2017 - NSW DoI STIS

Sand Transport Information System (STIS) STIS002

Task 1: Development of Strategic Design Criteria (SDC)
Task 2: Integrated Sand Delivery Management Plan (ISDMP)

Technical Report

July 2018

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Approved by

Signed by: Simon Brandi Mortensen

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Task 1: Development of Strategic Design Criteria (SDC)
Task 2: Integrated Sand Delivery Management Plan (ISDMP)

Prepared for NSW Department of Industry

Represented by Mr Matthew Harry

View of Letitia pier from Duranbah

2017-11-08

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1 Introduction

The Tweed Sand Bypassing (TSB) is a joint marine sand delivery project between the NSW and Qld governments, which captures and transfers sand updrift of the Tweed River Entrance and from the Tweed River to the southern Gold Coast beaches. The system has been operating for 16 years. The project has a dual objective:

a. Establish and maintain a navigable depth in the entrance to Tweed River
b. Achieving and maintaining a continuing supply of sand to the southern Gold Coast beaches at a rate that is consistent with the natural littoral drift.

A continuous natural supply of sand to Gold Coast is of key importance to both coastal protection of beachfront properties and maintaining a high overall level of beach amenity.

The beaches from Duranbah to North Kirra hosts some of Australia's best surf spots and all (except Duranbah) form part of the world's 8th surfing reserve. As a result, it is important that operation of the TSB does not negatively affect surfing conditions along these beaches.

To ensure the TSB will continue to be successful in meeting these criteria into the future, the NSW Department of Industry (DoI) has commissioned DHI to carry out a Strategic Sand Delivery Investigation. The purpose of the investigations is to develop an efficient and practical Integrated Sand Delivery Management Plan (ISDMP) that can improve best practice of how ongoing sand removal and placement operations is managed in the future.

Several parameters, calculated on the basis of bathymetry surveys, are used to describe the status of studied area. These parameters, defined as Key Performance Indicators (KPIs), are measures of the health of the various beaches and indicate the evolution in time of the status of the domain. The detailed definition of these KPI can be found in Section 4.

Work presented in this report involves the development of a suite of Key Performance Criteria (KPCs). The KPCs defines targeted operational outcomes to guide the ISDMP for sand supply legislative requirements, navigational safety, beach health and surfing amenity. In other words, KPCs are numerical target for the KPIs to improve the quality of the considered area. The description of the KPCs can be found in Section 5

The ISDMP will be supported by a Decision Aid Tool (DAT) to assist in providing dynamic decision support on an ongoing basis. A User manual (see Ref. /8/) details the features provided by the DAT, a step-by-step guide and a FAQ section.

2 Input data description and datum definitions

2.1 Vertical and horizontal datum

Vertical levels are unless otherwise mentioned given in metres relative to the Australian Height Datum (AHD). Figure 2.1 presents the tide levels at the Tweed River entrance in 1999, extracted from the Concession Agreement.

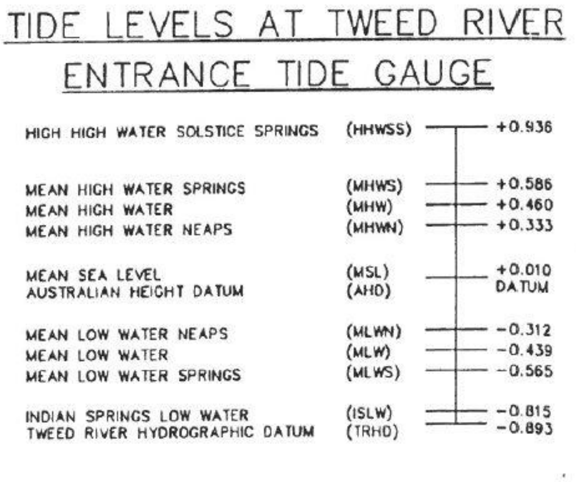

Figure 2.1 Tidal diagram extracted from the Concession Agreement,1999.

Table 2.1 lists the tidal water levels extracted from the Maritime Safety Queensland (MSQ) tide tables from 2010. The water levels from the Concession Agreement and from the MSQ tide tables are generally in agreement. For this project, the updated water levels from 2010 have been used.

Table 2.1 Tidal levels at Tweed River. Derived from Queensland Tide Tables, 2010.

	Water level (m AHD)
HAT (Highest Astronomical Tide)	1.06
MHWS (Mean High Water Spring)	0.61
MHWN (Mean High Water Neap)	0.36
MSL (Mean Sea Level)	0.00
MLWN (Mean Low Water Neap)	–0.31
MLWS (Mean Low Water Spring)	–0.57
LAT (Lowest Astronomical Tide)	–0.893

Horizontal coordinates are given in MGA-56, which is a transverse Mercator projection based on the geodetic coordinate system: GDA-94.

2.2 Bathymetric surveys

Bathymetric surveys have been made available to DHI from the period 1993 to 2017, with a total of 27 survey campaigns. The most comprehensive surveys are most often completed annually and cover the Letitia Spit, Duranbah and Tweed River entrance as well as the Gold Coast beaches up to Currumbin. Surveys done prior to 2016 are typically done in three smaller campaigns as indicated in Figure 2.2 (top).

The horizontal datum used in the surveys varies. Surveys after 2016 appear to be in the widely used MGA-56 while older surveys are measured in the Australian Map Grid (AMG with the AGD66 geodetic coordinate system) or for the case along the NSW beaches the Integrated Survey Grid (ISG55-2 also using the AGD66 geodetic coordinate system).

As part of the quality assurance of the datum transformation carried out by DHI, it has been ensured that the transformed data conforms to rocky outcrops and structures. This was necessary because coordinates in the old AMG grid are quite similar to the coordinates of the MGA grid, but are displaced between 100–200 m. Figure 2.3 shows examples of how the extent of the survey data is expected to conform to rocky outcrops and structures.

The surveys along the NSW coastline typically extend out to about –20 m AHD, while the surveys along the Gold Coast beaches north of Kirra rarely extend past –15 m AHD.

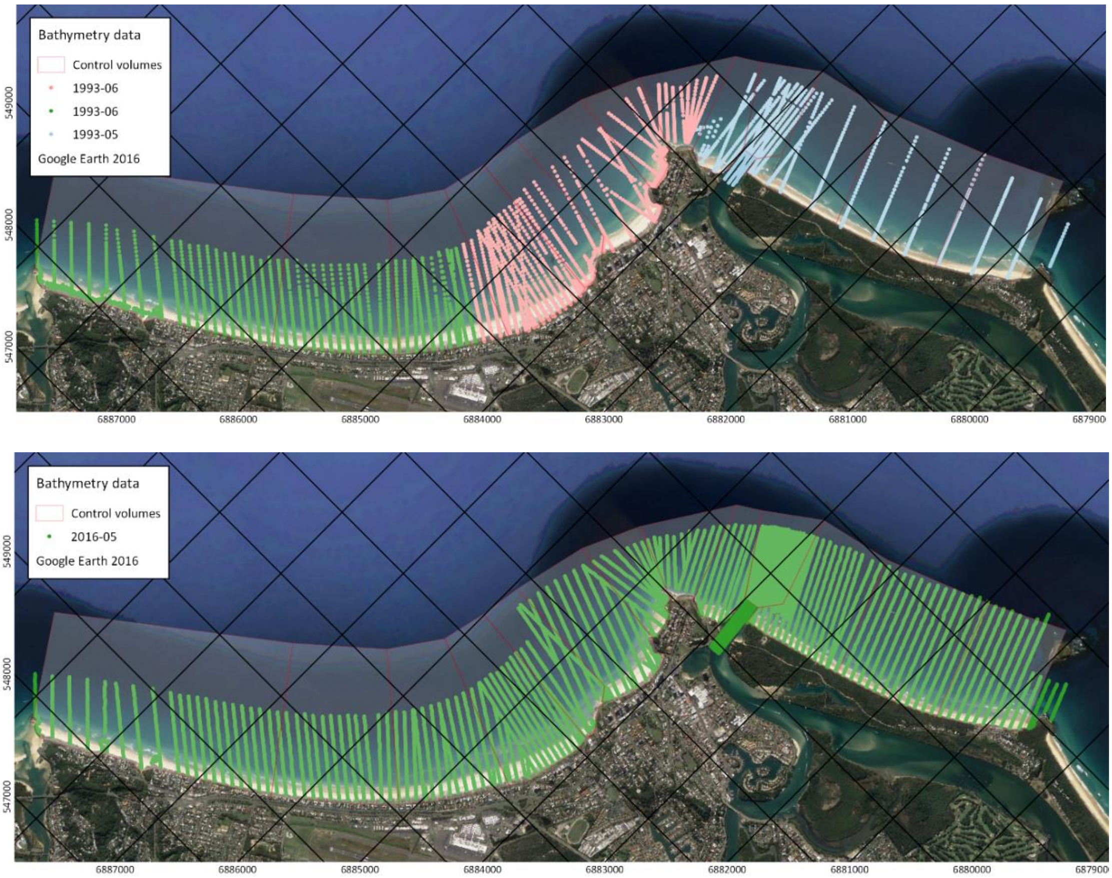

Figure 2.2 Examples of the data coverage. Top: Survey from 1993, which is composed of three parts. Bottom: Survey from 2016.

