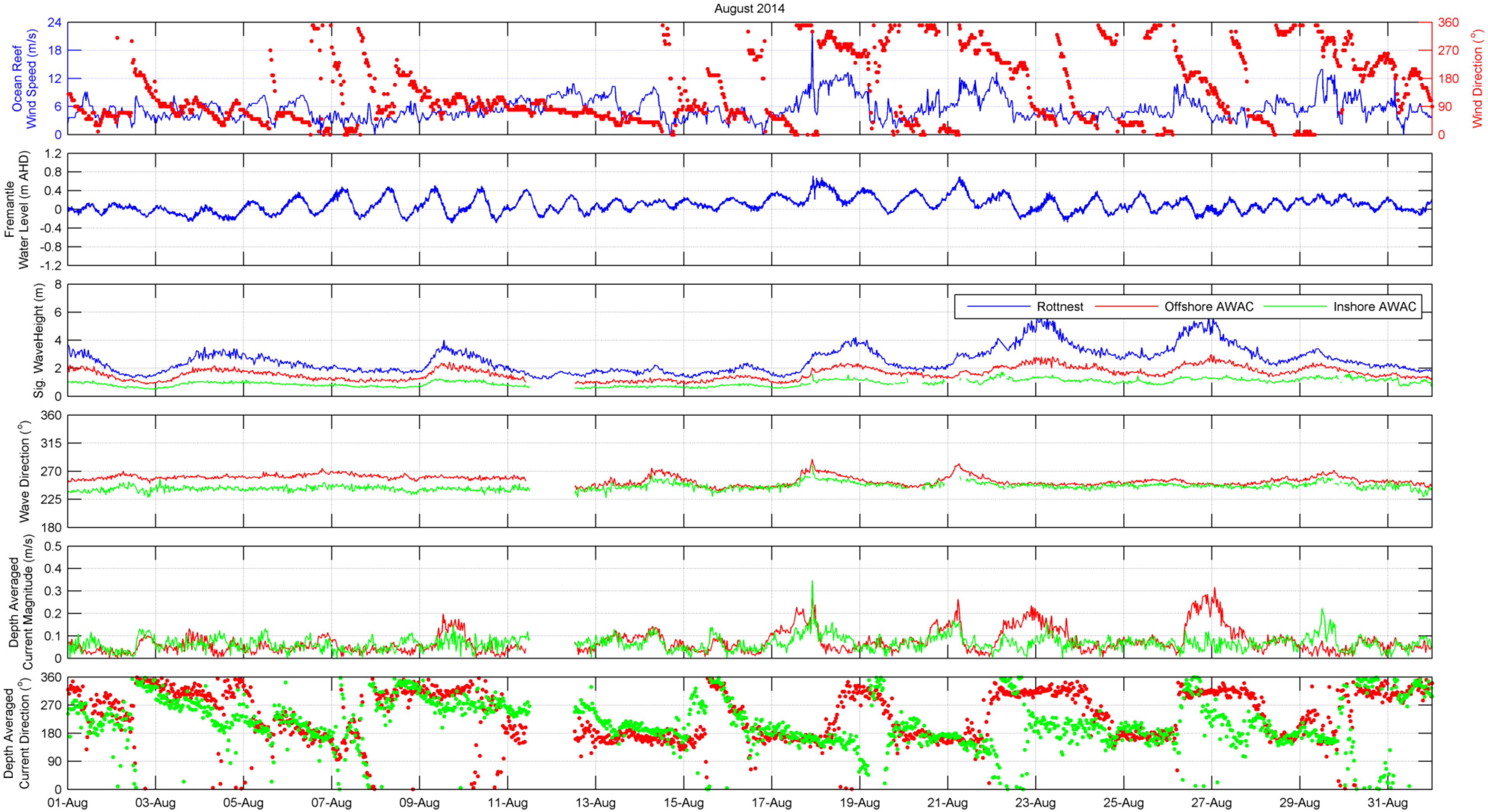

Figure A-7 Plot of measured metocean data during August 2014.

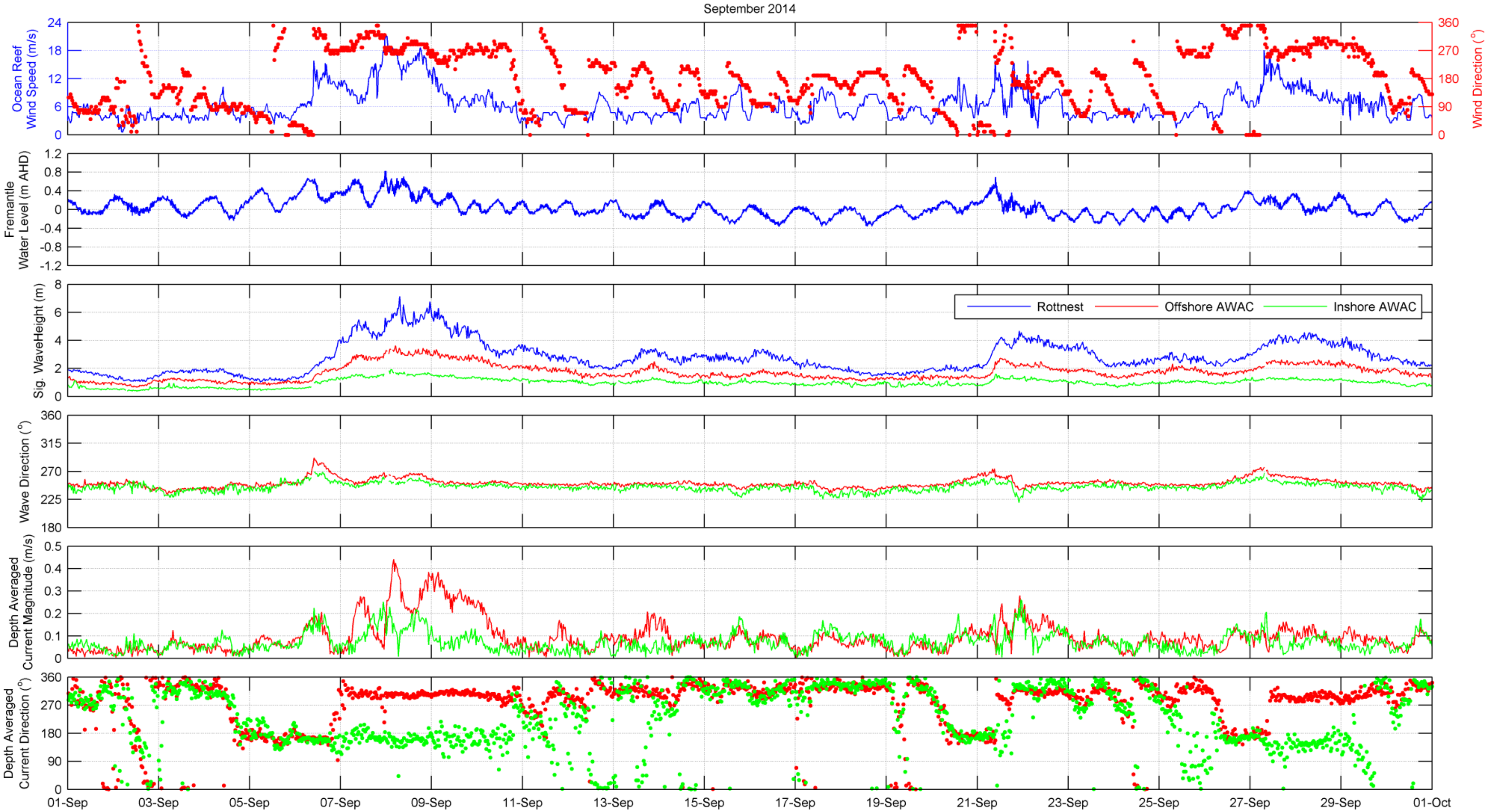

Figure A-8 Plot of measured metocean data during September 2014.

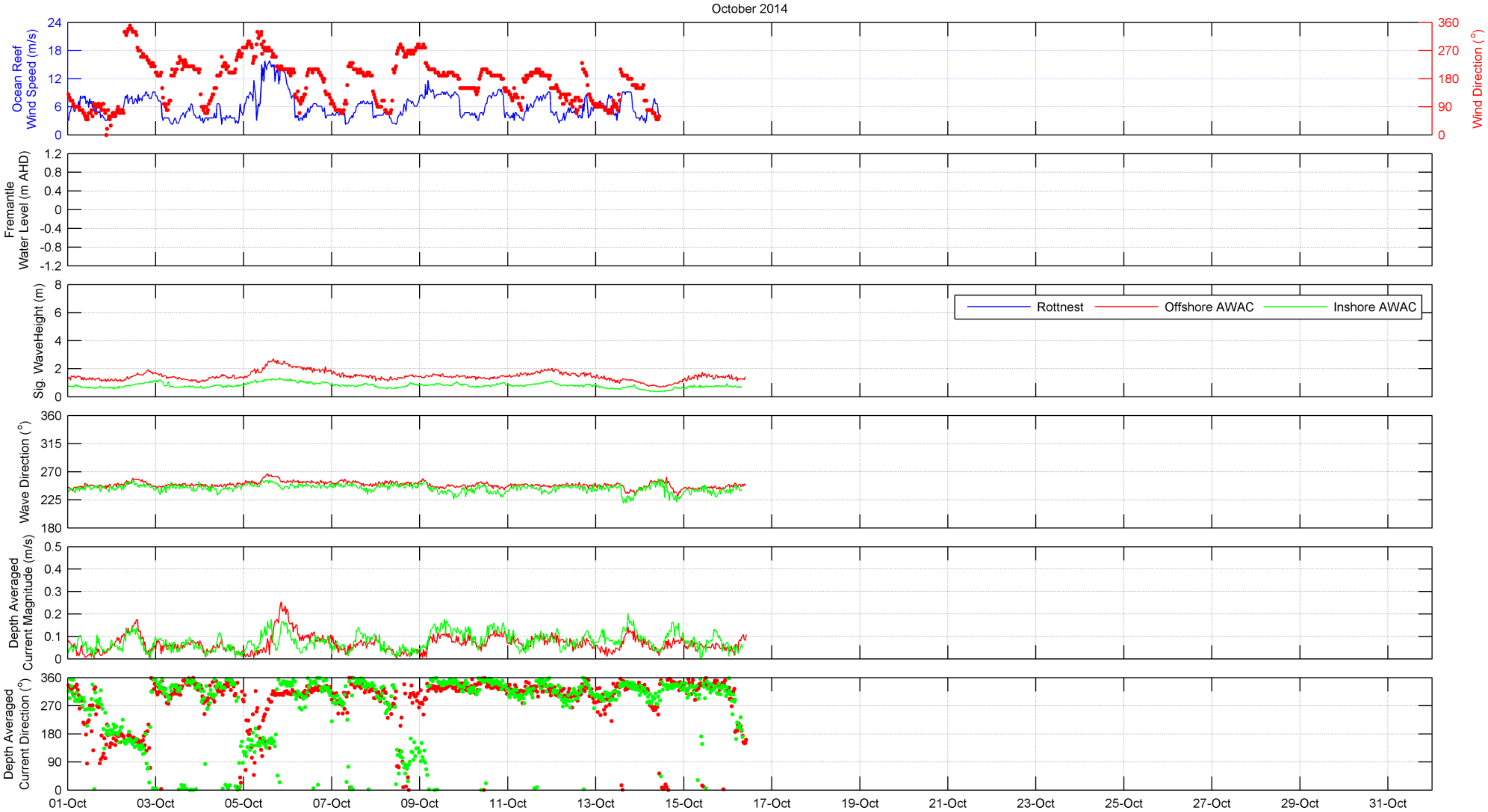

Figure A-9 Plot of measured metocean data during October 2014.

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APPENDIX B

SURVEYED SHORELINES (2014)

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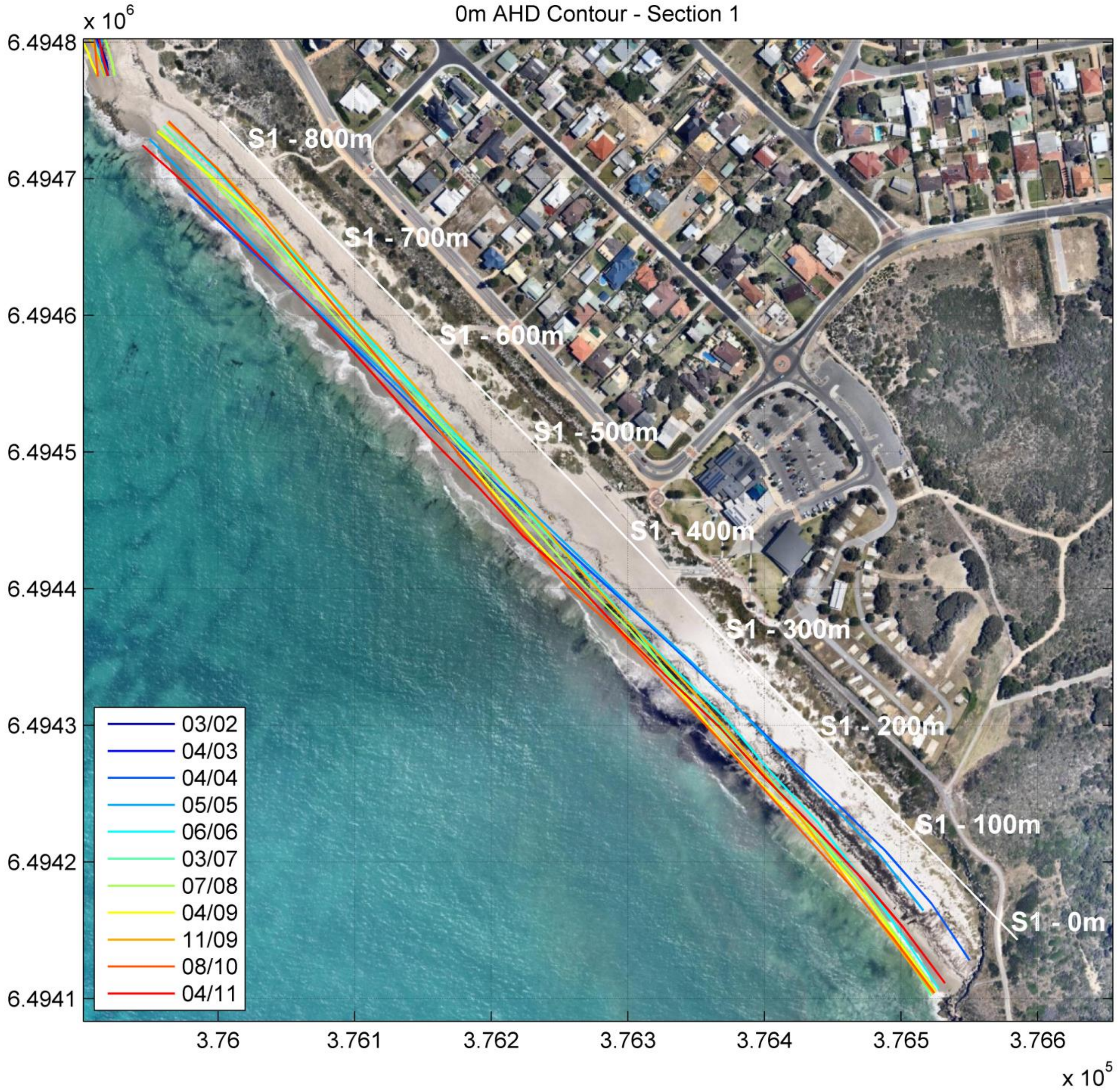

Figure B-1 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in Section 1. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

Figure B-2 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in Section 2. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

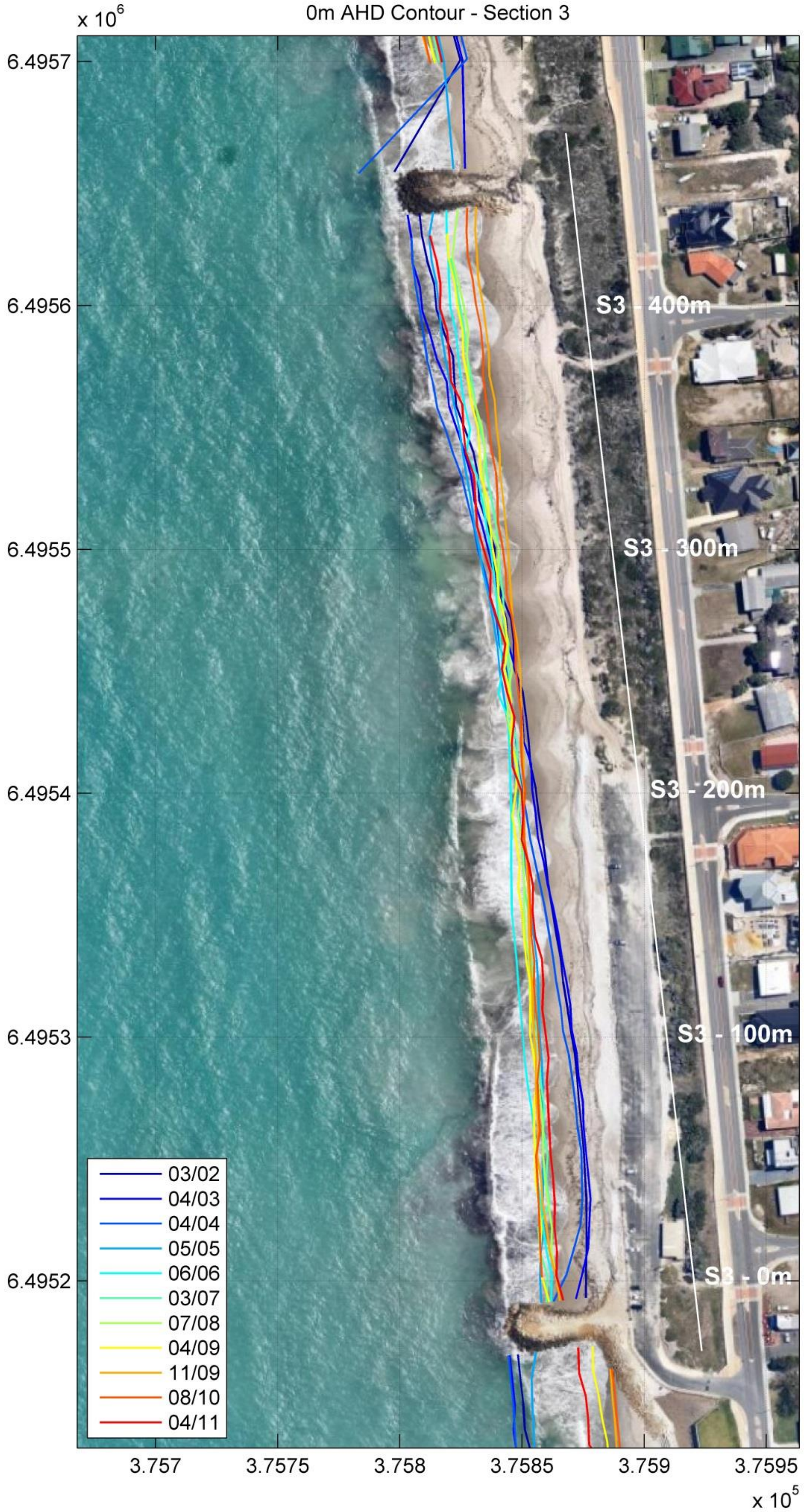

Figure B-3 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in Section 3. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

Figure B-4 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in Section 4. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

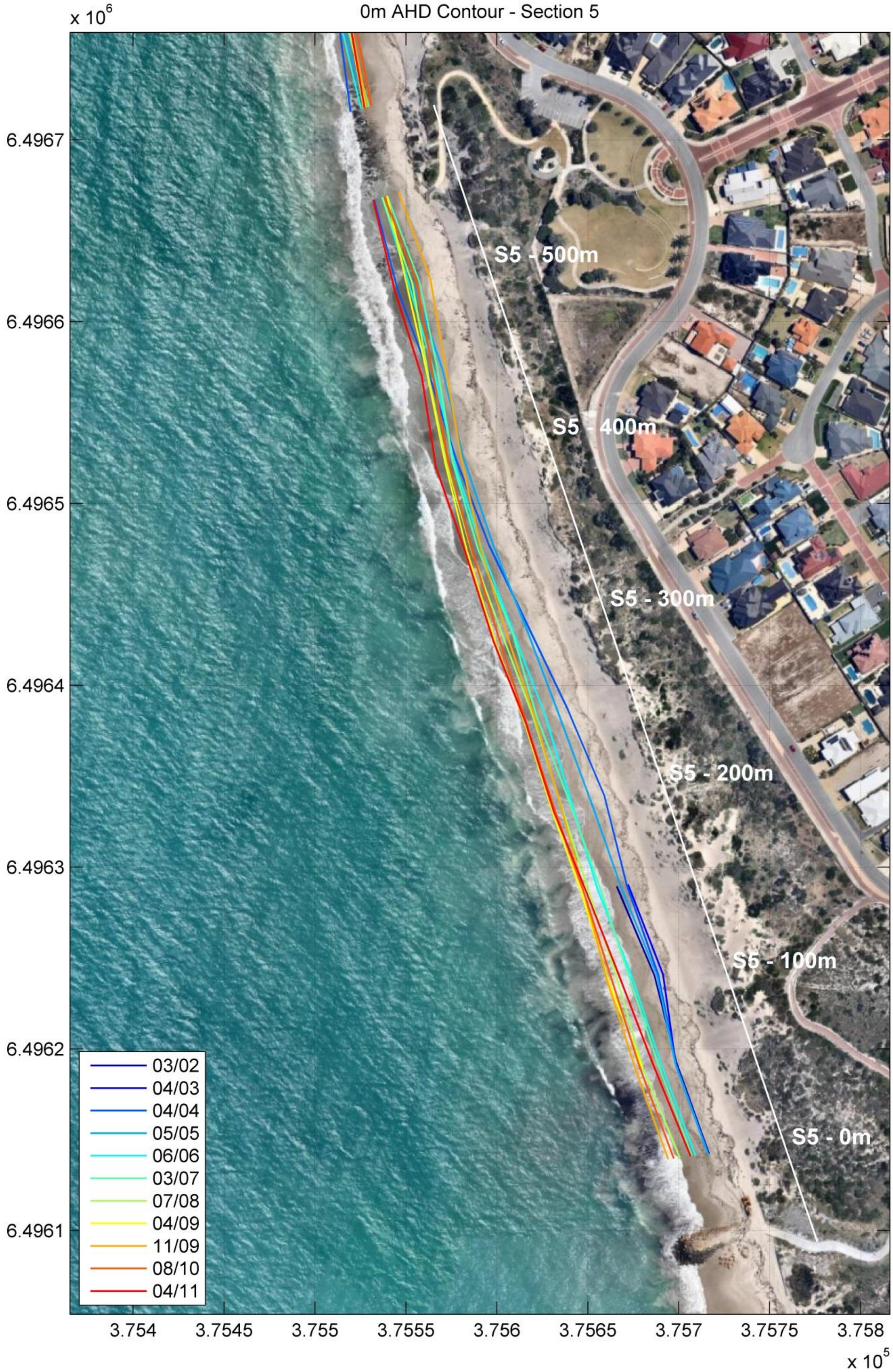

Figure B-5 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in Section 5. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

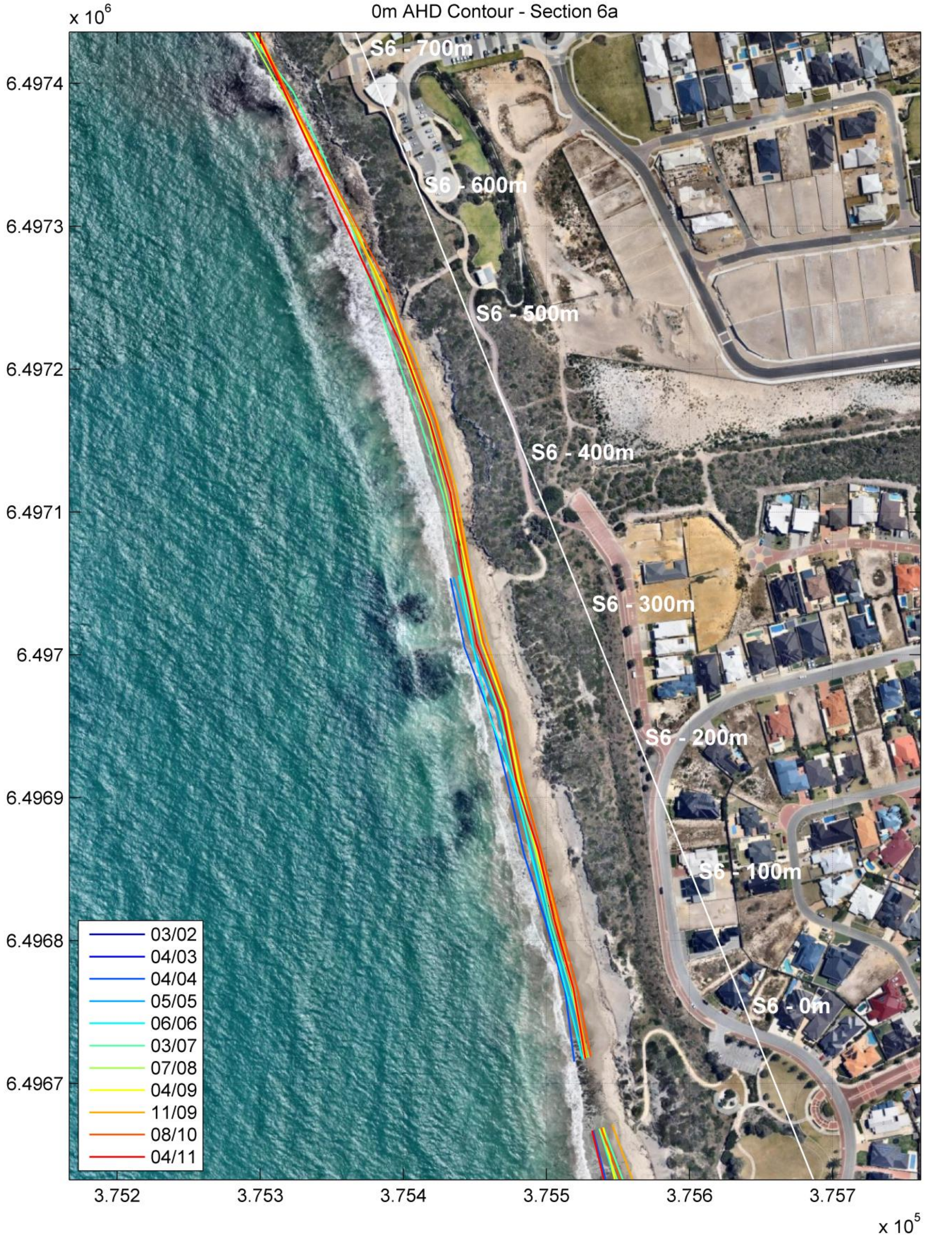

Figure B-6 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in the lower half of Section 6. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

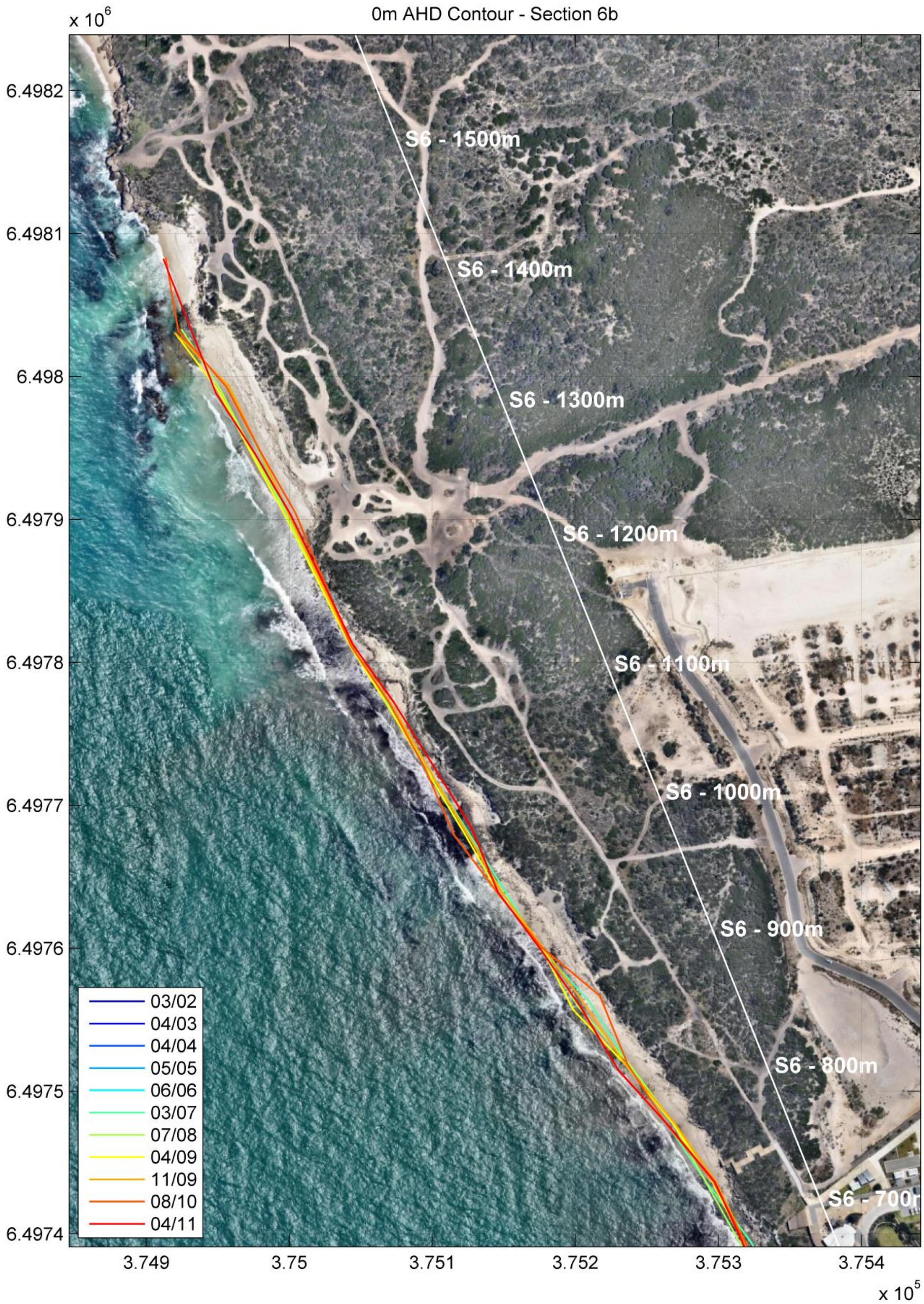

Figure B-7 Plot of 0 m AHD contour line derived from beach survey data for February to November 2014 in the lower half of Section 6. The white line is the baseline with chainage along this line shown. The aerial photo background is from November 2014.

Figure B-8 Vegetation lines transects utilised in the analysis of vegetation trends between 1969 and 2014

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APPENDIX C
FATAL FLAW MODEL COMPARISON

Shaping the Future

C. Appendix C

This appendix presents the interim results from a fatal flaw model assessment to determine the most appropriate model to use for storm erosion and morphology at Quinns Beach. The XBeach and Delft3D models were assessed. The model setup and results presented here are at reduced spatial extent and resolution compared to those presented in the main body of the report. In addition, these results include a bug associated with wind stress in the XBeach model that was subsequently identified and fixed by Cardno.

C.1.1 Model description

Delft3D is a model that solves the shallow water flow equations on a rectilinear or curvilinear grid. It has numerous modules that compute a range of processes including hydrodynamics (D-Flow), waves (D-Waves) and morphology (D-Morphology). It has a unique two way interface with the D-Waves (SWAN) wave model where by radiation stresses are included as a forcing term for the hydrodynamic model and D-Flow water levels and currents influences are included in the wave model. This allows for the introduction of wave driven currents and water level setup and the inclusion of their influences on sediment transport and morphology. It should be noted that forcing due to waves is effectively the 'average' influence of the wave processes over a 15 – 30 minute period. Delft3D performs well where alongshore transport processes are dominant, however, not as well for cross shore transport (Trouw, 2012). The so called 'two-way' coupling that is possible between D-Flow and D-Waves is of critical importance in modelling the hydrodynamics affected by the complex reef system offshore from Quinns Beach.

D-Morphology makes use of the results of the D-Flow and D-Waves modules and is able to be executed in an 'online' mode wherein changes to the bed morphology due to sediment transport subsequently influence the modelled waves and currents. The sediment transport module supports both bed load and suspended load transport of non-cohesive sediment. Beach profile change is accomplished through activation of 'dry cell' erosion to maintain realistic erosion of beaches and dunes.

XBeach is a 2D morphological model developed specifically to assess the time varying response of coastlines to storm and tropical cyclone conditions. It has specific formulations for dune erosion, overwash and breaching. Differing to Delft3D, XBeach does not model the short waves directly, rather it uses the results of SWAN to calculate and apply a non-stationary (time varying) long wave boundary condition to the model and then solves the propagation of the short wave envelope, non-stationary shallow water equations, sediment transport and morphology (Roelvink et al, 2009). Avalanching is used to model dune erosion and cross-shore transport is calculated specifically from a balance of onshore transport by wave skewness and asymmetry and offshore transport by return flow. Whilst XBeach includes the influence of wind on the hydrodynamics, it does not include the processes associated with wave growth within the model domain.

C.1.2 Model setup

C.1.2.1 Model grid

A curvilinear grid was designed to follow the coastline, with local grid refinement through the study area and adjacent to the shoreline. At the offshore boundary end of the grid, the grid cells were parallel to the -27 metre contour line. The Delft3D grid, shown in Figure C-1, extends offshore to the -27 metre AHD contour line. Laterally the Deflt3D grid covers the area from Burns Beach to Jindalee. The XBeach model has a smaller domain, extending only out to the -23 metre AHD contour line and 1 kilometre North and 2 kilometres South of the study area. The high variability of the bathymetry due to the reef systems caused instability issues at the boundaries of the initial Delft3D grid. These issues prompted the extension of the Delft3D model domain.

Both grids had a fine resolution along the beach and within the nearshore area in order to resolve the morphological processes along the beaches in the study area. The grid resolution of 5 metre cross-shore and 15 metres alongshore enabled a reasonable representation of the non-erodible structures which impact on the sediment transport: the groynes, the revetment, the headland and the limestone cliffs. Resolution gradually increased up to 100 metres at the offshore boundary. The coarser size shortened computational run times while still reproducing the effects of the limestone reefs.

C.1.2.2 Simulation period and timestep

The simulation period started on 04 September 2014 and ended on 11 September 2014. The period, which involved a storm, that affected Quinns Beach on 08 September 2014, would enable short term erosion changes to be observed in the study area. Cardno carried out beach surveys before and after the storm. The measured changes due to the storm have been used to calibrate and validate the numerical models.

The time step used in the Delft3D model is dependent on the Courant number in each grid cell of the model domain. The Courant Number is given by the following equation (Deltares 2011):

$$\text{Courant Number} = (\Delta t \sqrt{gH})/(\{\Delta x, \Delta y\})$$

Where Δt is the time step, g is the acceleration of gravity, H is the water depth and $\{\Delta x,\Delta y\}$ is the minimal value of the grid spacing in either direction. Given the chosen grid cell size, and the requirement to keep the Courant Number below approximately 10, the time step was set to be 3 seconds for the Delft3D model. The time steps for XBeach were not manually entered as XBeach automatically calculates the time steps based on the Courant criterion.

C.1.2.3 Boundary conditions

Flow Boundary Conditions

The models were bound by 3 open boundaries: West, North and South boundary.

The West offshore boundary consisted of time series water level data from the Fremantle tide gauge. The model extent and the unavailability of metocean data measurements, North and South of the domain meant that forcing conditions at the lateral boundaries were unknown. A Neumann boundary condition was applied on the North and South boundaries. This boundary condition allows the specification of a ‘zero gradient’ boundary condition, allowing wind and wave driven currents to flow freely out of the domain.

Wave Boundary Conditions

D-Waves, the wave component of Delft3D, and the XBeach model use the SWAN 2D output from the wave modelling runs (**Section 5.3**) at the model boundaries (offshore and lateral).

Wind Boundary conditions

Spatially constant and temporally varying wind data was applied to both models. Wind data from the Bureau of Meteorology’s (BoM) stations at Swanbourne, Ocean Reef, Rottnest Island, Garden Island, Mandurah, Bunbury and Lancelin were interpolated onto the coarse grid using an inverse-square weighting approach, whereby the wind u and v components at any given point is the weighted mean of the measured winds. The weights are inversely proportional to the square of the distance from each station. All wind data was 10 minute averages 10 m above ground level.

C.1.2.4 Sediment transport parameters

The Delft3D model adopted the van Rijn (2007) sediment transport model for non-cohesive sediments while the sediment transport formulation of Soulsby-van Rijn (Soulsby, 1997) was utilised in the XBeach model. Both models used the initial sediment thickness map shown in **Figure C-3**. No initial sediment was applied to Spearwood reef ridge and the offshore region. Sediment transport in the offshore region (approximately beyond the -6mAHD contour line) is irrelevant to the storm erosion modelling; the sediment transport models were therefore limited to changes on the beach and up to the closure depth. The limestone rocks along Sections 5 and 6, the groynes, the headland, the GSC revetment and the Mindarie Marina did not contribute to the sediment budget and therefore had zero metres of sediment. The nearshore area where Spearwood reef was not present had 3 metres of sediment allocated. For the area from the beach to the closure depth (about -5mAHD), a constant thickness of 5 metres was added to the bed level so as to mimic the equilibrium beach profile; there was no sediment at closure depth (-5mAHD + 5 metres) while the beach, at an elevation of 3mAHD for example, had 8 metres of sediment.

The sediment composition varies considerably at Quinns Beach; the median grain size varied from 283 µm to 444 µm with an average of 340 µm. A median grain size of 340 µm was used in both the Delft3D and the XBeach model. The latter model enabled the inclusion of a D90 value of 500 µm.

C.1.2.5 Other parameters

The bed friction, for both model domains, was defined by the constant Chezy coefficient of 55 $m^{1/2}/s$.

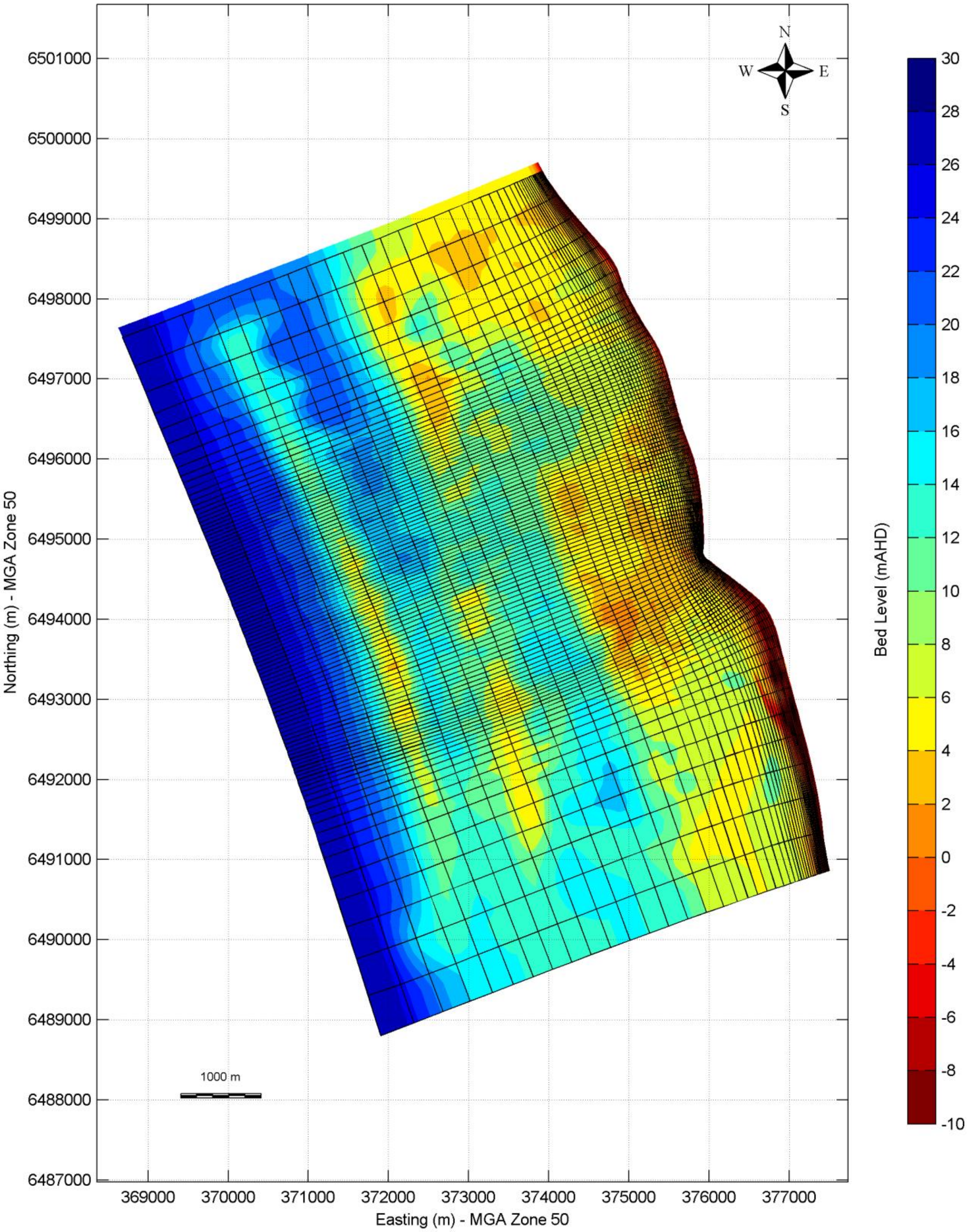

Figure C-1 The grid set up and bathymetry used in the Delft3D model. LiDAR was used from the 5mAHD depth to the offshore boundary, October 2014 Hydrographic survey was used in the nearshore area and Cardno's Pre-September-Storm Survey complemented by the Dynascan Survey was used for the beach area. Note that for display purposes the grid has been de-refined by a factor of 3, i.e. 3 grid cells are represented by 1 grid cell.

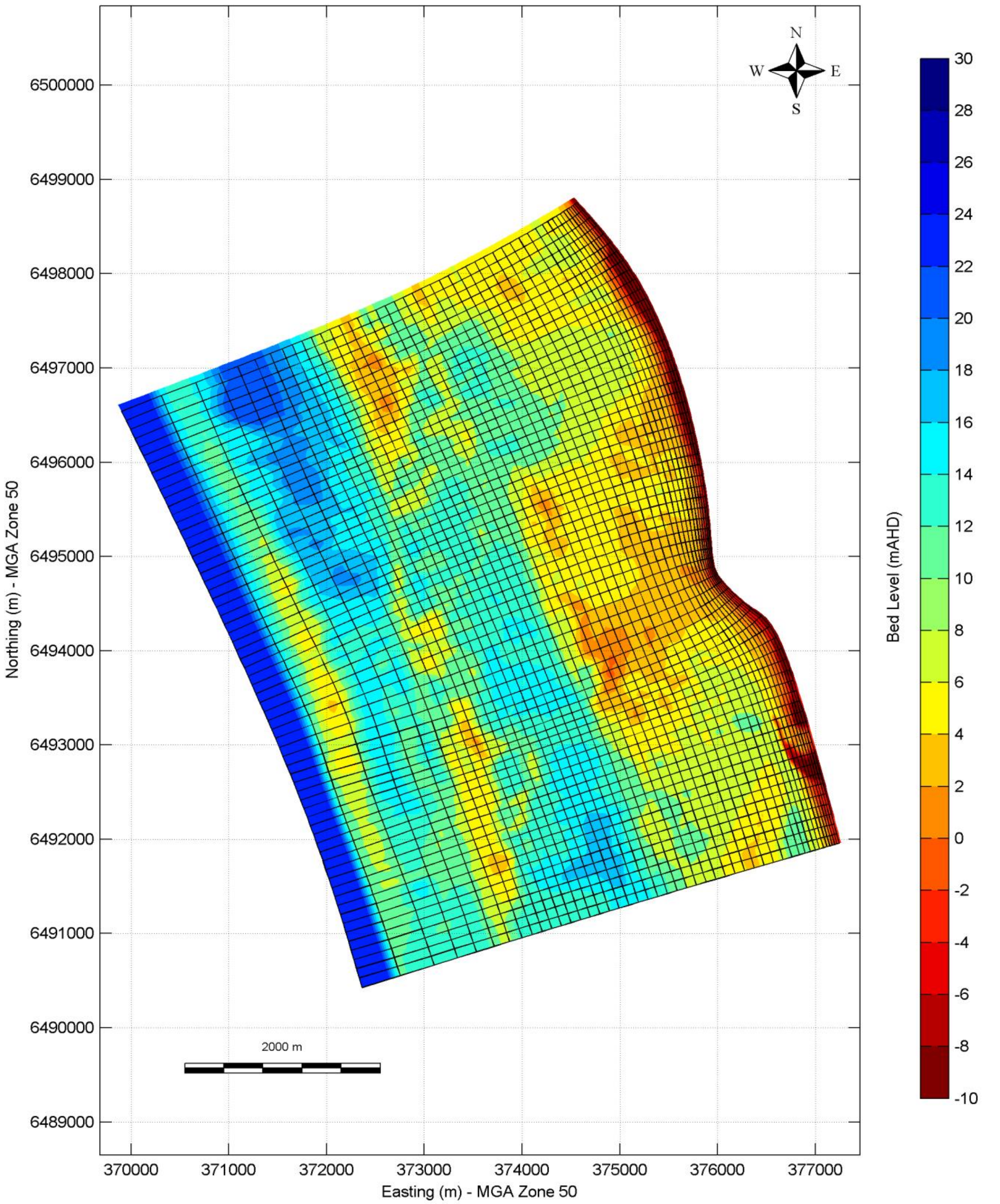

Figure C-2 The grid set up and bathymetry used in the XBeach model. LiDAR was used from the 5mAHD depth to the offshore boundary, October 2014 Hydrographic survey was used in the nearshore area and Cardno's Pre-September-Storm Survey complemented by the Dynascan Survey was used for the beach area. Note that for display purposes the grid has been de-refined by a factor of 3, i.e. 3 grid cells are represented by 1 grid cell.

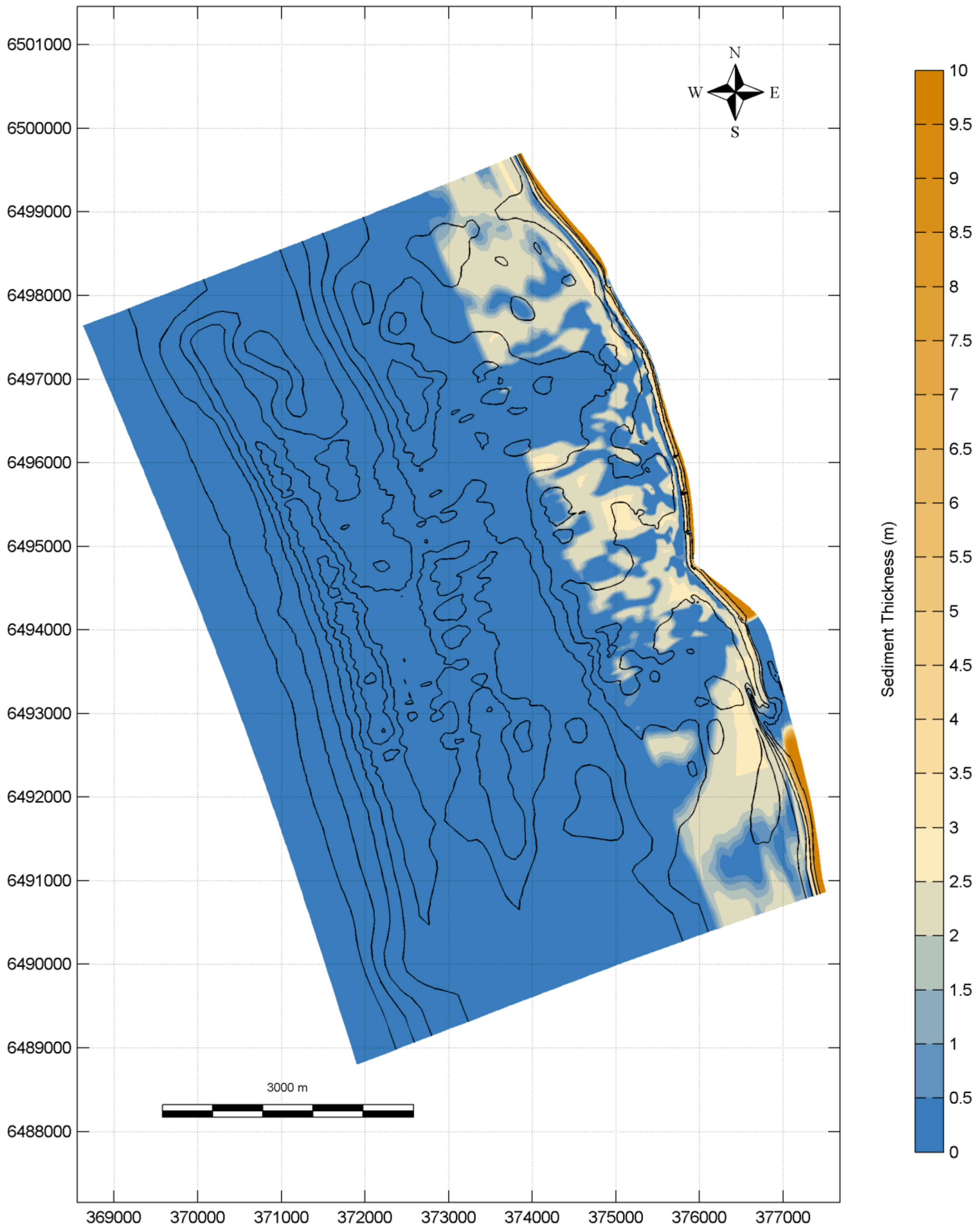

Figure C-3 Initial sediment thickness used in both models.

C.1.3 Modelled Currents

Figure C-4 and **Figure C-5** present the time series plots of the modelled and measured current at the offshore and Inshore AWAC locations respectively. When the wind speed was higher during the storm (from the 07 September), the models overestimated the depth average velocity by (approximately) 0.5 m/s at the offshore location. At the inshore location the current was slightly overestimated in the XBeach model while the Delft3D model reproduced closer estimations of the velocities. The models correctly replicated the current direction at the offshore location during the storm. The current direction at the nearshore location was not well reproduced, with XBeach predicting northward currents, whilst southward currents were measured and the Delft3D model oscillating between northward and southward currents.

Figure C-6 shows the vector current variations, modelled through Delft3D and XBeach. The model extents of the XBeach model were limited due to long simulation times. The model currents at the Inshore location in XBeach are driven by wave setup on Quinns Rocks. The Delft3D model extends over some of the reefs offshore of Alkimos (at approximately 6498000 m N) the setup on this reef likely establishes a water level gradient that forces the flow over Quinns Rocks towards the south. Both models predicted the formations of complex recirculation zones driven by wave setup on the reefs.

Along the beach where modelled current is more critical, both models produced southward currents in the littoral zone (< 5m depth) at the peak of the storm on 07 September 2014 (**Figure C-7**). The XBeach model produced higher currents along the beach (above the 0 mAHD contour line).

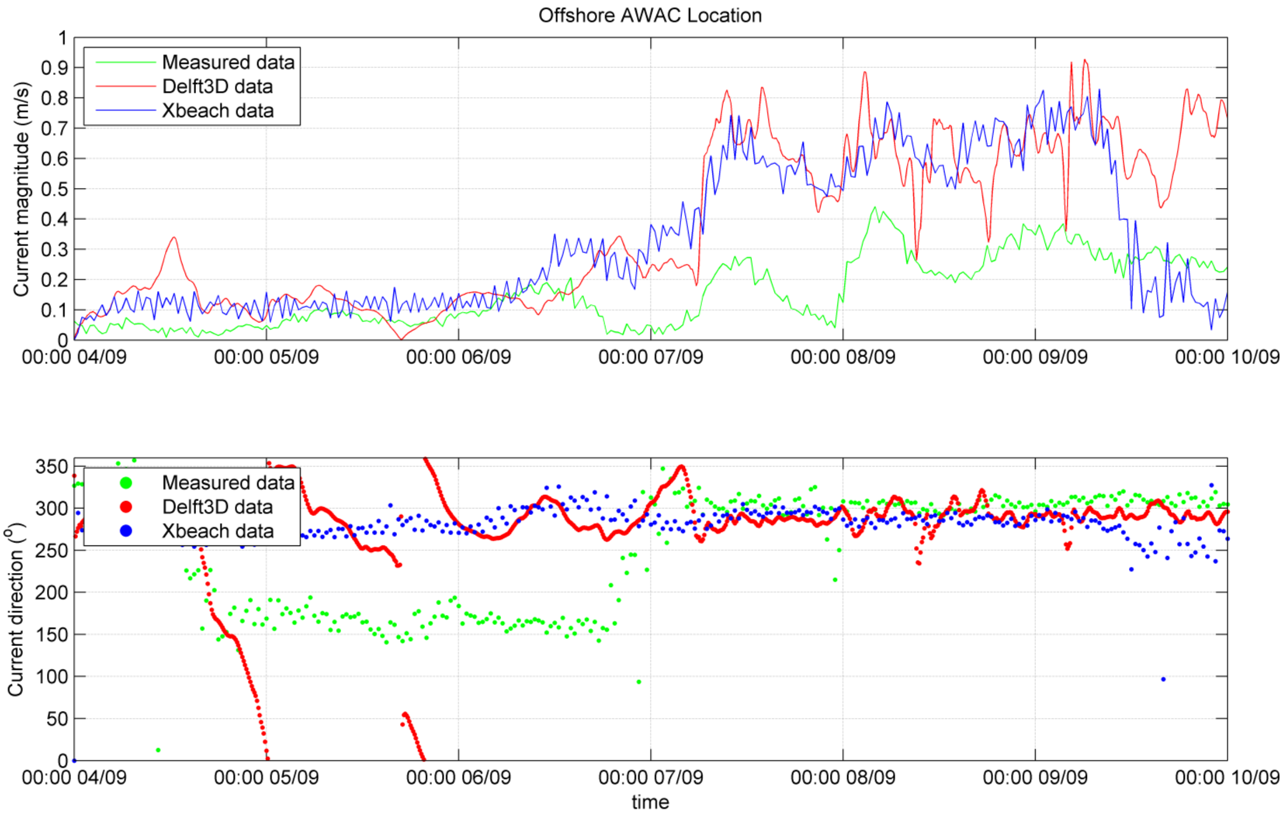

Figure C-4 Measured and modelled depth average current data at the Offshore AWAC location

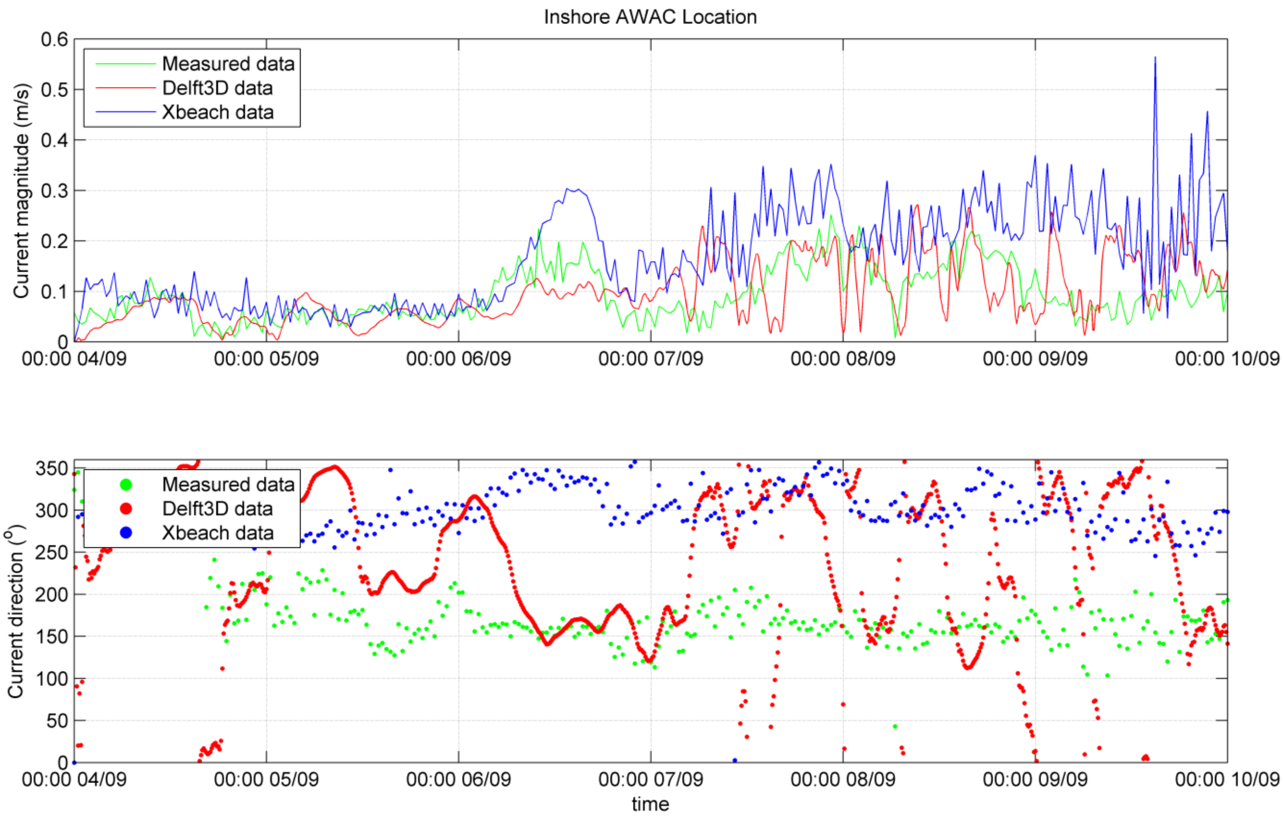

Figure C-5 Measured and modelled depth average current data at the Inshore AWAC location

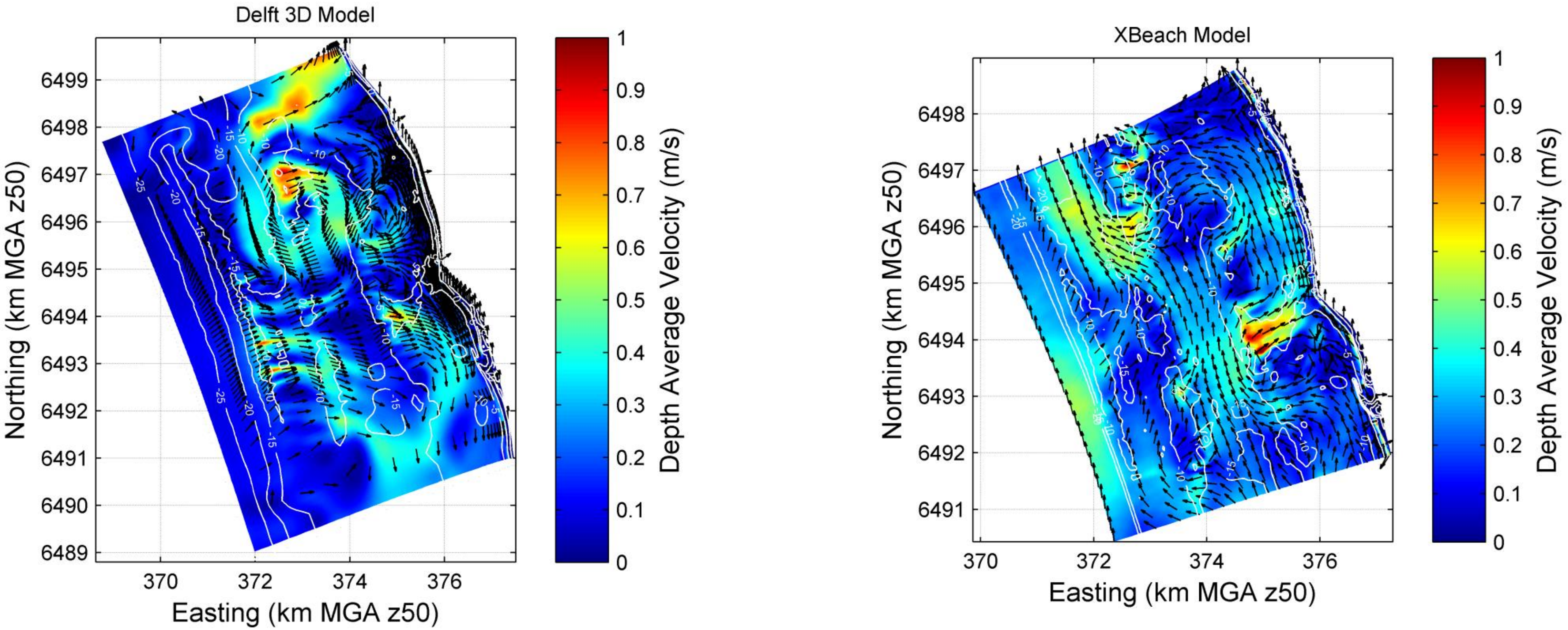

Figure C-6 Vector current map for each model at the peak of the storm (23:30 07 September 2014)

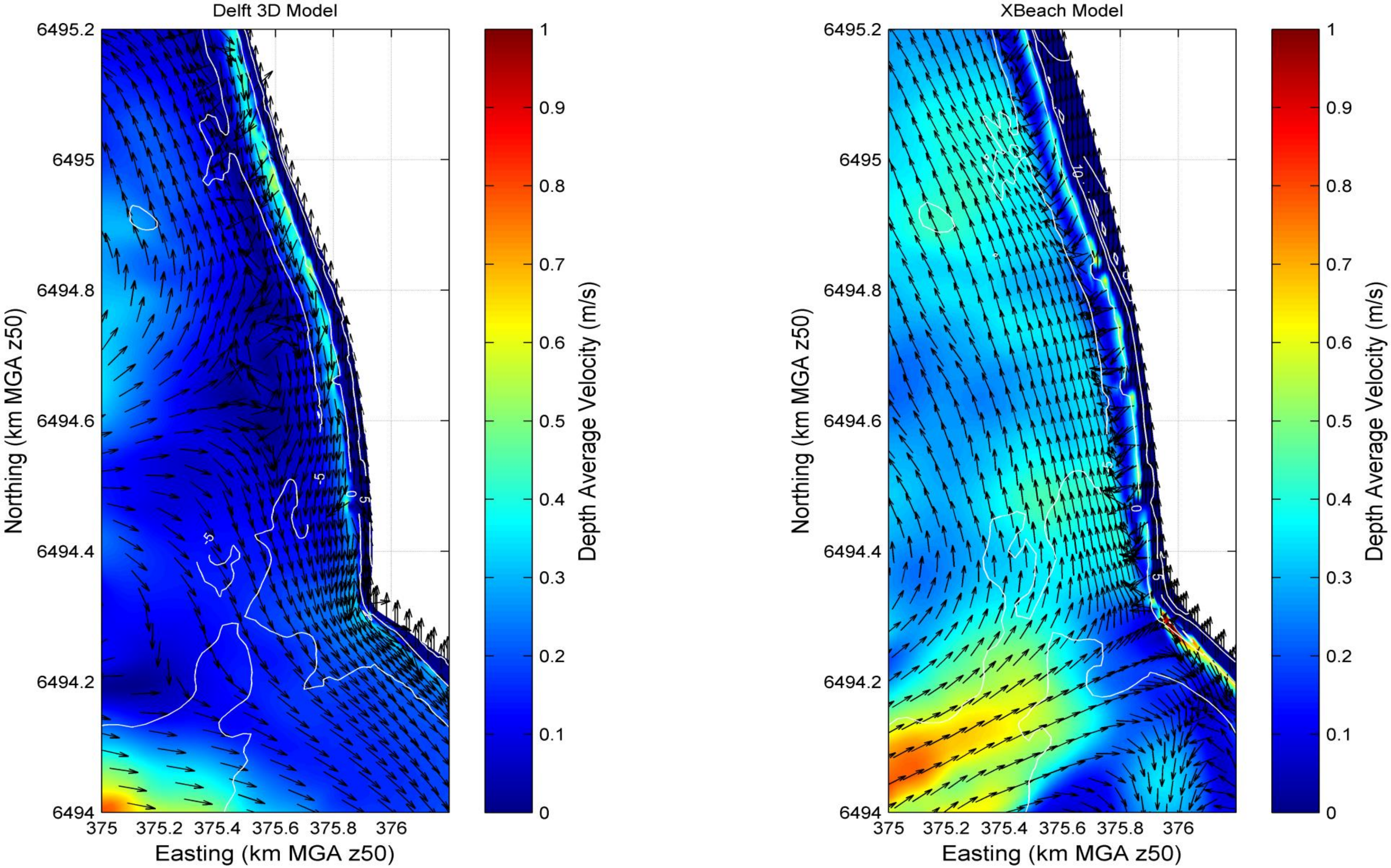

Figure C-7 Zoomed in vector current map for each model at the peak of the storm (23:30 07 September 2014)

C.1.4 Sensitivity analysis

The response of each model to changes in sediment transport parameters was analysed in order to determine which model reproduced most accurately the morphological changes at Quinns Beach. Sediment transport in the Delft3D model is calibrated through adjustment of suspended and bed load transport factors for wave and currents separately; a combination of the factors included in five versions of the model is shown in **Table C-1**.

The XBeach depends on its avalanching scheme, for transport from the dry dune face to the wet swash zone; the critical wet slope (under water) and dry slope (above water) were therefore altered in the model. In addition XBeach includes specific parameterisation of crosshore sediment transport due to wave skewness and asymmetry. The parameter *facua* adjusts both of these processes the effect of increasing (or decreasing) the shoreward transport of sediment. The parameter variations in the XBeach model are shown in **Table C-2**.

C.1.4.1 Evaluation criterion

The Brier Skill Score (BSS) was used to assess the performance of each model.

$$BSS = 1 - \left(\frac{\langle |x_m - x_p|^2 \rangle}{\langle |x_p - x_b|^2 \rangle} \right)$$

Where x_m is the modelled post-storm profile, x_b is the measured pre-storm profile and x_p is the measured post-storm profile.

The Cardno beach survey profiles on 04 September 2014 and 11 September 2014 were used as the measured pre-storm profiles and the measured post-storm profiles respectively. Profiles from each section (1 to 6) were used in determining the BSS. The significance of the BSS is given by the following: BSS< 0 bad, 0-0.3 poor, 0.3-0.6 reasonable/fair, 0.6-0.8 good and 0.8-1 excellent (van Rijn et al., 2003). **Figure C-9** also shows examples of a high and low BSS for a profile.

Figure C-8 Profile locations where the XBeach and Delft3D models were assessed.

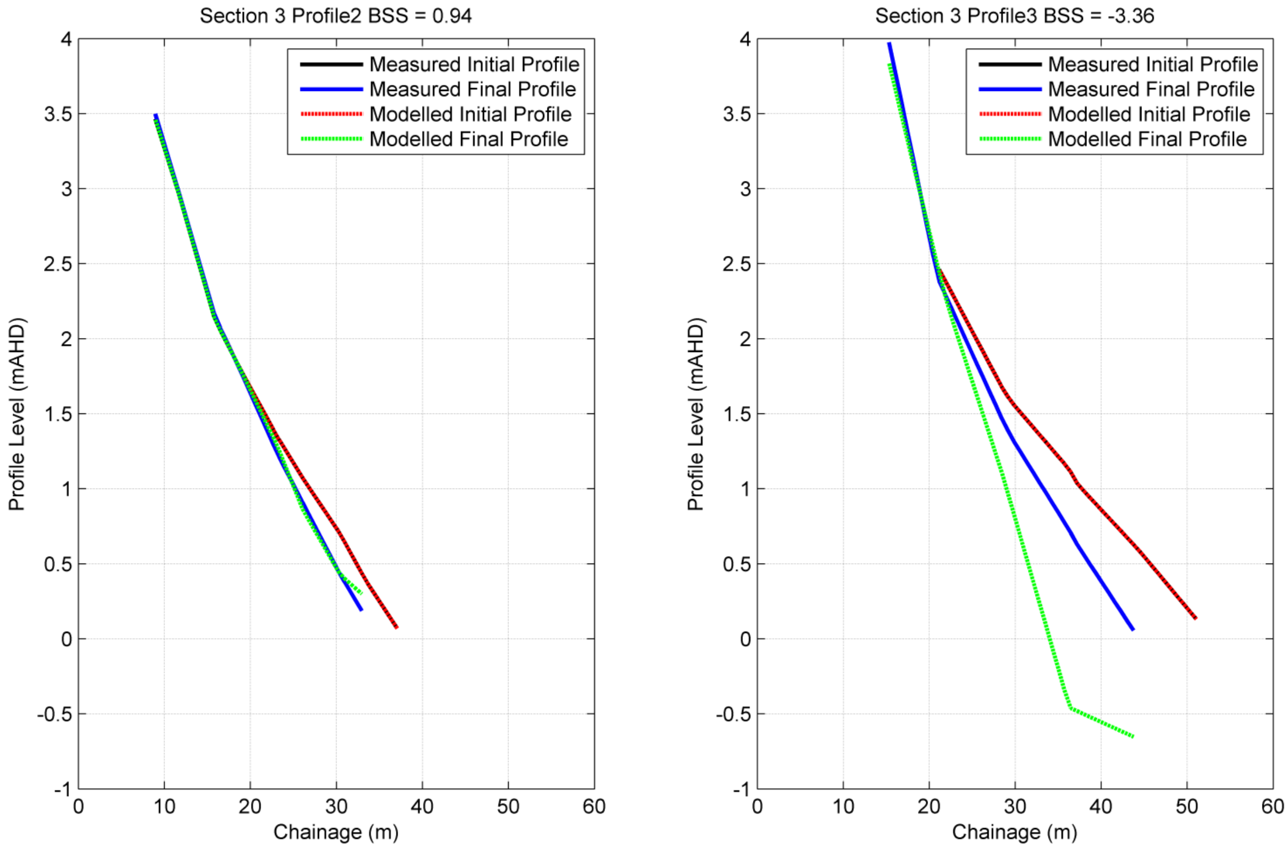

Figure C-9 Example of a profile with high BSS (left) and another with low BSS (right)

The overall scores for the Delft3D models and XBeach models are shown in **Table C-1** and **Table C-2** respectively. All profiles were included in the calculation of the overall BSS values. The Delft3D models had very low scores with negligible morphological change modelled above 0 m AHD. **Figure C-10** presents an expanded view of the morphological change produced by the numerical models down to 5m depth along a profile in Section 3. Delft3D modelled cross-shore transport towards the beach which is not a physically realistic outcome. The reasons for this are being investigated.

The XBeach model produced the expected beach storm response of the generation of a nearshore bar. Overall XBeach was found to perform reasonably, but with significant sensitivity to the facua parameter. The BSS for the XBeach_v1 parameter set are presented in **Table C-3**, the model excelled in Sections 3 and 4 where the nearshore currents and morphological response of the beach is constrained between two groynes.

Table C-1 Assessment of the Delft3D model using the Brier Skill Score

Model name	suspended sediment reference concentration factor	bed-load transport vector magnitude factor	Wave-related suspended sediment transport factor	Wave-related bed-load sediment transport factor	Brier Skill Score (BSS)
Delft3D_v1	1	1	1	1	-0.03
Delft3D_v2	1	1	0.1	0.1	0.01
Delft3D_v3	0.5	0.5	0.2	0.2	-0.01
Delft3D_v4	1	1	0.2	0.2	0.01
Delft3D_v5	1	1	0.1	0.2	0.01

Table C-2 Assessment of the XBeach model using the Brier Skill Score

Model name	critical avalanching slope under water	critical avalanching slope above water	Wave asymmetry and skewness time averaged flow factor	Brier Skill Score (BSS)
XBeach_v1	0.2	1	0.3	0.41
XBeach_v2	0.2	1	0.15	-4.07
XBeach_v3	0.4	1	0.3	0.37
XBeach_v4	0.4	1	0.15	-2.13
XBeach _v5	0.4	0.75	0.3	0.37
XBeach _v6	0.2	0.75	0.15	-4.10
XBeach _v7	0.3	1	0.22	-0.01

Table C-3 Assessment of each profile for XBeach_v1 model

Section	Profile	Brier Skill Score (BSS)
1	1	-0.11
	2	0.36
	3	0.26
2	1	0.34
	2	0.26
	3	0.31
3	1	0.15
	2	0.94
	3	0.76
4	1	0.90
	2	0.64
	3	0.78
5	1	0.11
	2	0.32
	3	0.26
6	1	0.27

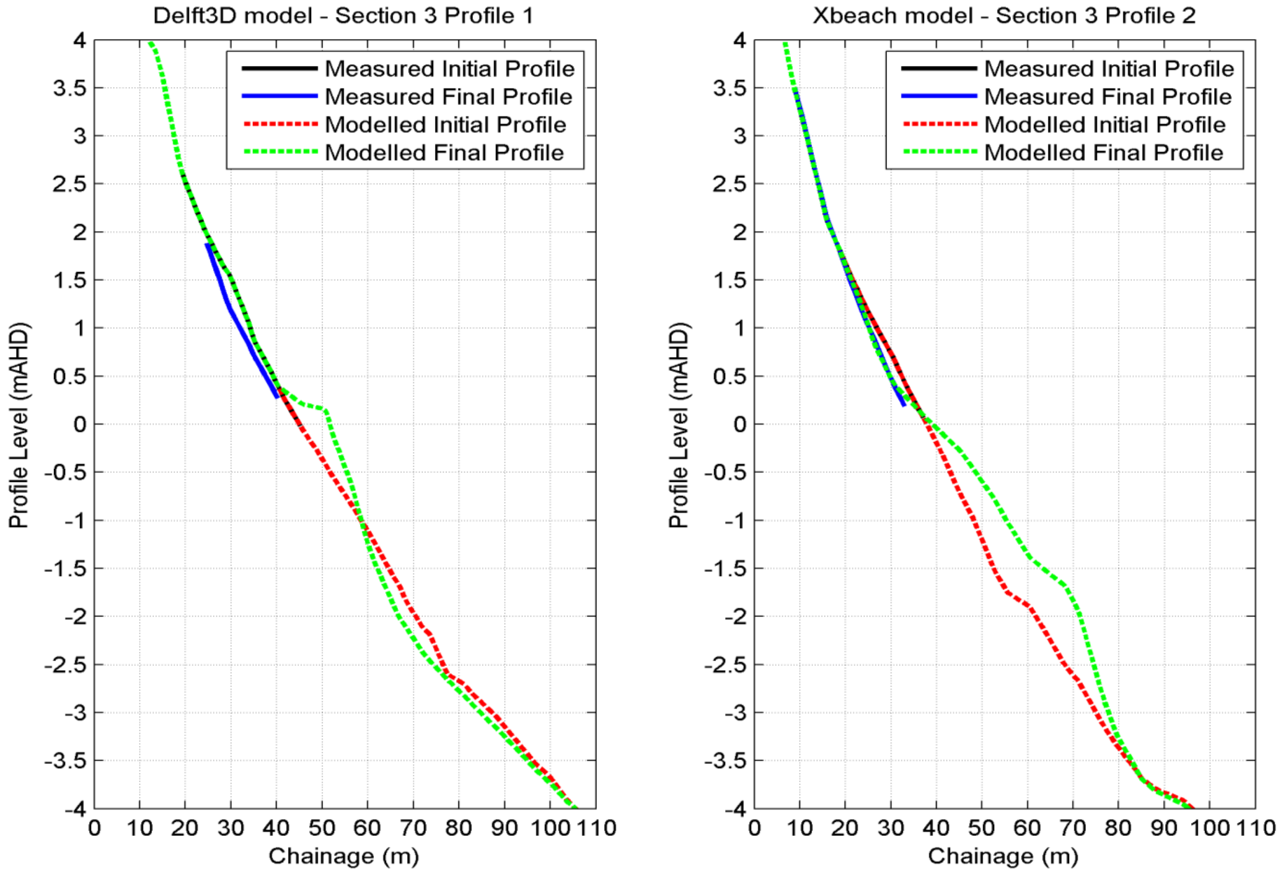

Figure C-10 Sub-aerial morphological changes experienced in both models

C.1.5 Summary

Cardno modelled the short term changes due to a storm using the Delft3D and XBeach models. The performance of each model was assessed in order to determine which model was most suited for subsequent stages of the project. Each model was setup to simulate the observed beach morphological changes that occurred between 4 September 2014 and 11 September 2014 due to a storm that impacted the study area on 8 September 2014.

Equivalent wave, water level and wind boundary conditions were applied to each of the model systems for the week long simulation and the modelled currents and beach morphological changes compared to the measured data.

Both XBeach and Delft3D have a roller modelling option that directly simulates and resolves the infra-gravity wave motions of the incident shortwave field, however it was not possible to get the Delft3D model to run with a stable configuration with this mode activated. As such the Delft3D model only simulated the quasi-steady wave setup process. The XBeach model was observed to poorly reproduce the observed current directions at both the nearshore and offshore locations.

Overall the XBeach model reproduced the beach morphological changes considerably better, both qualitatively and quantitatively compared to the Delft3D model and the XBeach model was selected for further investigations.

Detailed investigation into the cause of the discrepancy in the XBeach modelled currents identified an error in the wind stress formulation implemented in the model code utilised in the fatal flaw model selection phase of the project. Whilst this represented a significant error in the modelled current fields, the reproduction of the observed morphological changes suggests that the morphological changes observed between the groynes at Quinns Beach have little dependence on wind stress, with morphological changes driven by the littoral drift currents established at the shoreface.

Cardno worked with Deltares to correct the error in the wind stress implementation and compiled a new version that is utilised for the remainder of the study and the results presented in the report body.

Coastal Processes and Preliminary Options Assessment Report

APPENDIX D
SWAN ROUGHNESS COMPARISON

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D. Appendix D

D.1 Spatially Variable Roughness

Madsen bed roughness length scale of 0.6m for bed level < 8.5 m AHD

Madsen bed roughness length scale of 0.1m for bed level > 8.5 m AHD

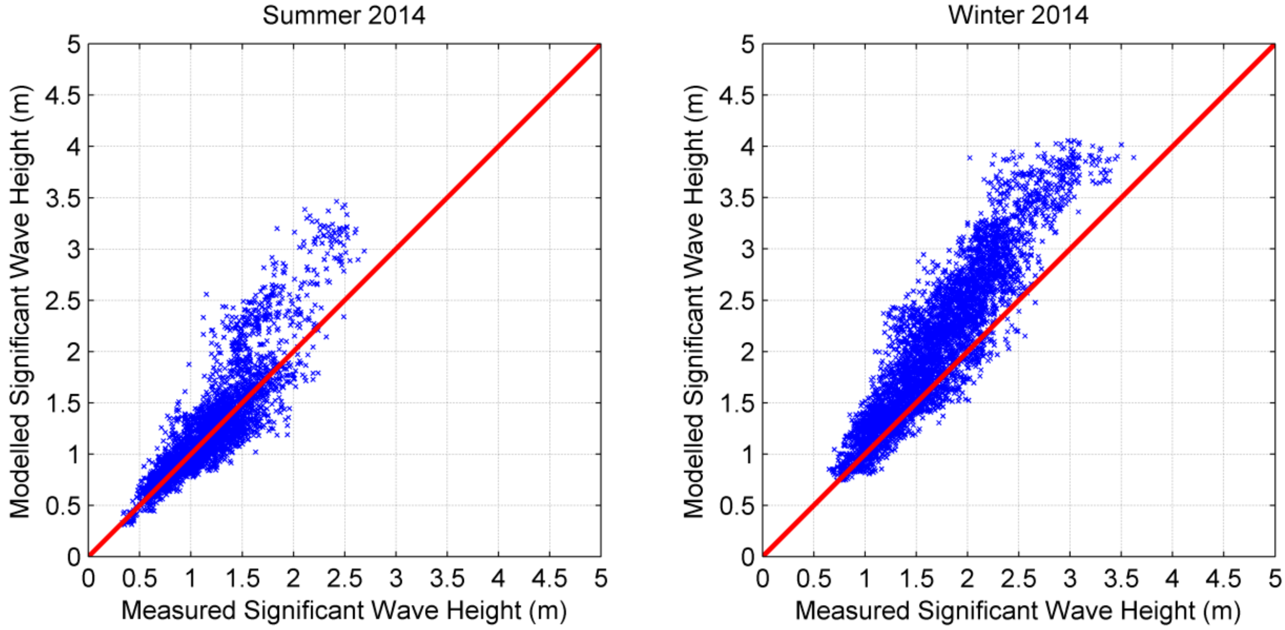

Figure D-1 Comparison between modelled and measured wave heights at the Offshore AWAC Location for spatially variable roughness map

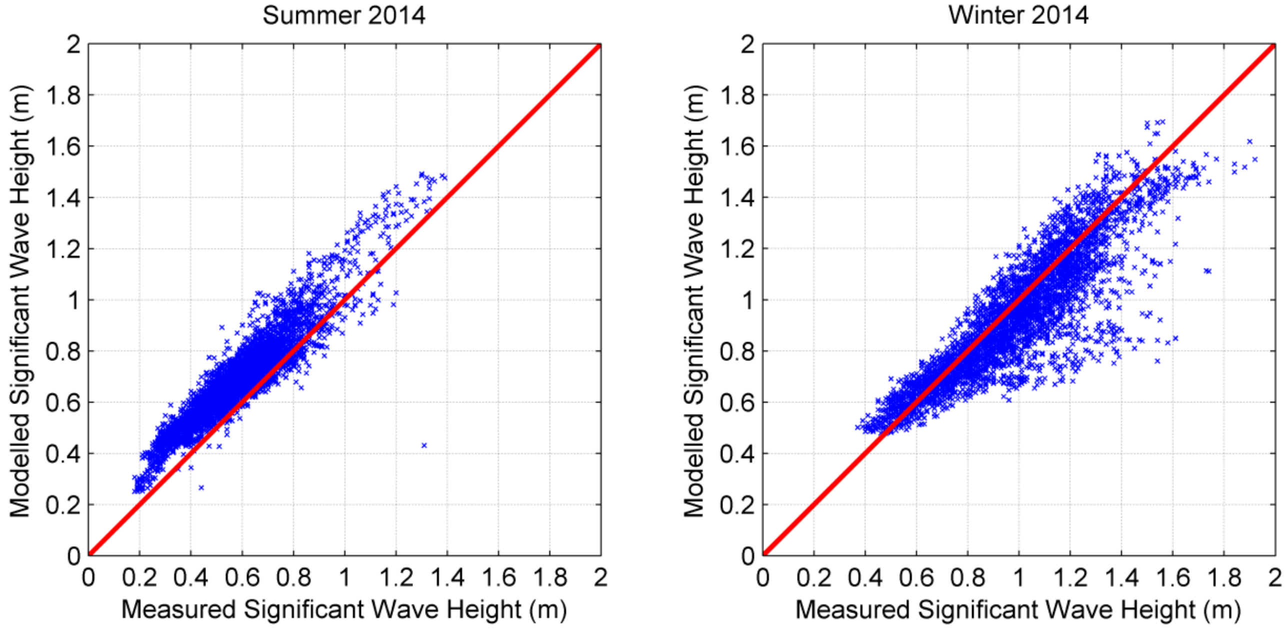

Figure D-2 Comparison between modelled and measured wave heights at the Inshore AWAC Location for spatially variable roughness map

Table D-1 Skill assessment statistics for wave height data

	Model Skill	RMSE
Summer Nearshore	0.89	0.12
Winter Nearshore	0.93	0.12
Summer Offshore	0.90	0.28
Winter Offshore	0.86	0.47

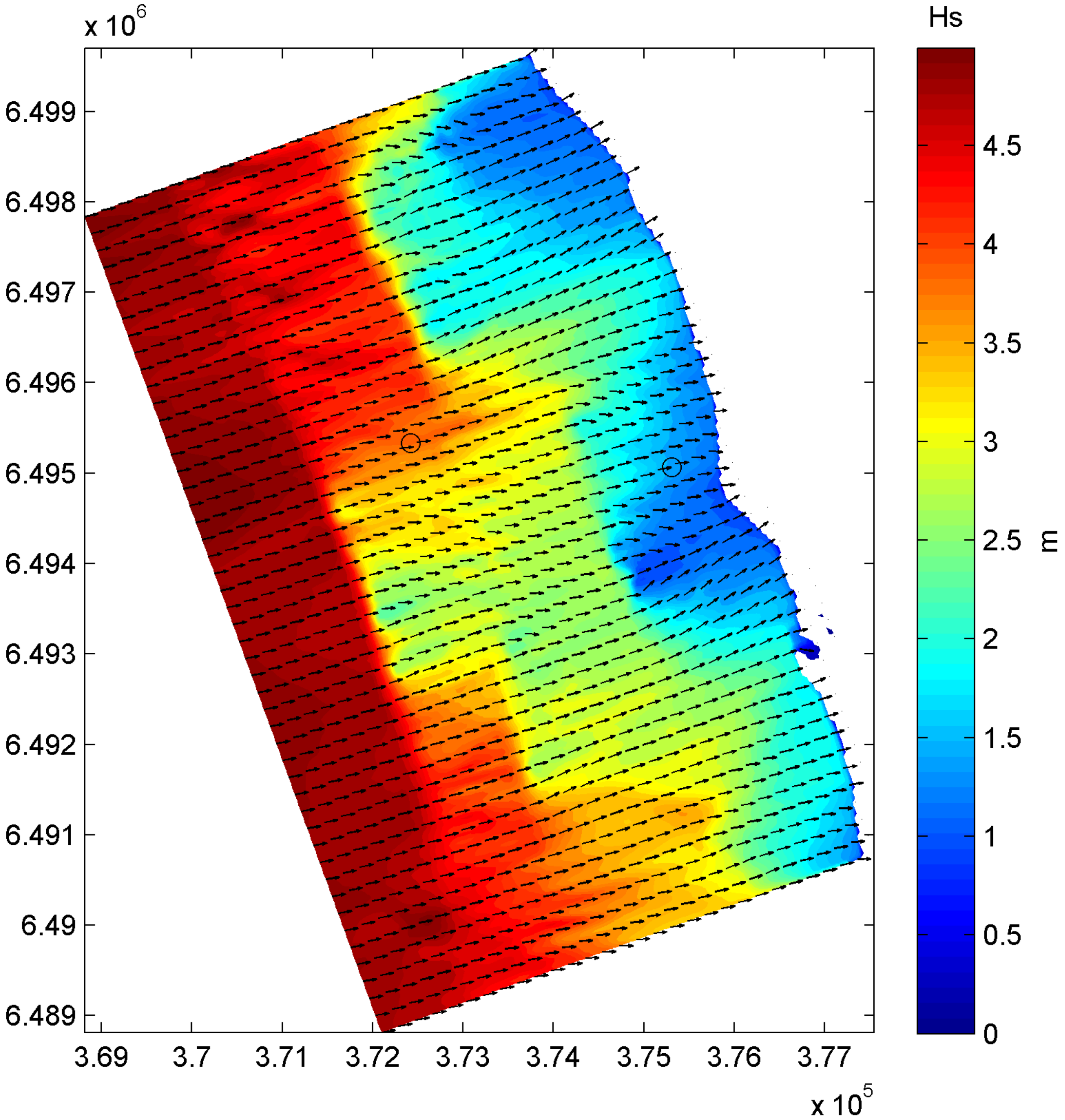

Figure D-3 Peak storm wave heights with spatial roughness map

D.2 Constant Roughness

Madsen bed roughness length scale of 0.42m for extent of 40m grid

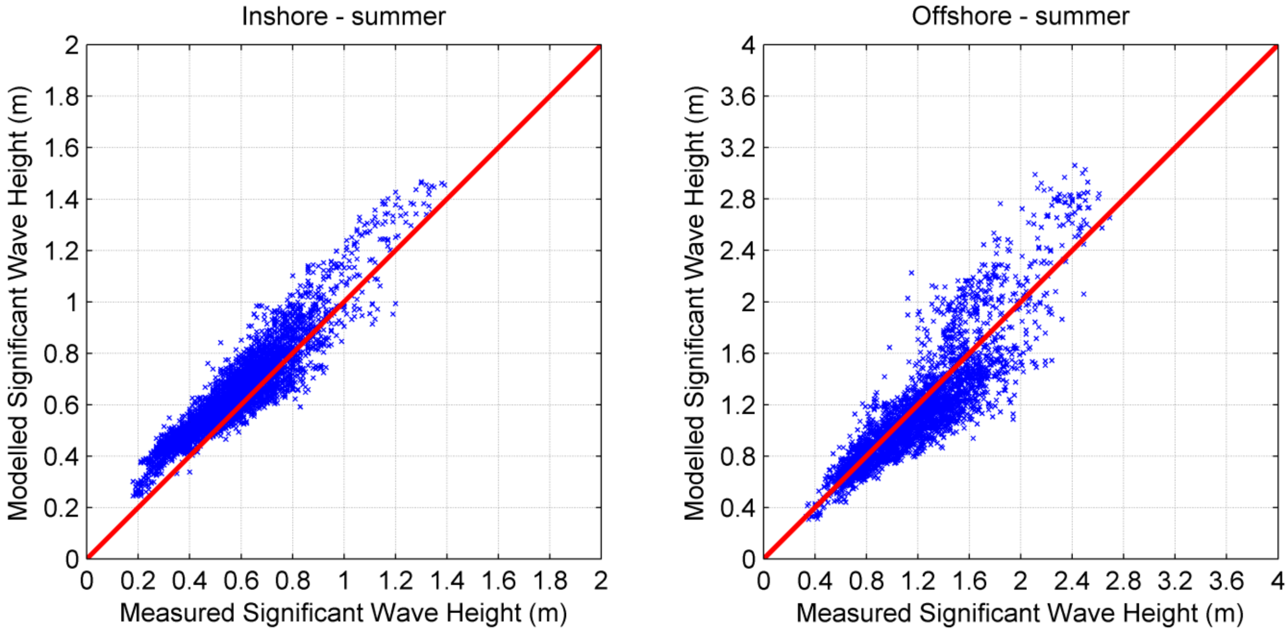

Figure D-4 Comparison between modelled and measured wave heights for summer

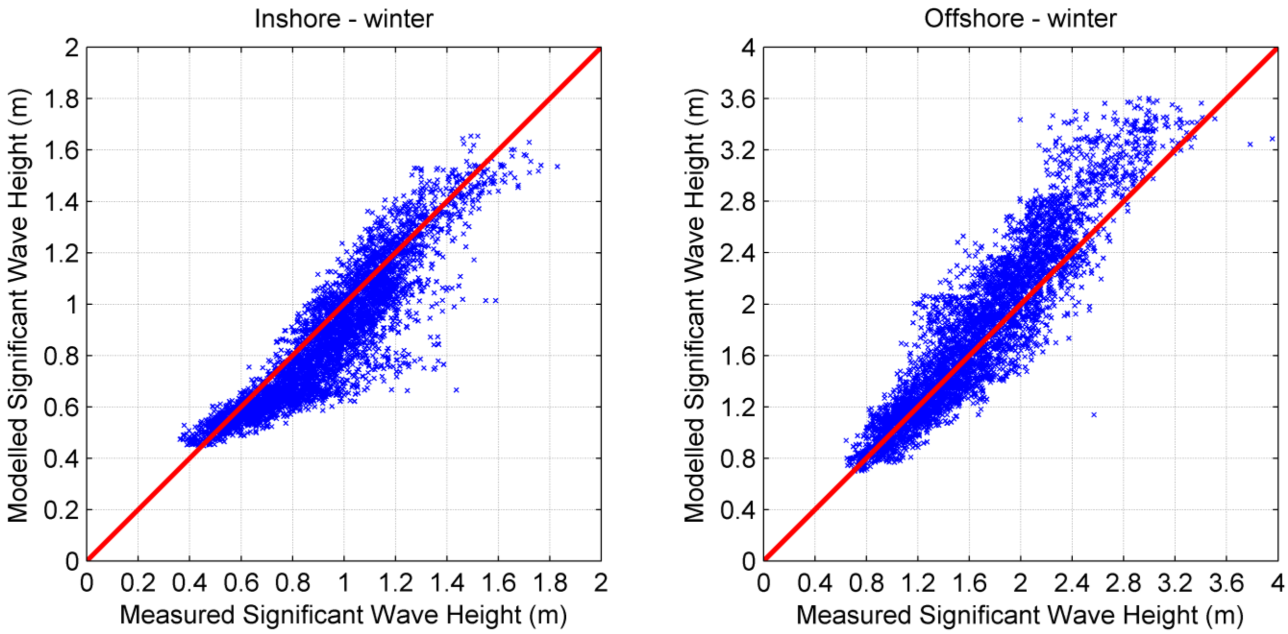

Figure D-5 Comparison between modelled and measured wave heights for winter

Table D-2 Skill assessment statistics for wave height data

	Model Skill	RMSE
Summer Nearshore	0.93	0.10
Winter Nearshore	0.90	0.15
Summer Offshore	0.93	0.22
Winter Offshore	0.93	0.29

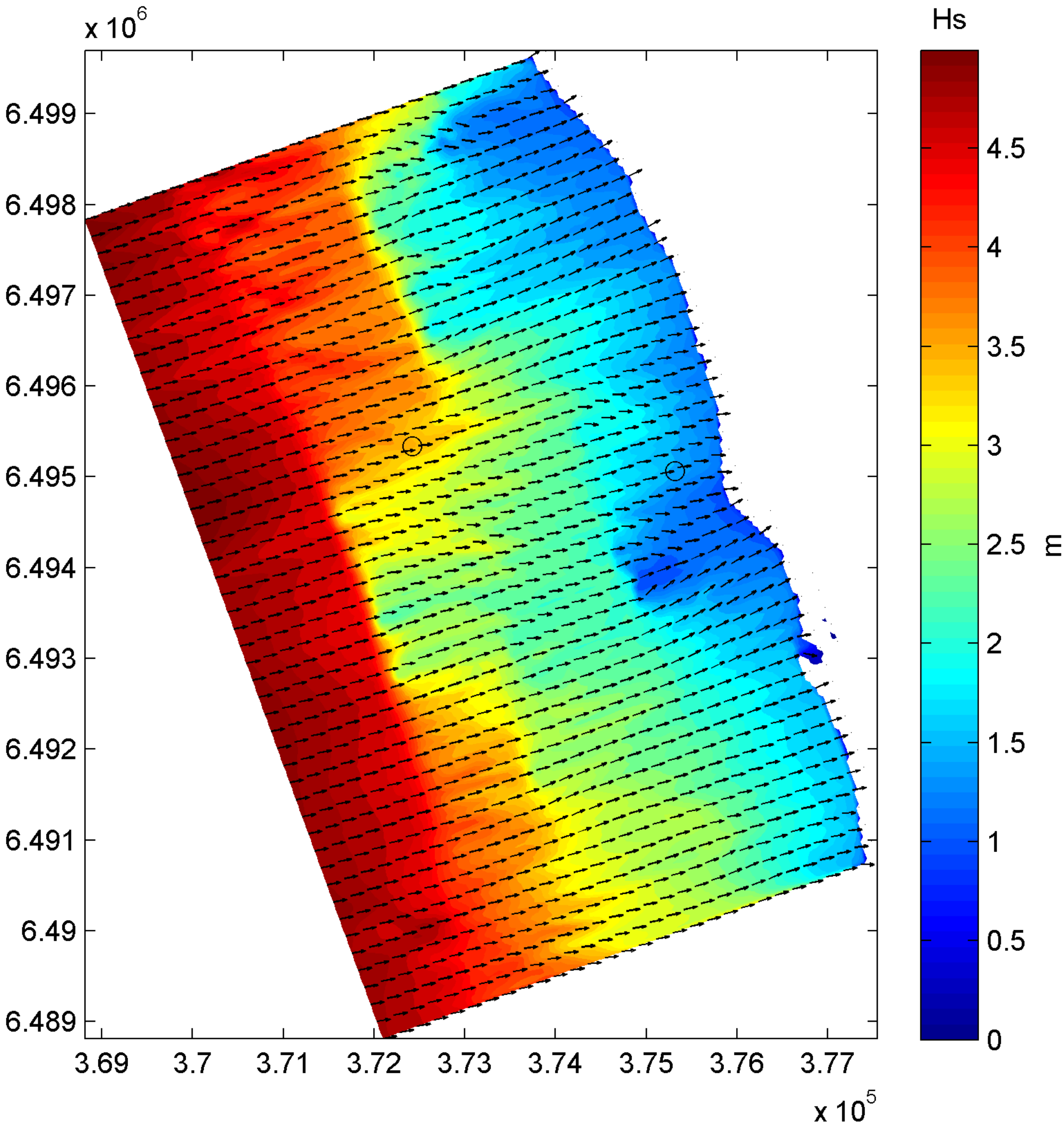

Figure D-6 Peak storm wave heights with constant roughness map, note reduction in wave height in northern end of Quinns beach, approximately 50%

Coastal Processes and Preliminary Options Assessment Report

APPENDIX E

XBEACH MODEL MORPHOLOGY SKILL

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E. Appendix E

Table E-1 XBeach model calibration metrics across the study area

Section	Profile	Chainage [m]	R^2	BSS	Measured Volume Change [m^3/m]	Modelled Volume Change [m^3/m]
1	1	0	0.84	-2.31	-3.5	-1.2
1	2	50	0.84	-1.6	-0.1	1.4
1	3	100	0.9	0.22	4.8	1.8
1	4	150	0.9	-0.28	2.0	0.6
1	5	200	0.91	0.11	2.3	-4.7
1	6	250	0.92	-0.13	2.7	-3.2
1	7	300	0.92	-0.3	0.9	-1.7
1	8	350	0.94	0.69	-2.1	-1.8
1	9	400	0.95	0.85	-2.6	-4.3
1	10	450	0.92	0.95	-2.4	-3.5
1	11	500	0.93	0.89	-5.1	-2.7
1	12	550	0.93	0.9	-4.6	-6.4
1	13	600	0.92	0.87	-4.6	-5.4
1	14	650	0.91	0.66	-5.8	-3.4
1	15	700	0.9	0.47	-5.3	-1.5
1	16	750	0.88	0.51	-8.2	-1.4
1	17	800	0.91	0.8	-3.2	-0.8
1	18	850	0.91	0.85	-5.3	-4.4
2	1	50	0.88	0.81	-9.6	-10.6
2	2	60	0.88	0.74	-10.4	-13.0
2	3	70	0.87	0.6	-10.9	-12.6
2	4	80	0.86	0.12	-5.8	-6.7
2	5	270	0.85	-6.22	0.9	3.4
2	6	280	0.81	-0.94	-1.1	-1.2
2	7	290	0.81	-4.66	3.2	-1.5
2	8	300	0.84	-0.57	4.6	0.5
2	9	310	0.88	0.43	0.3	0.9
2	10	320	0.84	-3.66	2.9	5.6
2	11	330	0.87	-3.61	1.7	4.8
2	12	340	0.86	-3.78	-0.8	5.1
2	13	350	0.85	-26.92	0.8	10.3
2	14	360	0.85	-21.19	1.7	7.4
2	15	370	0.79	-17.83	-1.3	5.5
2	16	380	0.83	-11.74	-2.6	9.4