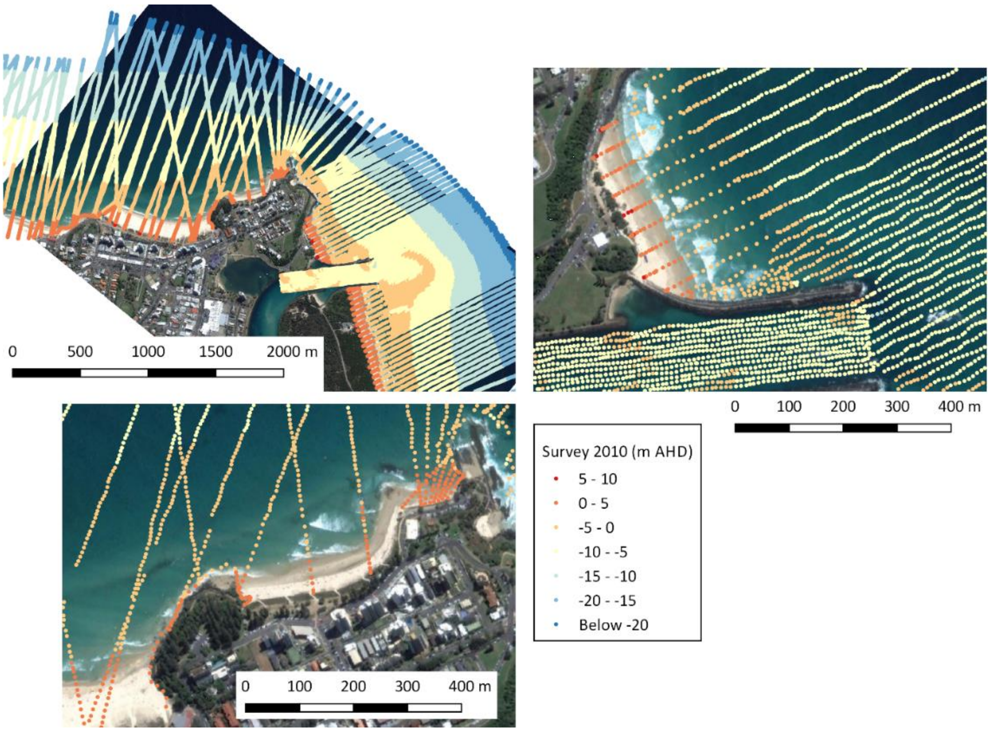

Figure 2.3 Examples of how the transformed bathymetry data is inspected visually to ensure that the transformation was successful.

2.3 Offshore wave climate

Wave measurements in the nearshore have been made available to DHI at three waverider buoy locations: Brisbane, Gold Coast and Tweed.

Table 2.2 Wave measurement information

Location	E (m MGA-56)	N (m MGA-56)	Bed level (m AHD)	Period
Brisbane	562,400	6,959,445	70	1976-2017
Gold Coast	543,530	6,906,570	17	1987-2017
Tweed	556,530	6,882,520	22	1995-2017

Offshore wave boundaries for the MIKE21 ST sediment transport model has been calculated based on a transformation of local wave buoy recordings using a linear shoaling/refraction matrix developed in DHI (2014).

2.4 Measured records of artificial sand bypass volumes

Monthly records of the artificial bypass rates (pumping and dredging) have been made available for this project, which was transformed to yearly rates. Figure 2.4 shows the artificial bypass rates on a yearly basis. The average annual bypass volumes from 2001 to 2008 was about 833,000 m^3/year, while the rates in the years after were reduced to about 440,000 m^3/year. The reduced bypass was adopted in order to fulfil the legislative agreement between NSW and Qld, which requires that the 500,000 m^3/year is bypassed to Qld ±200,000 m^3 (see Figure 3.4).

The figure shows that bypass by dredging often accounted for about 25% of the total bypass up to 2008. During the period 2009–2015 no dredging was done.

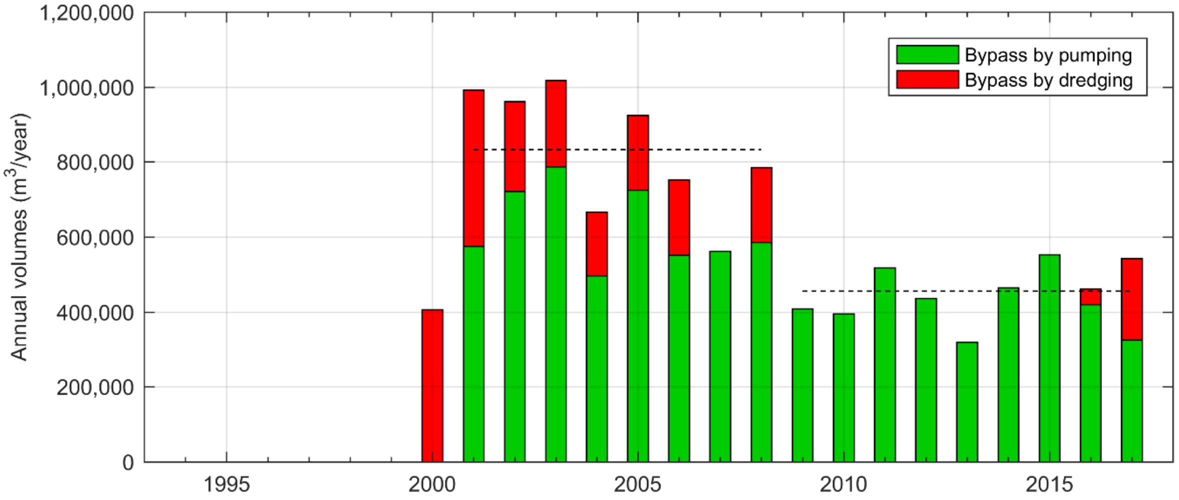

Figure 2.4 Yearly mechanical bypass volumes derived from TRESBP records. Bypass by pumping are coloured in green and bypass by dredging in red.

Figure 2.5 shows the distribution of sand bypassing in terms of placement areas (the location of the placement areas is indicated in Figure 2.6). The top panel shows the placement of dredged sand while the bottom panel shows the placement distribution of pumped sand. The majority of the bypassed sand (pumped and dredged) is placed in the Snapper Rocks East compartments. About 10% of the artificial bypass by pumping is disposed in Duranbah.

Two dredging campaigns were carried out in 2016 and 2017. The dredged material was placed in the Snapper Rocks East and in the Duranbah dump boxes.