Section	Profile	Chainage [m]	R^2	BSS	Measured Volume Change [m^3/m]	Modelled Volume Change [m^3/m]
2	17	390	0.82	-3.79	-3.0	2.2
2	18	400	0.81	0.08	-6.2	-2.3
2	19	410	0.83	0.26	-6.1	-5.2
2	20	420	0.75	0.8	-6.5	-6.1
2	21	430	0.7	0.91	-5.4	-5.7
2	22	440	0.79	0.97	-5.0	-3.5
2	23	450	0.5	0.84	-1.6	-3.5
3	4	30	0.92	-2.32	-3.4	-0.2
3	5	40	0.92	0.71	-5.9	-4.1
3	6	50	0.9	0.86	-8.7	-2.2
3	7	60	0.9	-0.52	-2.1	-1.0
3	8	70	0.87	0.22	-6.6	-2.5
3	9	80	0.9	0.65	-8.2	-4.1
3	10	90	0.86	-0.84	5.0	-4.1
3	11	100	0.9	-1.31	-0.3	0.0
3	12	110	0.92	0.77	-8.3	0.1
3	13	120	0.89	-2.48	-1.0	-1.3
3	14	130	0.9	-0.25	3.5	-2.3
3	15	140	0.9	0.53	-5.0	-2.4
3	16	150	0.92	0.27	-5.2	-0.6
3	17	160	0.93	0.17	-4.0	-1.6
3	18	170	0.91	0.55	-5.2	-1.3
3	19	180	0.91	-2.91	-1.6	-1.7
3	20	190	0.88	-0.2	-3.8	-2.7
3	21	200	0.9	0.81	-7.5	-2.1
3	22	210	0.89	-1.92	-0.9	-1.9
3	23	220	0.91	-2.26	-1.2	-2.2
3	24	230	0.9	0.67	-7.9	-1.6
3	25	240	0.89	0.41	-5.3	-2.6
3	26	250	0.87	-0.31	-3.6	-5.3
3	27	260	0.87	0.8	-5.8	-5.8
3	28	270	0.84	-0.8	-0.7	-3.9
3	29	280	0.88	0.29	-2.7	-5.3
3	30	290	0.88	0.88	-6.7	-5.7
3	31	300	0.88	0.81	-3.5	-5.7
3	32	310	0.86	0.88	-5.6	-6.8
3	33	320	0.88	0.75	-4.8	-8.2
3	34	330	0.86	0.67	-5.7	-8.6

Section	Profile	Chainage [m]	R^2	BSS	Measured Volume Change [m^3/m]	Modelled Volume Change [m^3/m]
3	35	340	0.88	0.91	-11.8	-11.2
3	36	350	0.87	0.82	-7.9	-11.4
3	37	360	0.88	0.9	-7.3	-8.4
3	38	370	0.88	0.9	-8.9	-7.1
3	39	380	0.88	0.8	-9.1	-10.1
3	40	390	0.86	0.91	-12.1	-12.2
3	41	400	0.88	0.87	-7.7	-9.8
3	42	410	0.88	0.94	-9.1	-9.3
3	43	420	0.87	0.82	-8.5	-10.5
3	44	430	0.87	0.8	-8.2	-8.4
4	1	50	0.86	-1.11	5.4	3.2
4	2	100	0.91	-0.35	3.2	2.7
4	3	150	0.91	0.63	-7.5	-2.6
4	4	200	0.91	0.7	-7.0	-5.7
4	5	250	0.85	-0.26	-7.3	-4.3
4	6	350	0.87	0.93	-24.8	-20.6
4	7	400	0.88	0.95	-20.8	-19.7
5	2	100	0.89	0.03	-6.4	1.4
5	3	150	0.9	0.72	10.1	8.0
5	4	200	0.9	-1.79	-0.6	4.1
5	5	250	0.9	0.79	-12.9	-5.9
5	6	300	0.89	0.32	-13.0	-4.1
5	7	350	0.88	0.14	-4.2	-0.9
5	8	400	0.86	-2.32	-1.1	4.6
5	9	450	0.87	0.4	7.3	14.5
5	10	500	0.67	0.46	4.6	8.2
5	11	550	0.67	0.58	-7.5	-2.6
6	1	0	0.82	-0.61	-2.0	-4.9
6	2	50	0.88	0.31	-4.5	-4.1
6	3	100	0.91	0.68	-6.6	-7.5
6	4	150	0.82	0.4	-11.2	-10.7
6	5	200	0.71	0.58	-4.1	-6.1
6	6	250	0.87	0.75	-4.8	-3.6
6	7	300	0.89	0.44	-10.1	-2.7
6	8	350	0.78	0.31	-2.7	-0.6
6	9	400	0.75	-0.24	-5.5	0.2
6	10	450	0.74	0.23	-5.9	-0.6
6	11	500	0.66	-0.38	-3.8	0.2

Section	Profile	Chainage [m]	R^2	BSS	Measured Volume Change [m^3/m]	Modelled Volume Change [m^3/m]
6	13	750	0.82	0.82	0.8	1.1
6	16	900	0.83	0.92	5.0	5.6
6	17	950	0.83	0.98	1.0	1.0
6	18	1000	0.82	0.9	4.8	5.0
6	20	1150	0.78	0.75	-7.1	-4.3
6	21	1200	0.67	-7.32	-1.9	0.3
6	22	1300	0.83	-0.1	-4.2	1.0
6	23	1350	0.85	0.17	-10.3	-1.1
6	24	1400	0.83	0.33	-10.3	-0.9

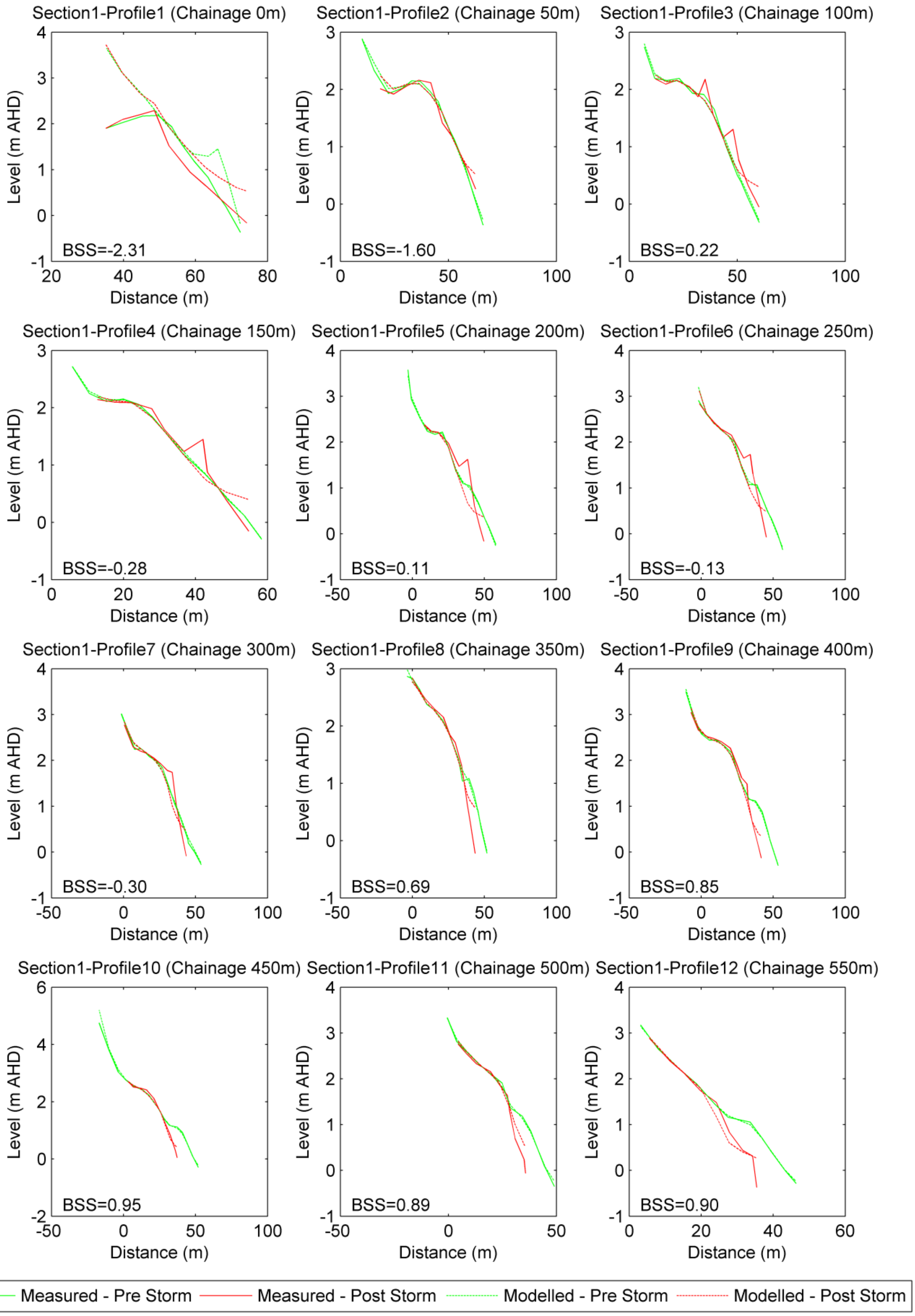

Figure E-2 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

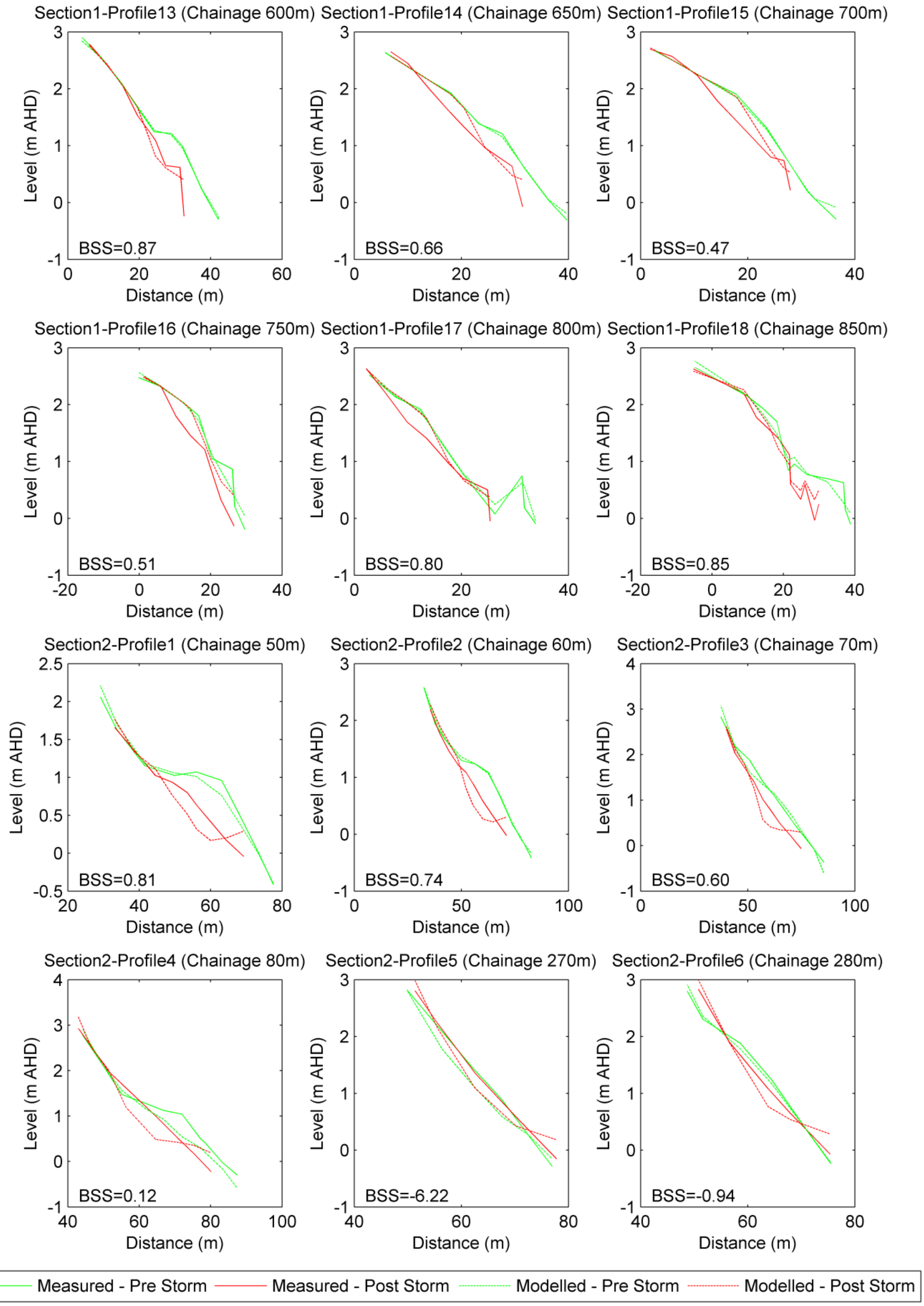

Figure E-3 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

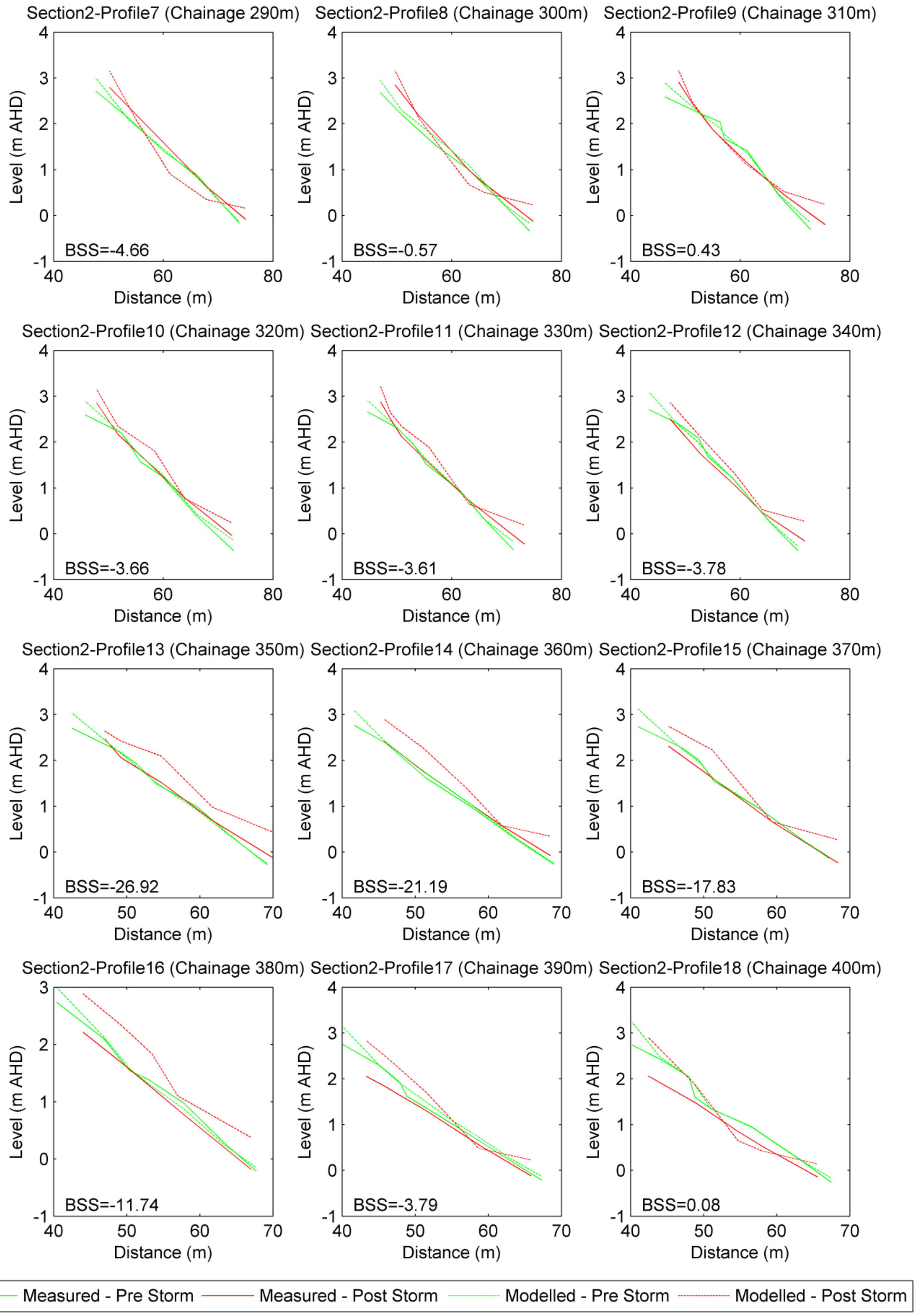

Figure E-4 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

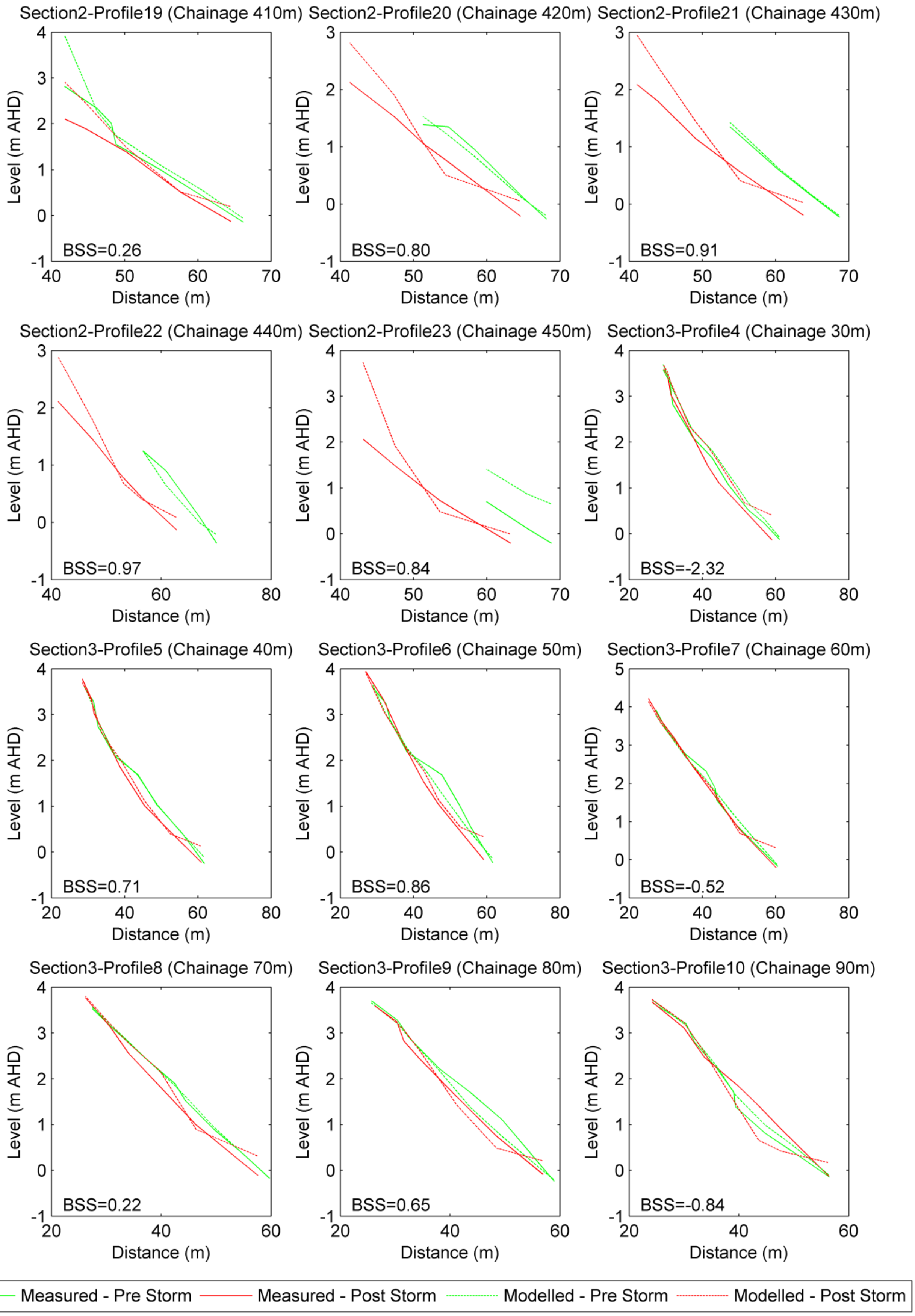

Figure E-5 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

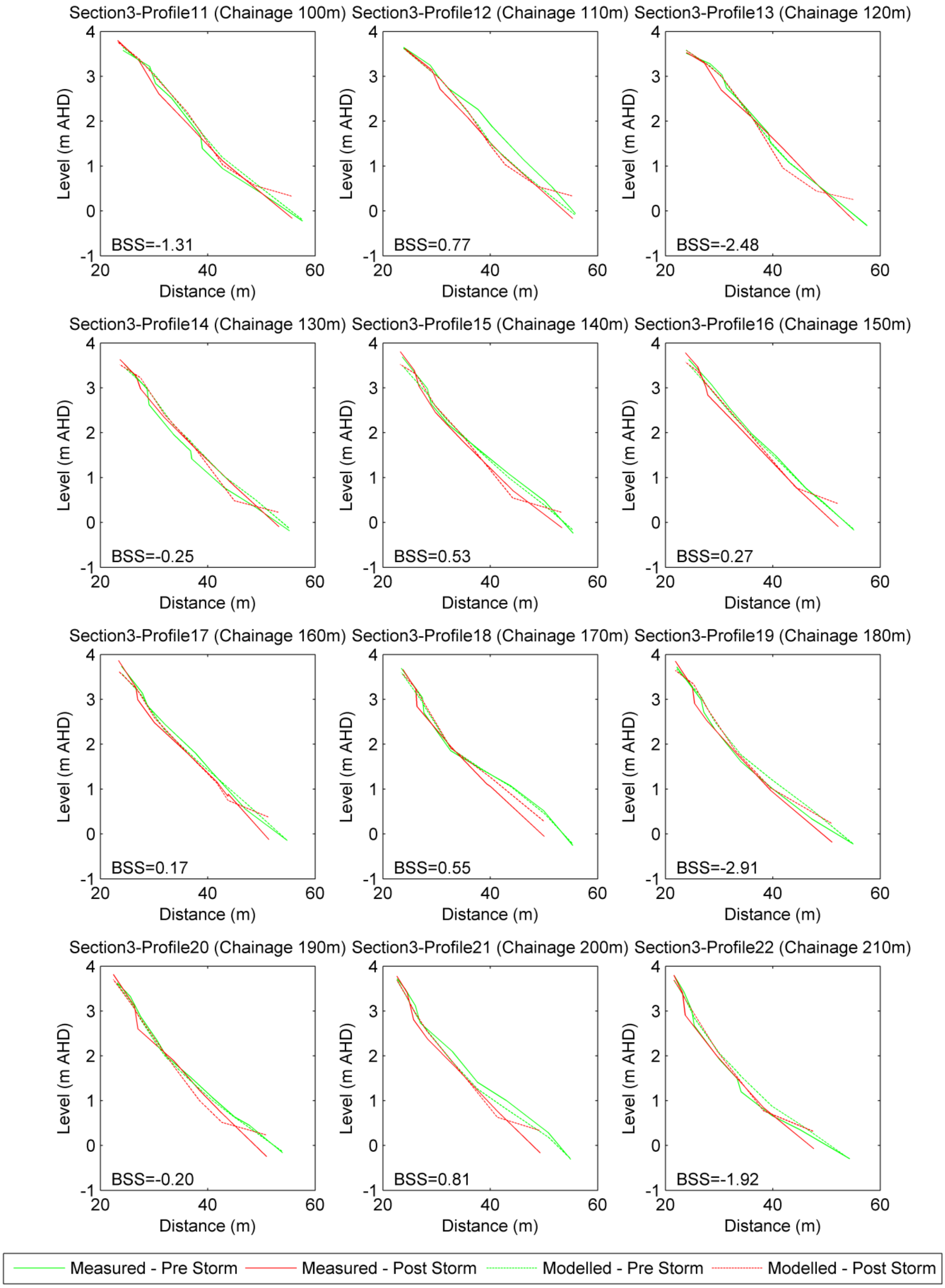

Figure E-6 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

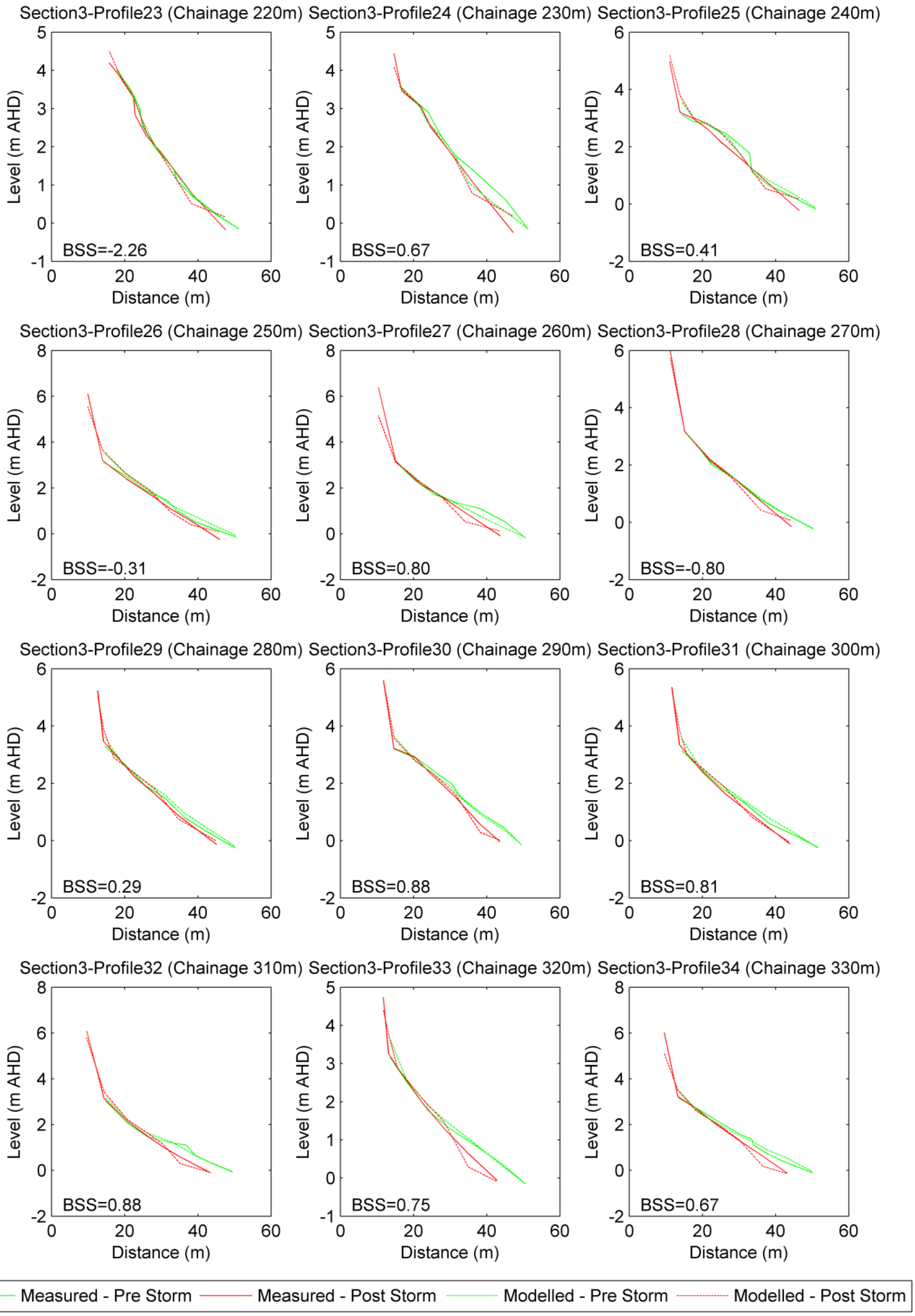

Figure E-7 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

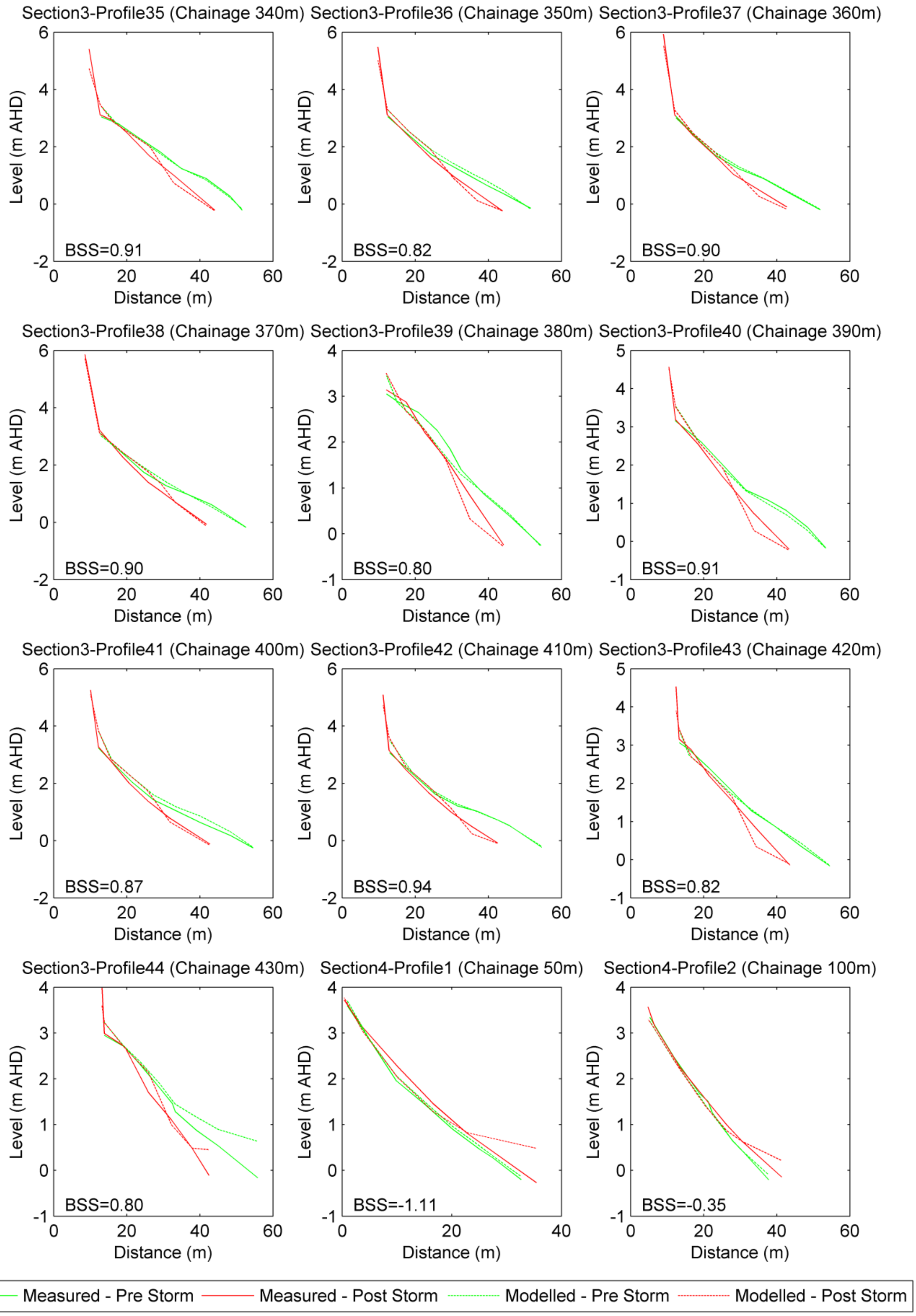

Figure E-8 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

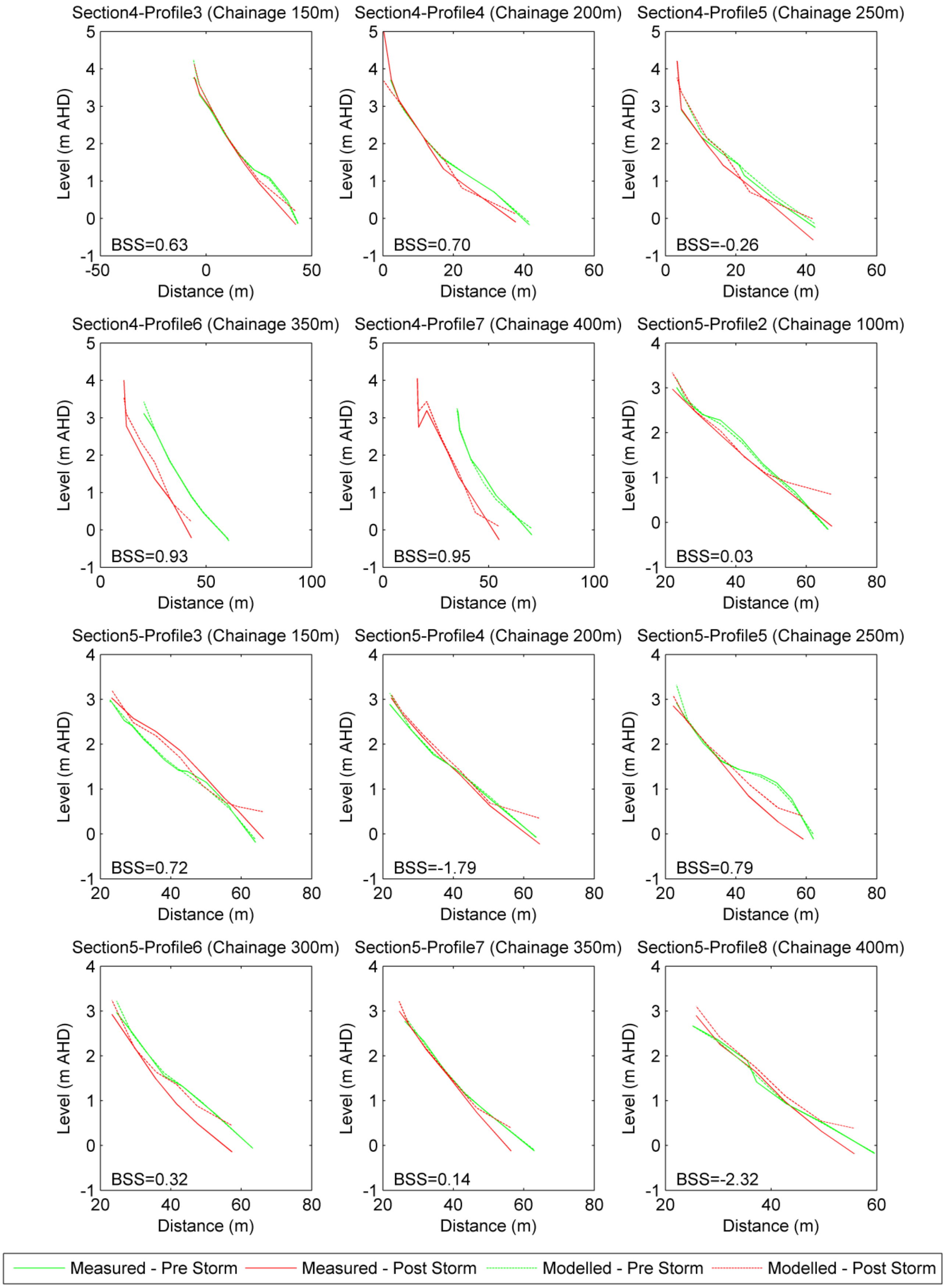

Figure E-9 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

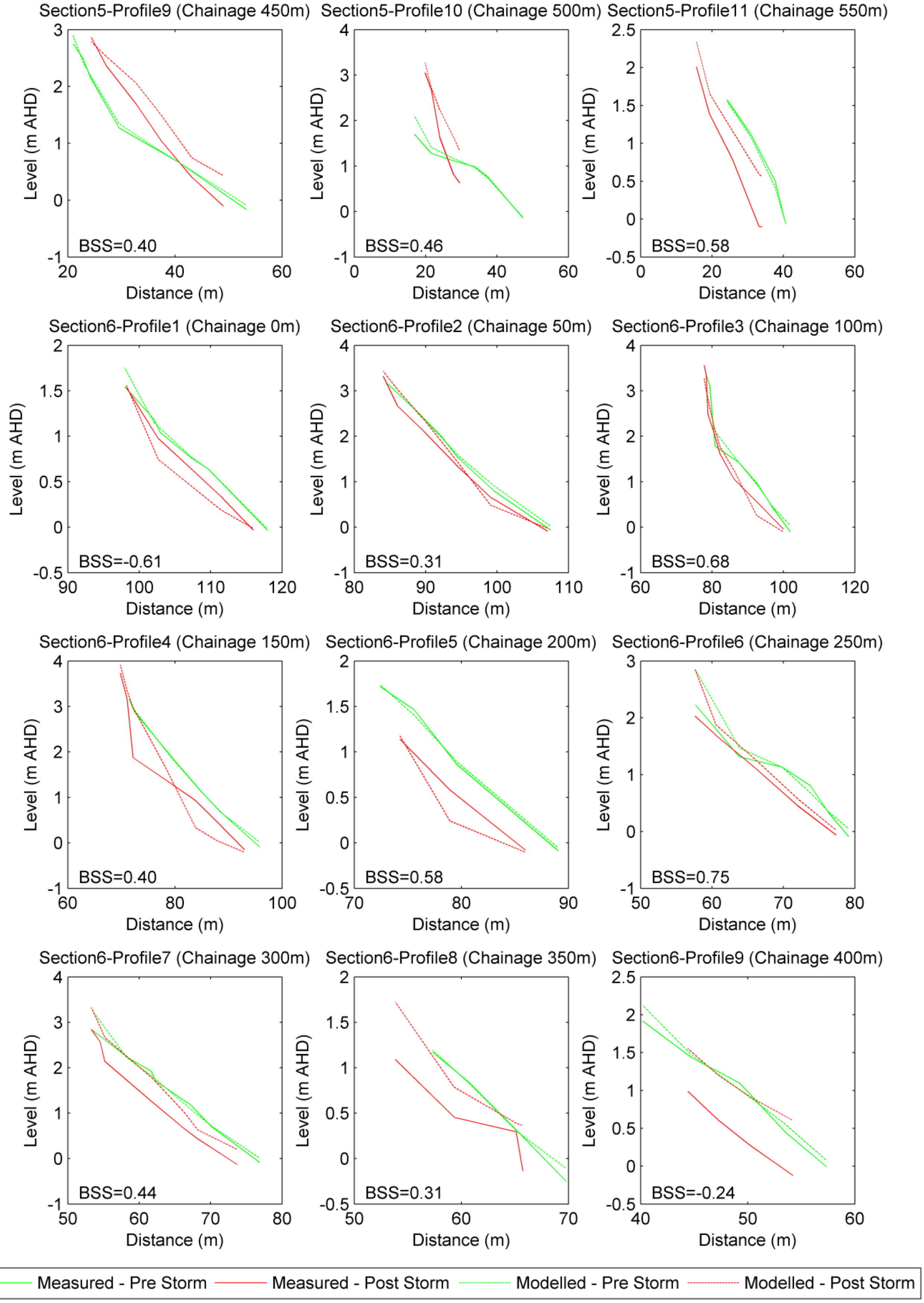

Figure E-10 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

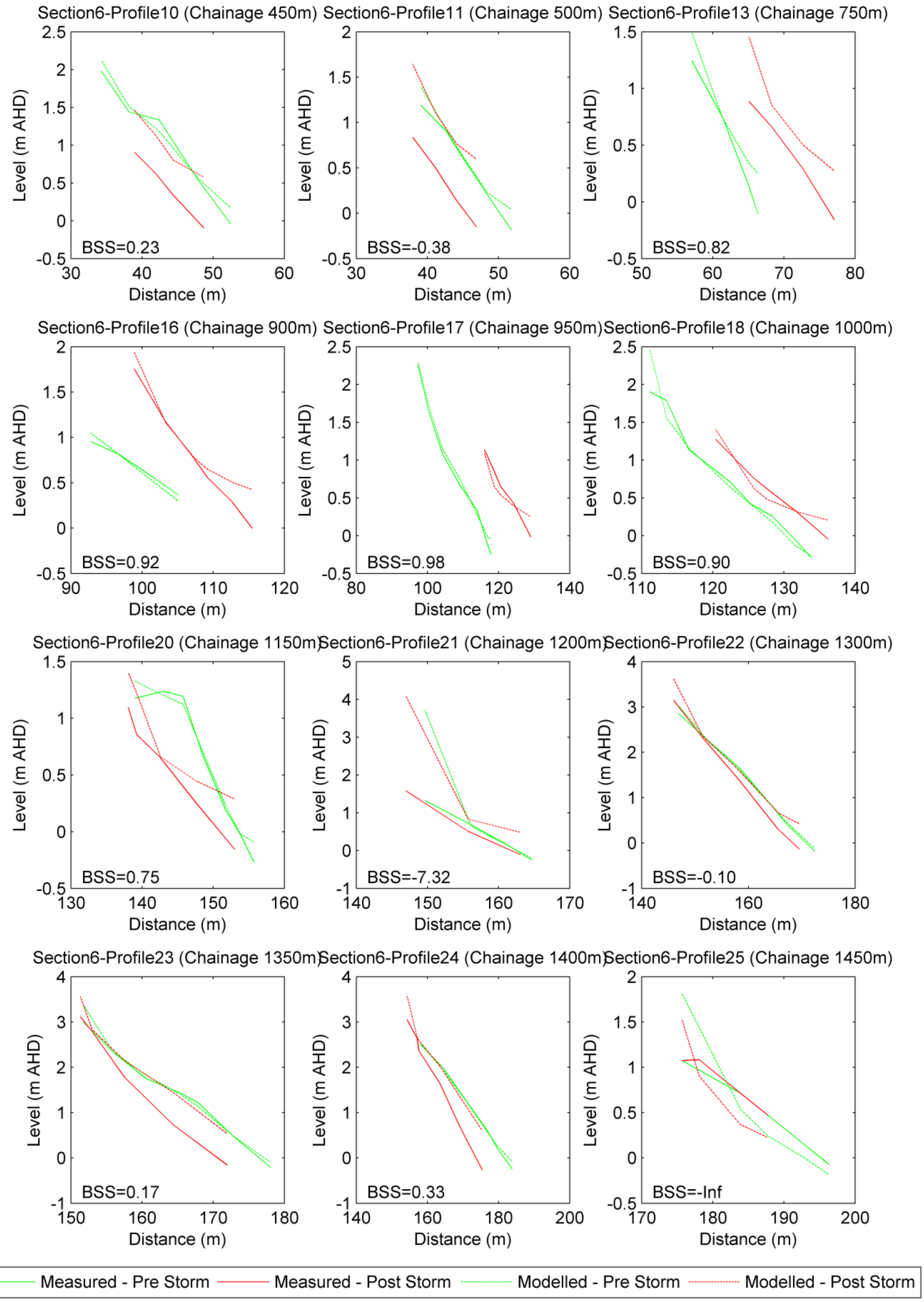

Figure E-11 Beach cross section comparison of measured and modelled change over the 9 September 2014 storm

Coastal Processes and Preliminary Options Assessment Report

APPENDIX F
LITPACK MODEL VALIDATION

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F. Appendix F

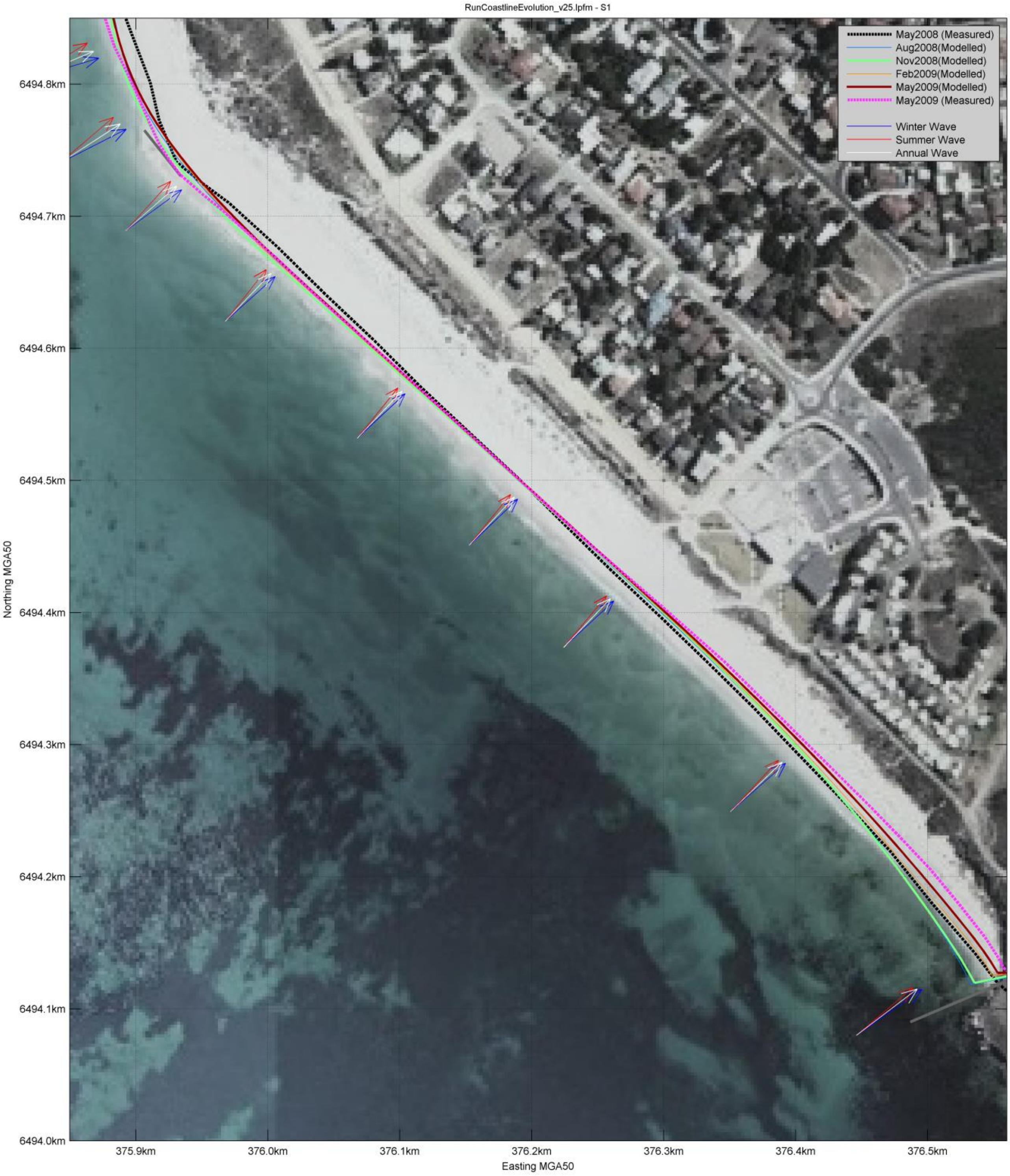


Figure F-1 Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 1

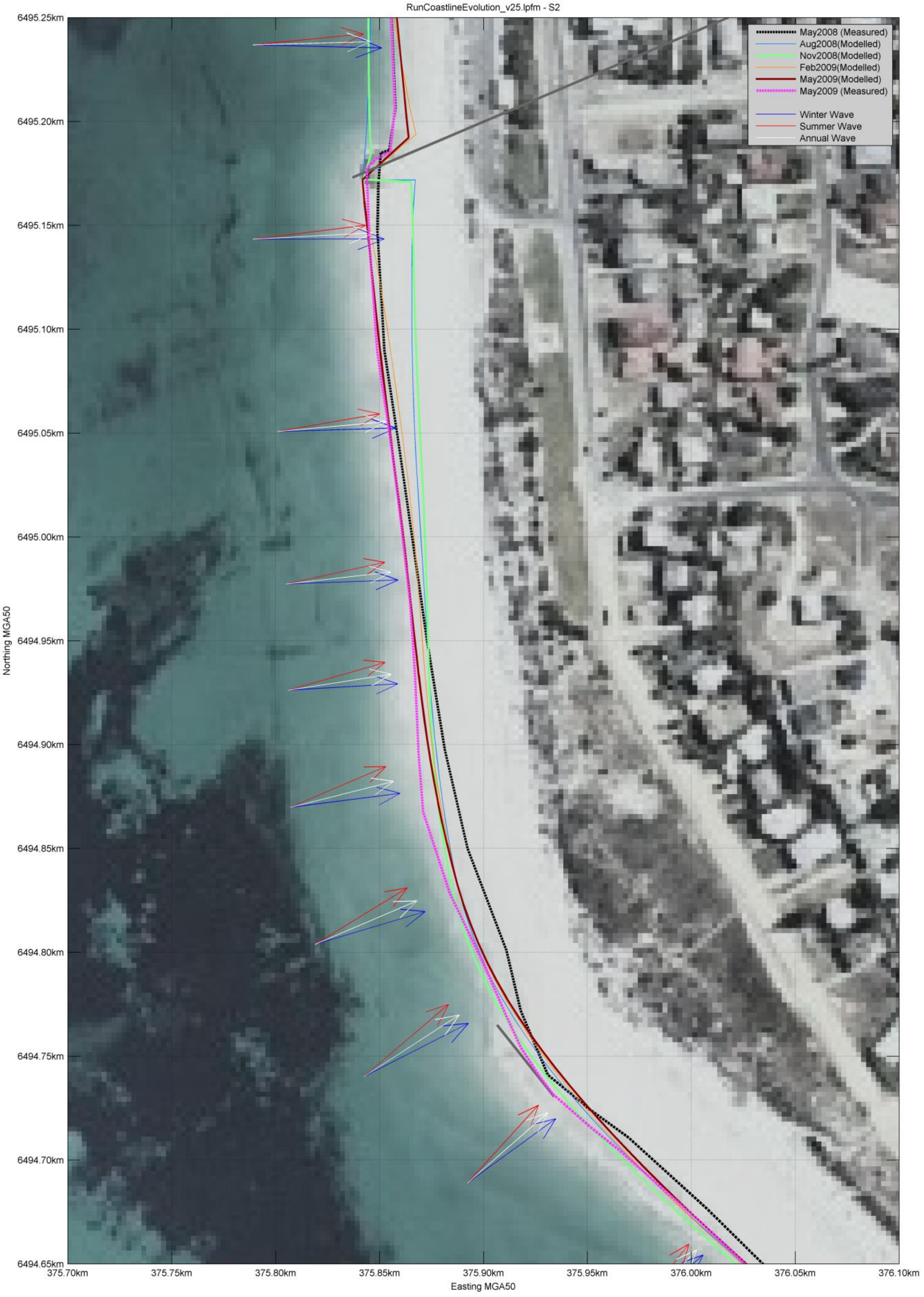


Figure F-2 Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 2

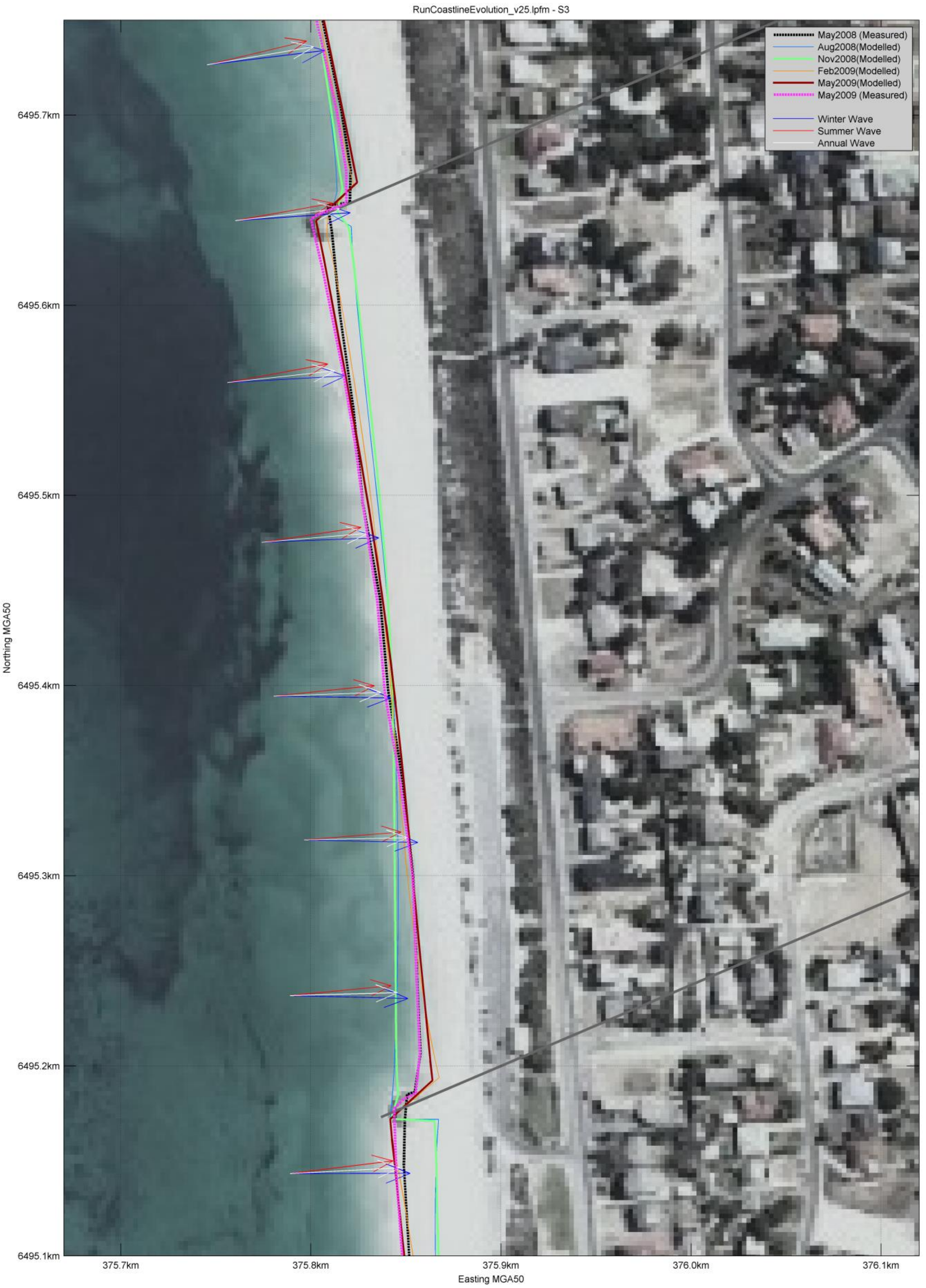


Figure F-3 Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 3

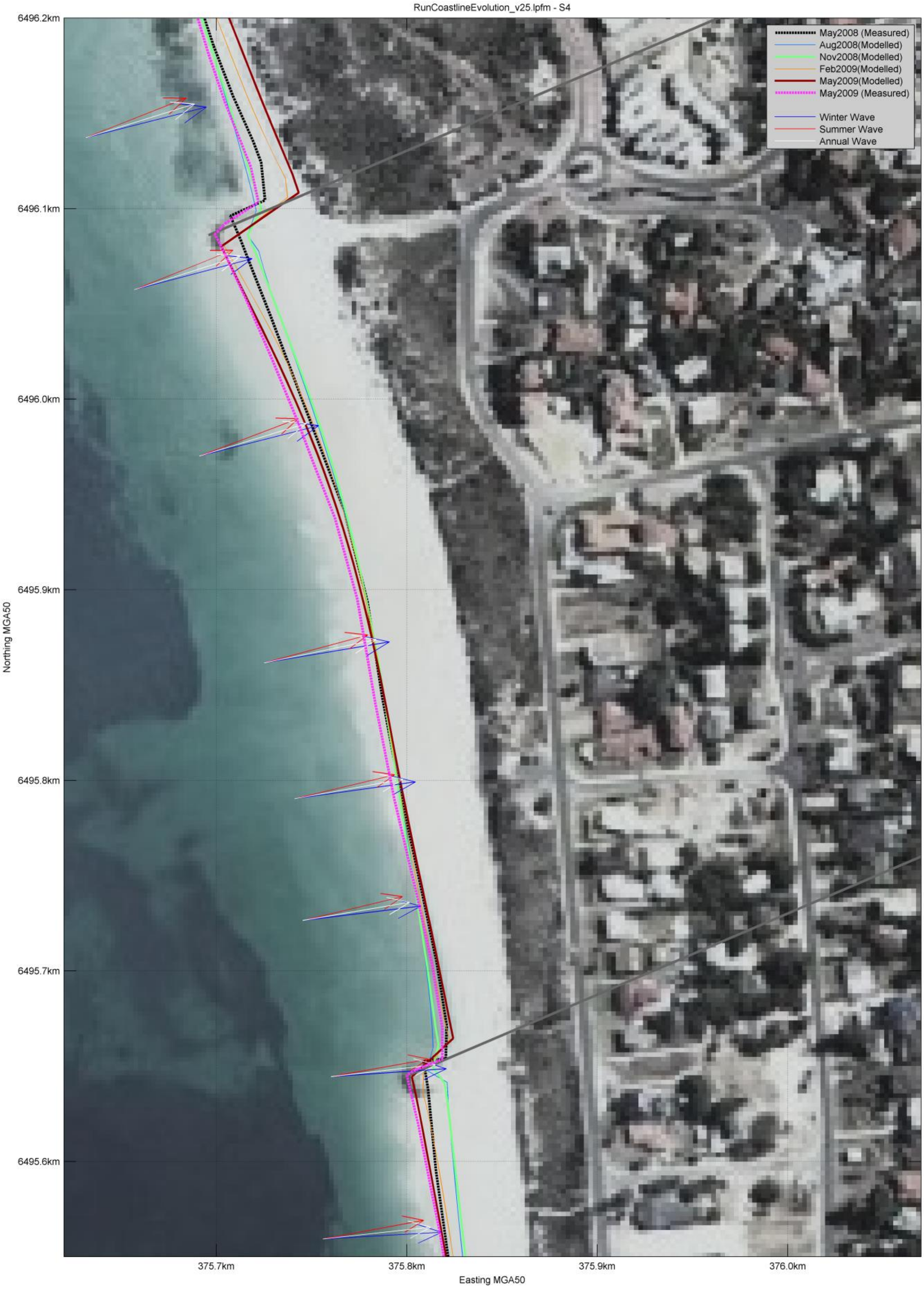


Figure F-4 Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 4

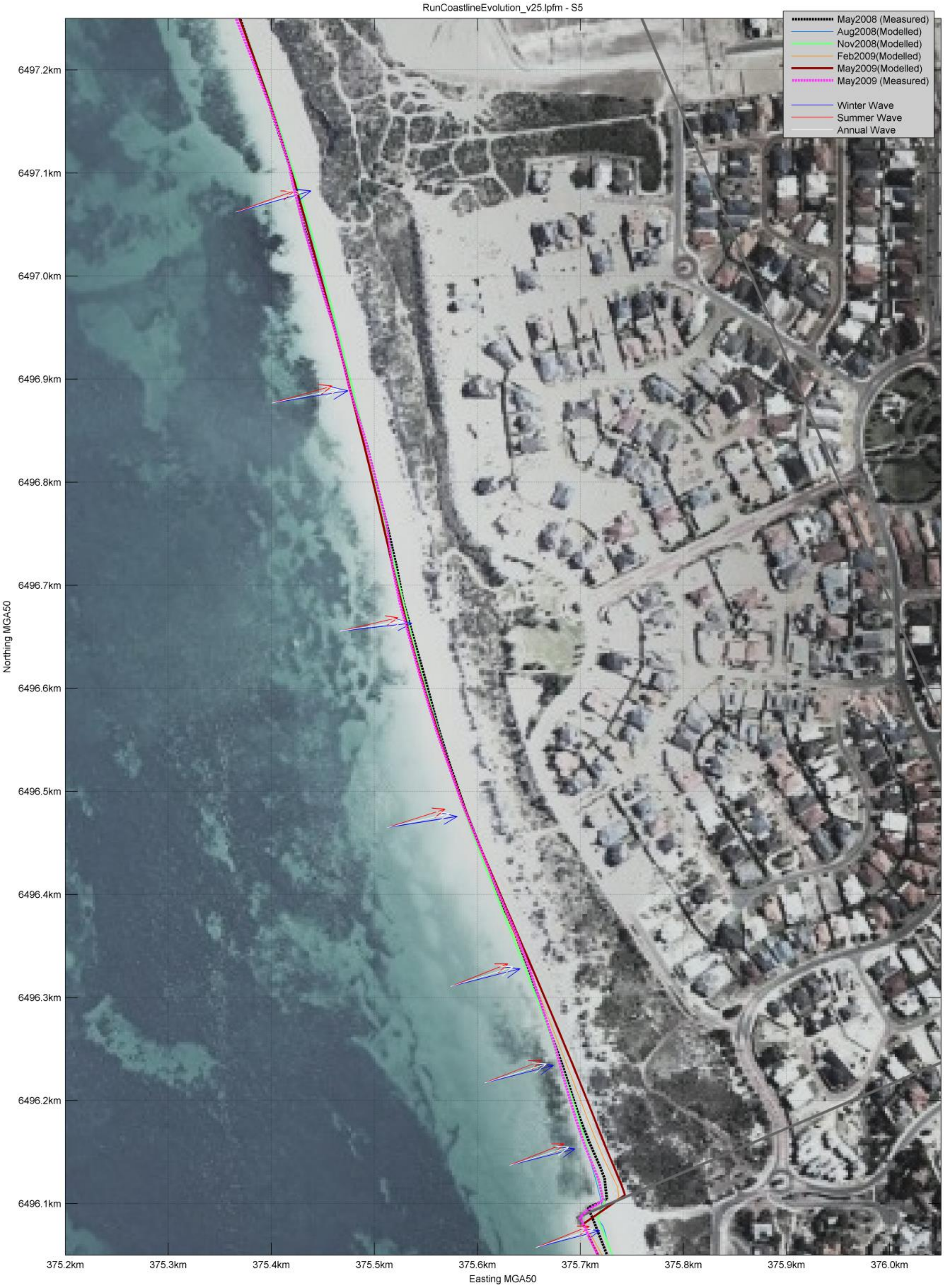
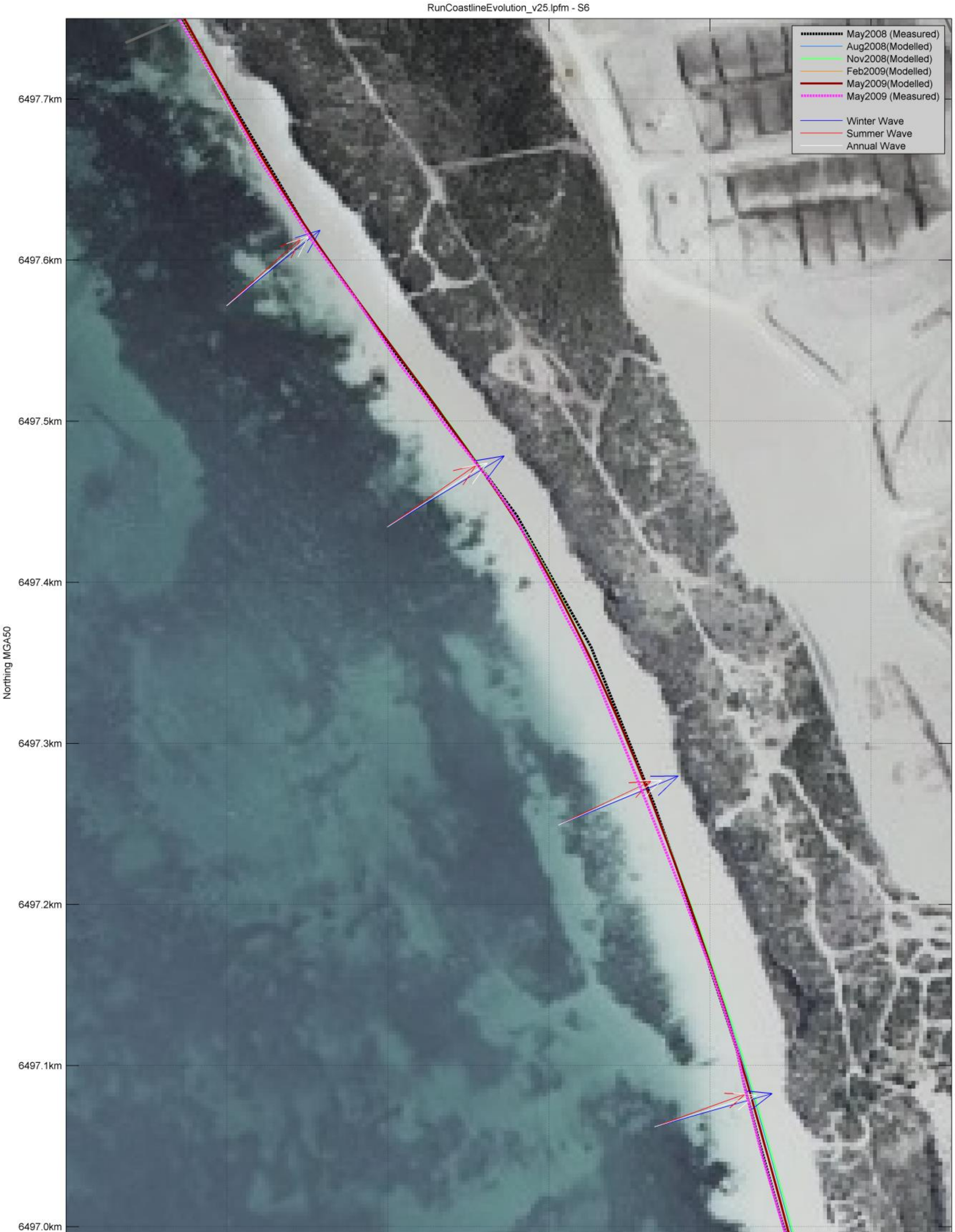


Figure F-5 Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 5



Modelling of Longshore Transport with Litline (May 2008 – May 2009) – Section 6

Figure F-6 Shoreline postions at the end of summer (1-May) from 10 year Litline simulation from 2005 through 2014.

Figure F-7 Shoreline postions at the end of winter (30 September) from 10 year Litline simulation from 2005 through 2014.

Coastal Processes and Preliminary Options Assessment Report

APPENDIX G

WORLEY PARSONS 2014 METOCEAN DATA COLLECTION REPORTS

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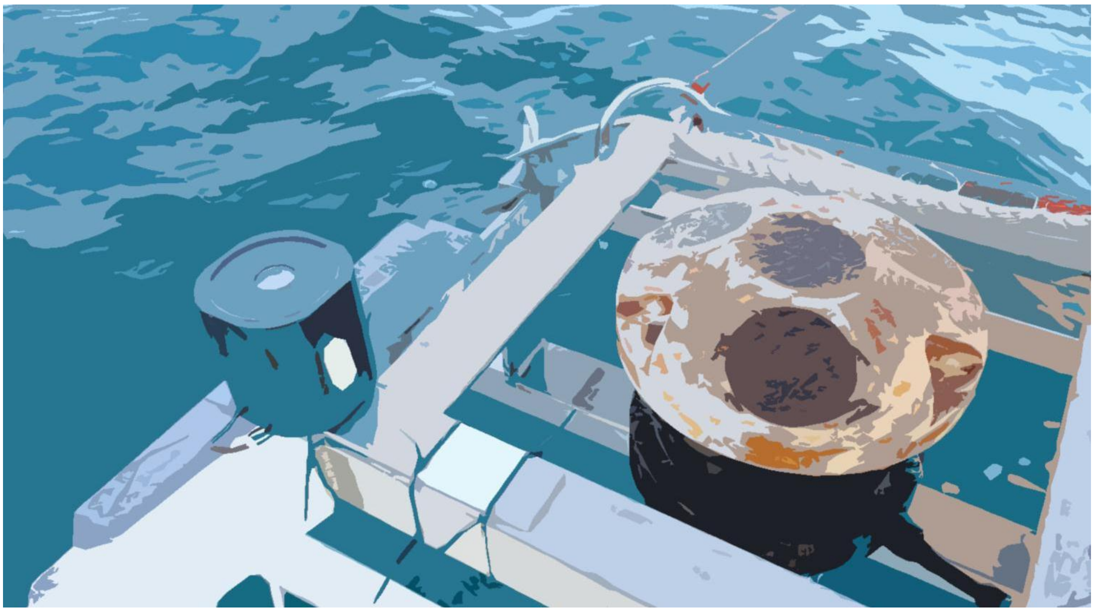
EcoNomics™

CITY OF WANNEROO

Quinns Rocks Metocean Data Collection

Field Survey Report No. 1 - Summer 2014



301012-01921 – FRP-001-Rev0

20 May 2014

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EcoNomics

CITY OF WANNEROO
QUINNS ROCKS METOCEAN DATA COLLECTION
FIELD SURVEY REPORT NO. 1 - SUMMER 2014

Disclaimer

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PROJECT 301012-01921 - QUINNS ROCKS METOCEAN DATA COLLECTION

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CUSTOMER APPROVAL	DATE
A	Issued for internal review	M Zed	S Free	K Y Lim	12-May-14	N/A	
B	Issued for client review	M Zed	S Free	K Y Lim	13-May-14		N/A
0	Issued as Final	M Zed	S Free	K Y Lim	20-May-14		

CONTENTS

1. INTRODUCTION

This field survey report provides an overview of the activities undertaken for the summer deployment of the Quinns Rocks Metocean Data Collection campaign between January and April 2014.

This report provides an overview of the tasks, equipment and methods used and the observations from the units following WorleyParsons standard Quality Assurance (QA) and Quality Control (QC) process in accordance with our Project Execution Plan (ref document no. 301012-01921-PM-PEP-0001). A summary of the Health, Safety and Environment (HSE) precautions undertaken during the works and environmental management tallies have also been included.

Appendices summarising the QA/QC'd field observations are included as attachments to this report, with this to be provided in electronic format, along with the raw data, following submission of the report.

1.1 Study Datum

Water depths and levels presented in this report are referenced to Chart Datum (CD), unless otherwise stated, and are in units of metres. Geographical positions are provided in geographic (Latitude/Longitude) coordinates unless stated otherwise.

All units are in standard SI units unless otherwise stated, with all bearings and directions provided in degrees True North.

2. DEPLOYMENT INFORMATION

2.1 Summary

The Quinns Rocks Metocean Data Collection campaign involved the installation of acoustic wave and current profilers at both an onshore and offshore location.

WorleyParsons initially deployed a 1 MHz Nortek Acoustic Waves and Current (AWAC) profiler at the inshore location and 600 kHz Teledyne RDI Acoustic Doppler Current Profiler (ADCP) at the offshore location on the 22 January 2014. Maintenance was performed on the Inshore AWAC on 18 March 2014, with the unit redeployed the same day. The maintenance on the offshore unit was postponed until 24 March 2014, with the unit replaced with a 1 MHz AWAC unit to enable a quick re-deployment and reduce data gaps.

2.2 Frames

The frames used to deploy the acoustic units were custom built for the AWAC. The frames are made from high quality stainless steel, with 2 x 25kg lead weights used to increase stability on the seabed during extreme events.

Each frame was connected to 10 m of rope and an additional 15 m of chain (total length approximately 25m) for additional stability of the unit and use in retrieval. During deployment, a digital altimeter, owned and developed by WorleyParsons, is used to ensure the frame is situated in an upright position within the acceptable range required (nominally within 8 degrees of the vertical). A depiction of the frames, with the temporary placement of the digital altimeter during deployment, is shown in Figure 2-1.

The ADCP unit frame was similar to that of the AWAC's in terms of materials and overall weight, with the only difference being that the ADCP transducers sit approximately 20cm higher than that of the AWAC.

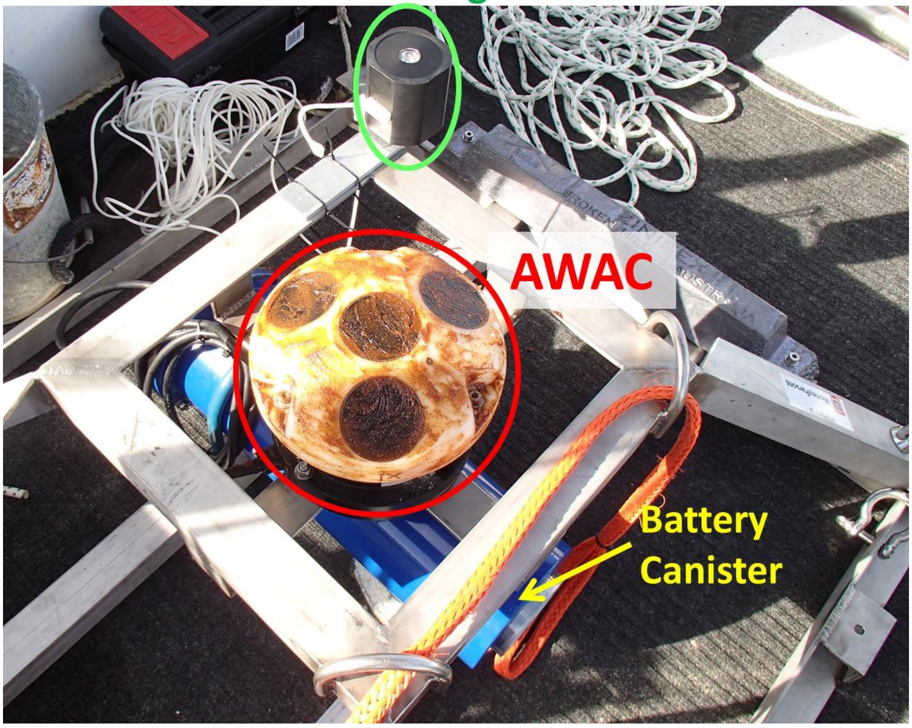


Figure 2-1 WorleyParsons standard AWAC frame with digital altimeter shown.

2.3 Locations and Deployment Periods

The locations of the inshore and offshore units is provided in , with these shown graphically in Figure 2-2.

WorleyParsons endeavour to always re-deploy units in the exact same location following maintenance trips but variable bathymetry and inclement weather conditions often result in the units being relocated adjacent to their original location. Both units were redeployed within 40m of their original location.

Table 2-1 Deployment coordinates for Inshore and Offshore Units.

Unit		Type	Longitude	Latitude	Depth range over record (m)
Inshore Unit	Before Maintenance	AWAC	115.6843 °E	31.6734 °S	5.37 – 6.29
	After Maintenance	AWAC	115.6846 °E	31.6729 °S	5.17 – 5.96
Offshore Unit	Before Maintenance	ADCP	115.6540 °E	31.6700 °S	13.50 – 14.51
	After Maintenance	AWAC	115.6552 °E	31.6697 °S	14.08 – 14.83

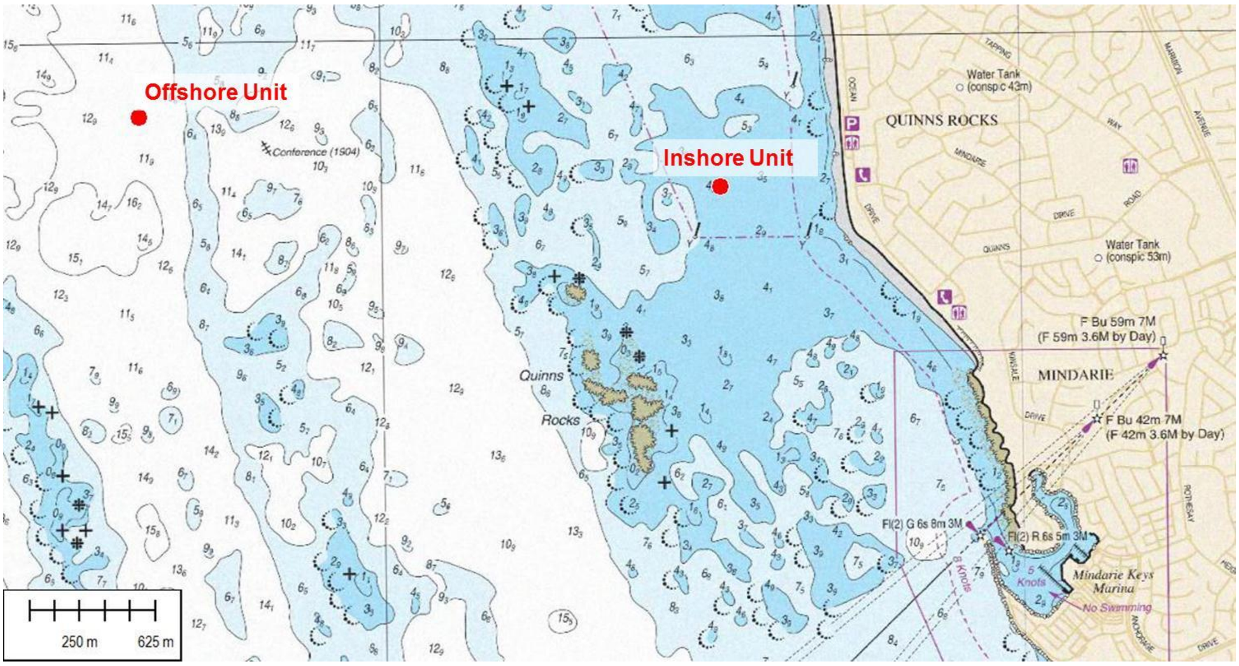


Figure 2-2 Location of Inshore and Offshore units (with reference to Mindarie Keys Marina). Map supplied by City of Wanneroo.

2.4 Deployment Configuration

The units were deployed as per the specifications provided by the City of Wanneroo on 15 January 2014 (a week before the first deployment), with a summary of the unit configuration provided in Table 2-2 and Table 2-3 for the Inshore and Offshore AWAC units, respectively.

The ADCP unit was configured with the same deployment parameters, for both wave and current measurement, as that of the AWAC units, with the only difference being that the ADCP recorded 2100 samples per wave burst at 2Hz as opposed to the 2048 samples per wave burst at 2Hz in the AWAC.

Table 2-2 Configuration of the Quinns Inshore AWAC Unit

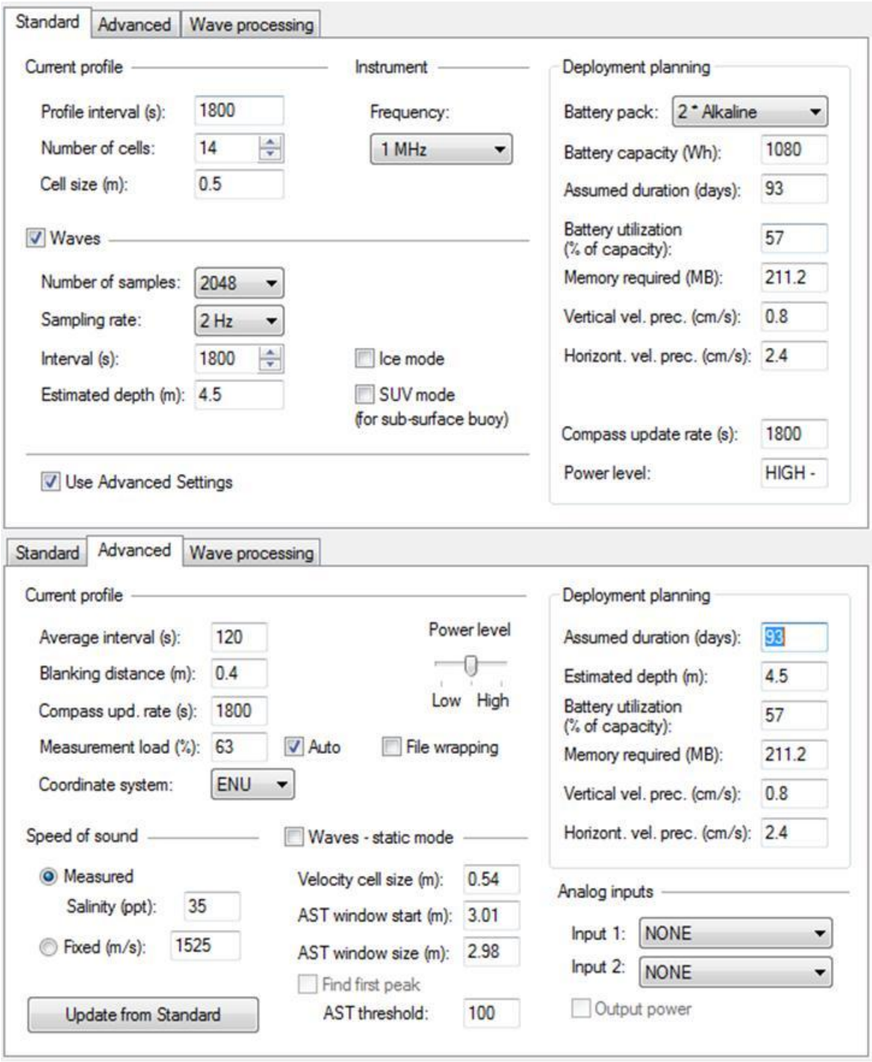


Table 2-3 Configuration of the Quinns Offshore AWAC Unit

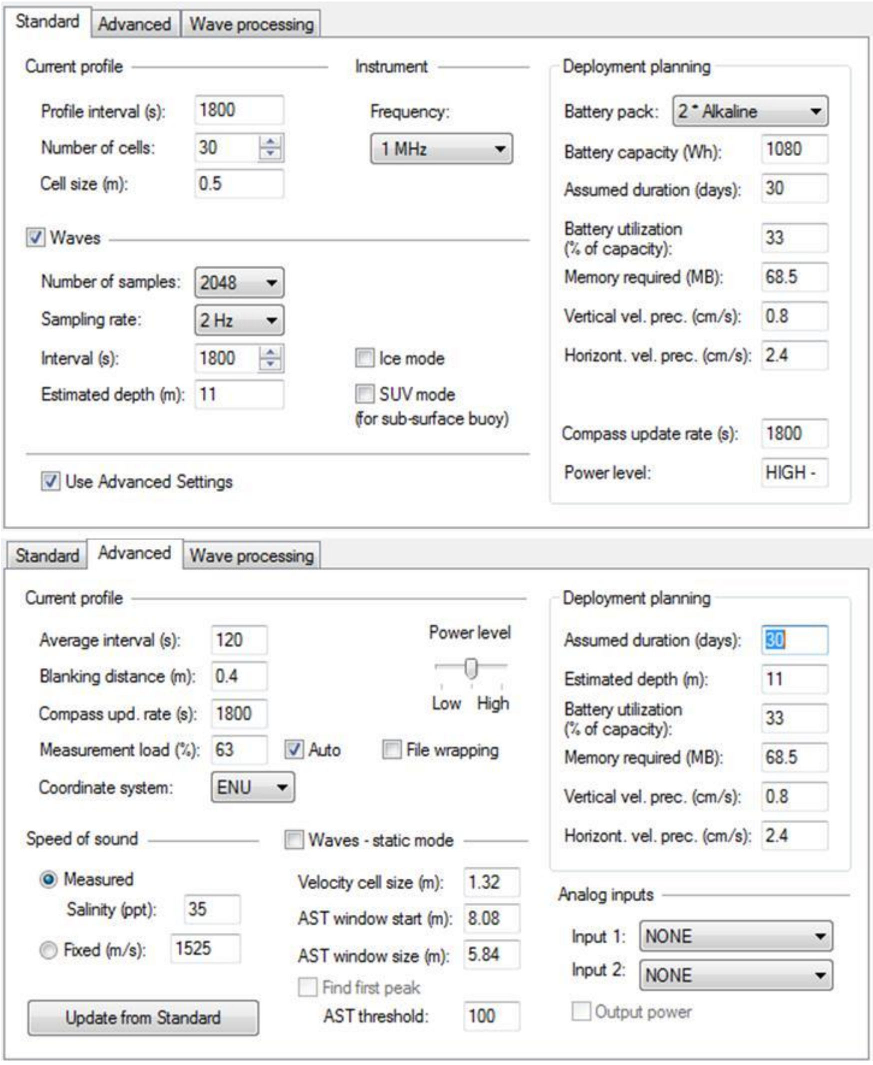
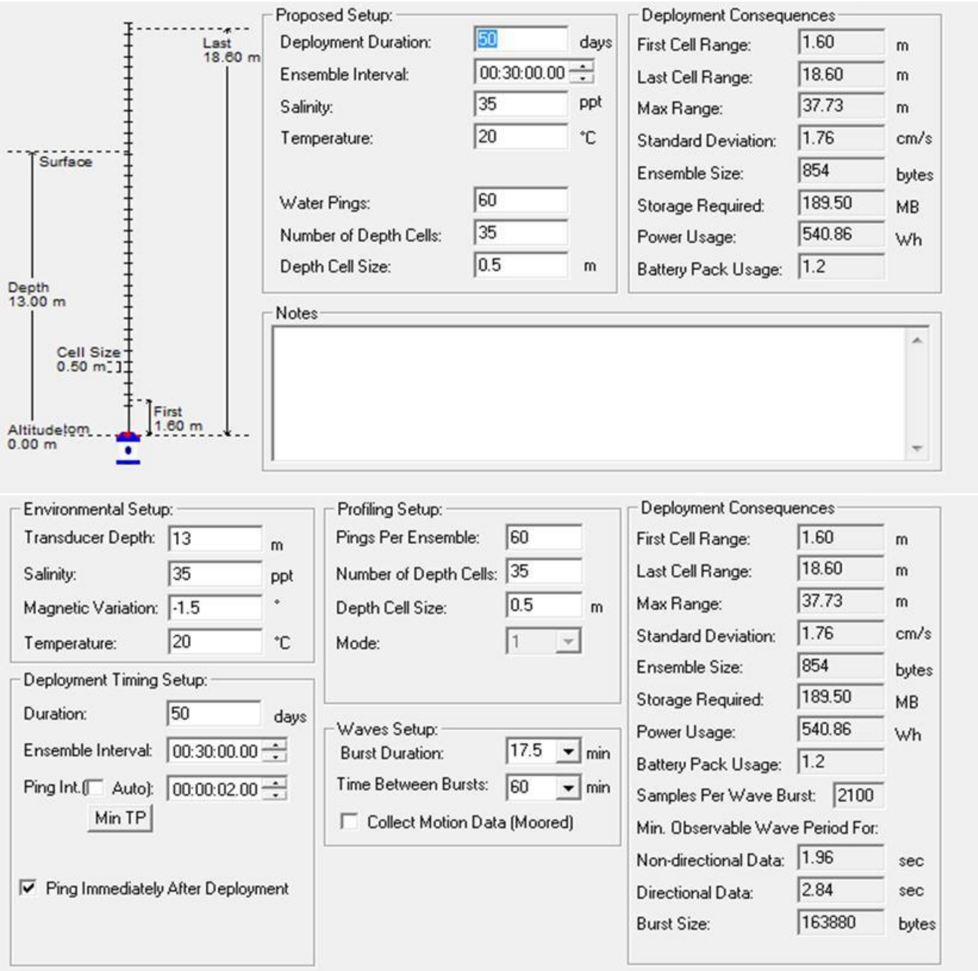


Table 2-4 Configuration of the Quinns Offshore ADCP Unit



2.5 Data Periods

A summary of the deployment, maintenance and final retrieval dates for the units is provided in Table 2-5.

Table 2-5 Summary of deployment periods for the inshore and offshore AWAC units

Location	Pre-Maintenance		Post-Maintenance		Total Duration
	Deployment	Retrieval	Deployment	Retrieval	
Inshore Unit	22/01/2014 15:00	18/03/2014 8:30	18/03/2014 12:30	30/04/2014 13:00	98 Days
Offshore Unit	22/01/2014 11:00	24/03/2014 9:30	24/03/2014 10:00	30/04/2014 13:00	98 Days

3. RESULTS

3.1 QA/QC

3.1.1 Compass Calibration

A compass calibration was performed on both the inshore and offshore units during the field deployment. For the initial deployment, the AWAC unit was successfully deployed with an estimated maximum error after the calibration of <1 degree. An attempt at calibrating the taller ADCP frame proved to be more sensitive to the ferrous materials at the boat ramp on the day of deployment and as such a compass check was performed before removing the unit from the frame on retrieval with this showing a <2 degree error, which was considered acceptable.

3.1.2 Data Interrogation

WorleyParsons standard method of QA/QC involves a first pass analysis of the raw hydrodynamic and wave information retrieved from the unit. Part of this process includes:

- Confirming the pitch and roll on the unit is within the "accurate range" of within 8 degrees to the vertical (with values preferably less than 5)
- Ensuring wave period, and associated wave parameters, calculated from the spectral binary files, is within acceptable ranges and removing all parameters over the corresponding time if not.
- Consistency check for dominant wave and current direction following maintenance events.

All data presented in the appendices have undergone this standard QA/QC check and following this process it is confirmed that over the deployment period from 22 January to 30 April 2014 at least 99% of the data collected at both the inshore and offshore sites is considered suitable for use.

3.2 Temperature

The near-seabed water temperature, as recorded by the AWAC and ADCP units at the Inshore and Offshore locations is presented in Figure 3-1 and Figure 3-2, respectively.

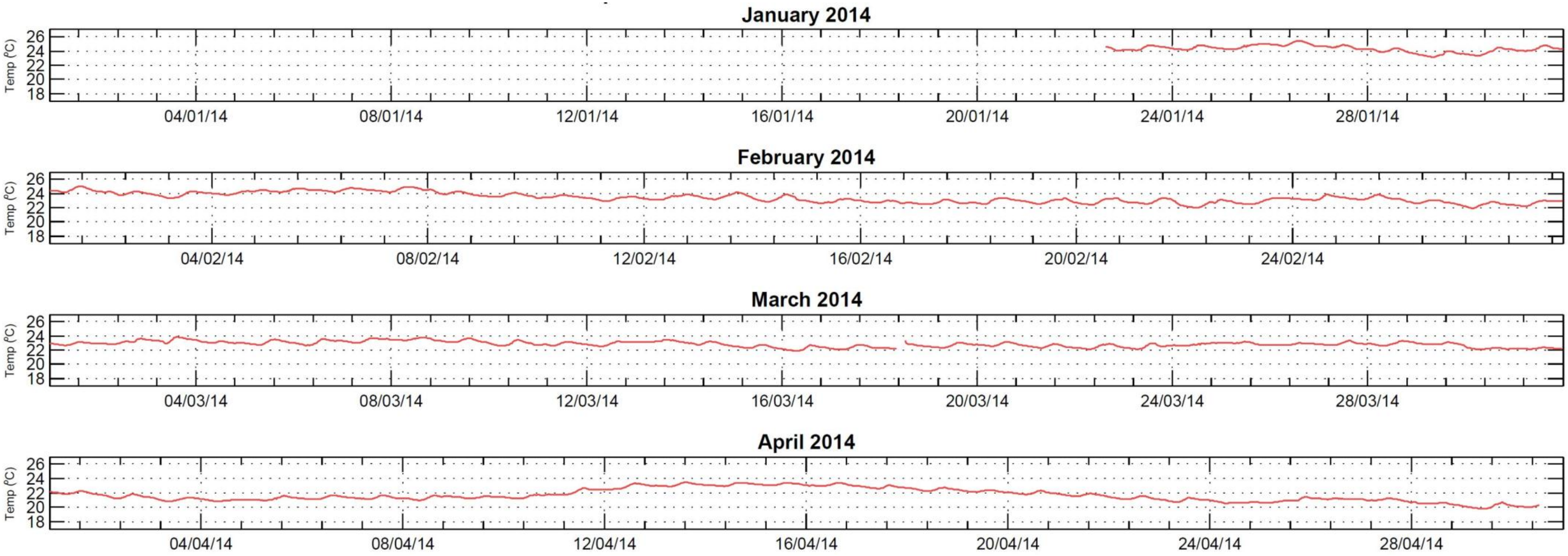


Figure 3-1 Near-seabed water temperature data as recorded at the Inshore location.

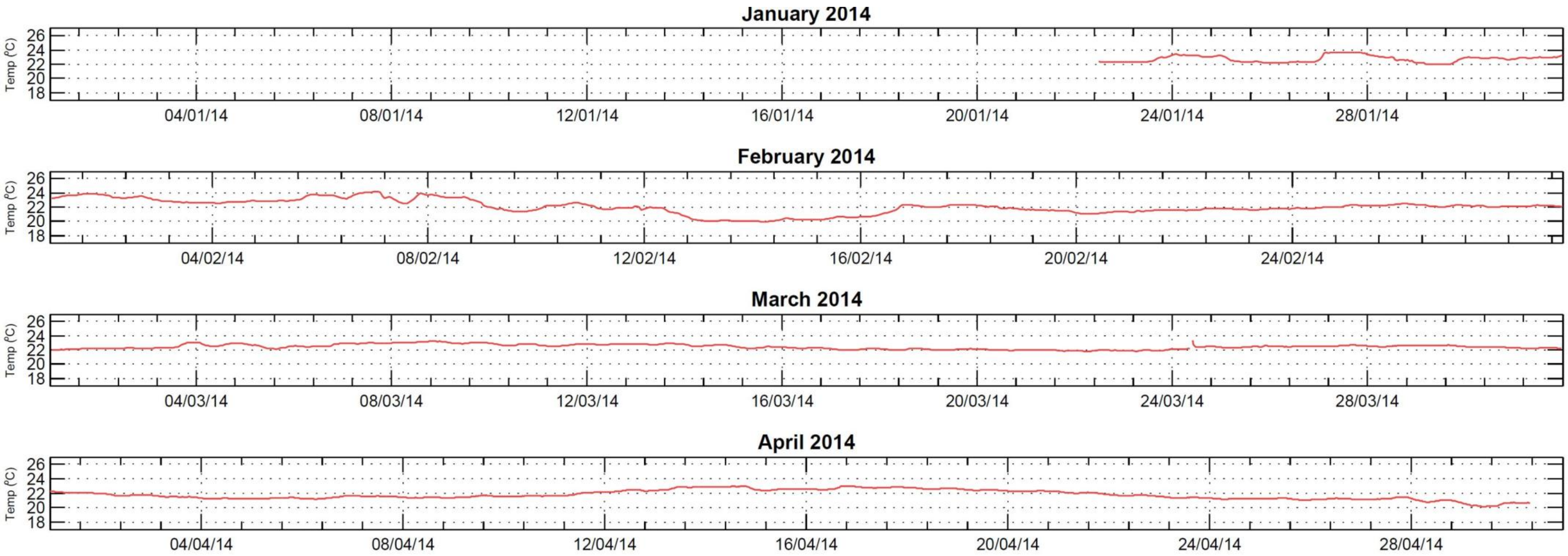


Figure 3-2 Near-seabed water temperature data as recorded at the Offshore location.

3.3 Currents and Water Levels

A summary of the hydrodynamic components captured by the Inshore and Offshore units is presented in Appendix 1. This is inclusive of:

- Surface elevation
- Seabed current speed and direction
- Surface current speed and direction

3.4 Waves

A summary of the wave parameters captured by the Inshore and Offshore units is presented in Appendix 2. This is inclusive of:

- Significant Wave Height
- Maximum Wave Height
- Peak Wave Period
- Mean Wave Period
- Peak Wave Direction
- Mean Wave Direction
- Sea and Swell Significant Wave Height
- Sea and Swell Peak Wave Period
- Sea and Swell Peak Wave Direction

4. HEALTH AND SAFETY

4.1 Daily Field Reports

Daily reports documenting all site activities undertaken and evidence of any health and safety meetings have been prepared during each field day.

These daily field reports have been included in Appendix 3.

4.2 Waste Management

All rubbish was stored and appropriately disposed, batteries were recycled and all materials were removed from the vessel and the marine environment. Statistics for waste management are based on Frm PP-13-020-01 (Contractor Environmental Close Out Report Proforma). A summary of waste management during FT04 and to date is tallied in Table 4-1.

Table 4-1 To date waste management tally for Quinns Rocks Metocean Deployment

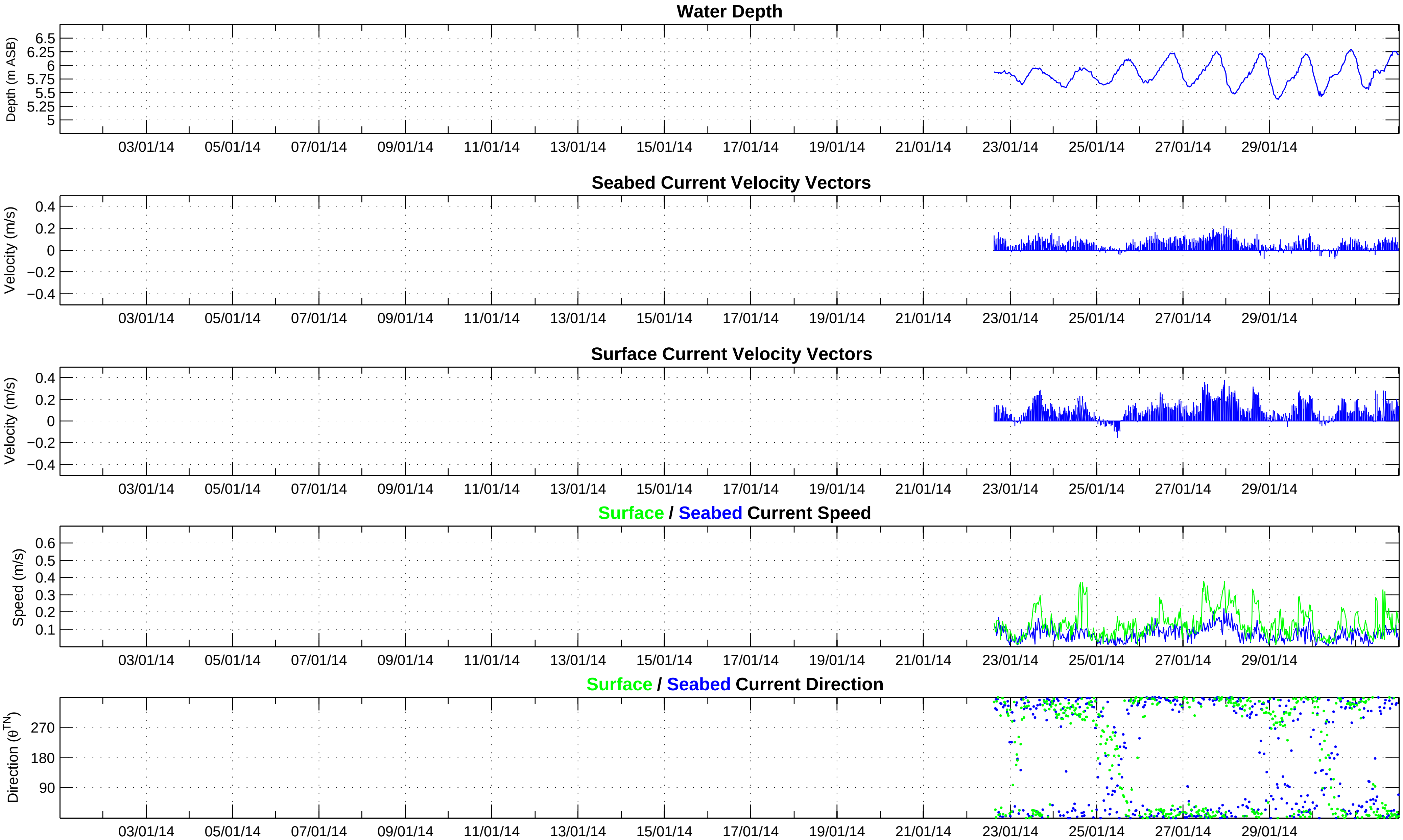
Statistic	Deployment 22/01/2014	Maintenance 1 18/03/2014	Maintenance 2 24/03/2014	Recovery 30/04/2014	Cumulative to Date
Total volume of General Waste disposed to offsite (m^3)	0.050 (1 bin, approx.)	0.050 (1 bin, approximate)	0.050 (1 bin, approximate)	0.050 (1 bin, approximate)	**0.200**
Total volume of domestic effluent disposed to offsite (m^3)	0.010 (approx.)	0.010 (approx.)	0.010 (approx.)	0.010 (approx.)	**0.040**
Total volume of Cardboard and Paper recycled (m^3)	<0.001 (approx.)	<0.001 (approx.)	<0.001 (approx.)	<0.001 (approx.)	**0.003**
Volume of Glass recycled (m^3)	<0.001 (approx.)	N/A	N/A	N/A	**0.001**
Volume of Aluminium cans recycled (m^3)	<0.001 (approx.)	N/A	<0.001 (approx.)	<0.001 (approx.)	**0.003**
Volume of Plastic Bottles recycled (m^3)	0.020 (approximate)	0.020 (approximate)	0.020 (approximate)	0.020 (approximate)	**0.080**

5. SUMMARY

The summer deployment campaign for the Quinns Rocks Metocean Data Collection project has seen successful data capture of wave, current and water level information at the Inshore and Offshore locations.