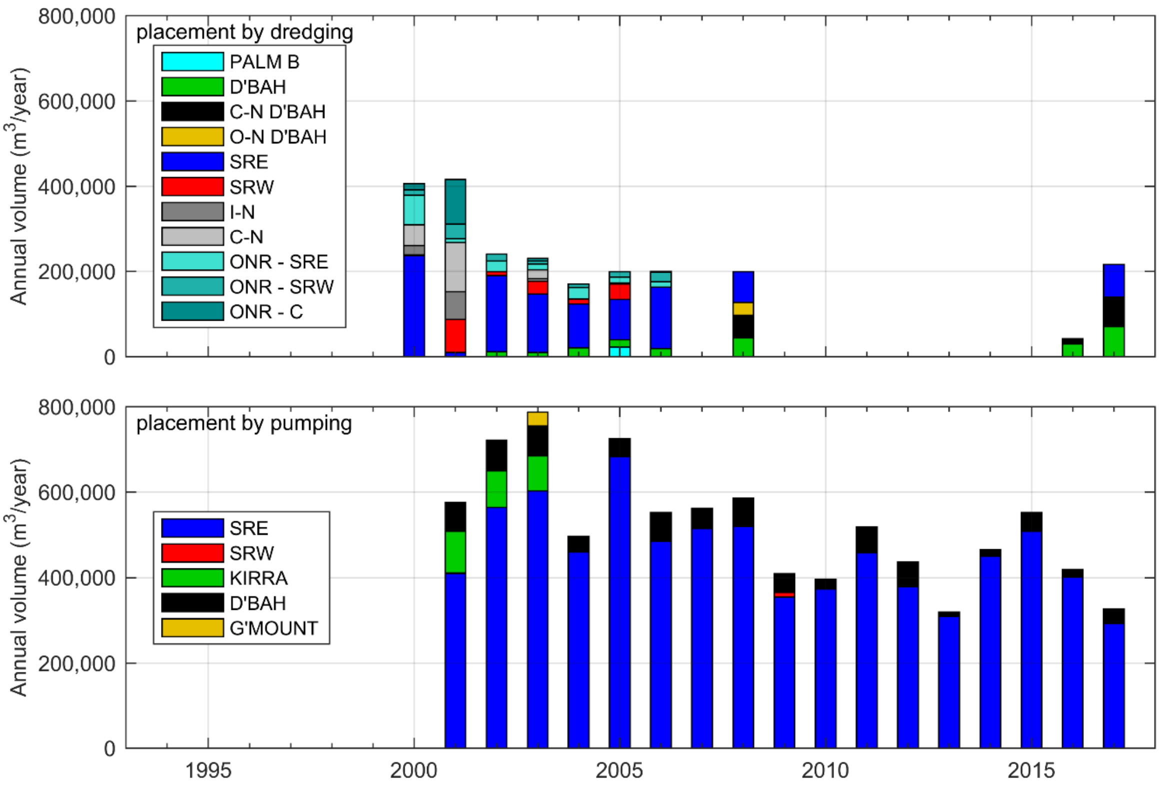

Figure 2.5 Distribution of the yearly artificial bypass volumes over placement areas. Derived from TRESBP records.

Figure 2.6 Location of disposal areas of the dredged sand. Background image: Google Earth, 2016.

2.5 Surf Quality Review

DHI has gathered a detailed library of more than 1,170 individual files consisting of surf reports from websites (www.swellnet.com, www.coastalwatch.com), media articles and images from years 1999 to 2015 (see Figure 2.7). As future operations of the bypass system are expected to operate in line with the natural rates, this study has focused on analysing surf event from 2010 to 2015, which is are considered most representative to future operations.

Figure 2.7 Pictures from the surfing conditions at Snapper Rocks / Kirra in June 2012.
Source : http://www.mydailynews.com.au/story/2012/06/12/rough-weather-closes-beaches/

For each surf event the surf quality has been rated on a scale from 1 to 10. A score of 1 corresponds to very poor borderline surfable conditions, while 10 corresponds to world class excellent conditions. A rating of 5 or 6 corresponds to average conditions.

A separate ranking has been given for Duranbah, Snapper Rocks, Greenmount and Kirra where available. In order to reduce bias, two individual ratings have been provided by Swellnet, Coastalwatch and DHI surf specialists.

As observed from Figure 2.4 the period of 2001 to 2008 experienced sand bypassing rates up to twice the estimated natural average of 500,000 m^3/year. The excess supply of sand led to the creation of the famous Superbank and the loss of Kirra and Greenmount as individual waves.

Following 2008, bypass rates were reduced to natural levels and the surfing conditions responded accordingly.

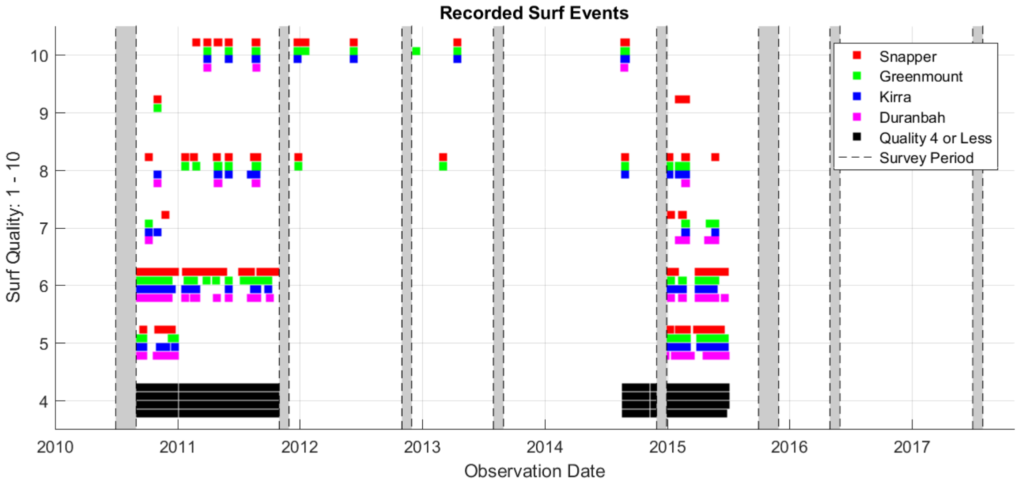

Figure 2.8 Figure showing registered average to excellent surf conditions during the period of 2010 to 2015 in relation to bathymetry survey campaigns.

2.6 Surf Amenity Analysis

The surf amenity analysis was undertaken using DHI's non-linear 2D Boussinesq Wave Model (MIKE 21 BW) coupled with DHI's surfing amenity analysis model, OPTISURF. OPTISURF provides a detailed breakdown of surfable "rides" by length, speed and wave face height for a given offshore wave condition and bathymetry configuration.

2.6.1 Wave scenario selection

From the surf quality review, 26 December 2011 was selected as a representative event of excellent surfing conditions at Snapper, Greenmount and Kirra. Details of this report for this event can be found on http://www.coastalwatch.com/news/article.aspx?articleId=9962. Between 2010 and 2015 this is the closest reported high-quality event to a survey period. For this date, the integral wave parameters from the Tweed Waverider buoy are listed in Table 2.3.

Table 2.3 Tweed Waverider buoy integral parameters 2011-12-26.

H_s	T_p	MWD
3.29 m	12.8 s	84°

2.6.2 Model bathymetries

Two model bathymetries were generated from survey data for two periods known to produce good surfing conditions. First was from November 2011 as the nearest survey prior to the representative surfing event. Second was from bathymetry surveyed in 1997 known to produce good surfable waves in MIKE21 and CFD simulations (Mortensen, 2010). Figure 2.9 and Figure 2.10 show the model domain for the 1997 and 2011 bathymetry configurations respectively. Figure 2.11, Figure 2.12, Figure 2.13 and Figure 2.14 show detailed bathymetry configurations for the Superbank and Kirra surf areas with the 2J –5m design contour overlaid. The review of the 2J bathymetry previously mentioned can be found in Section 5.1.