Following WorleyParsons standard QA/QC procedures it was shown that over the deployment period from 22 January to 30 April 2014 at least 99% of the data collected at both the inshore and offshore sites can be considered suitable for use.

Appendix 1 - Currents and Water Levels



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: January 2014 (22−Jan−2014 to 31−Jan−2014)

Data source: AWAC

Data summary: January 2014

Number of Records: 450

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

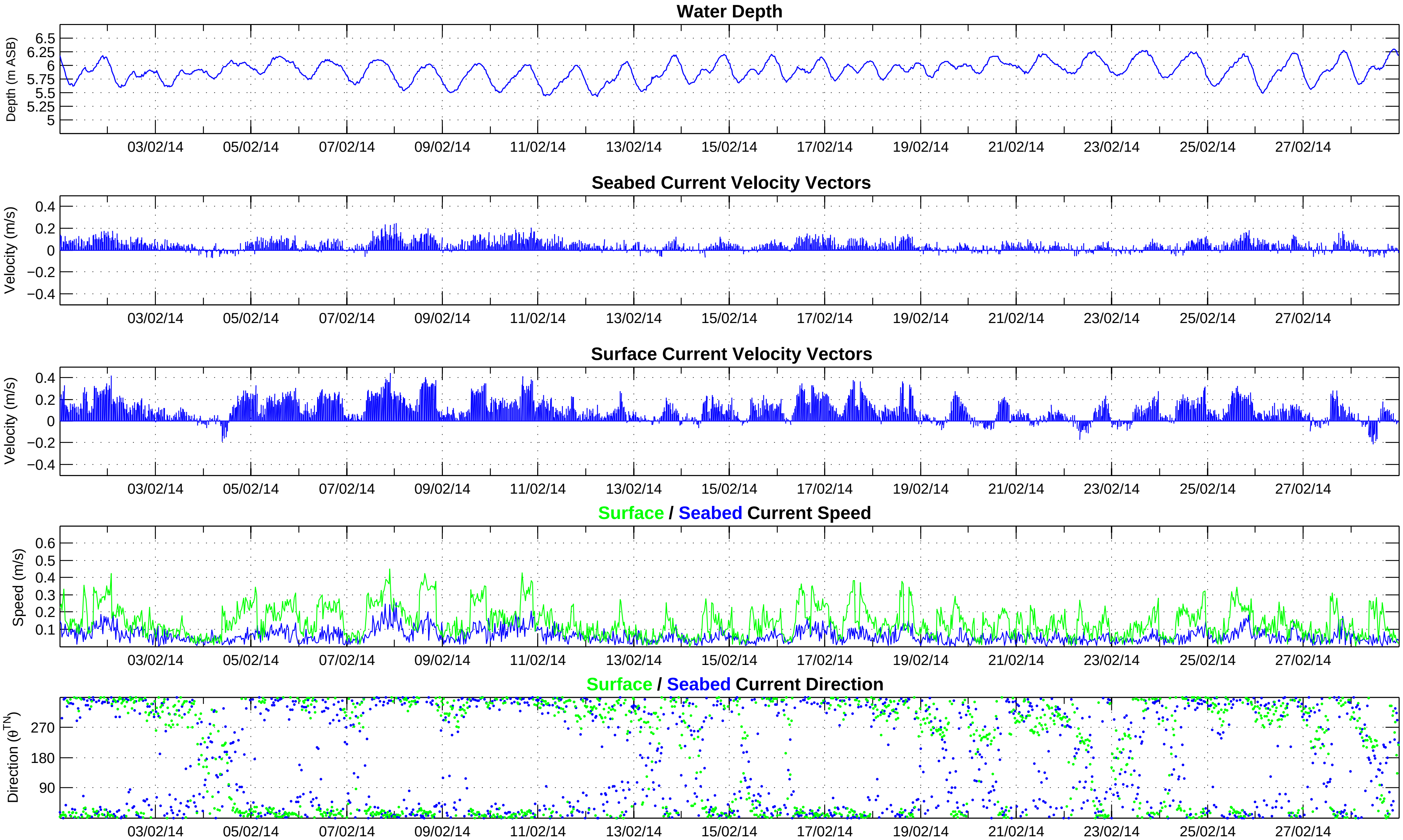
Max Curr Spd: 0.38 m/s

Mean Curr Spd: 0.13 m/s

StdDev. Curr Spd: 0.08 m/s

Current Summary January 2014

WorleyParsons
resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843^{o}E , 31.6734^{o}S]

Data period: February 2014 (01−Feb−2014 to 28−Feb−2014)

Data source: AWAC

Data summary: February 2014

Number of Records: 1344

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.45 m/s

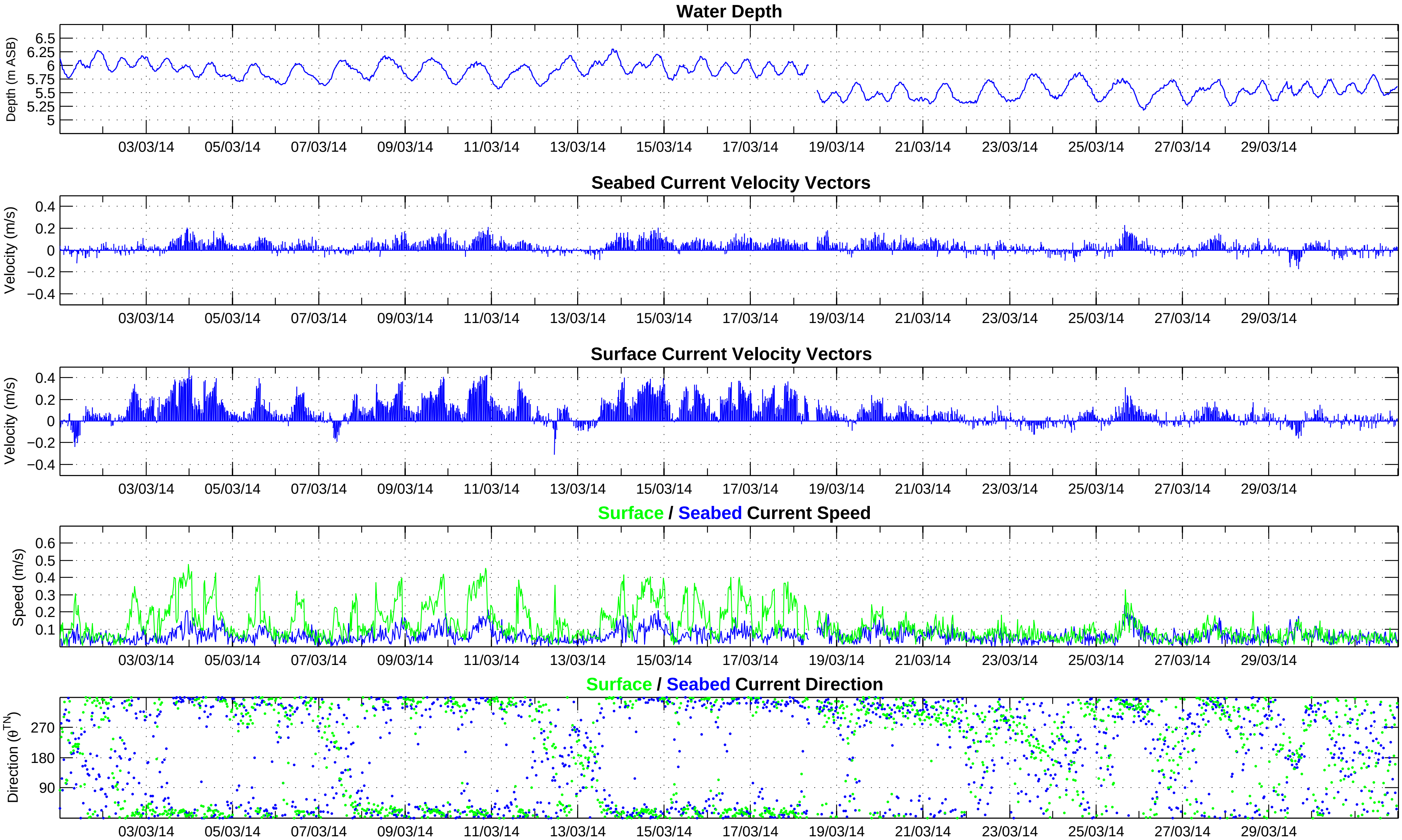
Mean Curr Spd: 0.14 m/s

StdDev. Curr Spd: 0.09 m/s

Current Summary February 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: March 2014 (01−Mar−2014 to 31−Mar−2014)

Data source: AWAC

Data summary: March 2014

Number of Records: 1480

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.48 m/s

Mean Curr Spd: 0.12 m/s

StdDev. Curr Spd: 0.10 m/s

Current Summary March 2014

WorleyParsons

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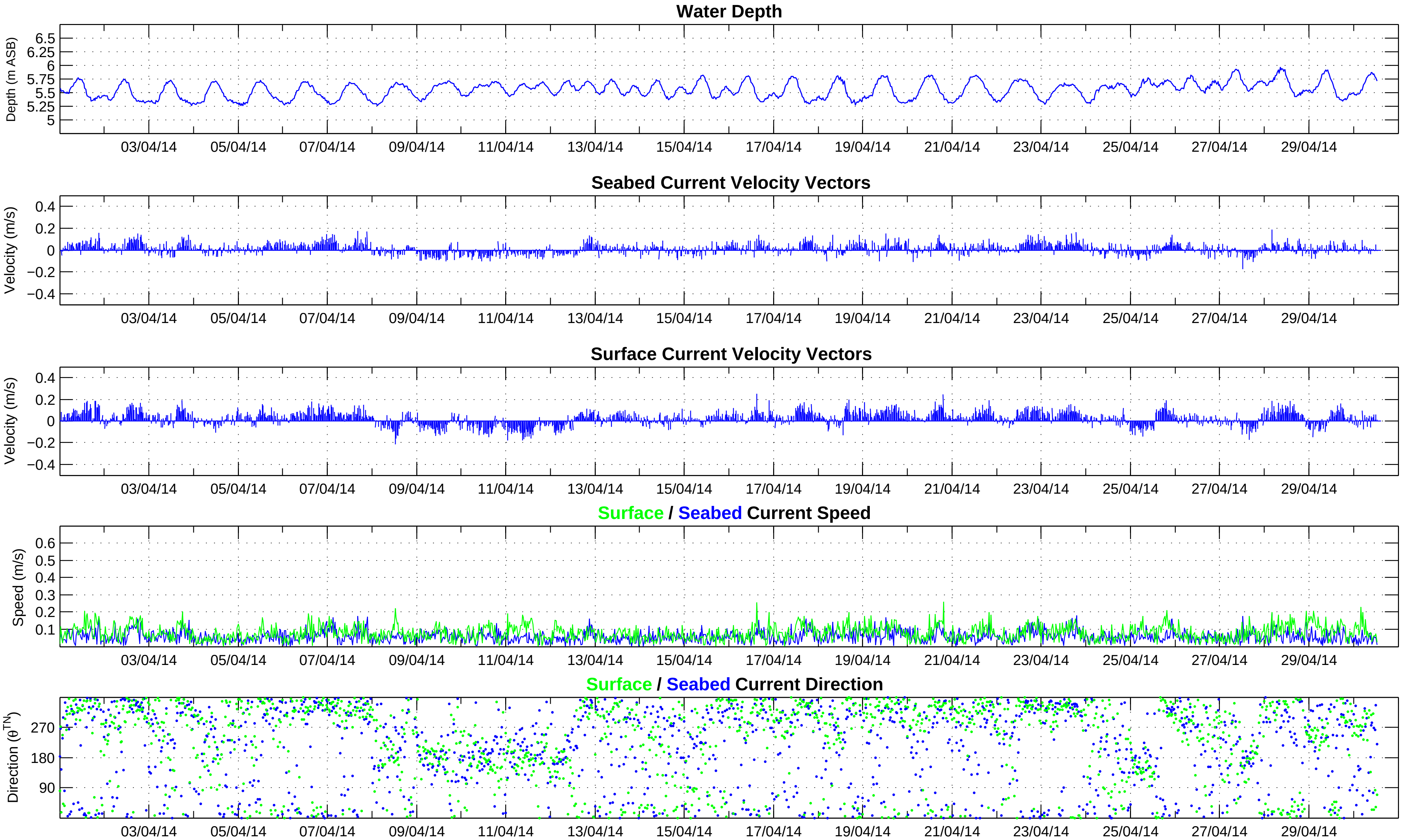

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843^{o}E , 31.6734^{o}S]

Data period: April 2014 (01−Apr−2014 to 30−Apr−2014)

Data source: AWAC

Data summary: April 2014

Number of Records: 1419

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.26 m/s

Mean Curr Spd: 0.08 m/s

StdDev. Curr Spd: 0.04 m/s

Current Summary April 2014

WorleyParsons

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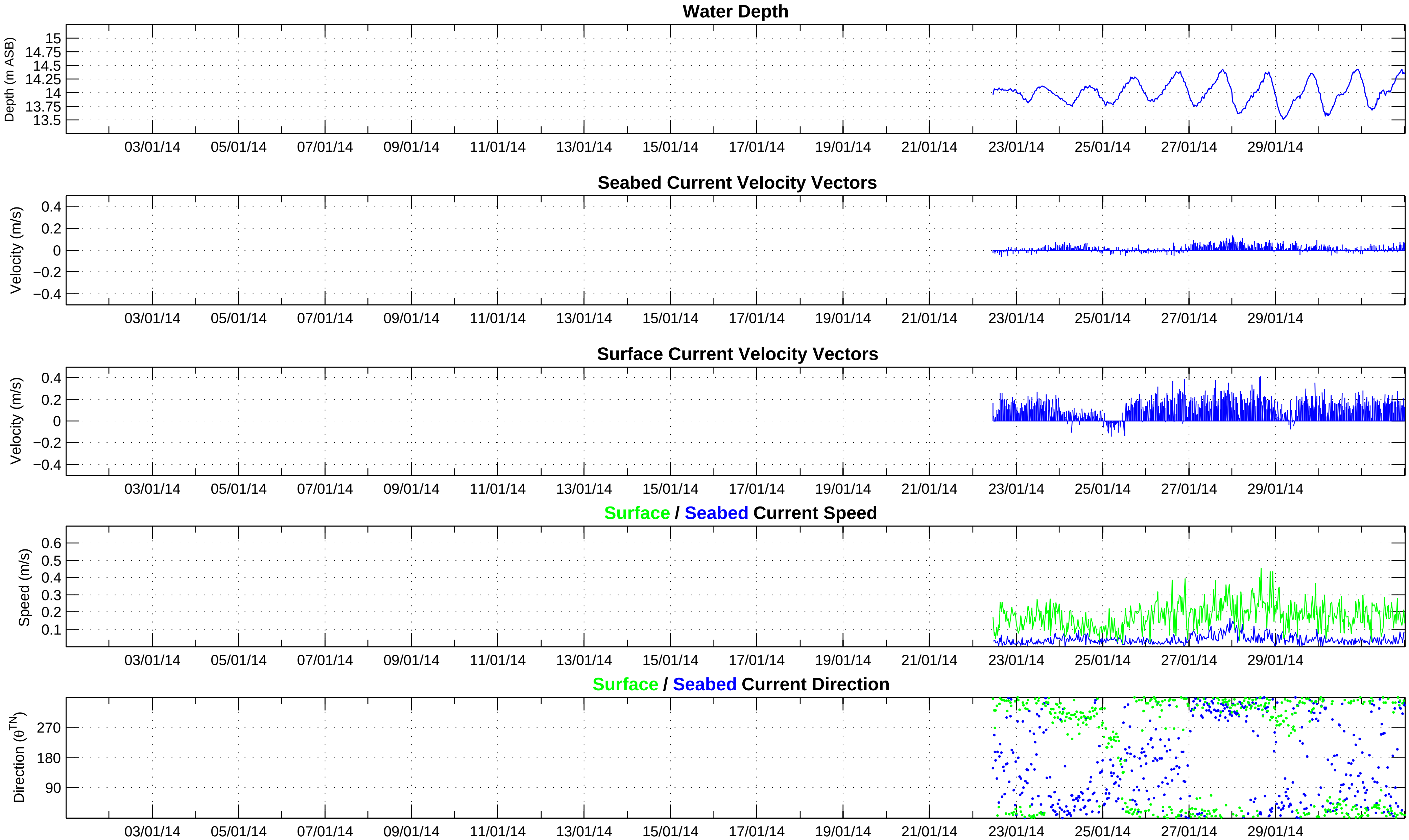

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540^{o}E , 31.6700^{o}S]

Data period: January 2014 (22−Jan−2014 to 31−Jan−2014)

Data source: AWAC

Data summary: January 2014

Number of Records: 458

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.45 m/s

Mean Curr Spd: 0.18 m/s

StdDev. Curr Spd: 0.07 m/s

Current Summary January 2014

WorleyParsons
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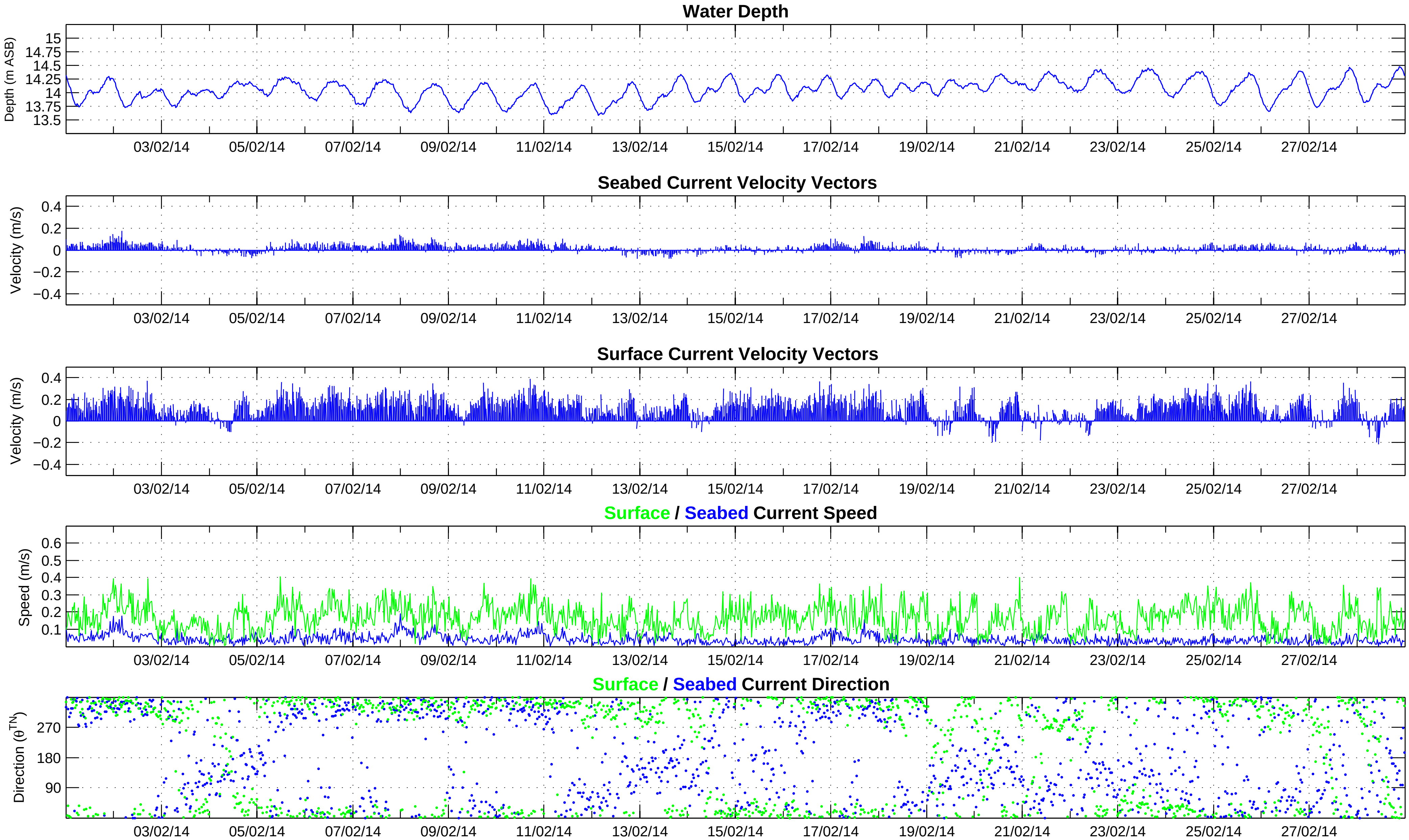

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540°E , 31.6700°S]

Data period: February 2014 (01−Feb−2014 to 28−Feb−2014)

Data source: AWAC

Data summary: February 2014

Number of Records: 1344

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.41 m/s

Mean Curr Spd: 0.17 m/s

StdDev. Curr Spd: 0.08 m/s

Current Summary February 2014

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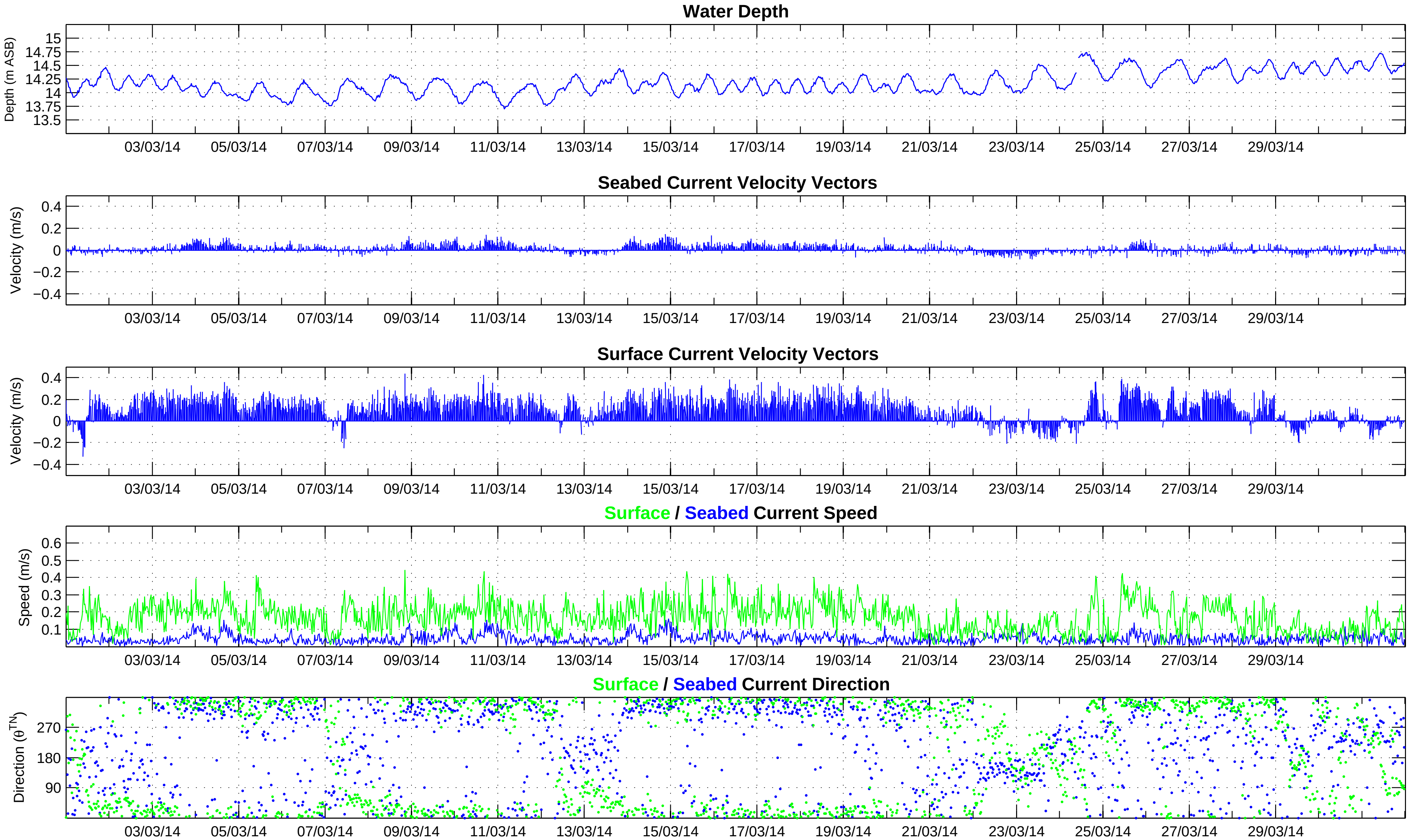

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540°E , 31.6700°S]

Data period: March 2014 (01−Mar−2014 to 31−Mar−2014)

Data source: AWAC

Data summary: March 2014

Number of Records: 1487

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.44 m/s

Mean Curr Spd: 0.17 m/s

StdDev. Curr Spd: 0.08 m/s

Current Summary March 2014

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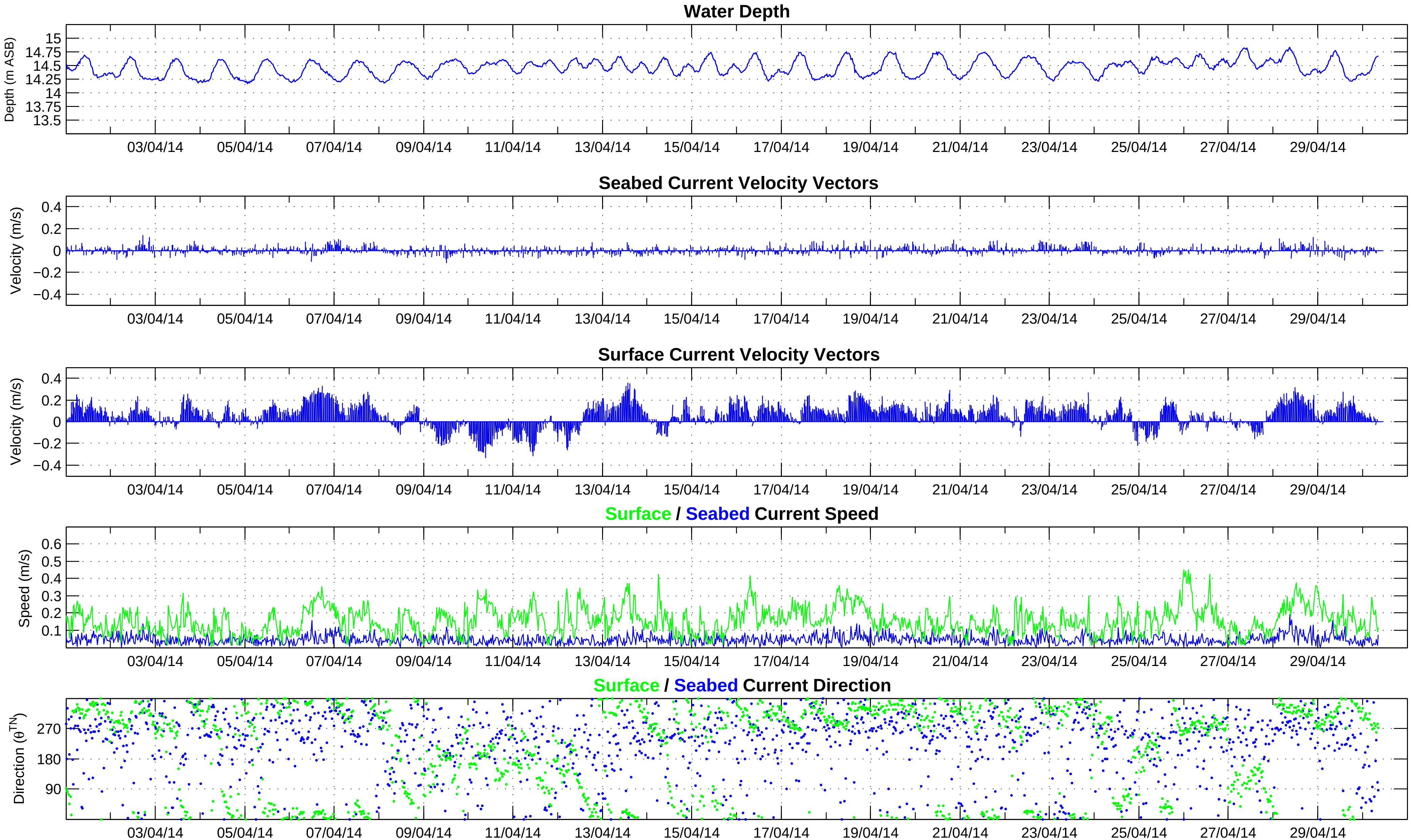

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540^{o}E , 31.6700^{o}S]

Data period: April 2014 (01−Apr−2014 to 30−Apr−2014)

Data source: AWAC

Data summary: April 2014

Number of Records: 1411

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.45 m/s

Mean Curr Spd: 0.16 m/s

StdDev. Curr Spd: 0.08 m/s

Current Summary April 2014

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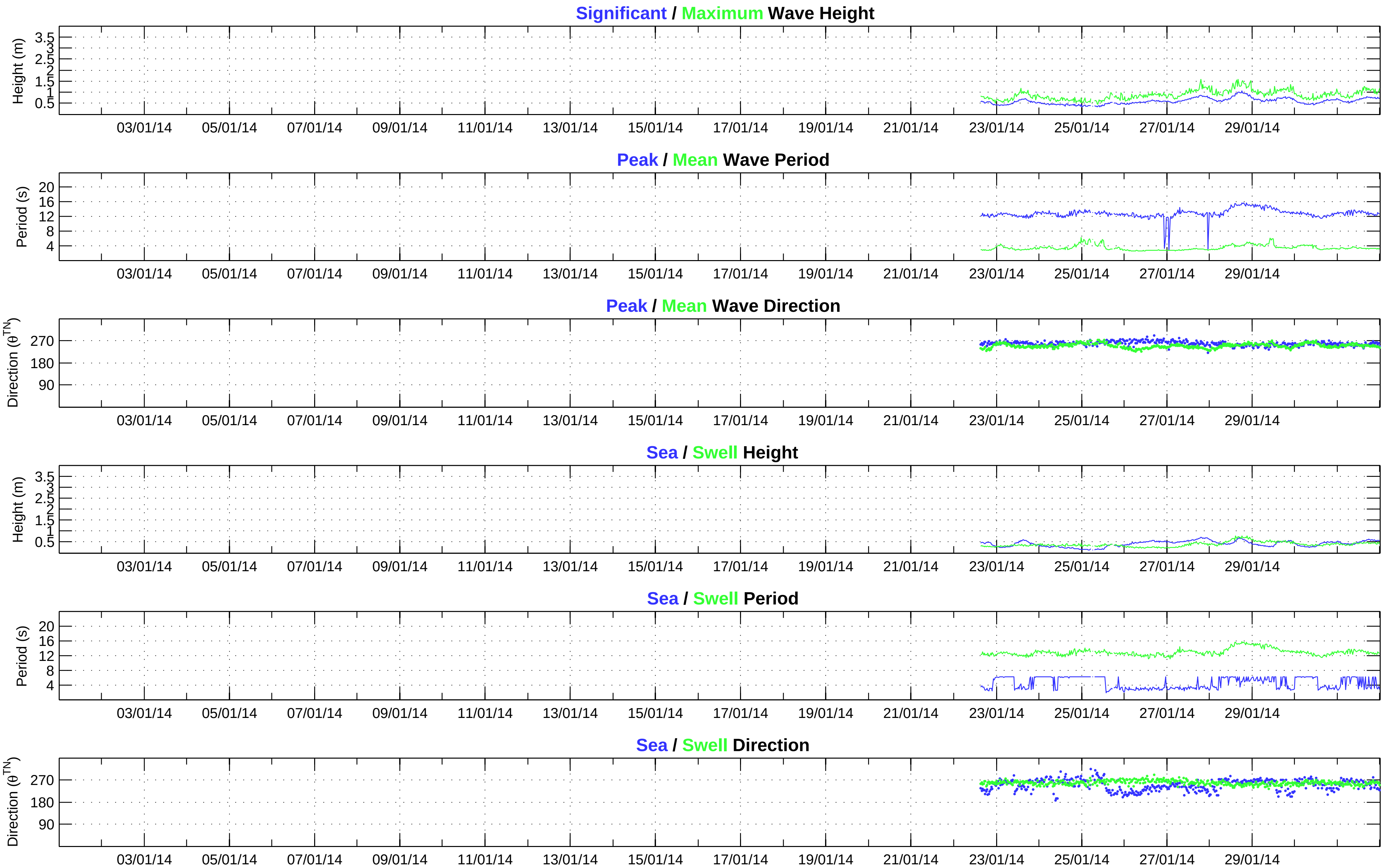
Appendix 2 - Wave Parameters



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: January 2014 (22−Jan−2014 to 31−Jan−2014)

Data source: AWAC

Data summary: January 2014

Number of Records: 450

Missing data (%): 0.01

Key Data Statistics:

Max Hs: 1.05 m	Max Tp: 15.67 s
Mean Hs: 0.59 m	Mean Tp: 12.81 s
StdDev. Hs: 0.14 m	StdDev. Tp: 1.25 s

Wave Summary January 2014

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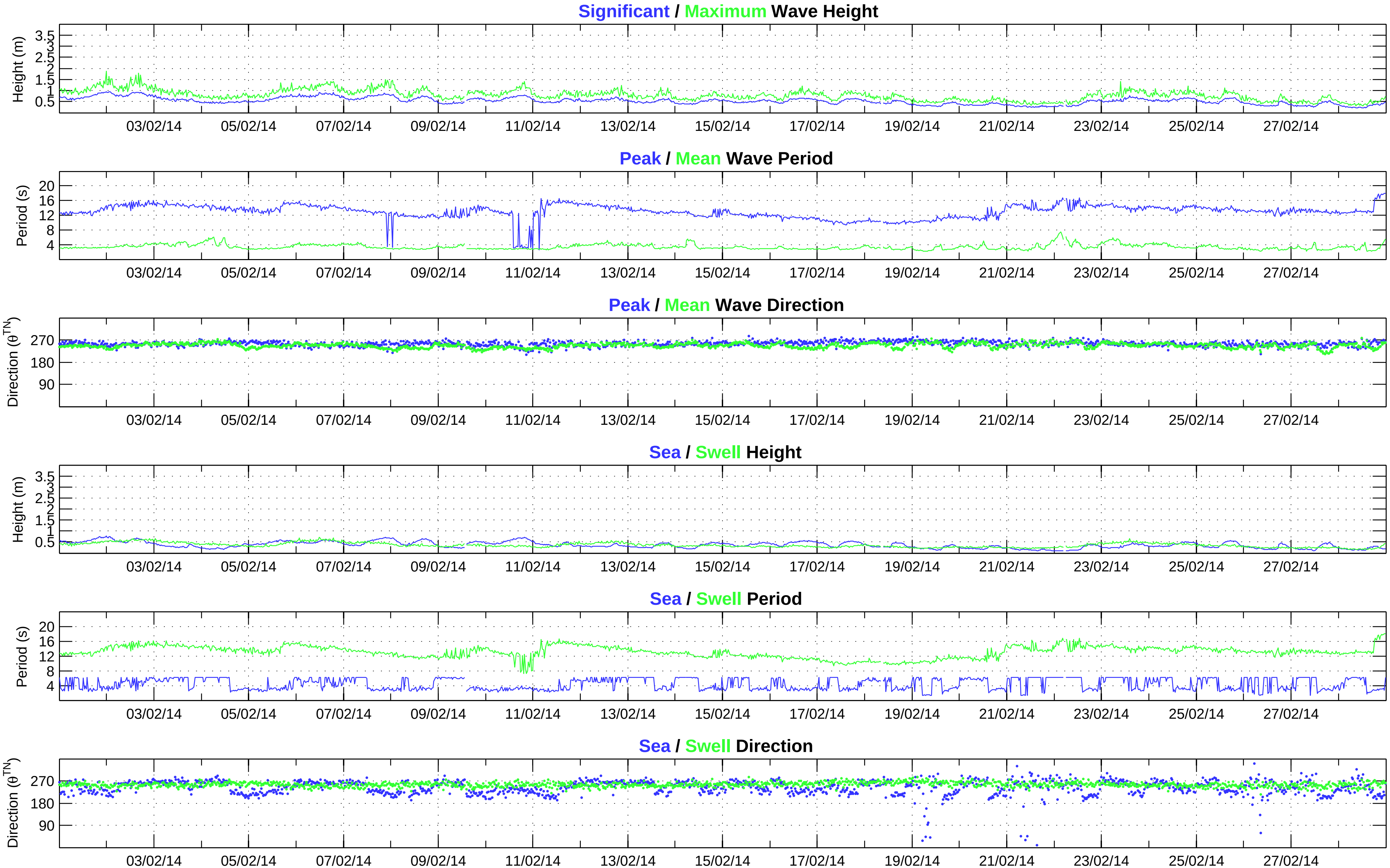

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: February 2014 (01−Feb−2014 to 28−Feb−2014)

Data source: AWAC

Data summary: February 2014

Number of Records: 1344

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 0.95 m	Max Tp: 18.01 s
Mean Hs: 0.53 m	Mean Tp: 12.97 s
StdDev. Hs: 0.16 m	StdDev. Tp: 1.96 s

Wave Summary February 2014

WorleyParsons

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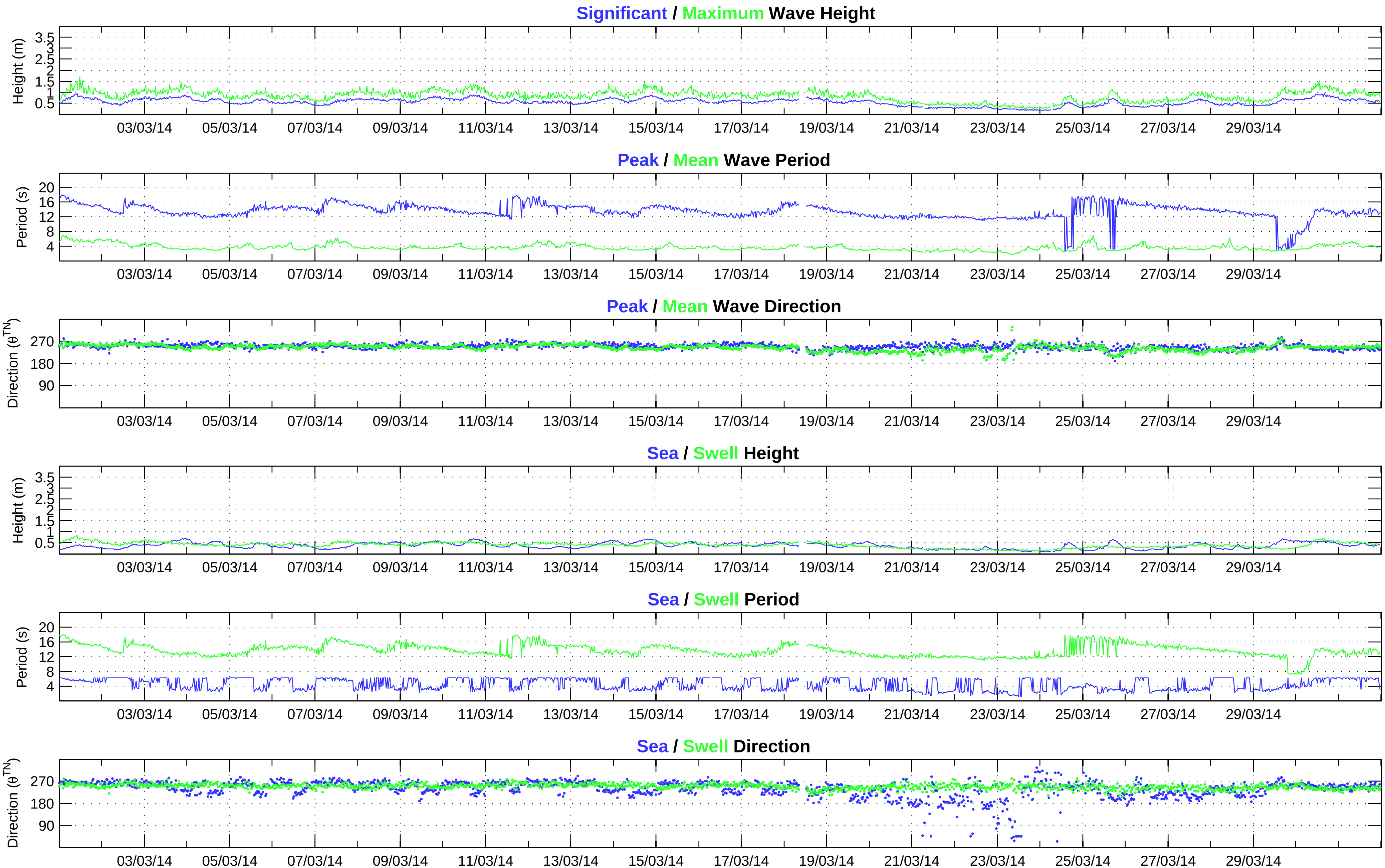

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: March 2014 (01−Mar−2014 to 31−Mar−2014)

Data source: AWAC

Data summary: March 2014

Number of Records: 1481

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 0.93 m	Max Tp: 17.88 s
Mean Hs: 0.56 m	Mean Tp: 13.45 s
StdDev. Hs: 0.16 m	StdDev. Tp: 2.14 s

Wave Summary March 2014

WorleyParsons

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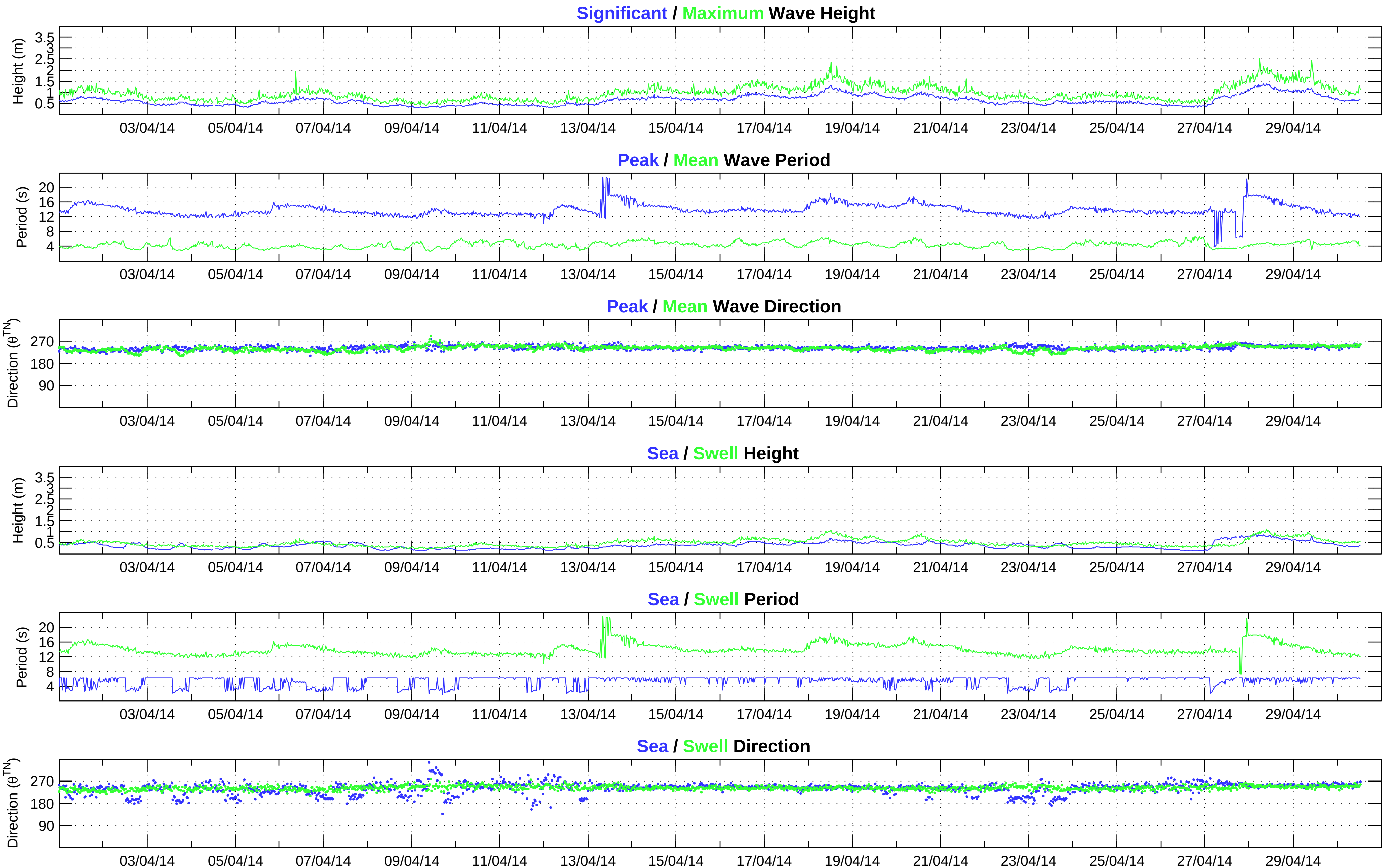

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Inshore AWAC [115.6843°E , 31.6734°S]

Data period: April 2014 (01−Apr−2014 to 30−Apr−2014)

Data source: AWAC

Data summary: April 2014

Number of Records: 1419

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 1.39 m	Max Tp: 22.80 s
Mean Hs: 0.64 m	Mean Tp: 13.83 s
StdDev. Hs: 0.22 m	StdDev. Tp: 1.65 s

Wave Summary April 2014

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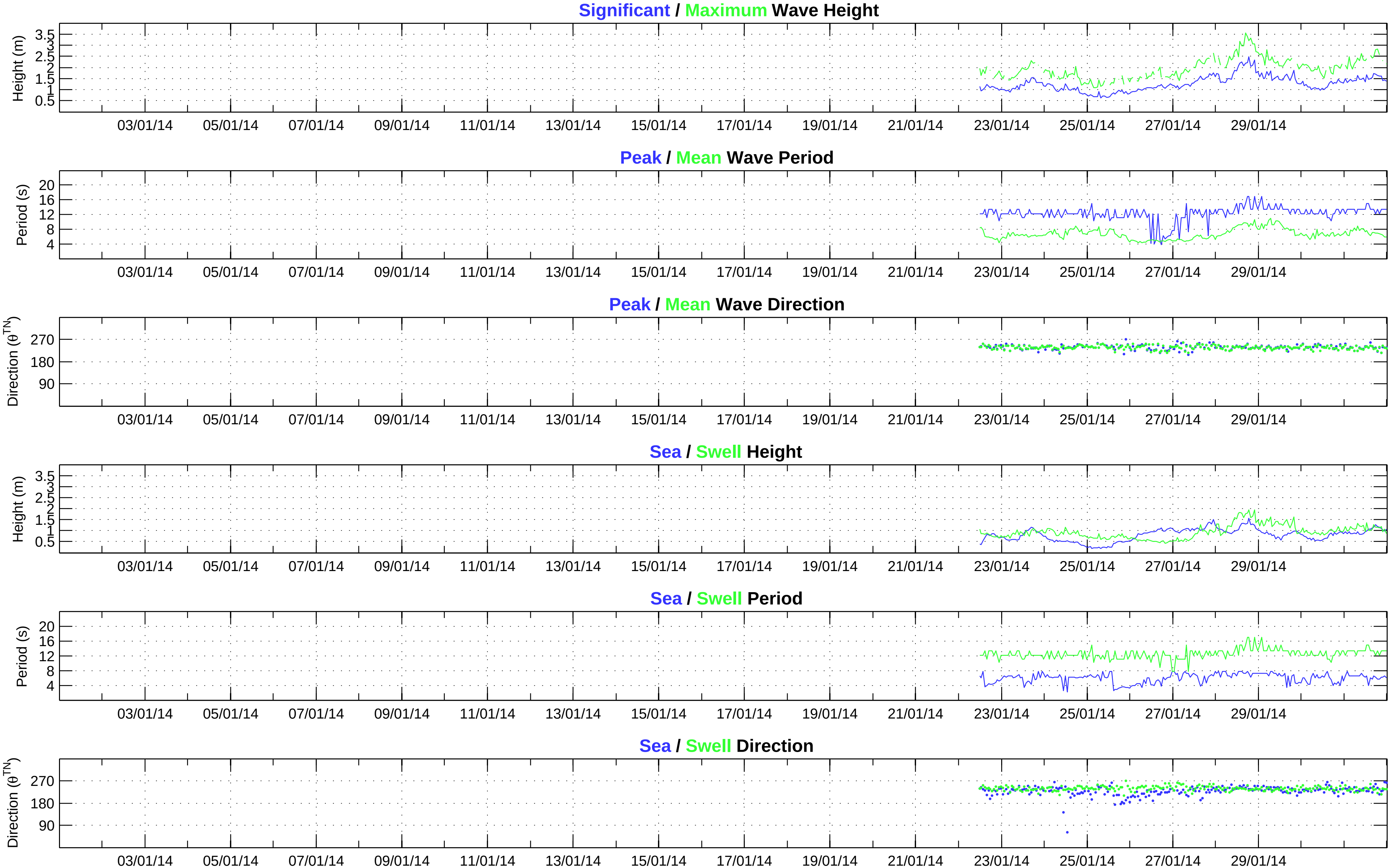