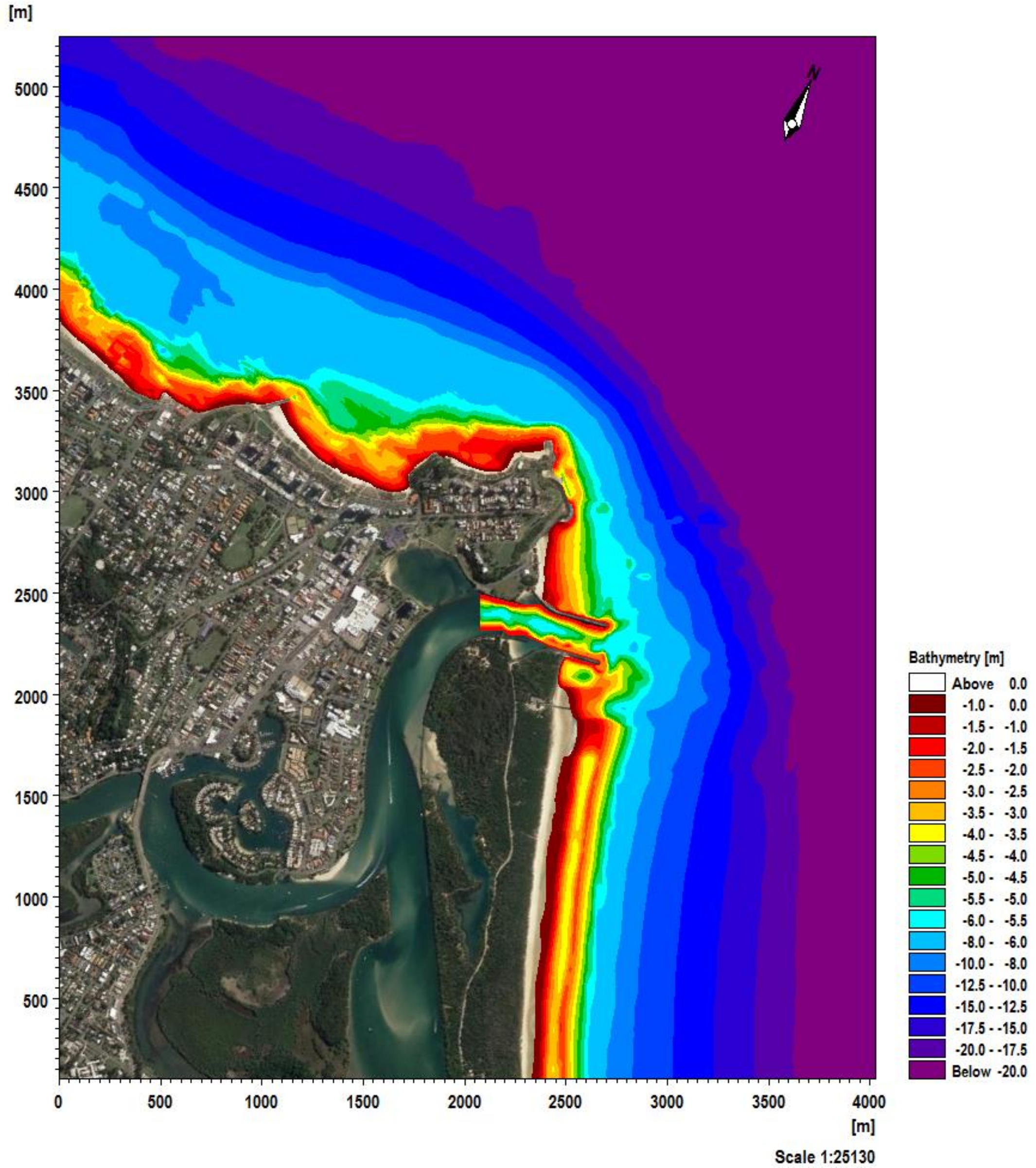

Figure 2.9 Model bathymetry 1997.

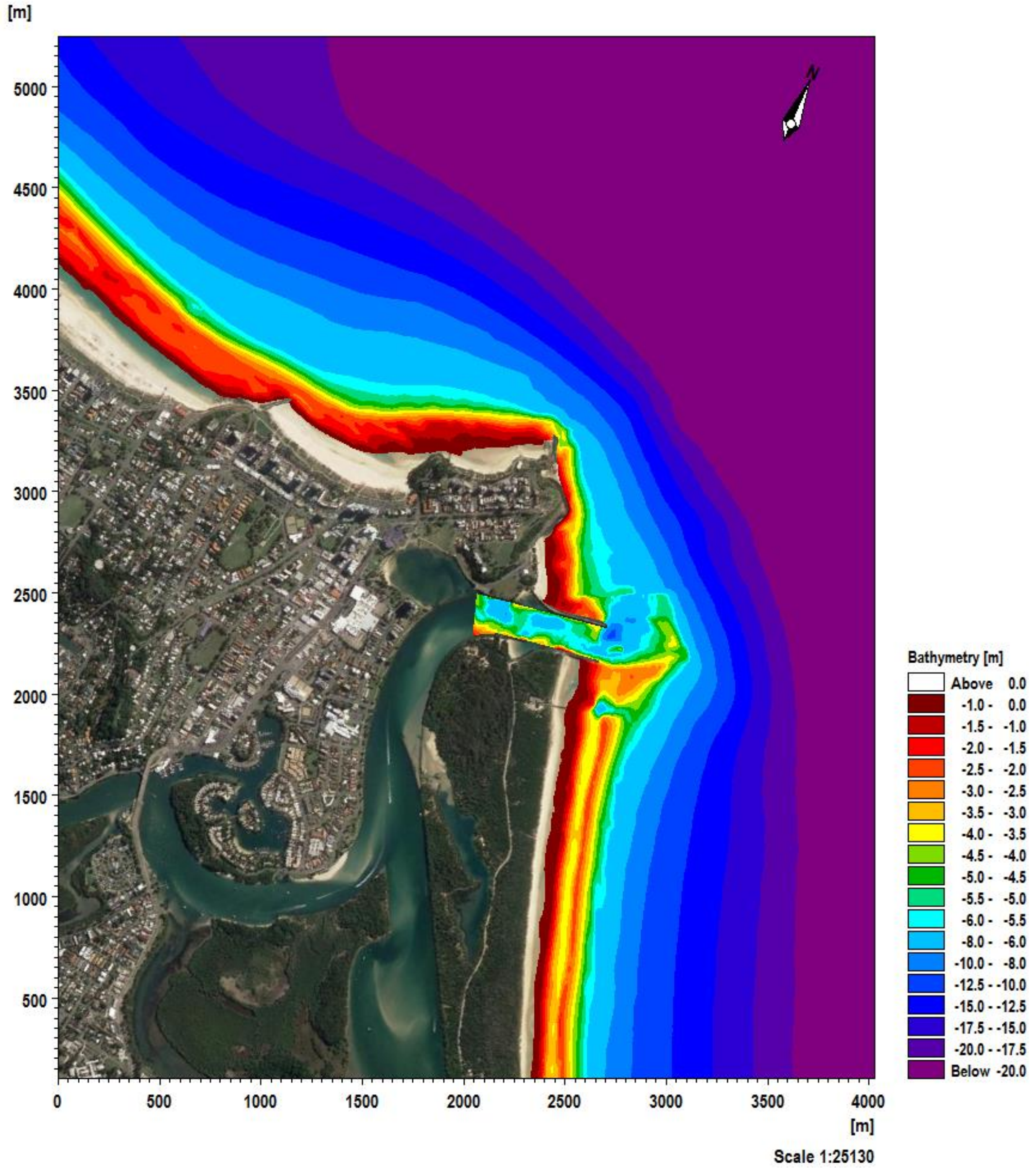

Figure 2.10 Model bathymetry 2011.

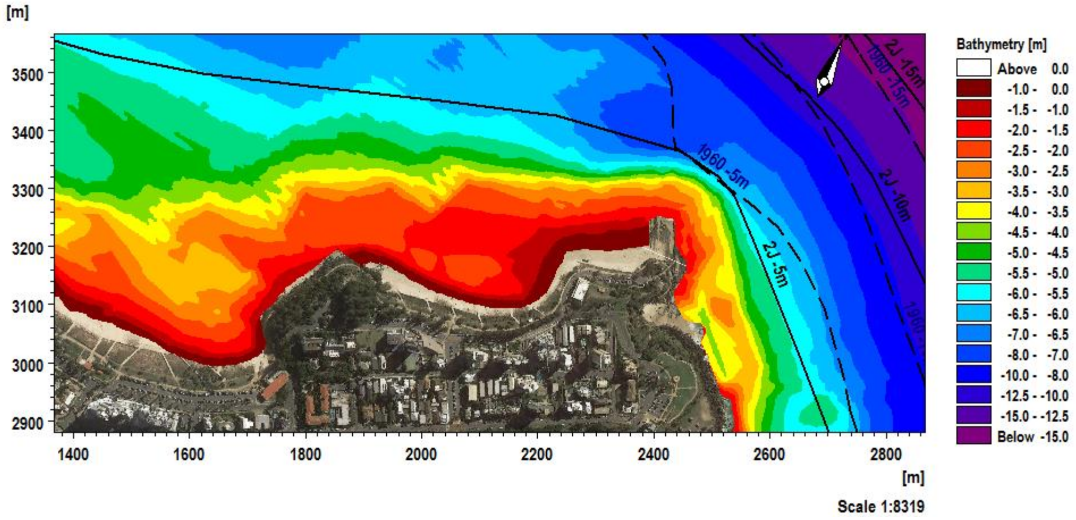

Figure 2.11 Bathymetry Superbank 1997.