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540°E , 31.6700°S]

Data period: January 2014 (22−Jan−2014 to 31−Jan−2014)

Data source: AWAC

Data summary: January 2014

Number of Records: 229

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 2.49 m	Max Tp: 16.90 s
Mean Hs: 1.27 m	Mean Tp: 12.23 s
StdDev. Hs: 0.35 m	StdDev. Tp: 2.10 s

Wave Summary January 2014

WorleyParsons
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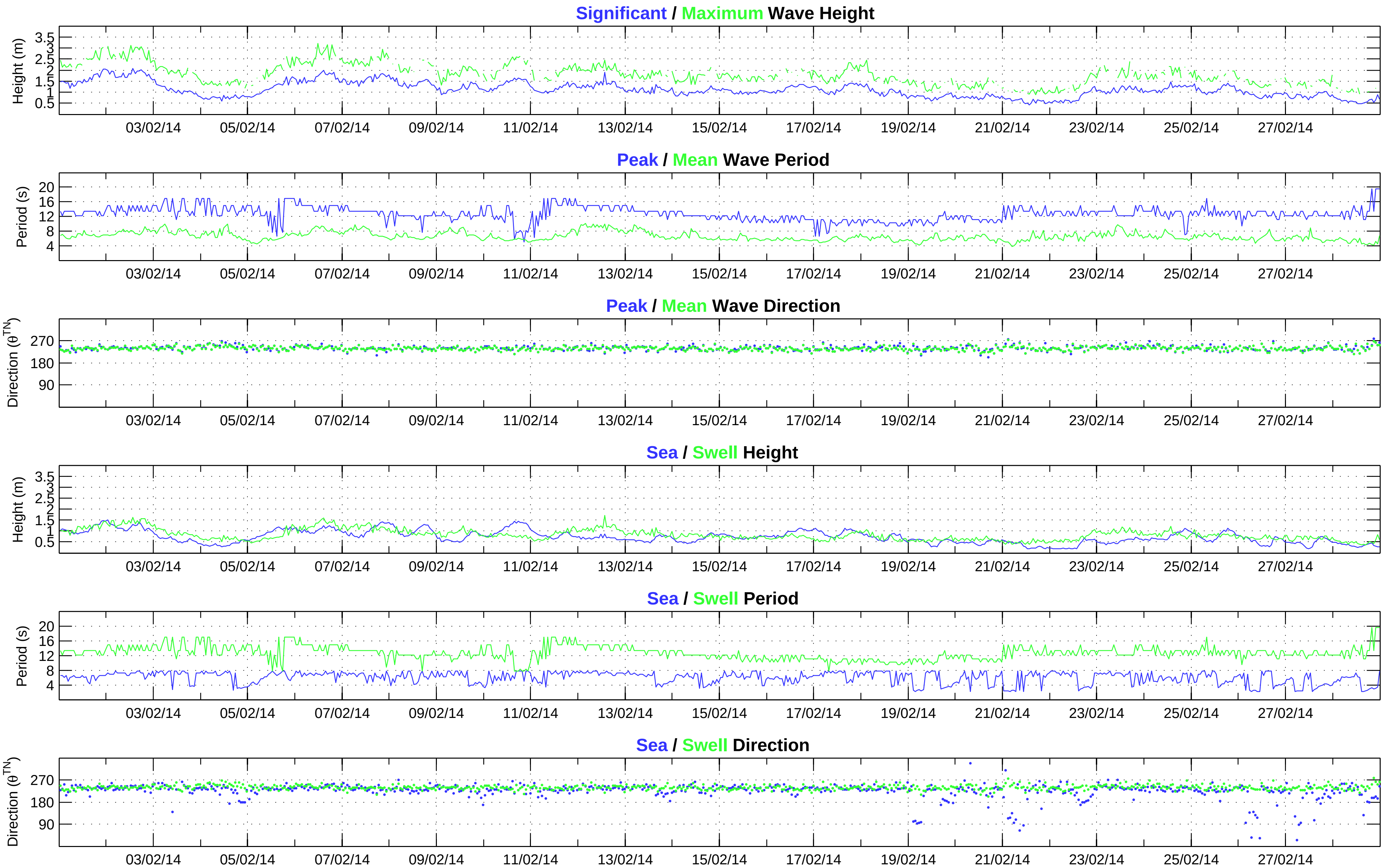

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540^{o}E , 31.6700^{o}S]

Data period: February 2014 (01−Feb−2014 to 28−Feb−2014)

Data source: AWAC

Data summary: February 2014

Number of Records: 672

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 2.07 m	Max Tp: 19.50 s
Mean Hs: 1.12 m	Mean Tp: 12.66 s
StdDev. Hs: 0.34 m	StdDev. Tp: 1.97 s

Wave Summary February 2014

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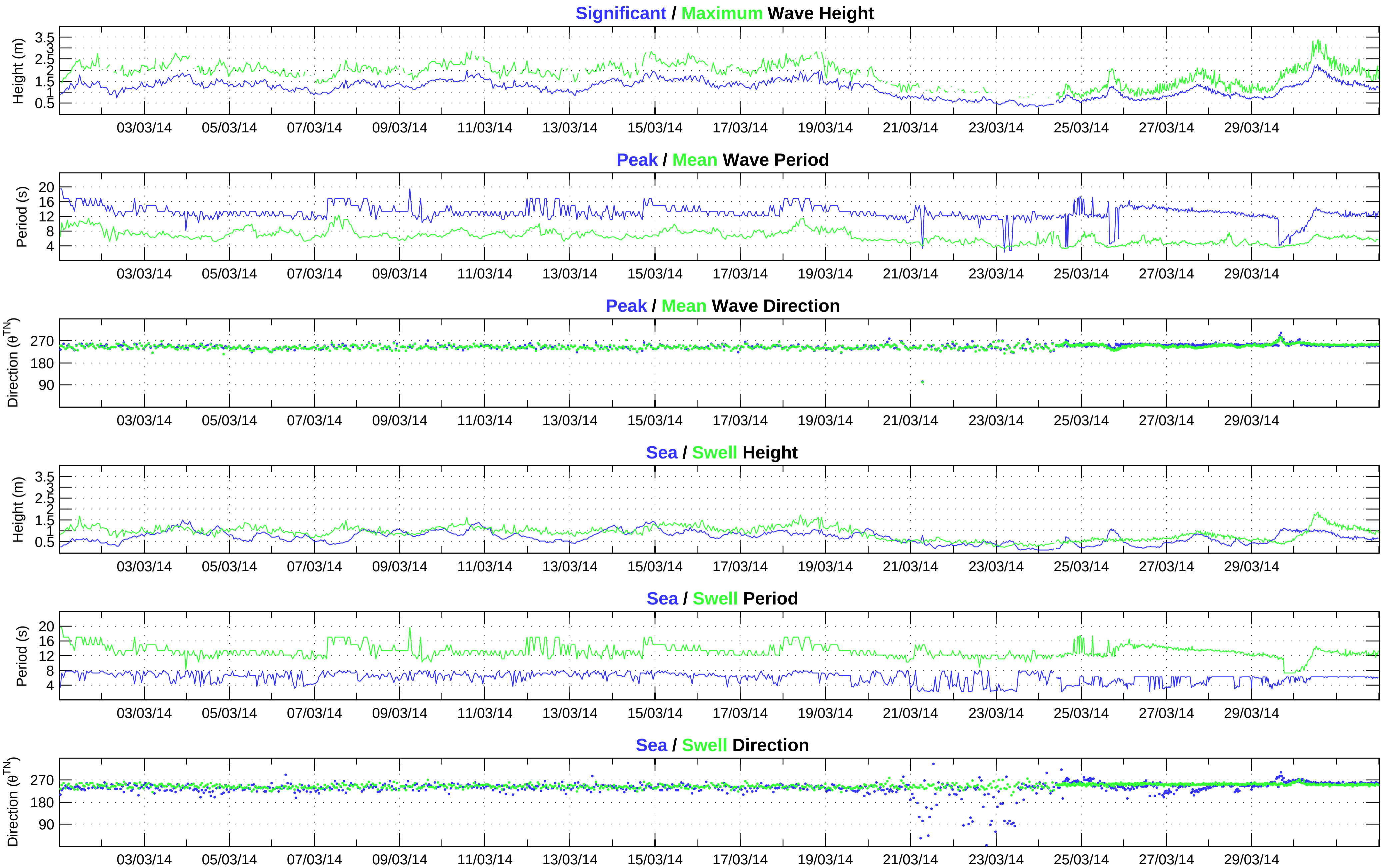

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540^{o}E , 31.6700^{o}S]

Data period: March 2014 (01−Mar−2014 to 31−Mar−2014)

Data source: AWAC

Data summary: March 2014

Number of Records: 926

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 2.24 m

Mean Hs: 1.16 m

StdDev. Hs: 0.37 m

Max Tp: 19.50 s

Mean Tp: 12.89 s

StdDev. Tp: 2.21 s

Wave Summary March 2014

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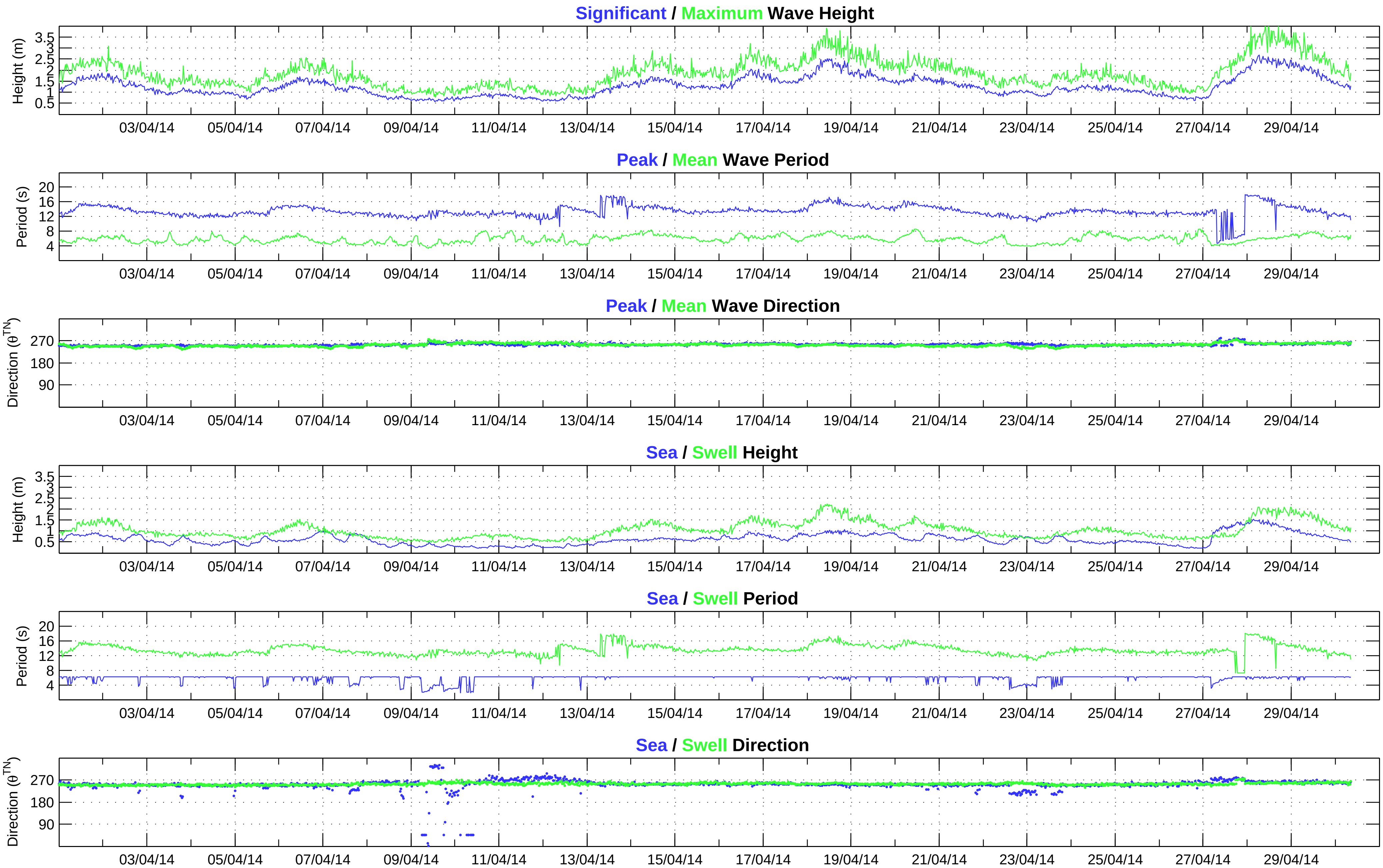

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Quinns Offshore AWAC [115.6540°E , 31.6700°S]

Data period: April 2014 (01−Apr−2014 to 30−Apr−2014)

Data source: AWAC

Data summary: April 2014

Number of Records: 1411

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 2.69 m	Max Tp: 18.02 s
Mean Hs: 1.26 m	Mean Tp: 13.38 s
StdDev. Hs: 0.45 m	StdDev. Tp: 1.66 s

Wave Summary April 2014

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Appendix 3 - Daily Field Reports

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DAILY PROGRESS REPORT

1. Particulars

Date	22/01/14	**Day**	1
Project No.	301012-01921		
Scope	Quinns rock metocean data download		
Team	Claudio Del Deo, Glen Underhay, Matthew Zed (client rep Karl Ilich from DoT onboard)	**Contact Details**	NW-0423187853 CDD -0449065691 MZ- 0410368117
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
07:00	08:00	1	Launch vessel, load equipment, travel to offshore site from Mundarie boat ramp to the offshore deployment location.
08:00	10:00	2	Deployed ADCP unit offshore with assistance of the digital altimeter unit to ensure deployment was level
10:00	11:30	1.5	Deployed AWAC unit inshore with assistance of the digital altimeter unit to ensure deployment was level
11:30	14:30	3	Lunch while waiting for at least 3 hours of observations at inshore location
14:30	15:30	1	Travel to nearshore site, perform interim nearshore AWAC retrieval and download (to confirm correct function) and redeployment with use of digital altimeter.
15:30	17:30	2	Travel to Mundarie boat ramp, retrieve vessel, unload equipment from boat. MZ and CDD back to office

4. Programme for Next 24 Hours

Sleeping

5. Comments

Seas calm in the morning with good visibility. Winds increased slightly in the afternoon with the sea-breeze but visibility still good.

1. Particulars

Date	18/03/14	**Day**	1
Project No.	301012-01921		
Scope	Quinns rock metocean data download		
Team	Nicola Willson, Glen Underhay, Matt Zed (client rep Rory Ellyard from city of Wanneroo onboard)	**Contact Details**	NW-0423187853, GU-0404882433 MA- 0410368117
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
07:00	08:00	1	Launch vessel, load equipment, travel to offshore site from Mundarie boat ramp, search for ADCP on GPS point using grapple hook. Poor visibility meant instrument not found after approx. 45 mins of searching
08:00	09:00	1	Travel to nearshore site, retrieved AWAC on GPS point using grapple hook. Travel to Mundarie boat ramp
09:00	11:30	2:30	Buy chain and anchor for new frame, MZ started downloading data at jetty (stopped as too long). Instrument set up and compass calibration of new AWAC on private floating jetty opp cafe
11:30	12:30	1	Travel to nearshore site, deployed new AWAC on old frame. Checked instrument was flat using electronic spirit level (green light) -retrieved.
12:30	14:30	2	Travel to Mundarie boat ramp, retrieve vessel, unload equipment from boat. MZ to office, NW to home

4. Programme for Next 24 Hours

Download AWAC data – approx. 10 hrs

5. Comments

Rough conditions on arrival to site, seas 0.4 – 1.0m with winds SW 8-10 knots. Water clarity very low (less than 3m visibility)

1. Particulars

Date	24/03/14	**Day**	1
Project No.	301012-01921		
Scope	Quinns rock metocean data download		
Team	Nicola Willson, Andrew Larsen, Matthew Zed	**Contact Details**	NW-0423187853, AL-0438078172 MZ- 0410368117
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
07:00	08:00	1	Compass calibration on AWAC (one retrieved from Inshore site 18/03/14) in boat ramp car park
07:00	10:00	3	Launch vessel, load equipment, travel to offshore site from Mundarie boat ramp, deployed AWAC on new frame approx. 15 m from ADCP site in 12 m of water. Checked instrument was flat using digital altimeter -retrieved. Retrieved ADCP using retrieval rope. Capstan cannot take weight of frame so winched up on crane approx. 0.5 m at a time
10:00	12:00	2	Travel to Mundarie boat ramp, cleaned ADCP frame, retrieved vessel, unload equipment from boat. MZ & NW to office, AL took boat back and cleaned frame to Brad for freighting to Sydney

4. Programme for Next 24 Hours

Download ADCP data (approx. 12 hrs) and process

5. Comments

Calm sea, good visibility during field operations

1. Particulars

Date	30/04/14	Day	1
Project No.	301012-01921		
Scope	Quinns rock metocean data download		
Team	Andrew Larsen, Kloe Hunt	Contact Details	AL-0438078172
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
07:00	08:00	1	Launch vessel, load equipment, travel to offshore site from Mundarie boat ramp.
08:00	10:00	2	Retrieved offshore AWAC using retrieval rope. Capstan cannot take weight of frame so winched up on crane approx. 0.5 m at a time
10:00	11:00	1	Retrieved inshore AWAC using retrieval rope. Capstan cannot take weight of frame so winched up on crane approx. 0.5 m at a time
11:00	12:00	1	Travel to Mundarie boat ramp, cleaned unit frames, retrieved vessel, unload equipment from boat. AL took boat back and cleaned frame

4. Programme for Next 24 Hours

Download AWAC data (approx. 12 hrs) and process

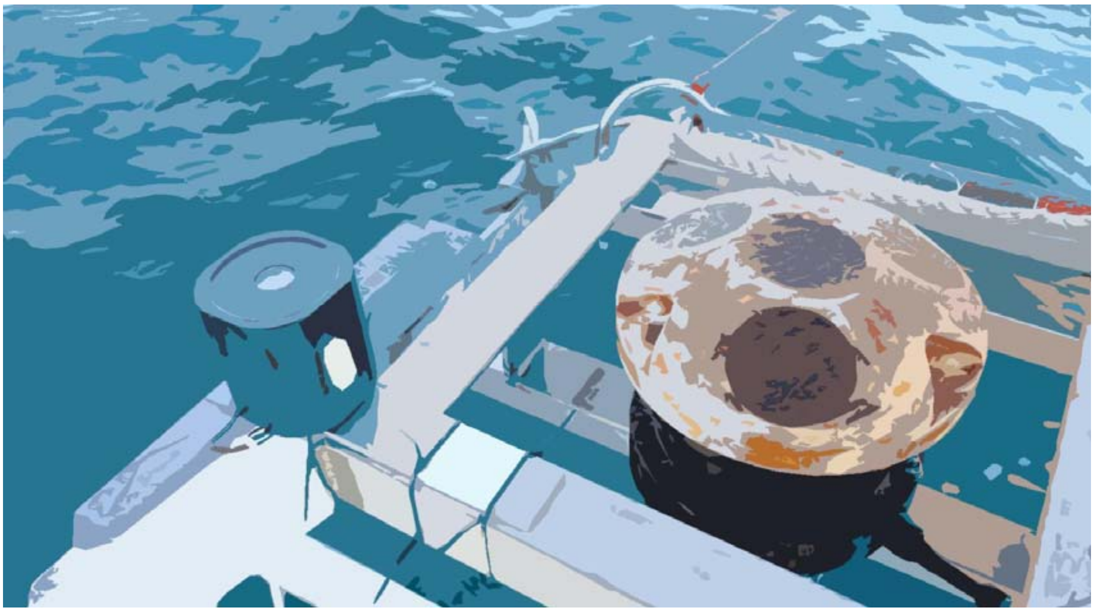
5. Comments

Calm sea with moderate water visibility during field operations

CITY OF WANNEROO

Quinns Rocks Metocean Data Collection

Field Survey Report No. 2 - Winter 2014



301012-01921 – FRP-002

14 Nov 2014

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ABN 61 001 279 812

WorleyParsons Consulting

City of Wanneroo

CITY OF WANNEROO
QUINNS ROCKS METOCEAN DATA COLLECTION
FIELD SURVEY REPORT NO. 2 - WINTER 2014

Disclaimer

PROJECT 301012-01921 - QUINNS ROCKS METOCEAN DATA COLLECTION

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CUSTOMER APPROVAL	DATE
0	Issued for use	D Hansen	C Del Deo	K Y Lim	14-Nov-14	N/A	

CONTENTS

1. INTRODUCTION

This field survey report provides an overview of the activities undertaken for the winter deployment of the Quinns Rocks Metocean Data Collection campaign between June and October 2014.

This report provides an overview of the tasks, equipment and methods used and the observations from the units following WorleyParsons standard Quality Assurance (QA) and Quality Control (QC) process in accordance with our Project Execution Plan (ref document no. 301012-01921-PM-PEP-0001). A summary of the Health, Safety and Environment (HSE) precautions undertaken during the works and environmental management tallies have also been included.

Appendices summarising the QA/QC'd field observations are included as attachments to this report, with this to be provided in electronic format, along with the raw data, following submission of the report.

1.1 Study Datum

Water depths and levels presented in this report are referenced to Chart Datum (CD), unless otherwise stated, and are in units of metres. Geographical positions are provided in geographic (Latitude/Longitude) coordinates unless stated otherwise.

All units are in standard SI units unless otherwise stated, with all bearings and directions provided in degrees True North.

2. DEPLOYMENT INFORMATION

2.1 Summary

The Quinns Rocks Metocean Data Collection campaign involved the installation of acoustic wave and current profilers at both an onshore and offshore location.

WorleyParsons deployed 2 - 1 MHz Nortek Acoustic Waves and Current (AWAC) profiler at the inshore and offshore locations on the 27 June 2014. Maintenance was performed on both AWACs on August 11 2014, with both units redeployed the following day.

2.2 Frames

The frames used to deploy the acoustic units were custom built for the AWACs. The frames are made from high quality stainless steel, with 2 x 25kg lead weights used to increase stability on the seabed during extreme events.

Each frame was fitted with an acoustic realise mechanism to avoid surface buoy susceptible to being cut off by passing vessels, and they alert thieves to the valuable equipment tethered below. This device is capable of automatically releasing the buoy connected to the retrieve rope when necessary.

During deployment, a digital tilting sensor (accelerometer), owned and developed by WorleyParsons, is used to ensure the frame is situated in an upright position within the acceptable range required (nominally within 8 degrees of the vertical). A depiction of the frames, with the temporary placement of the digital altimeter during deployment, is shown in Figure 2-1.

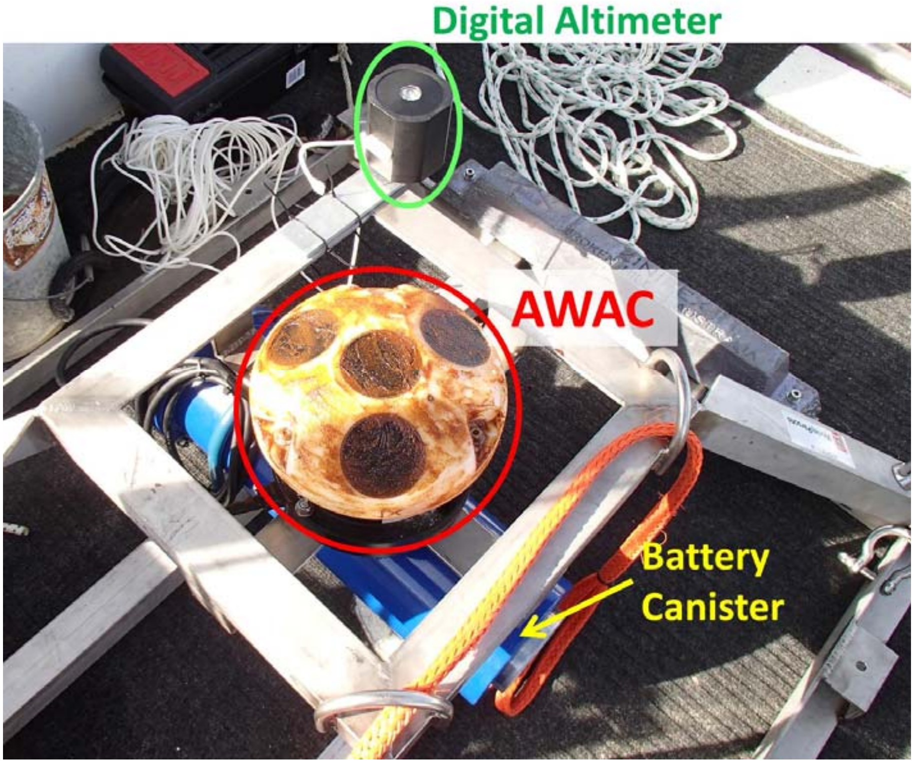


Figure 2-1 WorleyParsons standard AWAC frame with digital altimeter shown.

2.3 Locations and Deployment Periods

The locations of the inshore and offshore units is provided in Table 2-1, with these shown graphically in Figure 2-2.

Table 2-1 Deployment coordinates for Inshore and Offshore Units.

Unit		Type	Longitude	Latitude	Depth range over record (m)
Inshore Unit	Before Maintenance	AWAC	115.6840 °E	31.6731 °S	5.25 – 6.12
	After Maintenance	AWAC	115.6840 °E	31.6731 °S	5.25 – 6.15
Offshore Unit	Before Maintenance	AWAC	115.6556 °E	31.6697 °S	13.80– 14.75
	After Maintenance	AWAC	115.6556 °E	31.6697 °S	13.75 – 14.60

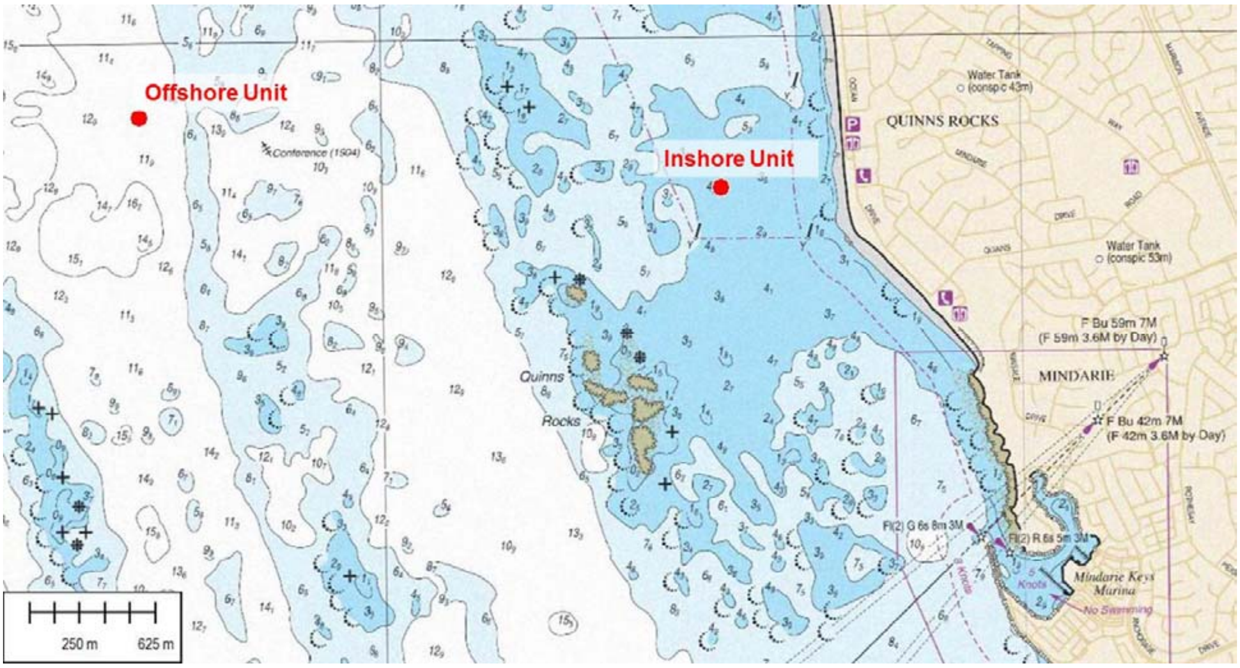


Figure 2-2 Location of Inshore and Offshore units (with reference to Mindarie Keys Marina). Map supplied by City of Wanneroo.

2.4 Deployment Configuration

The units were deployed as per the specifications provided by the City of Wanneroo on 27 January 2014 with a summary of the unit configuration provided in

Table 2-2 for the Inshore and Offshore AWAC units..

Table 2-2 Configuration of the Quinns AWAC Units

Parameter	Inshore	Offshore
Profile interval (s)	1800	1800
Number of cells	14	30
Cell size (m)	0.50	0.50
Average interval (s)	120	120
Blanking distance (m)	0.40	0.40
Measurement load (%)	63	38
Power level	HIGH-	HIGH-
Number of wave samples	2048	2048
Wave interval (s)	1800	1800
Wave sampling rate (Hz)	2	2
Wave AST Ice mode	DISABLED	DISABLED
Wave AST SUV mode	DISABLED	DISABLED
Compass upd. rate (s)	1800	1800
Coordinate System	ENU	ENU
Speed of sound (m/s)	MEASURED	MEASURED
Salinity (ppt)	35	35
Analog input 1	NONE	NONE
Analog input 2	NONE	NONE
Analog input power out	DISABLED	DISABLED
File wrapping	OFF	OFF
TellTale	OFF	OFF
Acoustic modem	OFF	OFF
Serial output	OFF	OFF
Baud rate	115200	115200
Onboard wave processing	DISABLED	DISABLED
Assumed duration (days)	93.0	30.0
Battery utilization (%)	57.0	32.0
Battery level (V)	11.4	11.9
Recorder size (MB)	3886	3886
Recorder free space (MB)	3885.972	3776.545
Memory required (MB)	211.2	68.6
Vertical vel. prec (cm/s)	0.8	1.0
Horizon. vel. prec (cm/s)	2.4	3.1
Instrument ID	WPR 2279	WPR 2282
Head ID	WAV 6736	WAV 6617
Firmware version	3.37 AST	3.37 AST
ProLog ID	695	807
ProLog firmware version	4.14	4.14
SD Card Inserted	YES	YES
SD Card Ready	YES	YES
SD Card Write protected	NO	NO
SD Card Type	SDHC	SDHC
SD Card Supported	YES	YES

2.5 Data Periods

A summary of the deployment, maintenance and final retrieval dates for the units is provided in Table 2-3.

Table 2-3 Summary of deployment periods for the inshore and offshore AWAC units

Location	Pre-Maintenance		Post-Maintenance		Total Duration
	Deployment	Retrieval	Deployment	Retrieval	
Inshore Unit	26/06/2014 09:30	11/08/2014 12:00	12/08/2014 12:30	16/10/2014 07:30	112 Days
Offshore Unit	26/06/2014 10:30	11/08/2014 10:00	12/08/2014 12:30	16/10/2014 09:30	112 Days

3. RESULTS

3.1 QA/QC

3.1.1 Compass Calibration

A compass calibration was performed on both the inshore and offshore units during the field deployment. For the initial deployment, the AWAC units were successfully deployed with an estimated maximum error after the calibration of <1 degree.

3.1.2 Data Interrogation

WorleyParsons standard method of QA/QC involves a first pass analysis of the raw hydrodynamic and wave information retrieved from the unit. Part of this process includes:

- Confirming the pitch and roll on the unit is within the “accurate range” of within 8 degrees to the vertical (with values preferably less than 5)
- Ensuring wave period, and associated wave parameters, calculated from the spectral binary files, is within acceptable ranges and removing all parameters over the corresponding time if not.
- Consistency check for dominant wave and current direction following maintenance events.

All data presented in the appendices have undergone this standard QA/QC check and following this process it is confirmed that over the deployment period from 22 January to 30 April 2014 at least 98% of the data collected at both the inshore and offshore sites is considered suitable for use.

3.2 Temperature

The near-seabed water temperature, as recorded by the AWAC and ADCP units at the Inshore and Offshore locations is presented in Figure 3-1 and Figure 3-2, respectively.

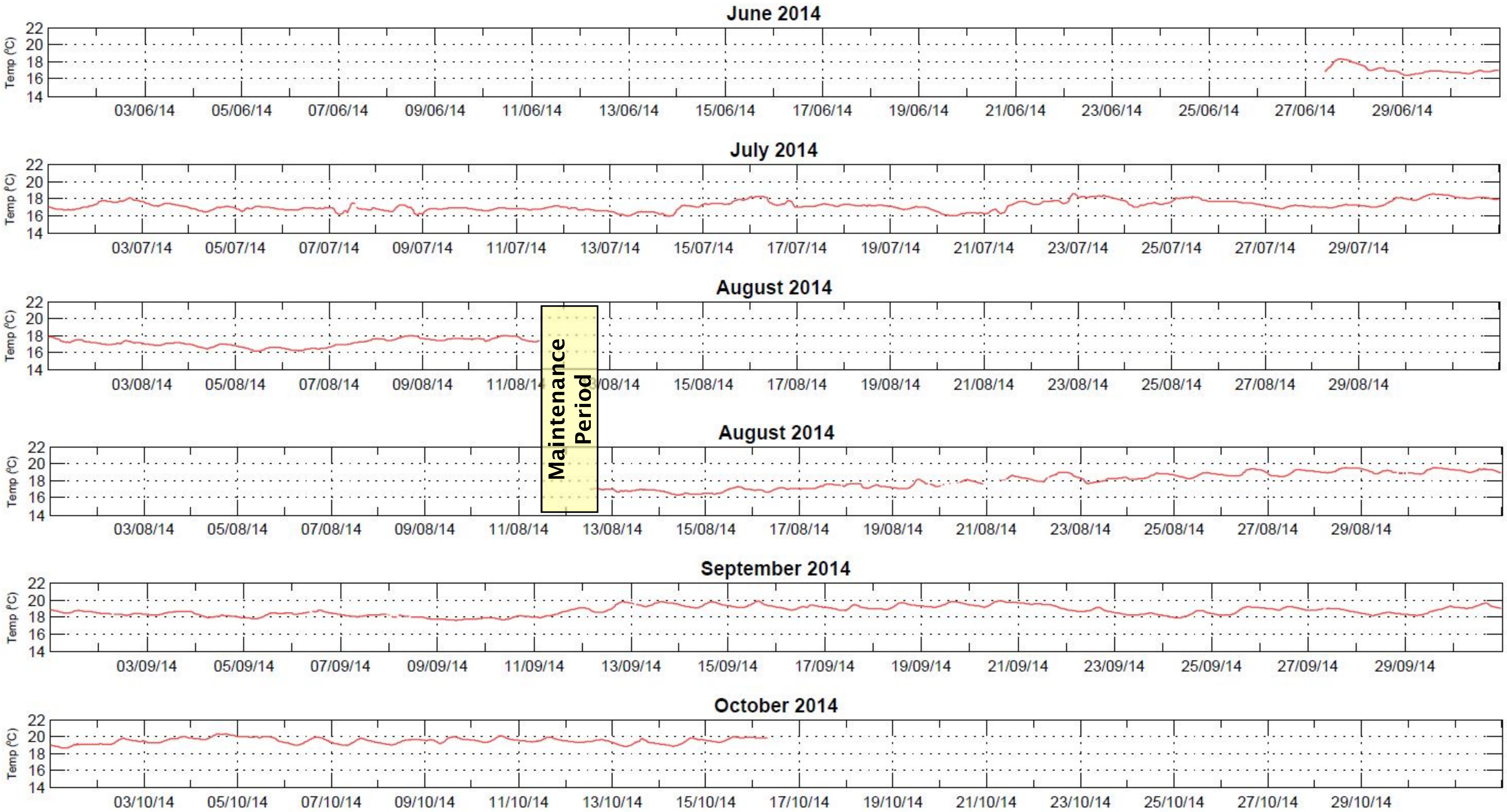


Figure 3-1 Near-seabed water temperature data as recorded at the Inshore location.

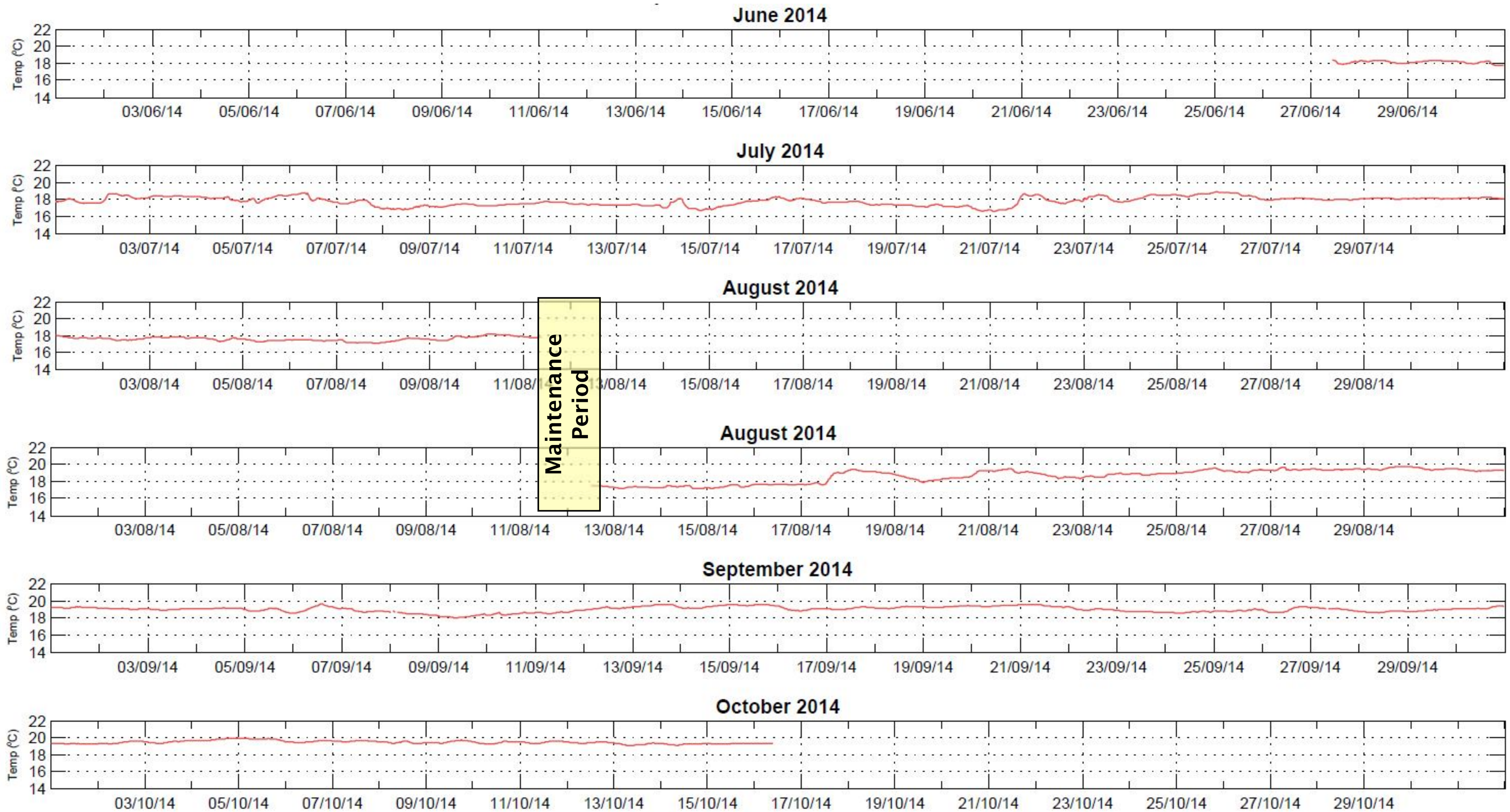


Figure 3-2 Near-seabed water temperature data as recorded at the Offshore location.

3.3 Currents and Water Levels

A summary of the hydrodynamic components captured by the Inshore and Offshore units is presented in Appendix 1. This is inclusive of:

- Surface elevation
- Seabed current speed and direction
- Surface current speed and direction

3.4 Waves

A summary of the wave parameters captured by the Inshore and Offshore units is presented in Appendix 2. This is inclusive of:

- Significant Wave Height
- Maximum Wave Height
- Peak Wave Period
- Mean Wave Period
- Peak Wave Direction
- Mean Wave Direction
- Sea and Swell Significant Wave Height
- Sea and Swell Peak Wave Period
- Sea and Swell Peak Wave Direction

4. HEALTH AND SAFETY

4.1 Daily Field Reports

Daily reports documenting all site activities undertaken and evidence of any health and safety meetings have been prepared during each field day.

These daily field reports have been included in Appendix 3.

4.2 Waste Management

All rubbish was stored and appropriately disposed, batteries were recycled and all materials were removed from the vessel and the marine environment. Statistics for waste management are based on Frm PP-13-020-01 (Contractor Environmental Close Out Report Proforma). A summary of waste management during FT04 and to date is tallied in Table 4-1.

Table 4-1 To date waste management tally for Quinns Rocks Metocean Deployment

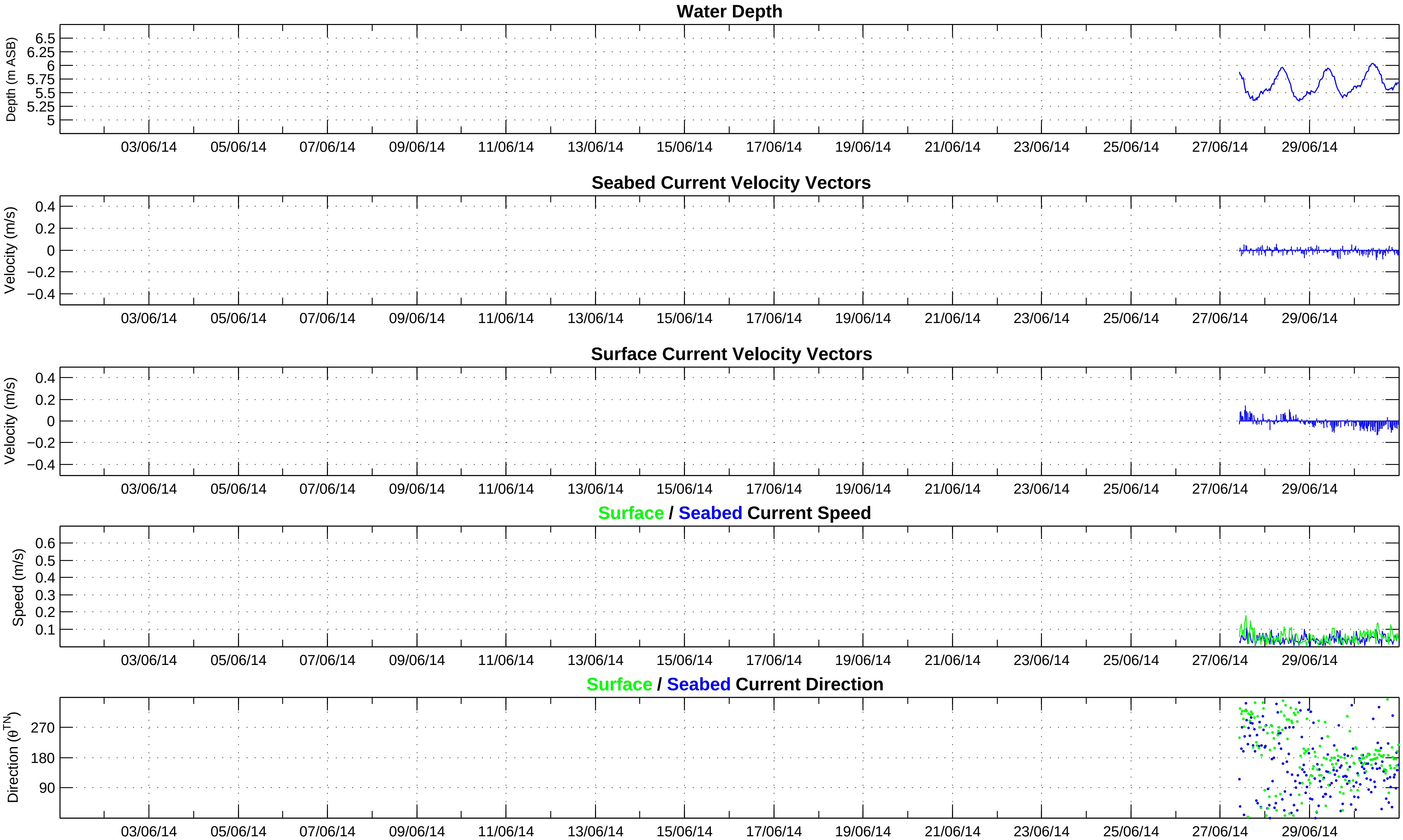
Statistic	Cumulative Summer	Deployment 26/06/2014	Maintenance 1 11/08/2014	Maintenance 2 12/08/2014	Recovery 16/10/2014	Cumulative to Date
Total volume of General Waste disposed to offsite (m^3)	**0.200**	0.050 (1 bin, approx.)	0.050 (1 bin, approximate)	0.050 (1 bin, approximate)	0.050 (1 bin, approximate)	**0.4**
Total volume of domestic effluent disposed to offsite (m^3)	**0.040**	0.010 (approx.)	0.010 (approx.)	0.010 (approx.)	0.010 (approx.)	**0.08**
Total volume of Cardboard and Paper recycled (m^3)	**0.003**	<0.001 (approx.)	<0.001 (approx.)	<0.001 (approx.)	<0.001 (approx.)	**0.006**
Volume of Glass recycled (m^3)	**0.001**	<0.001 (approx.)	N/A	N/A	N/A	**0.002**
Volume of Aluminium cans recycled (m^3)	**0.003**	<0.001 (approx.)	N/A	<0.001 (approx.)	<0.001 (approx.)	**0.006**
Volume of Plastic Bottles recycled (m^3)	**0.080**	0.020 (approximate)	0.020 (approximate)	0.020 (approximate)	0.020 (approximate)	**0.16**

5. SUMMARY

The winter deployment campaign for the Quinns Rocks Metocean Data Collection project has seen successful data capture of wave, current and water level information at the Inshore and Offshore locations.

Following WorleyParsons standard QA/QC procedures it was shown that over the deployment period from 26 June to 16 October 2014 at least 98% of the data collected at both the inshore and offshore sites can be considered suitable for use.