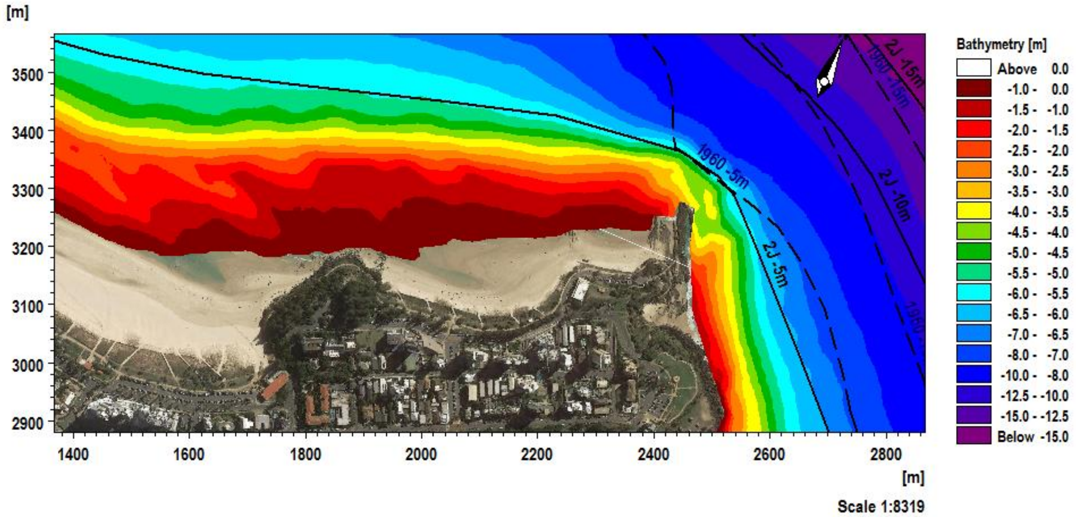

Figure 2.12 Bathymetry Superbank 2011.

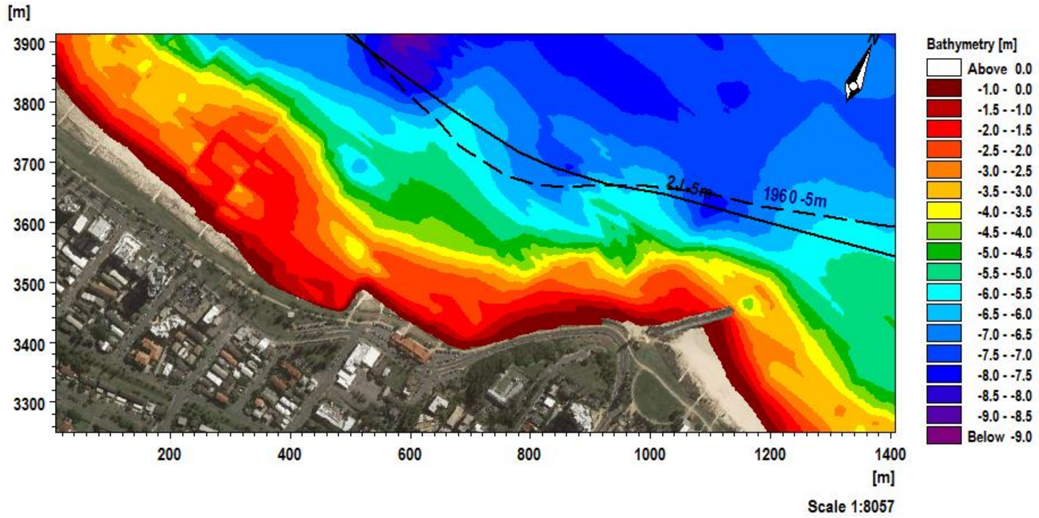

Figure 2.13 Bathymetry Kirra 1997.

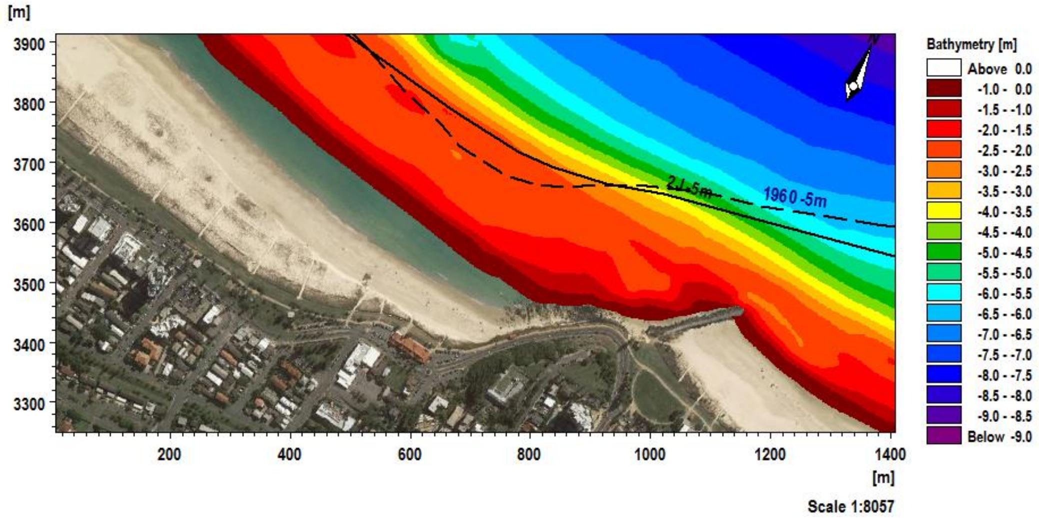

Figure 2.14 Bathymetry Kirra 2011.

Mean orientations of the –5 m contour (defined as Bank Orientation KPI in Section 5) for the two bathymetry configurations can be seen in Table 2.4. The Bank Orientation is defined as the normal orientation of the –5 m AHD depth contour measured positive as a clockwise rotation from True North. The orientation corresponds to the direction pointing away from the coast.

Table 2.4 Mean –5 m Bank Orientation comparison.

Location	Mean –5 m Bank Orientation		
	Design - 2J	1997 Bathymetry	2011 Bathymetry
Superbank	350°	343°	346°
Kirra	356°	342°	3°

2.6.3 OPTISURF Results

Two 40 minutes simulations were completed to provide a comparison of bank orientation and associated surfing amenity at Kirra and the Superbank (Snapper Rocks to Greenmount). Both models were forced with the same representative offshore wave condition to allow comparison between two bathymetry configurations. The details of the selected wave event and bathymetries are presented in Section 2.6.1 and Section 2.6.2 respectively. The OPTISURF analysis of the simulation are detailed in Section 2.6.3.

Superbank

For the Superbank, rides shorter than 50 m, with wave face heights less than 2 m or going left from the wave peak were excluded from analysis. OPTISURF statistics for the Superbank are shown below in Table 2.5.

Table 2.5 OPTISURF ride statistics for the Superbank

Bathymetry	No. of rides	Mean Height	Mean Length
1997	279	2.37 m	87 m
2011	416	2.40 m	113 m

Surfable rides are approximately 30% longer and there are approximately 49% more in 2011 than in 1997. While there is only a 3° difference in mean bank orientation, the bars in 2011 hold their angle more consistently throughout Rainbow Bay and Greenmount. The effect can be clearly seen in the track results where rides do not continue through Rainbow Bay towards Kirra with the 1997 bathymetry.