Appendix 1 - Currents and Water Levels



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: June 2014 (27−Jun−2014 to 30−Jun−2014)

Data source: AWAC

Data summary: June 2014

Number of Records: 172

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.18 m/s

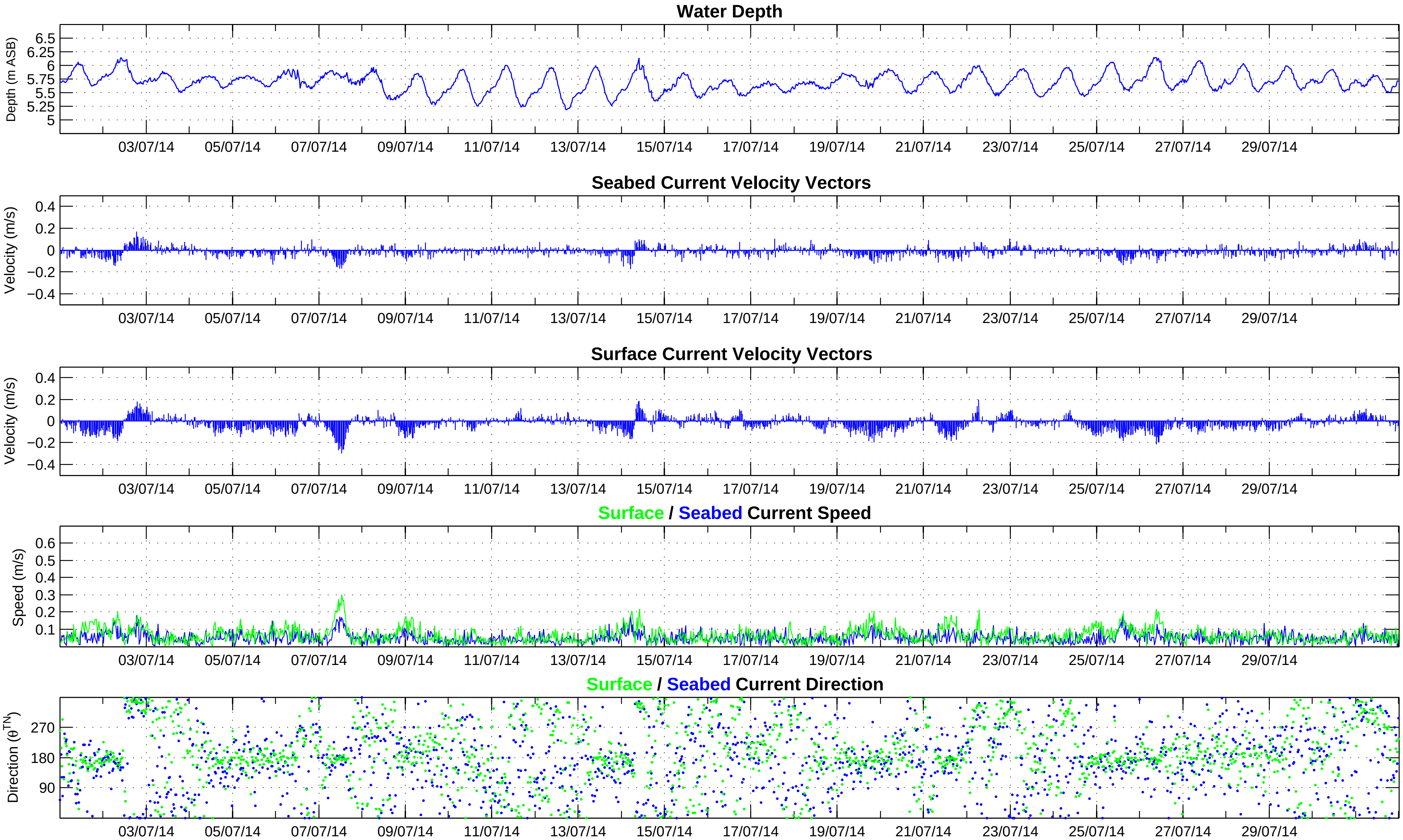
Mean Curr Spd: 0.06 m/s

StdDev. Curr Spd: 0.03 m/s

Current Summary June 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: July 2014 (01−Jul−2014 to 31−Jul−2014)

Data source: AWAC

Data summary: July 2014

Number of Records: 1488

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.30 m/s

Mean Curr Spd: 0.07 m/s

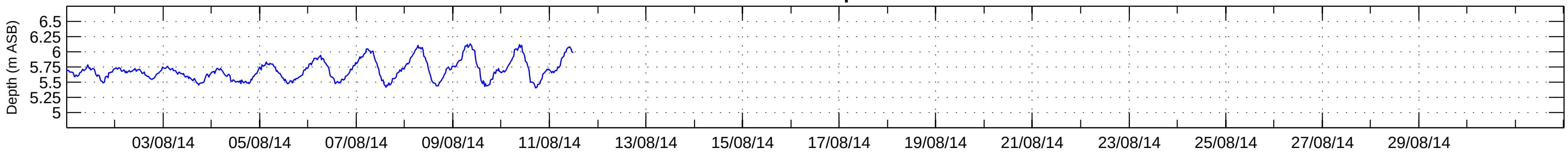
StdDev. Curr Spd: 0.04 m/s

Current Summary July 2014

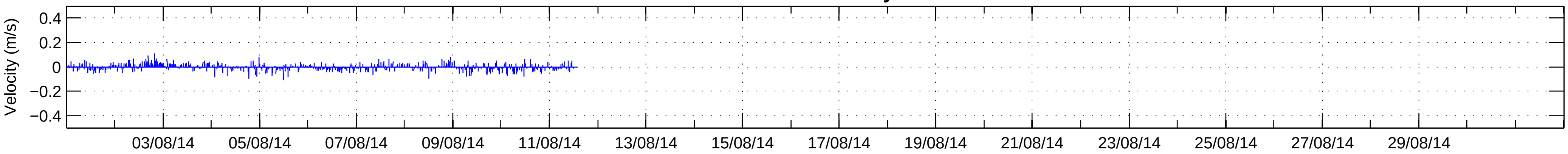
WorleyParsons

resources & energy

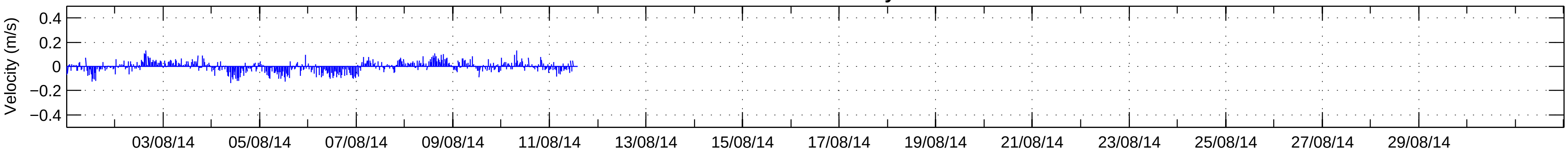
Water Depth



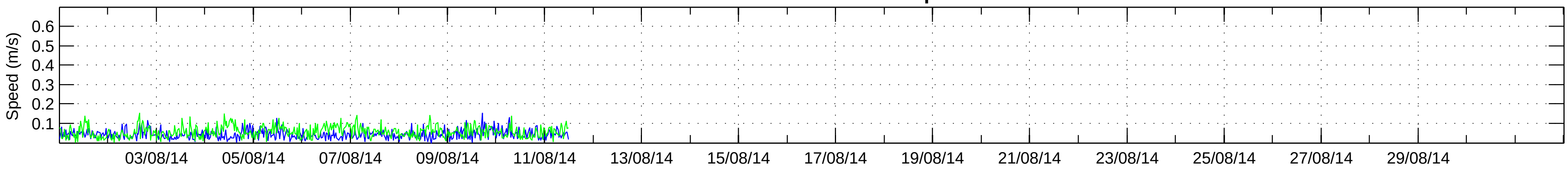
Seabed Current Velocity Vectors



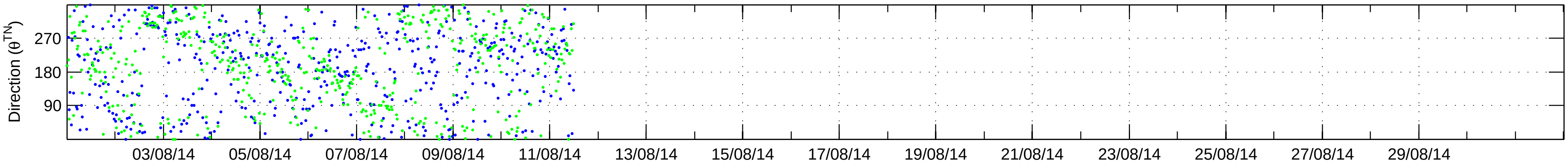
Surface Current Velocity Vectors



Surface / Seabed Current Speed



Surface / Seabed Current Direction



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840^{o}E , 31.6731^{o}S]

Data period: August 2014 (01−Aug−2014 to 11−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 505

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.15 m/s

Mean Curr Spd: 0.06 m/s

StdDev. Curr Spd: 0.03 m/s

Current Summary August 2014

WorleyParsons

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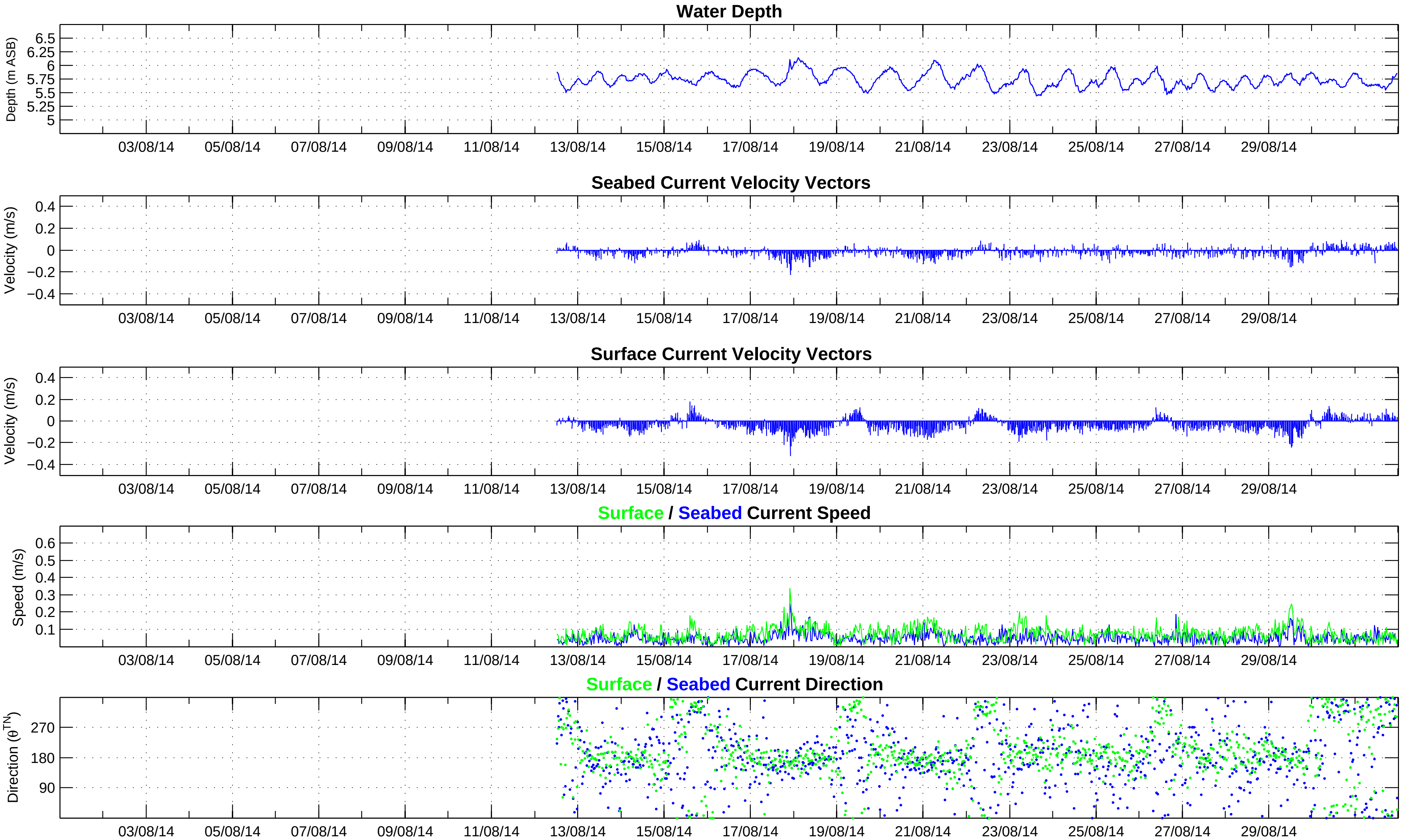


Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: August 2014 (12−Aug−2014 to 31−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 935

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

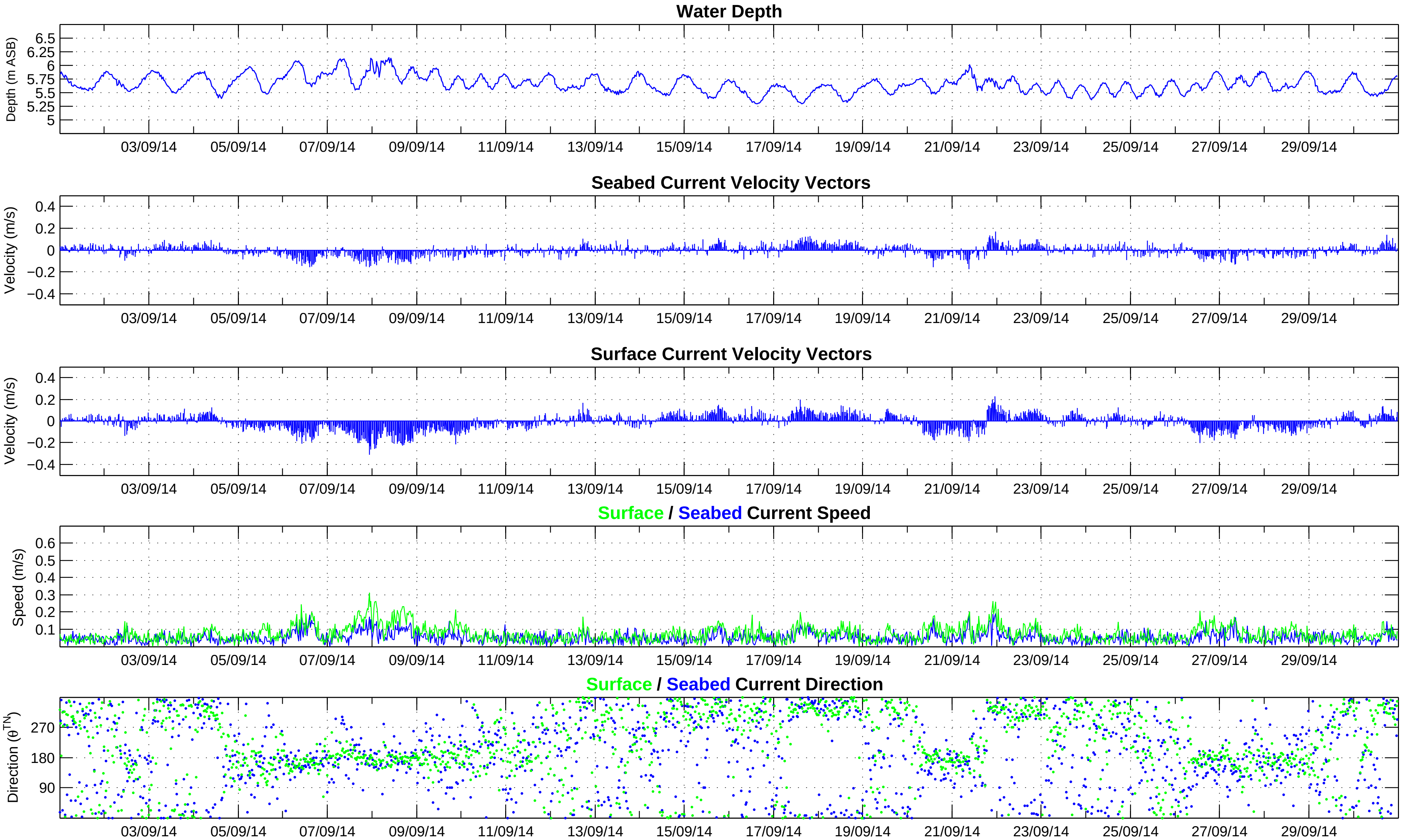
Max Curr Spd: 0.34 m/s

Mean Curr Spd: 0.07 m/s

StdDev. Curr Spd: 0.04 m/s

Current Summary August 2014

WorleyParsons
resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: September 2014 (01−Sep−2014 to 30−Sep−2014)

Data source: AWAC

Data summary: September 2014

Number of Records: 1440

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.31 m/s

Mean Curr Spd: 0.07 m/s

StdDev. Curr Spd: 0.05 m/s

Current Summary September 2014

WorleyParsons

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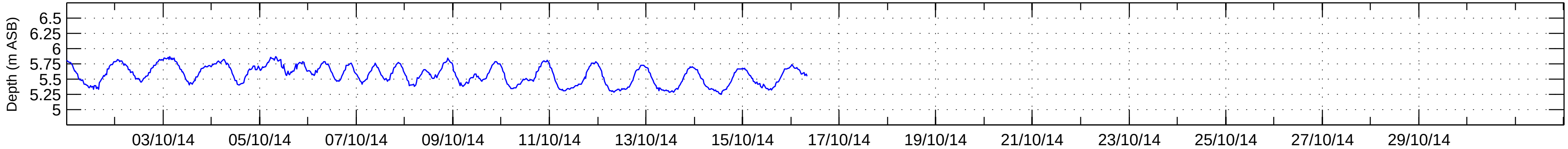
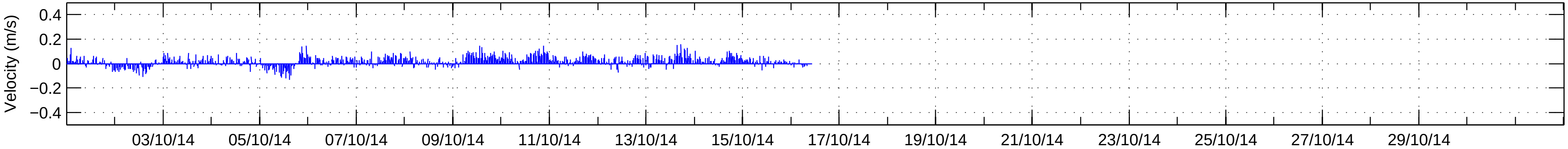
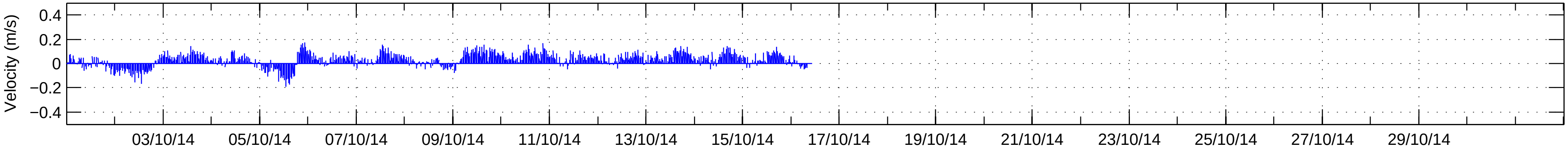
Water Depth



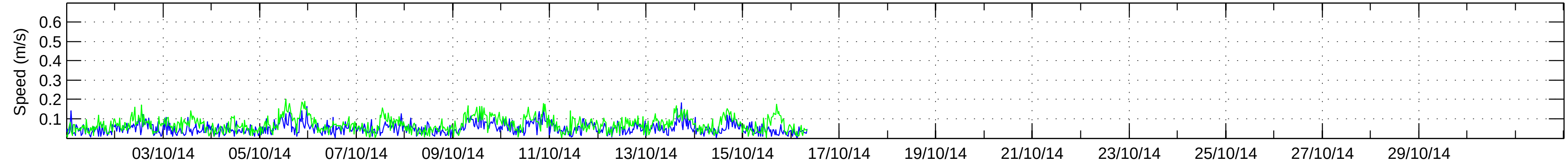
Seabed Current Velocity Vectors



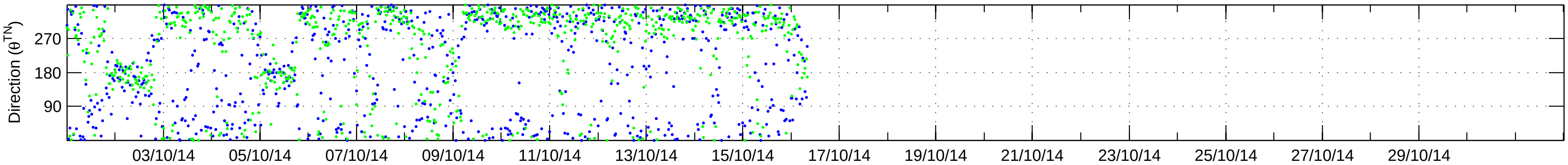
Surface Current Velocity Vectors



Surface / Seabed Current Speed



Surface / Seabed Current Direction



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: October 2014 (01−Oct−2014 to 16−Oct−2014)

Data source: AWAC

Data summary: October 2014

Number of Records: 738

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.20 m/s

Mean Curr Spd: 0.07 m/s

StdDev. Curr Spd: 0.04 m/s

Current Summary October 2014

WorleyParsons

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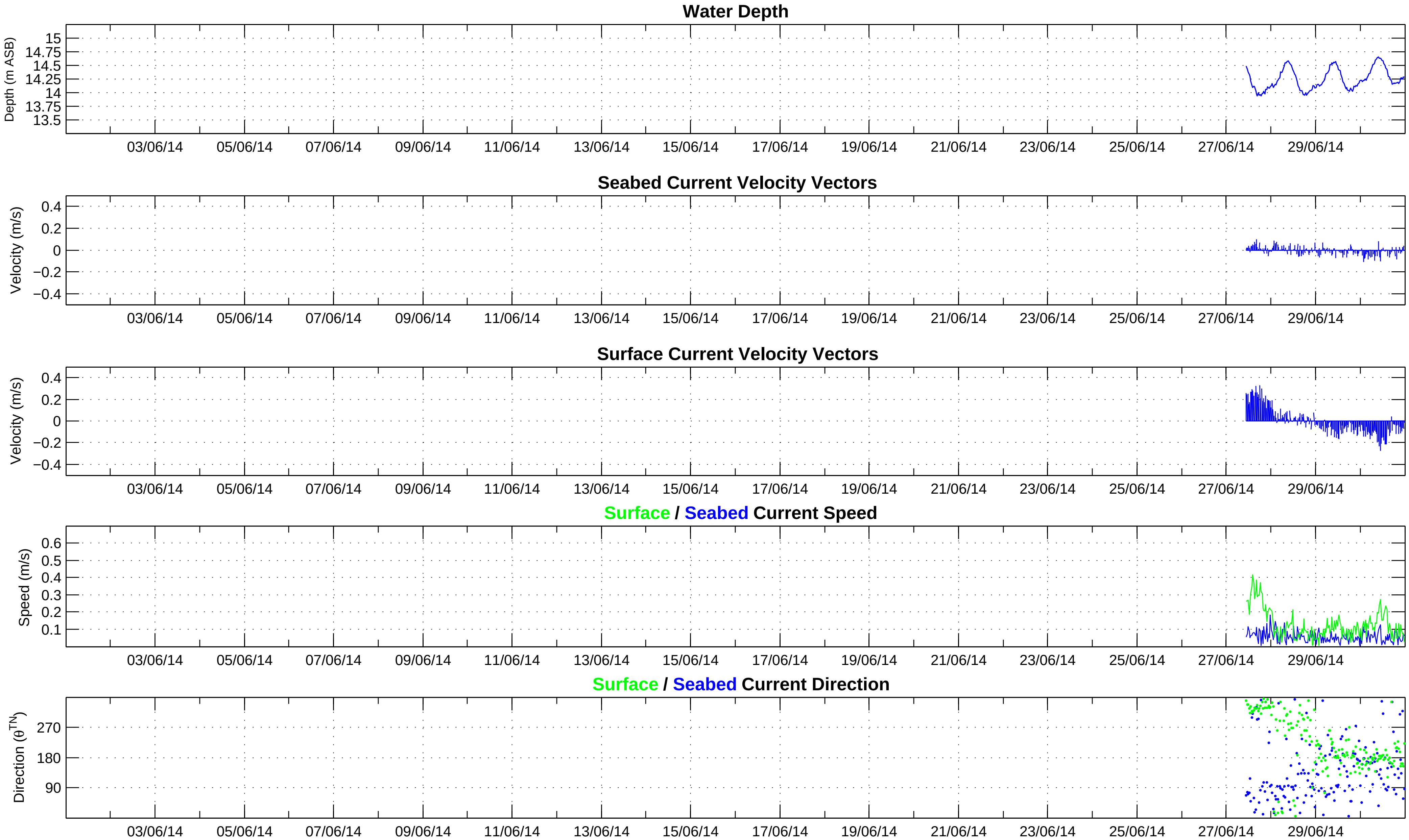

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556^{o}E , 31.6697^{o}S]

Data period: June 2014 (27−Jun−2014 to 30−Jun−2014)

Data source: AWAC

Data summary: June 2014

Number of Records: 171

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.42 m/s

Mean Curr Spd: 0.13 m/s

StdDev. Curr Spd: 0.08 m/s

Current Summary June 2014

WorleyParsons

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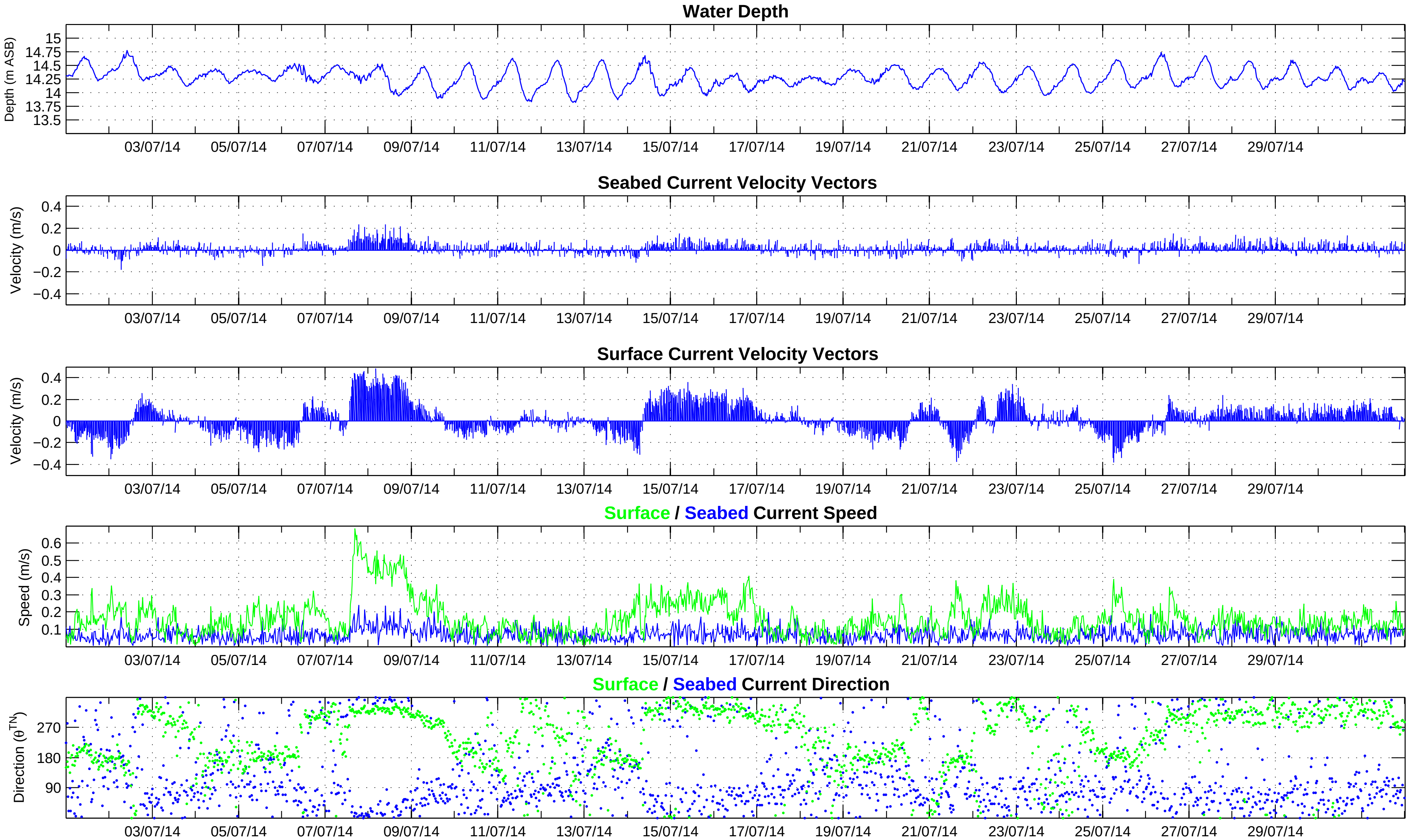

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: July 2014 (01−Jul−2014 to 31−Jul−2014)

Data source: AWAC

Data summary: July 2014

Number of Records: 1488

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.68 m/s

Mean Curr Spd: 0.16 m/s

StdDev. Curr Spd: 0.10 m/s

Current Summary July 2014

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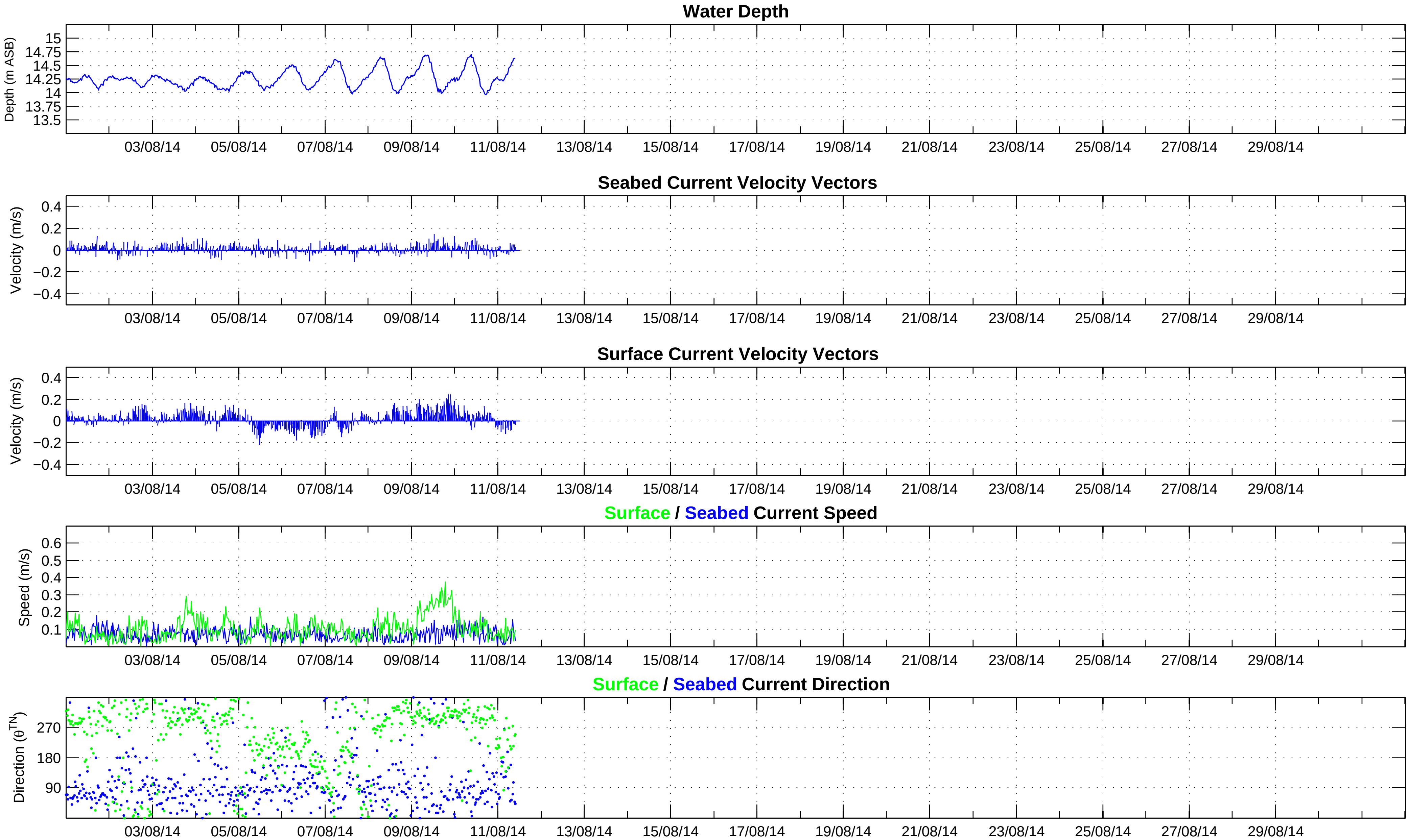


Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: August 2014 (01−Aug−2014 to 11−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 501

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

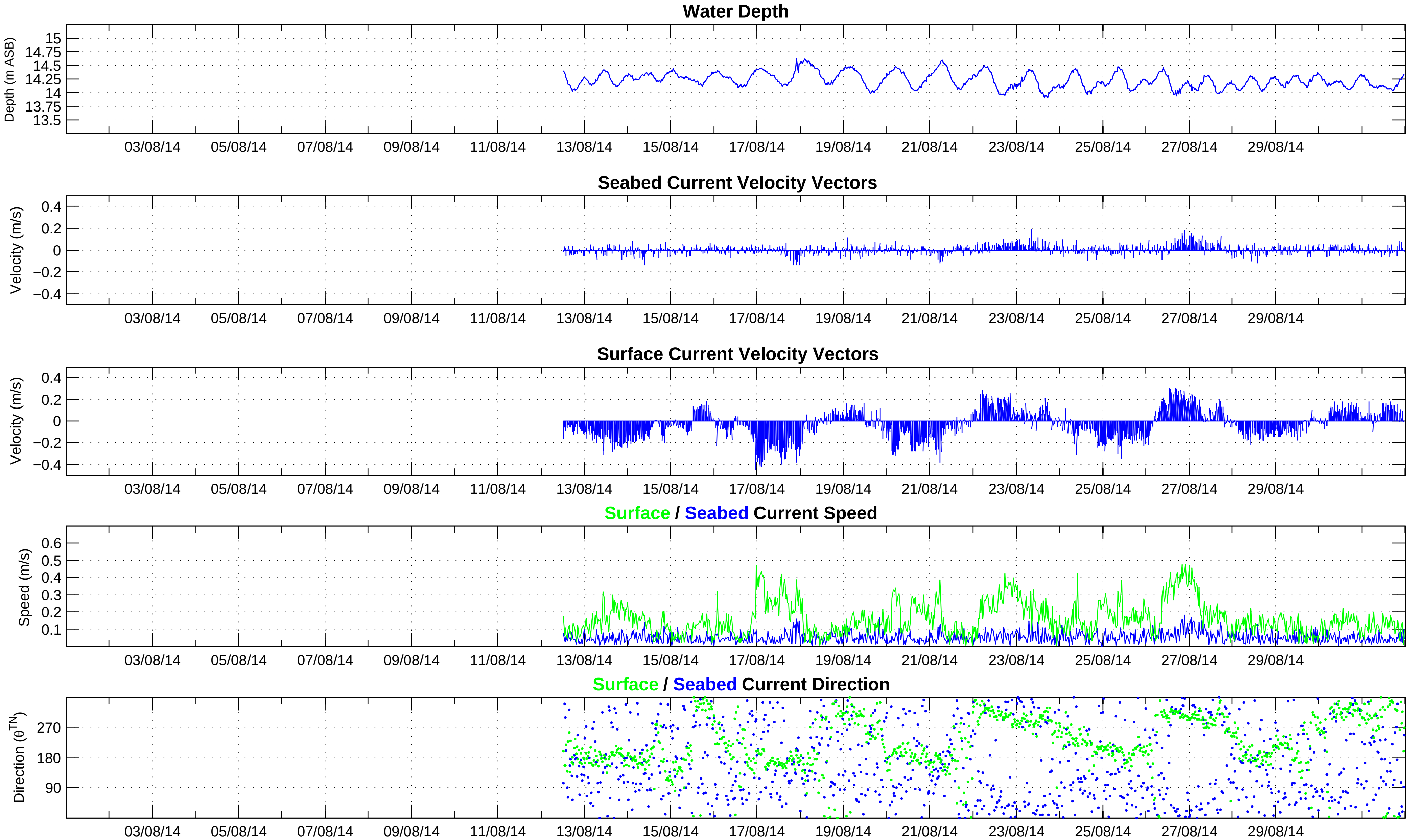
Max Curr Spd: 0.37 m/s

Mean Curr Spd: 0.11 m/s

StdDev. Curr Spd: 0.07 m/s

Current Summary August 2014

WorleyParsons
resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: August 2014 (12−Aug−2014 to 31−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 935

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.48 m/s

Mean Curr Spd: 0.16 m/s

StdDev. Curr Spd: 0.09 m/s

Current Summary August 2014

WorleyParsons

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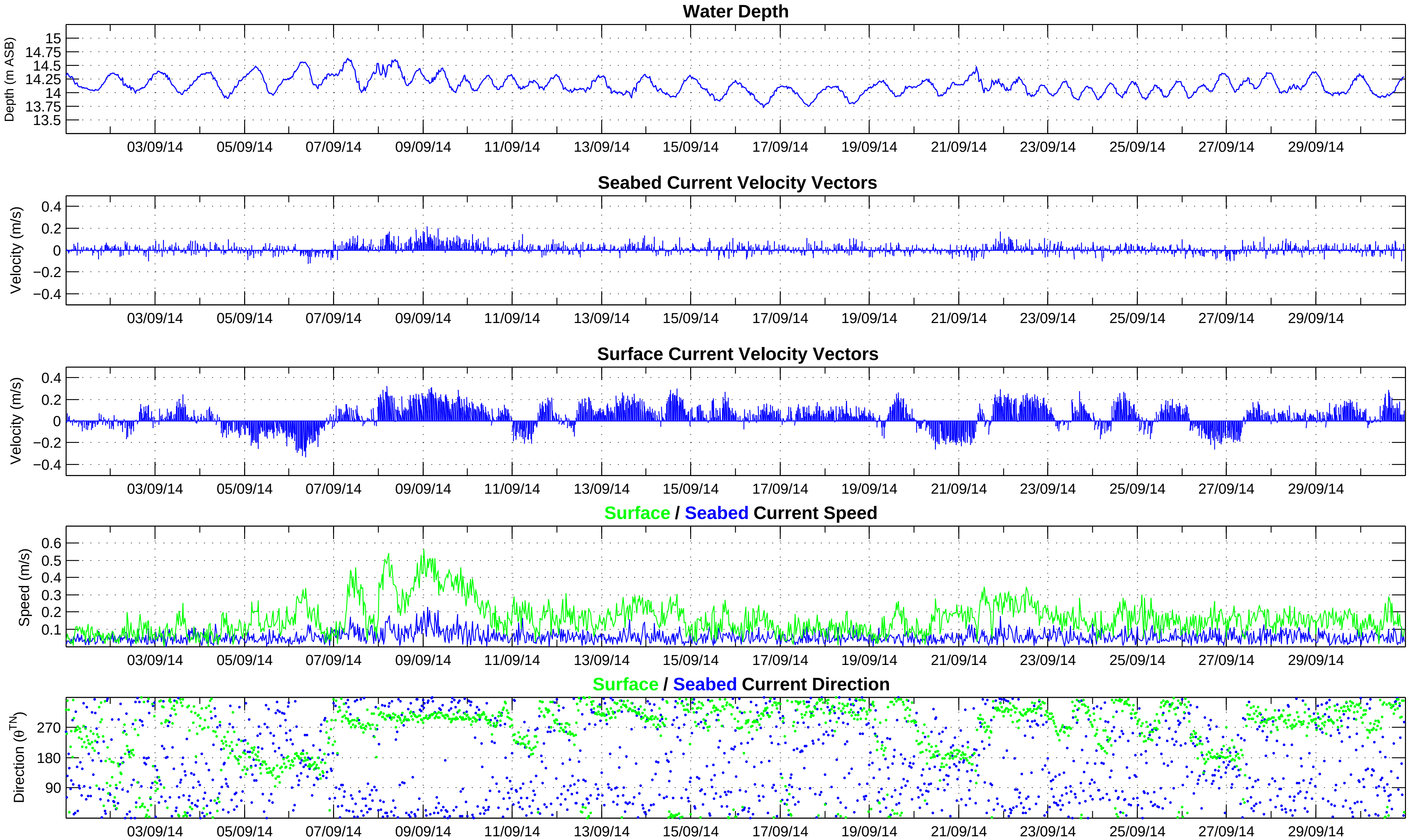

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556^{o}E , 31.6697^{o}S]

Data period: September 2014 (01−Sep−2014 to 30−Sep−2014)

Data source: AWAC

Data summary: September 2014

Number of Records: 1440

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.56 m/s

Mean Curr Spd: 0.16 m/s

StdDev. Curr Spd: 0.09 m/s

Current Summary September 2014

WorleyParsons

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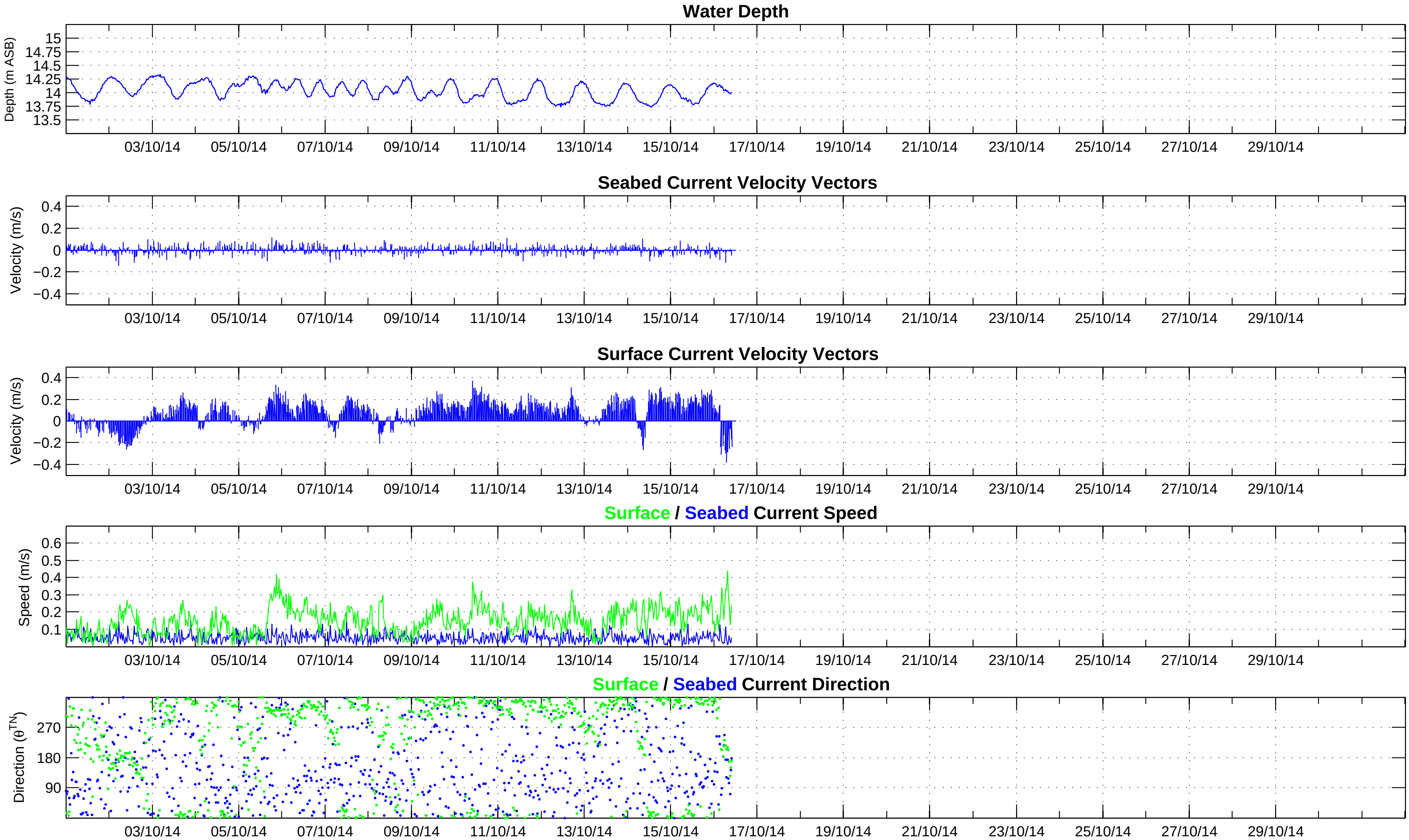


Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: October 2014 (01−Oct−2014 to 16−Oct−2014)

Data source: AWAC

Data summary: October 2014

Number of Records: 742

Missing data (%): 0.00

Record Depth: m ASB

Key Data Statistics:

Max Curr Spd: 0.44 m/s

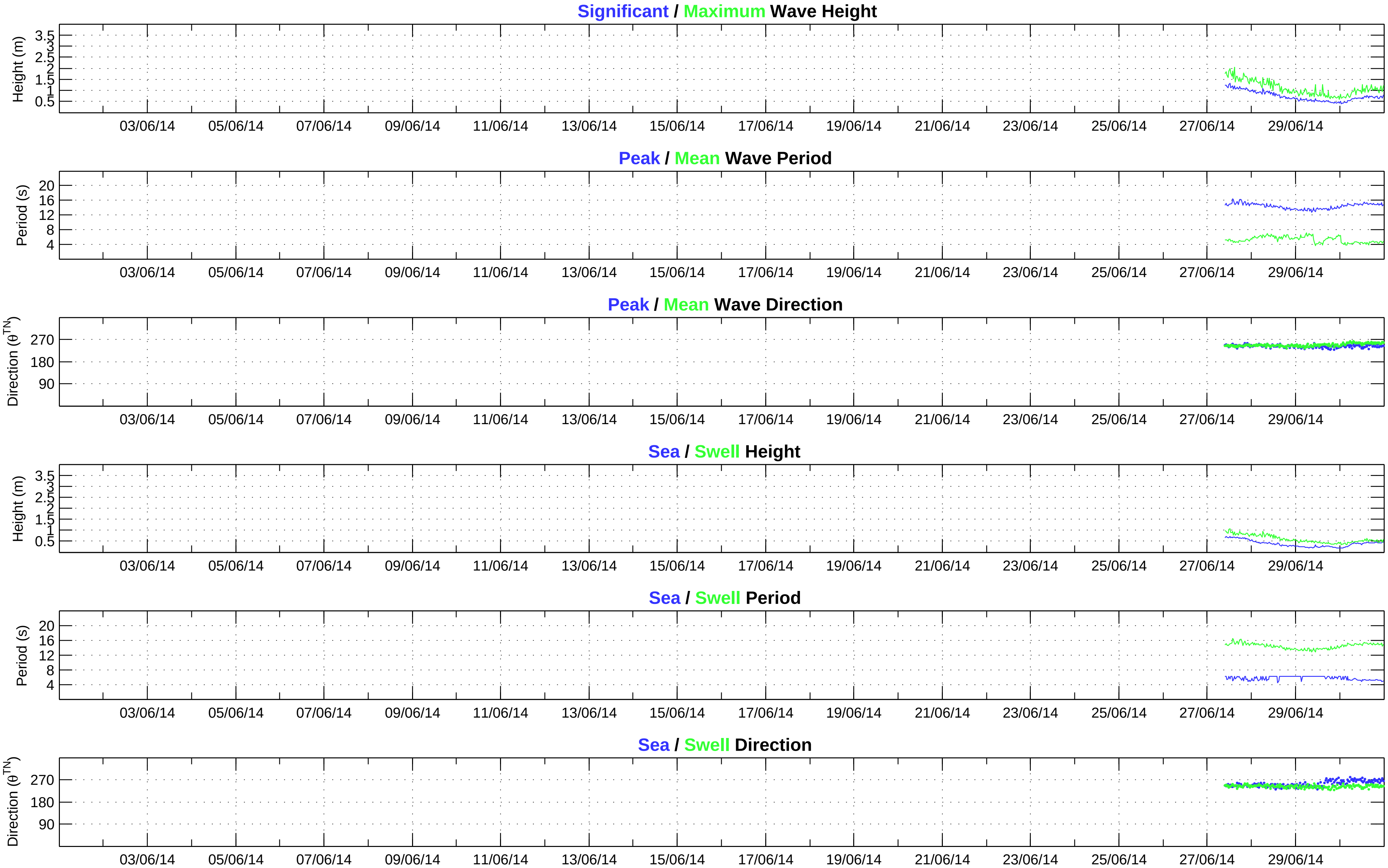
Mean Curr Spd: 0.15 m/s

StdDev. Curr Spd: 0.07 m/s

Current Summary October 2014

WorleyParsons
resources & energy

Appendix 2 - Wave Parameters



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: June 2014 (27−Jun−2014 to 30−Jun−2014)

Data source: AWAC

Data summary: June 2014

Number of Records: 173

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 1.33 m	Max Tp: 16.44 s
Mean Hs: 0.73 m	Mean Tp: 14.39 s
StdDev. Hs: 0.22 m	StdDev. Tp: 0.75 s