OPTISURF track plots are shown in Figure 2.15 and Figure 2.16. The distribution of surfable rides, ride length and maximum wave face height are shown in Figure 2.17.

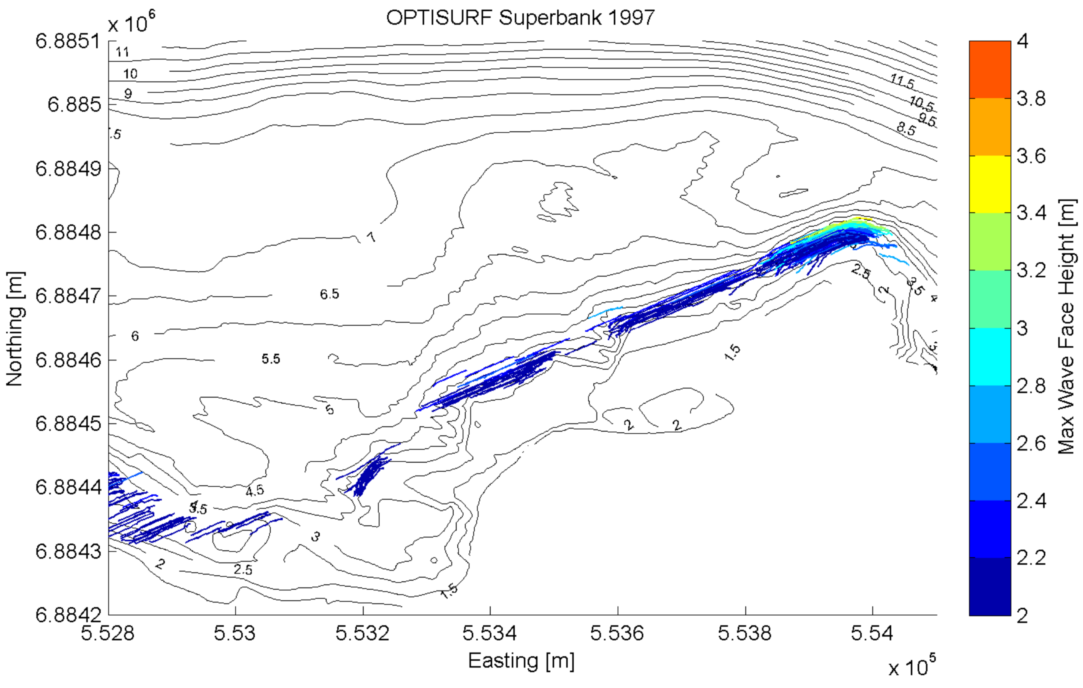

Figure 2.15 OPTISURF track results: Superbank 1997

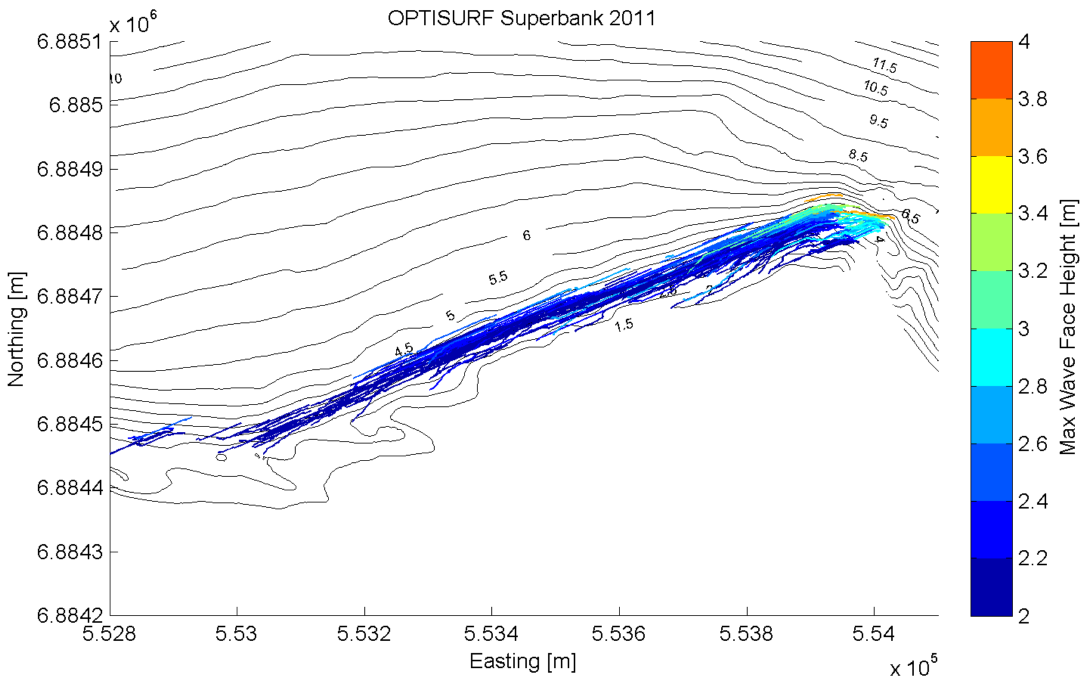

Figure 2.16 OPTISURF track results: Superbank 2011

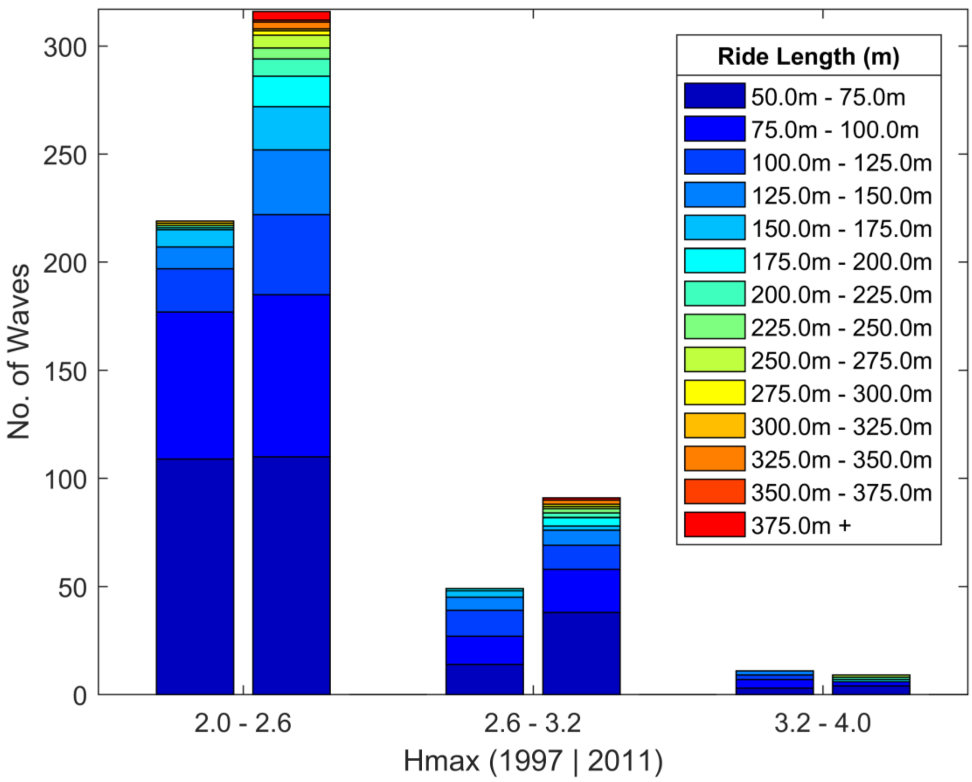

Figure 2.17 OPTISURF Superbank statistics

Kirra

For Kirra, there is a 21° difference in the mean bank orientation between 1997 and 2011.

For Kirra, rides shorter than 50 m, with wave face heights less than 1.6 m or going left from the wave peak were excluded from analysis. Statistics for Kirra are shown below in Table 2.6. Surfable rides are approximately 51% longer but there are approximately 10% less rides in 2011 compared to 1997.

Table 2.6 OPTISURF ride statistics for Kirra

Bathymetry	No. of rides	Mean Height	Mean Length
1997	235	1.96 m	74 m
2011	214	1.95 m	112 m

Another key difference between the two bathymetry configurations is the consistency of ride starting location. With 1997 bathymetry there is a clearly defined point break with all surfable rides peeling off the same series of sand bars and the angle of the rides are closely aligned to the angle of the bank, which suggests a steep wave face and potential good barrel section. In 2011 the starting location are more distributed along a 500 m section of the sand bank and each ride is aligned across the bank, which suggests that the later part of each ride contains a less steep wave face as the surfer is effectively riding what in surf terminology is referred to as the foam ball.

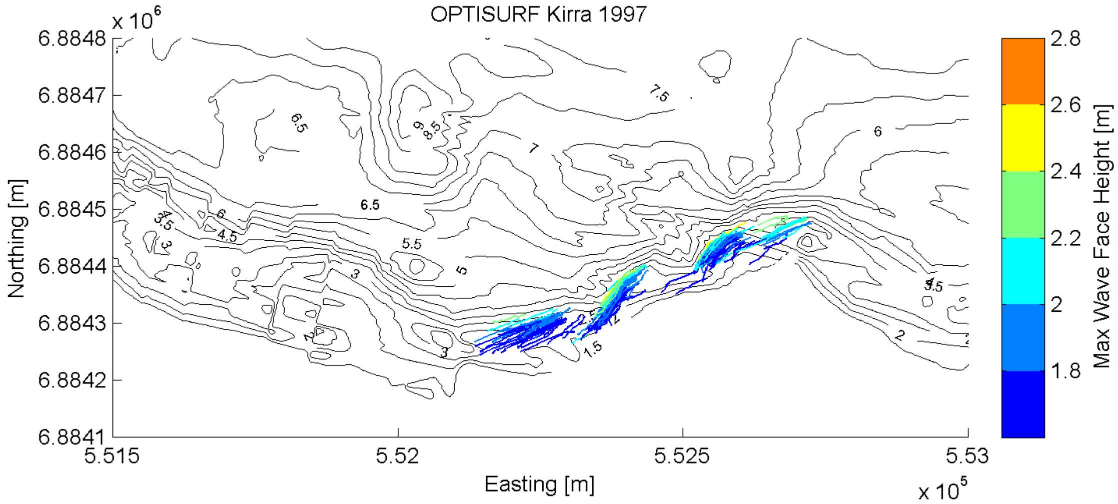

Figure 2.18 OPTISURF track results: Kirra 1997

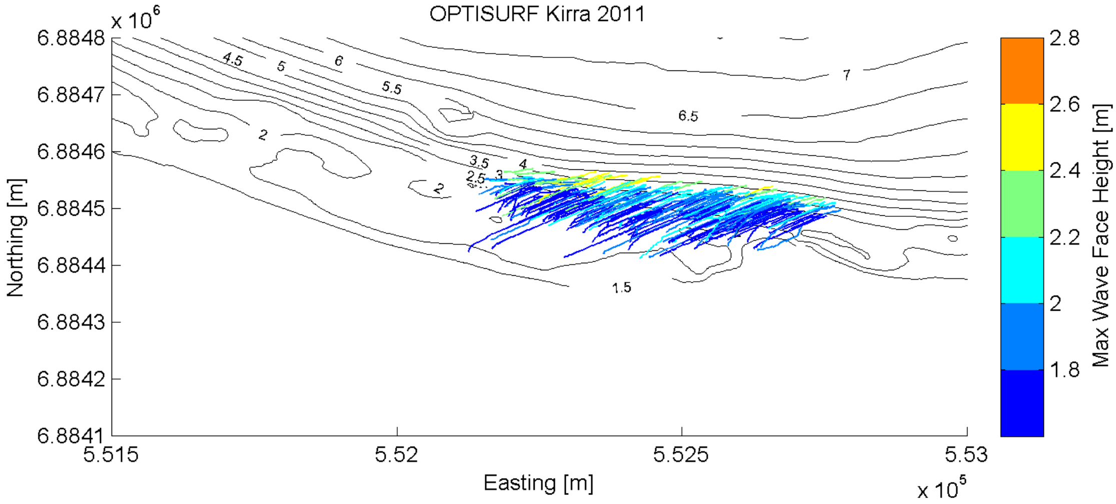

Figure 2.19 OPTISURF track results: Kirra 2011

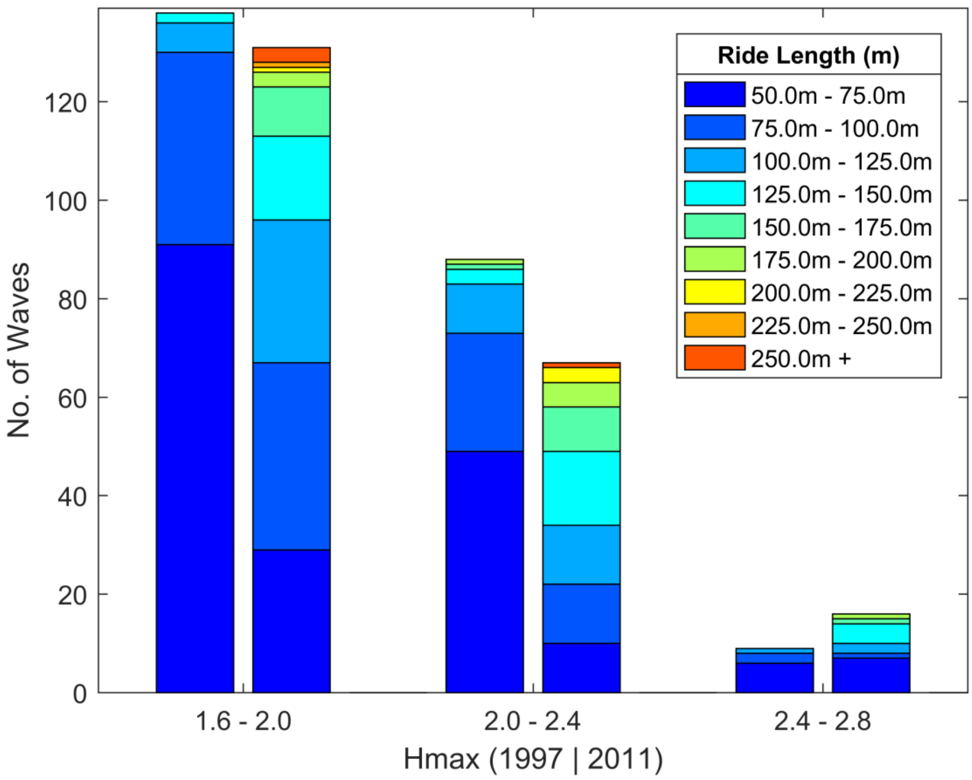

Figure 2.20 OPTISURF Kirra statistics

2.6.4 Surf Amenity Conclusions

For the analysed offshore wave condition both bathymetry configurations produce relatively good quality surf at both the Superbank and Kirra. The differences in surfing amenity can be attributed to bank orientation at Kirra and the consistency of long continuous bars at the Superbank.

The Superbank was effectively created between 2001 and 2008 due to excess supply of sand so it is logical that significantly less rides would be found for the 1997 bathymetry configuration.

Therefore, an orientation of approximately 346° is recommended for the Bank Orientation KPI (orientation of the –5 m contour) at the Superbank in order to ensure ideal surfing conditions.

Mortensen, 2010 confirmed good surfing conditions at Kirra in 1997, however the offshore wave condition used in that analysis was a strong southerly swell of 3 m, 15 s from 165°. It is possible the 1997 bathymetry configuration responds better to longer period southerly swells than easterly swells like the offshore condition analysed in this study. Yet based on model results it is still considered likely that surfing conditions at Kirra were better for the 1997 bathymetry compared to 2011, but further testing using a CFD model like used in Mortensen 2010 would be needed to confirm this.

As a compromise, the Bank Orientation KPI for Kirra should be at least aligned between the two configurations at an angle such as 352°.

As a 2D wave model the Boussinesq wave model used in this study is limited in the ability to resolve fully non-linear waves and overturning (barrels). Computational fluid dynamics (CFD) models are able to resolve such processes at the expense of very large computational requirements. If necessary CFD models could be developed to analyse a single wave for Kirra and the Superbank using a similar methodology to Mortensen, 2010.