Wave Summary June 2014

WorleyParsons

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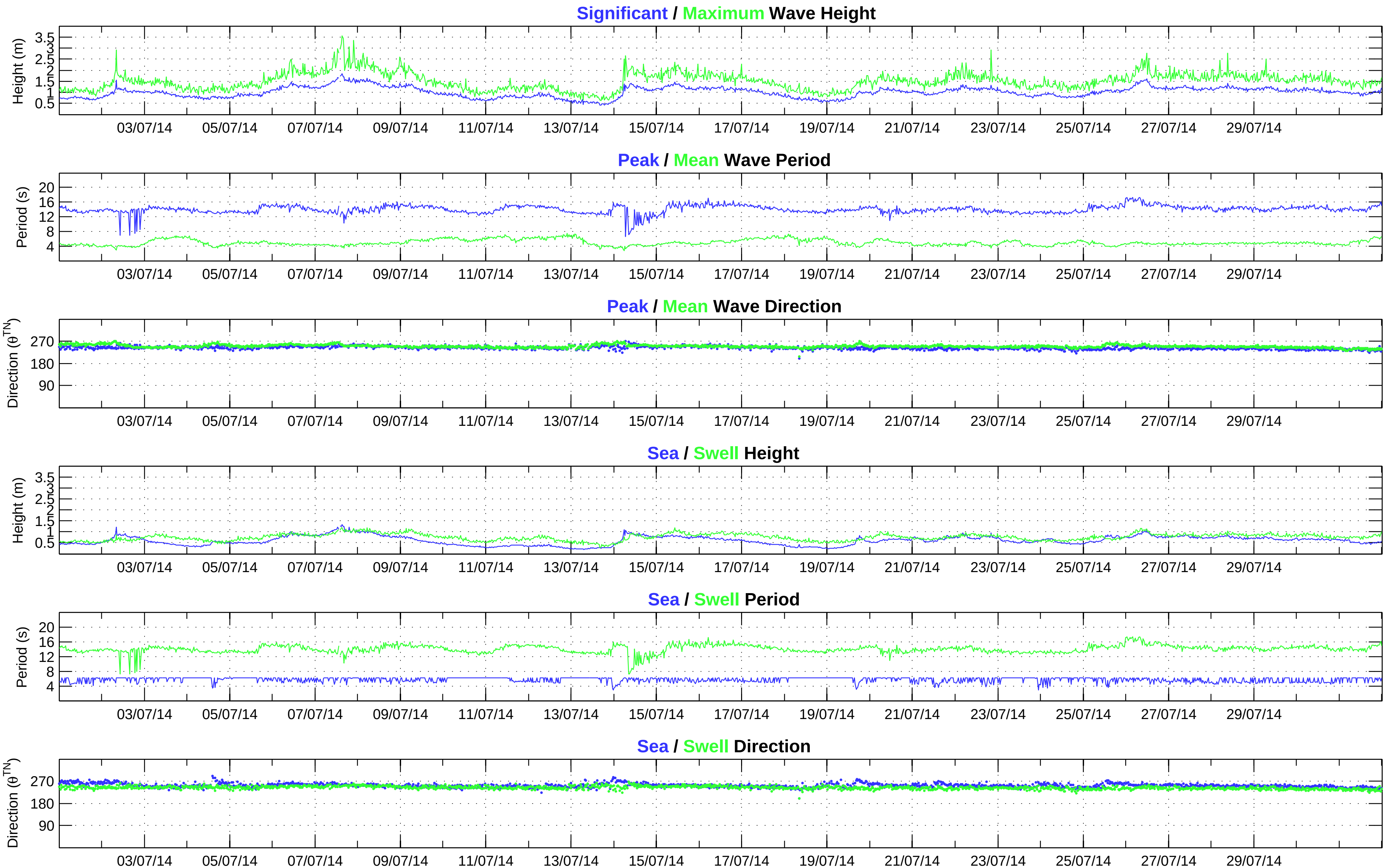


Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840^{o}E , 31.6731^{o}S]

Data period: July 2014 (01−Jul−2014 to 31−Jul−2014)

Data source: AWAC

Data summary: July 2014

Number of Records: 1488

Missing data (%): 0.00

Key Data Statistics:

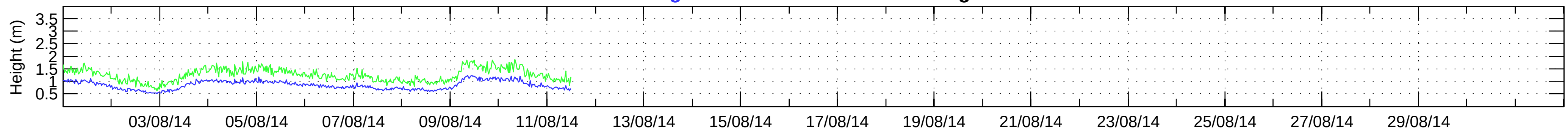
Max Hs: 1.84 m	Max Tp: 17.33 s
Mean Hs: 1.01 m	Mean Tp: 13.99 s
StdDev. Hs: 0.24 m	StdDev. Tp: 1.11 s

Wave Summary July 2014

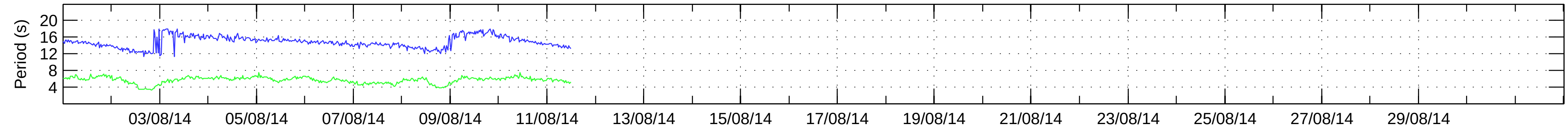
WorleyParsons

resources & energy

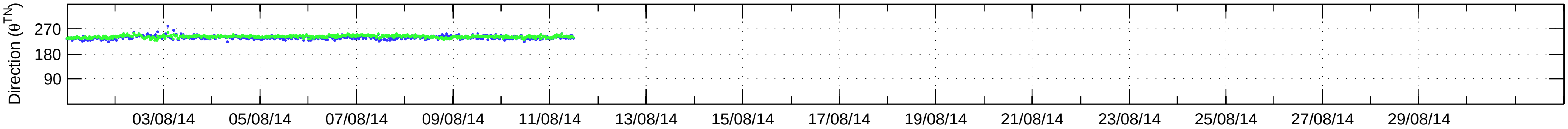
Significant / Maximum Wave Height



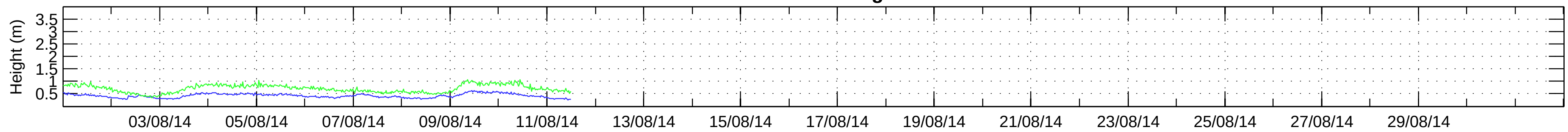
Peak / Mean Wave Period



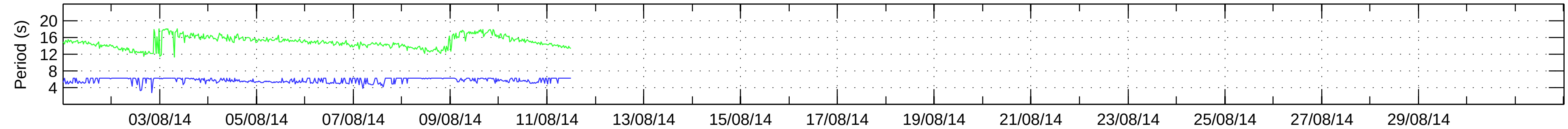
Peak / Mean Wave Direction



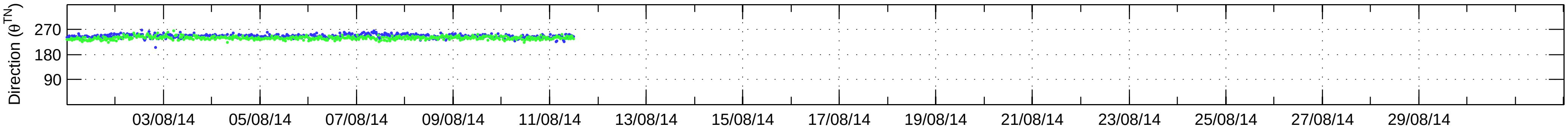
Sea / Swell Height



Sea / Swell Period



Sea / Swell Direction



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840^{o}E , 31.6731^{o}S]

Data period: August 2014 (01−Aug−2014 to 11−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 505

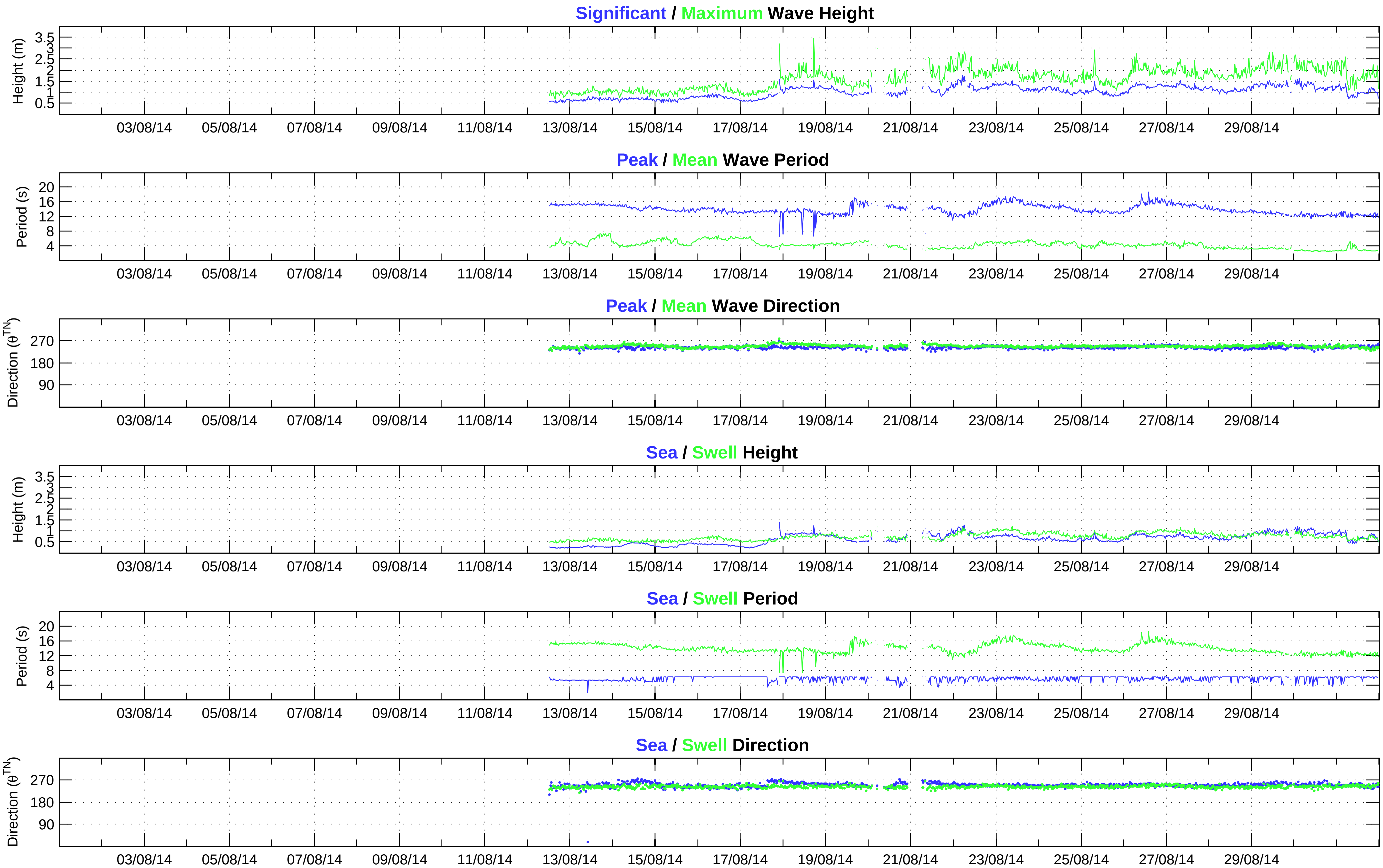
Missing data (%): 0.00

Key Data Statistics:

Max Hs: 1.24 m	Max Tp: 18.02 s
Mean Hs: 0.85 m	Mean Tp: 14.85 s
StdDev. Hs: 0.17 m	StdDev. Tp: 1.40 s

Wave Summary August 2014

WorleyParsons
resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: August 2014 (12−Aug−2014 to 31−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 935

Missing data (%): 0.04

Key Data Statistics:

Max Hs: 1.74 m

Mean Hs: 1.02 m

StdDev. Hs: 0.26 m

Max Tp: 18.58 s

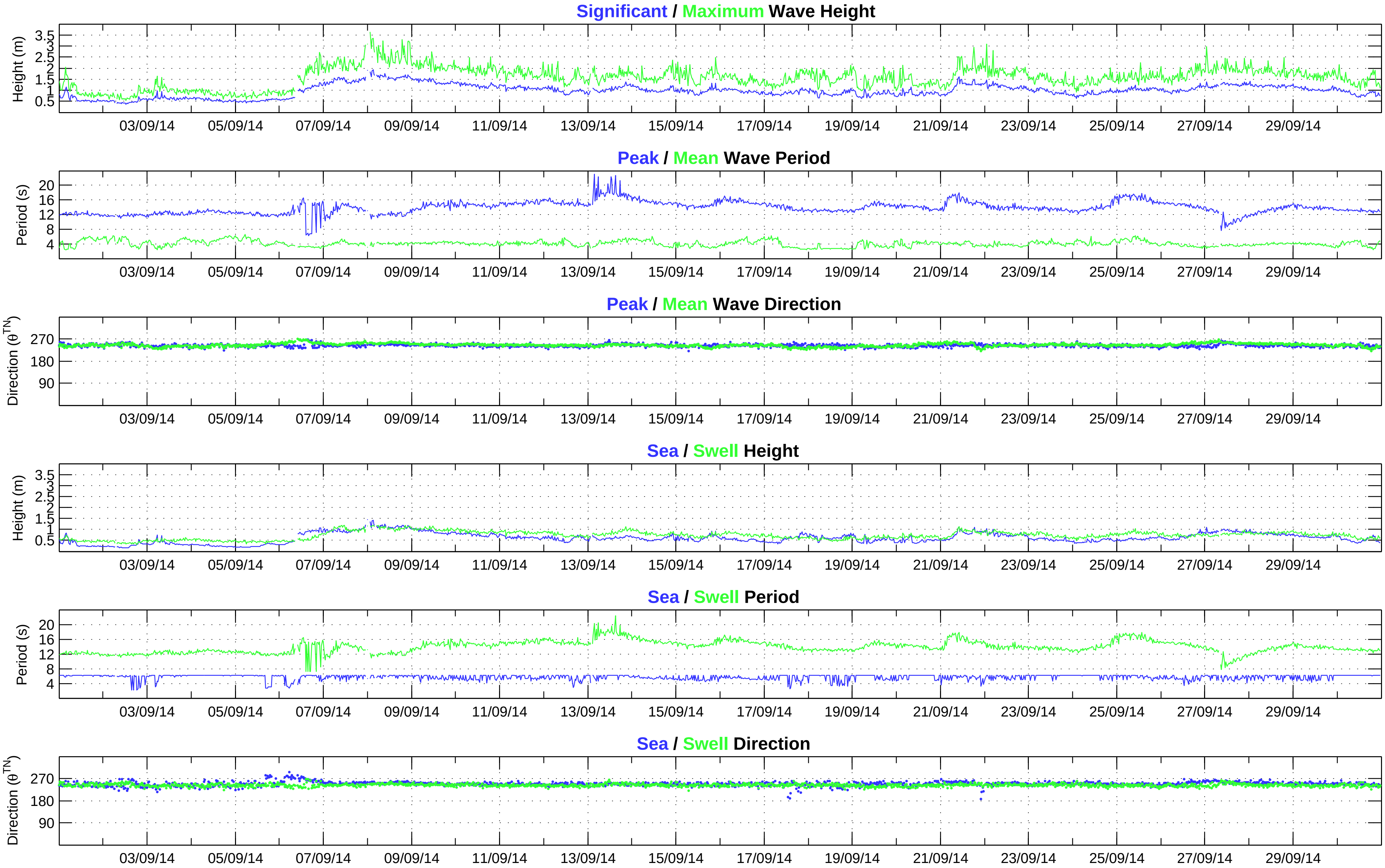
Mean Tp: 13.91 s

StdDev. Tp: 1.36 s

Wave Summary August 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: September 2014 (01−Sep−2014 to 30−Sep−2014)

Data source: AWAC

Data summary: September 2014

Number of Records: 1440

Missing data (%): 0.01

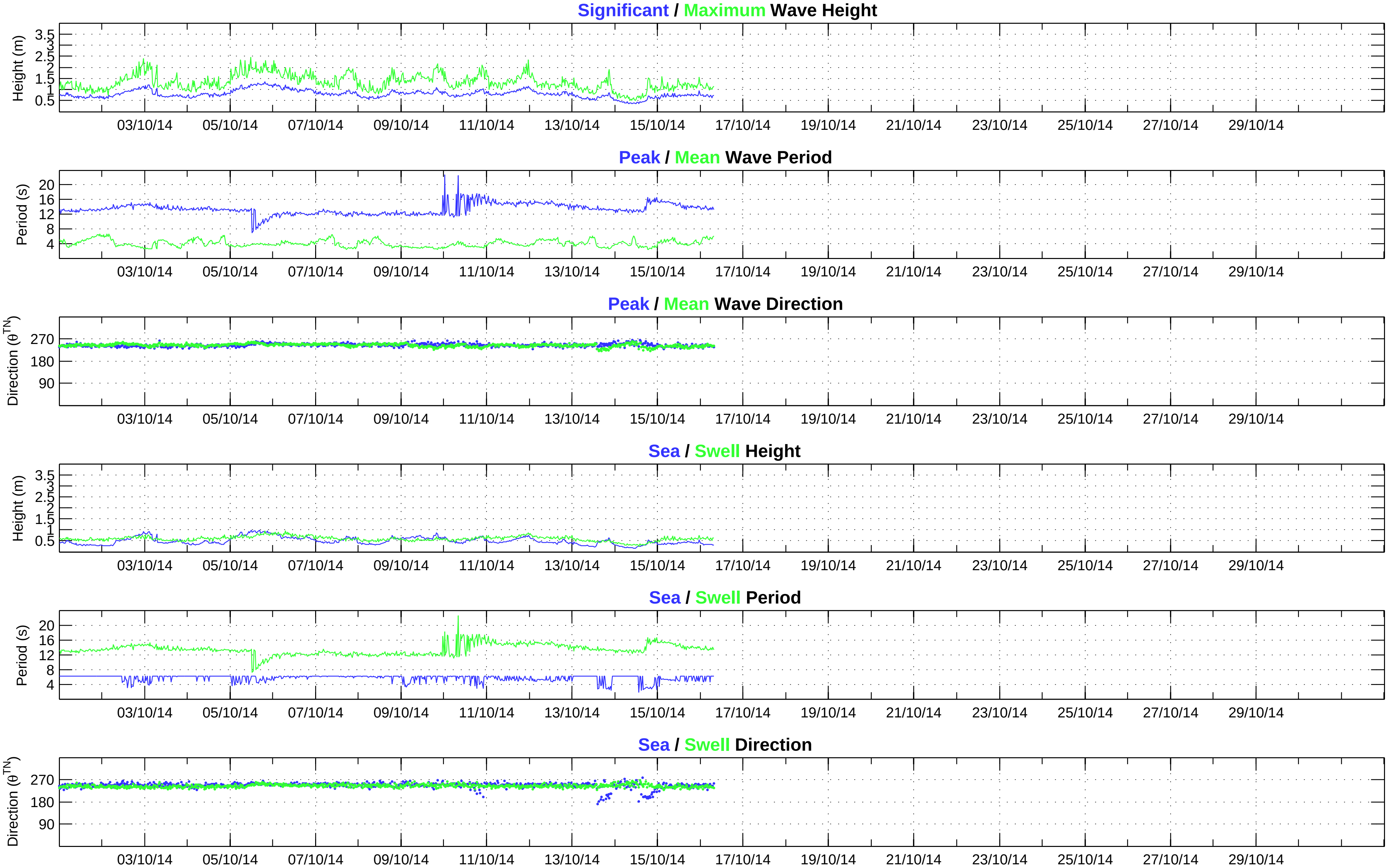
Key Data Statistics:

Max Hs: 1.92 m	Max Tp: 23.08 s
Mean Hs: 0.98 m	Mean Tp: 13.87 s
StdDev. Hs: 0.28 m	StdDev. Tp: 1.75 s

Wave Summary September 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Inshore [115.6840°E , 31.6731°S]

Data period: October 2014 (01−Oct−2014 to 16−Oct−2014)

Data source: AWAC

Data summary: October 2014

Number of Records: 737

Missing data (%): 0.00

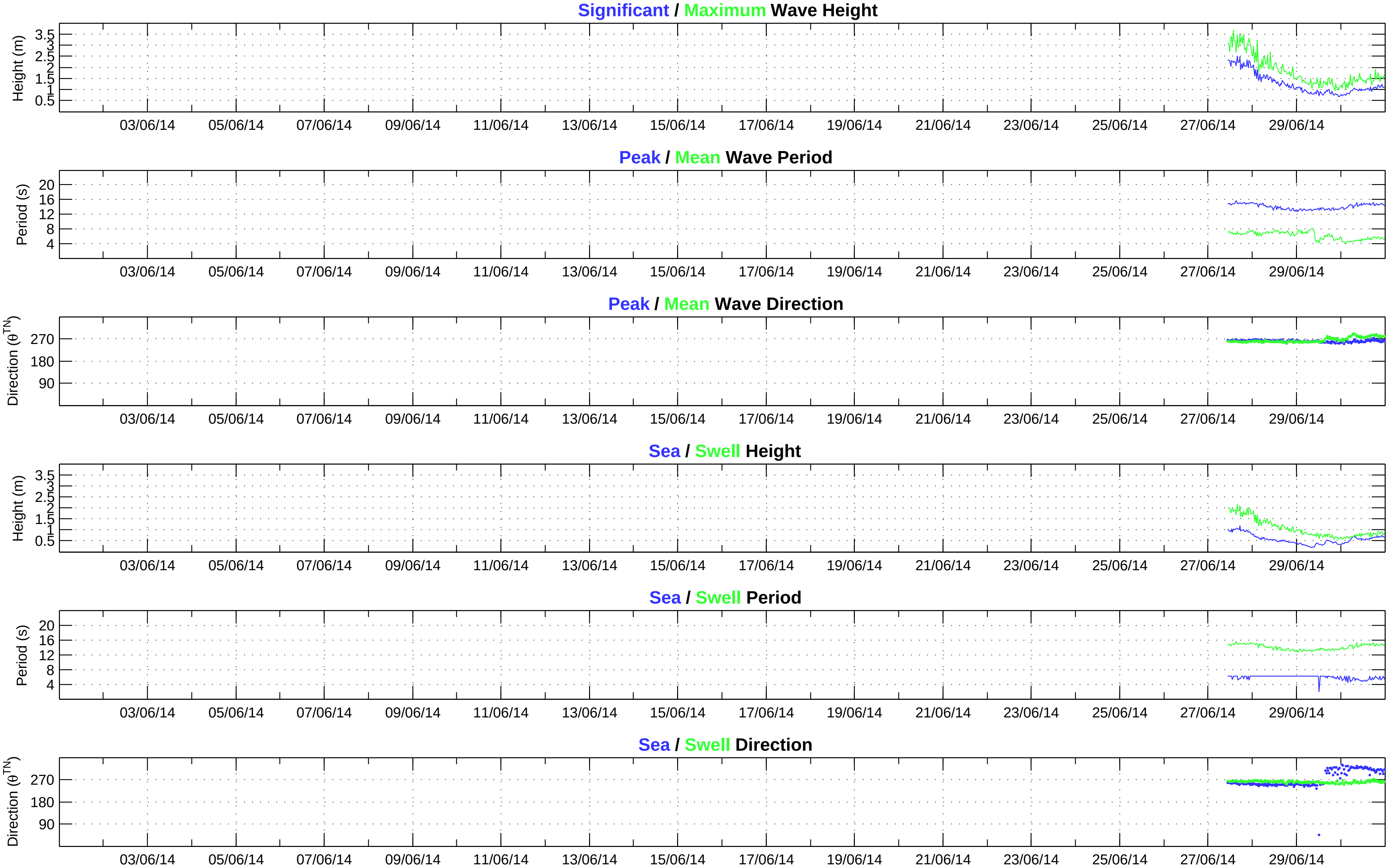
Key Data Statistics:

Max Hs: 1.36 m	Max Tp: 22.65 s
Mean Hs: 0.80 m	Mean Tp: 13.41 s
StdDev. Hs: 0.18 m	StdDev. Tp: 1.53 s

Wave Summary October 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: June 2014 (27−Jun−2014 to 30−Jun−2014)

Data source: AWAC

Data summary: June 2014

Number of Records: 172

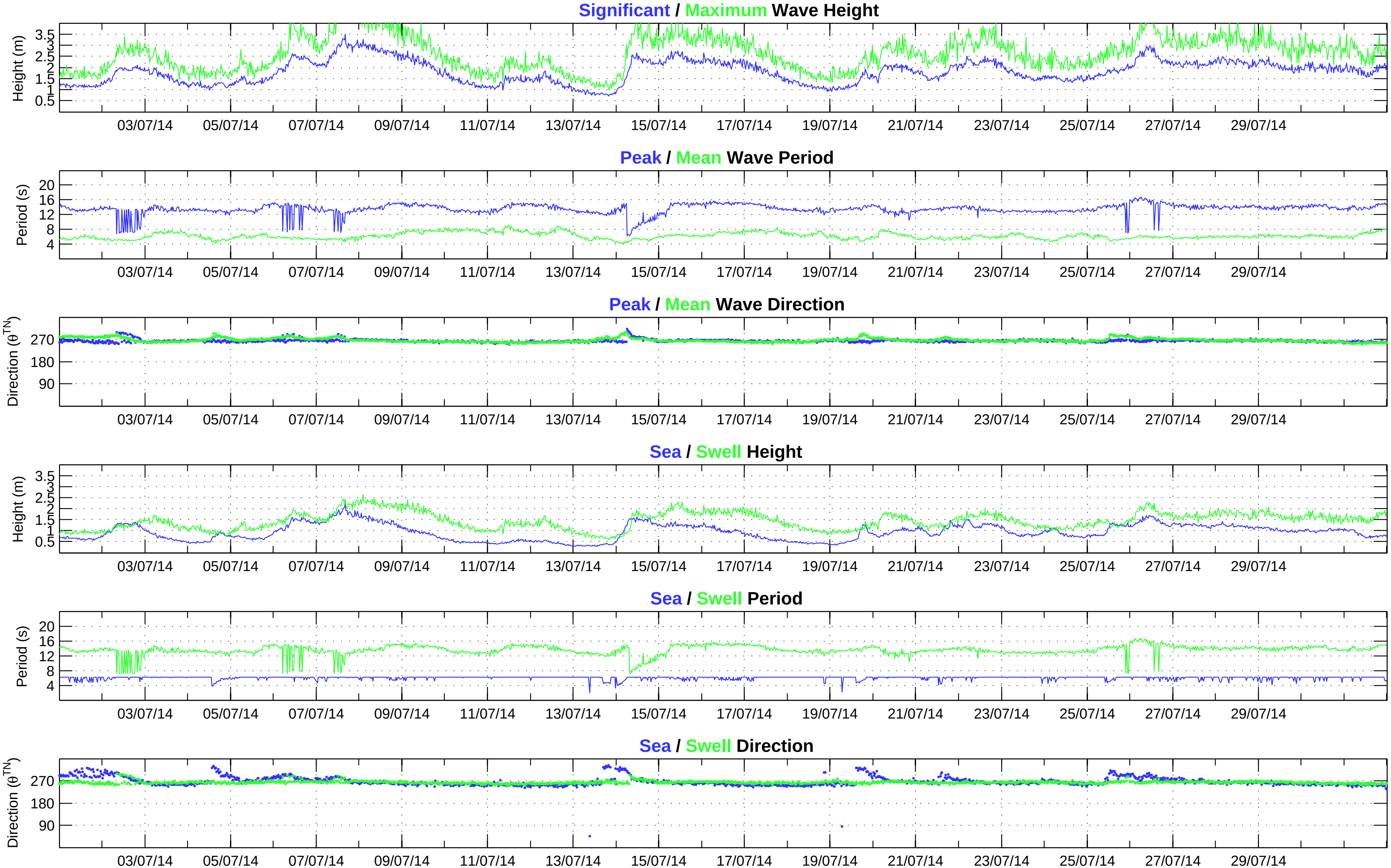
Missing data (%): 0.01

Key Data Statistics:

Max Hs: 2.52 m	Max Tp: 15.65 s
Mean Hs: 1.26 m	Mean Tp: 14.04 s
StdDev. Hs: 0.49 m	StdDev. Tp: 0.74 s

Wave Summary June 2014

WorleyParsons
resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: July 2014 (01−Jul−2014 to 31−Jul−2014)

Data source: AWAC

Data summary: July 2014

Number of Records: 1488

Missing data (%): 0.00

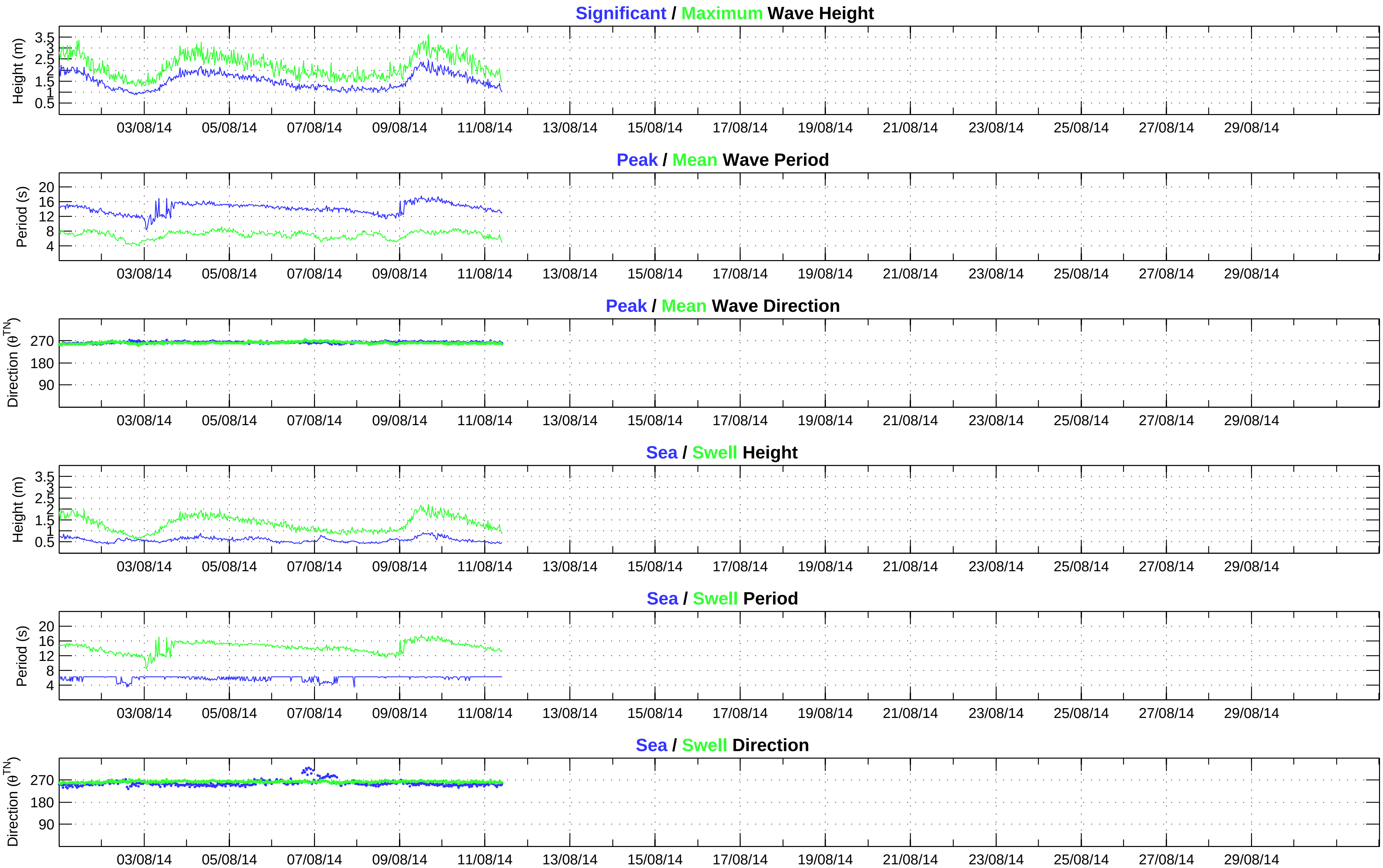
Key Data Statistics:

Max Hs: 3.50 m	Max Tp: 16.66 s
Mean Hs: 1.81 m	Mean Tp: 13.47 s
StdDev. Hs: 0.52 m	StdDev. Tp: 1.44 s

Wave Summary July 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: August 2014 (01−Aug−2014 to 11−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 501

Missing data (%): 0.00

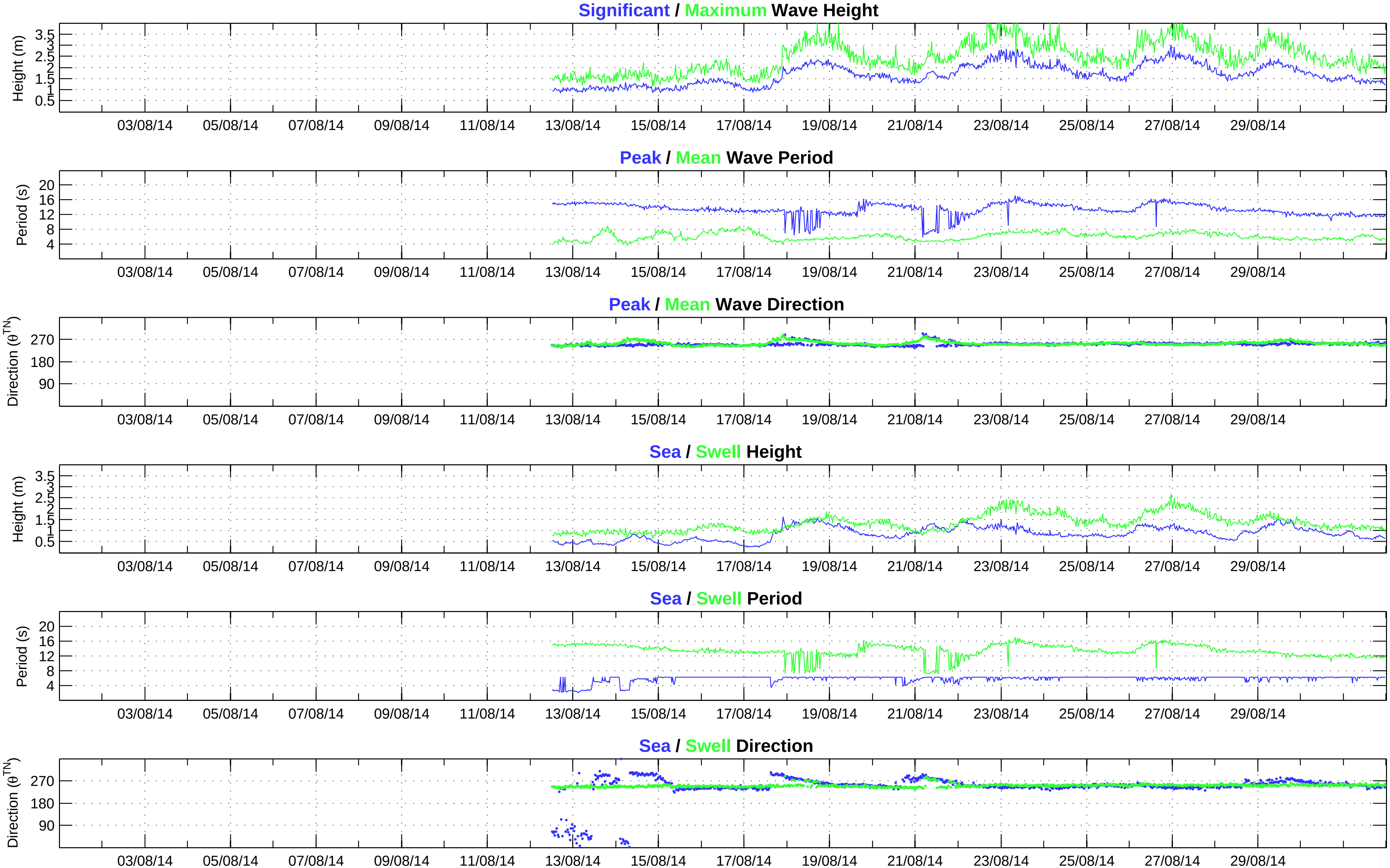
Key Data Statistics:

Max Hs: 2.45 m	Max Tp: 17.58 s
Mean Hs: 1.50 m	Mean Tp: 14.18 s
StdDev. Hs: 0.36 m	StdDev. Tp: 1.45 s

Wave Summary August 2014

WorleyParsons

resources & energy



Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556^{o}E , 31.6697^{o}S]

Data period: August 2014 (12−Aug−2014 to 31−Aug−2014)

Data source: AWAC

Data summary: August 2014

Number of Records: 935

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 3.00 m	Max Tp: 17.00 s
Mean Hs: 1.67 m	Mean Tp: 13.34 s
StdDev. Hs: 0.47 m	StdDev. Tp: 1.74 s

Wave Summary August 2014

WorleyParsons

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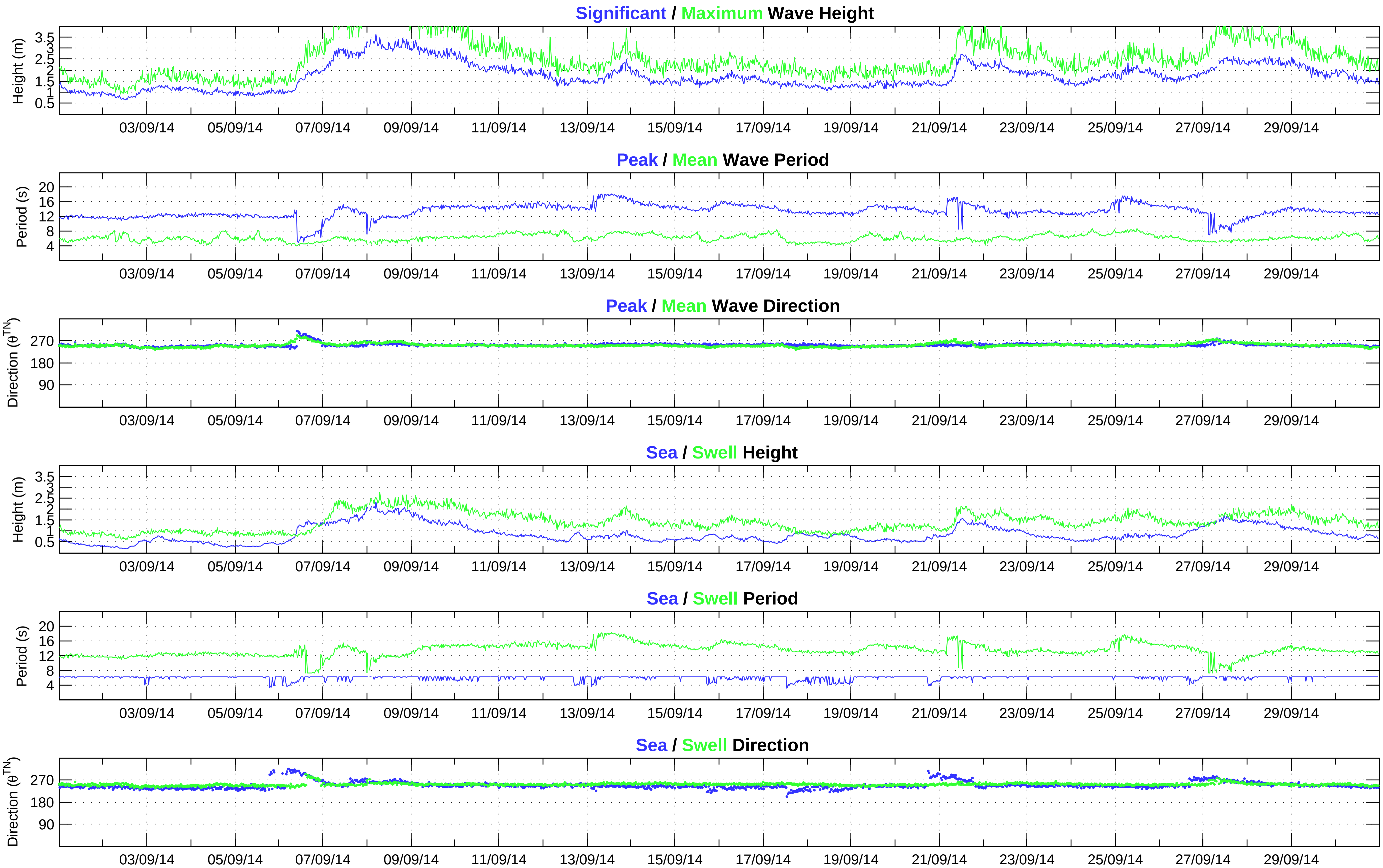

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556°E , 31.6697°S]

Data period: September 2014 (01−Sep−2014 to 30−Sep−2014)

Data source: AWAC

Data summary: September 2014

Number of Records: 1440

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 3.62 m	Max Tp: 18.11 s
Mean Hs: 1.73 m	Mean Tp: 13.39 s
StdDev. Hs: 0.58 m	StdDev. Tp: 1.88 s

Wave Summary September 2014

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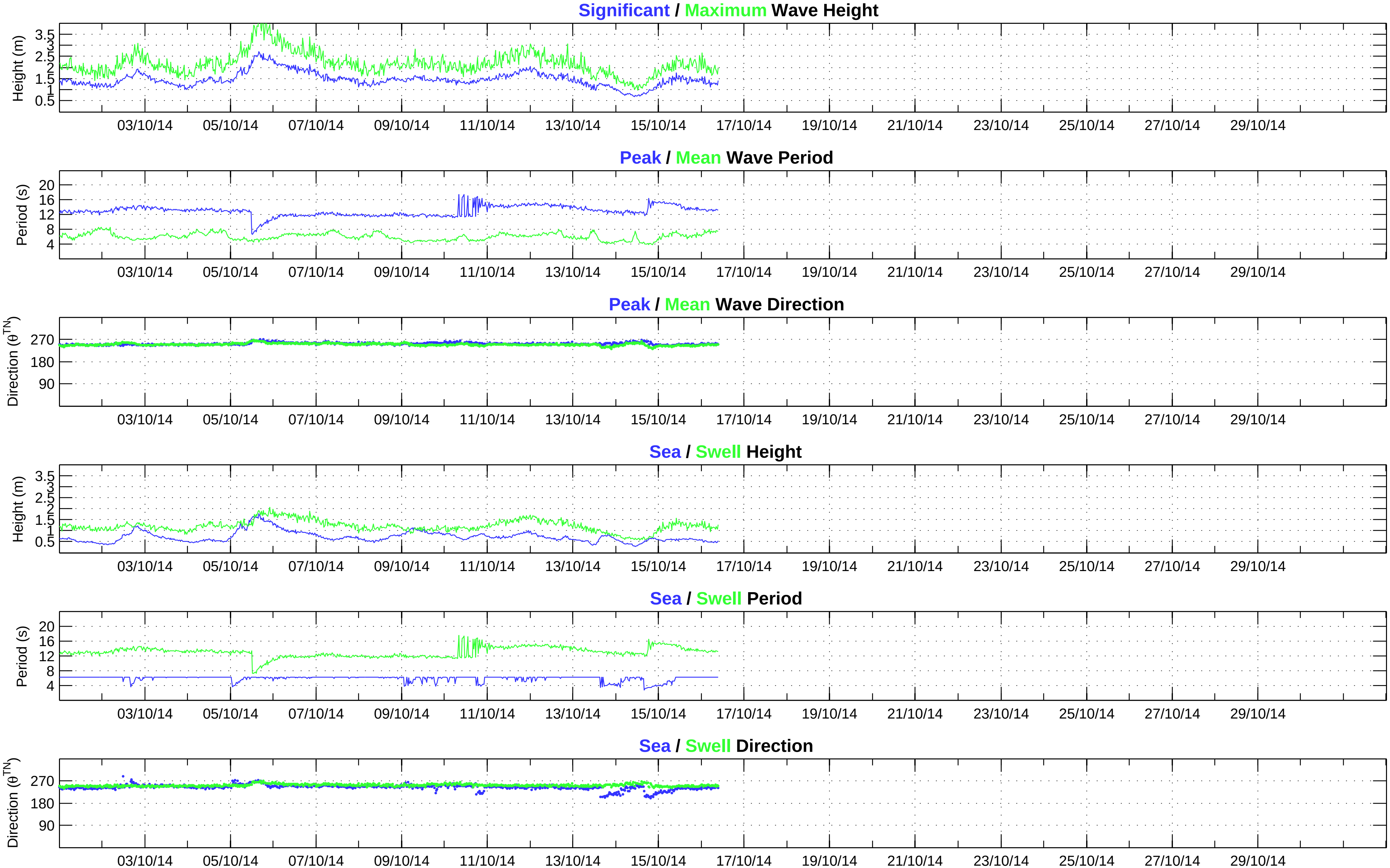

Data Information:

Project: 301012−01921 Quinns Rocks Metocean

Location: Offshore [115.6556^{o}E , 31.6697^{o}S]

Data period: October 2014 (01−Oct−2014 to 16−Oct−2014)

Data source: AWAC

Data summary: October 2014

Number of Records: 741

Missing data (%): 0.00

Key Data Statistics:

Max Hs: 2.71 m	Max Tp: 17.47 s
Mean Hs: 1.46 m	Mean Tp: 12.94 s
StdDev. Hs: 0.33 m	StdDev. Tp: 1.40 s

Wave Summary October 2014

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Appendix 3 - Daily Field Reports

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DAILY PROGRESS REPORT

1. Particulars

Date	27/06/14	Day	1
Project No.	301012-01921		
Scope	Quinns rock metocean instrument deployment		
Team	Nicola Willson, Andrew Larsen (Tim Stead as client representative)	Contact Details	NW-0439 871168, AL-0438078172
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
05:00	06:00	1	Travel to Mundarie boat ramp
06:00	08:00	2	Attached AWACs to frames. Compass calibration on AWACs (inshore and offshore) in boat ramp car park. Started AWACs in preparation for deployment.
08:00	10:00	2	Load equipment, launch vessel. Traveled to inshore site. Deployed inshore AWAC and anchor using winch and capstan. Used digital altimeter to confirm instrument was flat on seabed in 6m of water.Traveled to offshore site. Deployed offshore AWAC and anchor using winch and capstan. GPS points recorded.
10:00	11:00		Travel to Mundarie boat ramp, retrieved vessel, unload equipment and cleaned vessel
11:00	14:00	2	Returned vessel, took equipment back to equipment shed, returned to office.
14:00	14:30	0.5	Downloaded deployment data

4. Programme for Next 24 Hours

Provide client report

5. Comments

1-1.5 metre swell, poor visibility during field operations.

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DAILY PROGRESS REPORT

1. Particulars

Date	11//08/14	**Day**	1
Project No.	301012-01921		
Scope	Quinns rock metocean retrieval and data download		
Team	Andrew Larsen, Nicola Willson	**Contact Details**	AL-0438078172
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site. Take 5 at each site before lifting.

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
07:00	08:00	1	Load equipment, launch vessel, travel to offshore site from Mundarie boat ramp.
08:00	10:00	2	Retrieved offshore AWAC using acoustic release and retrieval rope. Capstan cannot take weight of frame so winched up on crane approx. 0.5 m at a time
10:00	12:00	2	Retrieved inshore AWAC using acoustic release and retrieval rope. Capstan cannot take weight of frame so winched up on crane approx. 0.5 m at a time
12:00	13:00	1	Travel to Mundarie boat ramp, cleaned unit frames, retrieved vessel, unload equipment. AL return vessel and cleaned frame
13:00	18:00	5	Download data from offshore unit.
18:00	-	-	Begin download of inshore unit. (left to run through the evening)

4. Programme for Next 24 Hours

Finalise download, redeploy AWAC units. Process data

5. Comments

Calm sea with moderate water visibility during field operations

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DAILY PROGRESS REPORT

1. Particulars

Date	12//08/14	**Day**	2
Project No.	301012-01921		
Scope	Quinns rock metocean redeployment		
Team	Andrew Larsen, Glen Underhay	**Contact Details**	AL-0438078172
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site. Take 5 at each site before lifting.

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
08:00	09:00	1	Finalise Data download and set instruments ready to begin logging
09:00	10:00	1	Load equipment, refuel vessel and travel Mundarie boat ramp.
10:00	11:00	1	Travel to inshore site and deploy AWAC
11:00	12:00	1	Travel to offshore site and deploy AWAC
12:00	13:00	1	Return to Mundarie boat ramp, retrieve and wash down Vessel. Unload equipment.
13:00	14:00	1	Return vessel

4. Programme for Next 24 Hours

Completed field trip.

5. Comments

Calm sea with moderate water visibility during field operations

1. Particulars

Date	16/10/14	**Day**	1
Project No.	301012-01921		
Scope	Final Quinns rock metocean AWAC retrieval and download		
Team	Andrew Larsen, Glen Underhay	**Contact Details**	AL-0438078172
Home Base	Perth office		

2. Health, Safety and Environment

Safety/Enviro Incidents?	None
Hazards Noted	Anchor and chain for instrument frames and ropes used for deployment and retrieval
HSE Meetings/ Safety Drills?	Toolbox meeting prior to vessel launch. Boat safety meeting on boat prior to travel to site. Take 5 at each site before lifting.

3. Summary of Events

Start Time	End Time	Duration (Hr:Min)	Event
06:00	07:00	1	Load vessel and travel to Mundarie ramp
07:00	08:00	1	Conduct prestart/tool box meeting, Launch Vessel
08:00	10:00	2	Travel to Offshore site and retrieve AWAC with acoustic release.
10:00	12:00	2	Travel to onshore site and retrieve AWAC with acoustic release.
12:00	13:00	1	Return to Mundari Ramp, retrieve and wash down vessel
13:00	14:00	1	Return vessel, transfer AWAC into vehicle and return to storage depo
14:00	18:00	4	Wash down units and frames. Begin down load of data (left to run through the evening) collected next morning for processing.

4. Programme for Next 24 Hours

Completed field trip.

5. Comments

Calm sea with moderate water visibility during field operations

About Cardno

Cardno is an ASX200 professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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