3 Pumping discharge review

3.1 Overview of permanent and temporary pipeline outlets

Figure 3.1 shows the system of pipelines that ensures that pumped sand from the TRESBP jetty is discharged back into the active coastal zone. The pipelines run underground from the sand slurry at the TRESBP facility, under the Tweed River and from there the pipelines are split to allow for sand to be bypassed at Duranbah Beach, at Snapper Rocks (eastern side, see Figure 3.2) at Snapper Rocks (western side) and at the Kirra Groyne. The discharge points at Kirra and at Duranbah require a temporary extension to function, whereas the two discharge points at Snapper Rocks are permanent.

Since 2008 about 90% of the sand bypassed by pumping has been discharged at Snapper Rocks East and the remaining 10% is discharged at Duranbah. The sand discharge at Snapper Rocks East occurs more or less all year and the volumes vary with the sand supply to the TRESBP jetty. The discharge at Duranbah is occasionally used during campaigns with a duration of 1–2 months. When sand is no longer discharged to Duranbah Beach, the temporary pipeline is dismantled (as indicated by the blue signatures in Figure 3.1).

Figure 3.1 Map view of the bypass pipeline system.

The sand discharge points at Snapper Rocks West and at Kirra have only been used occasionally since the commissioning of TRESBP, as indicated in Figure 3.3.

The Snapper Rocks East discharge pipeline (see Figure 3.2) is a pipeline located above ground on the eastern side of Snapper Rocks, right at the interface between land and sea. Sand disposed from the pipeline is discharged in the innermost part of the coastal zone where it is transported away by action of waves and currents.

Figure 3.2 90% of the sediment bypassed through pumping is released at the coast of Snapper Rocks East. The pipeline is located above the water surface and releases the sand directly into the sea. Picture taken from the lookout point at Duranbah by DHI on 2017-11-08 shortly after high tide.

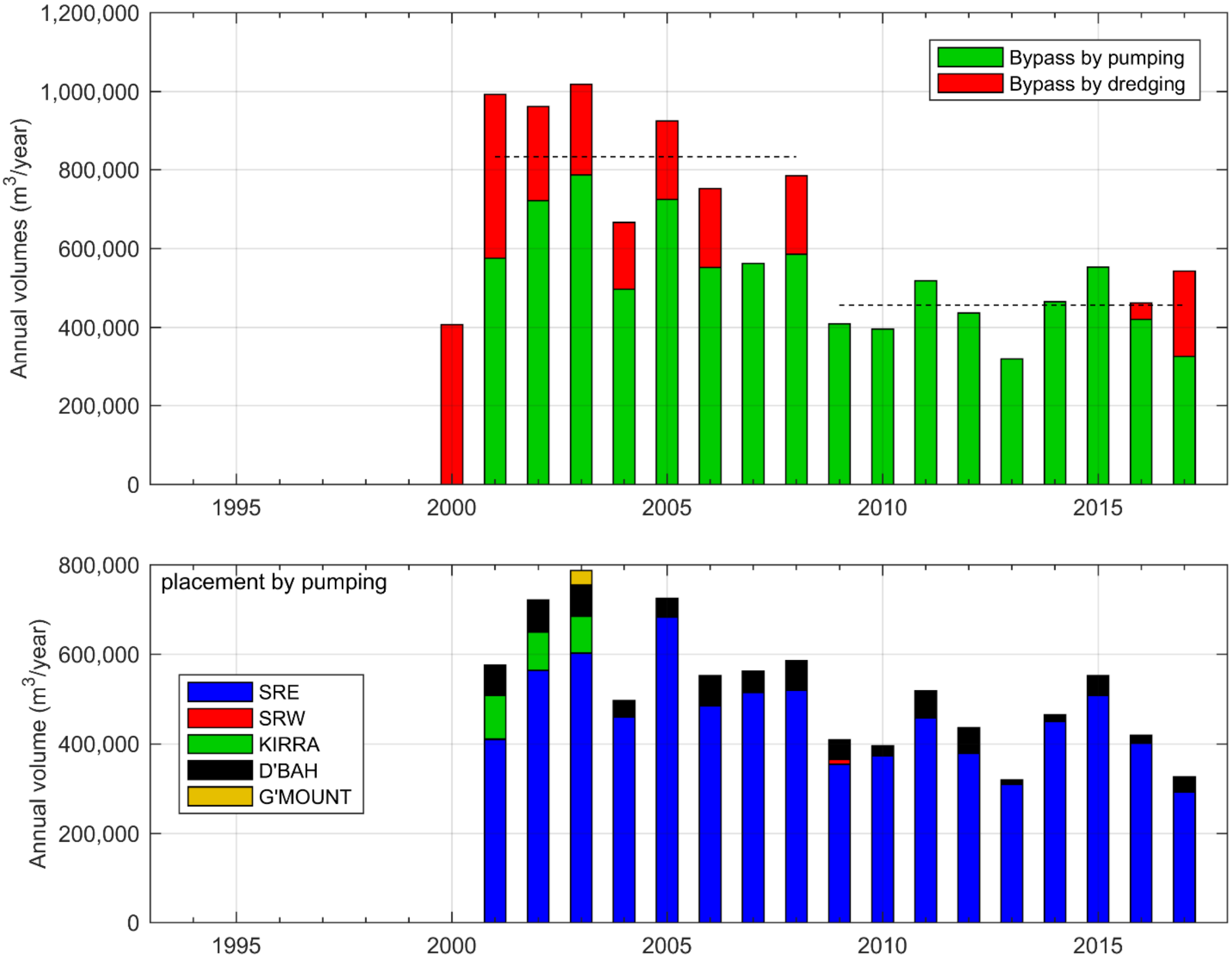

Figure 3.3 Annual discharge rates. Top: Rates distributed between dredge disposal and pumping. Bottom: Pumping rates.

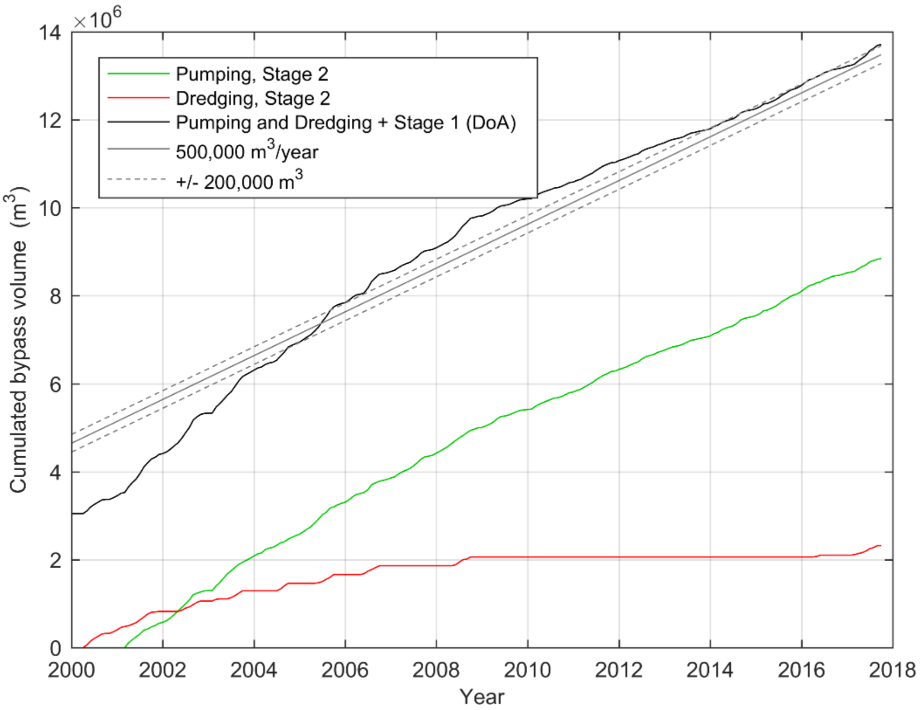

Figure 3.4 Accumulated volume by-passed to Qld by pumping and dredging

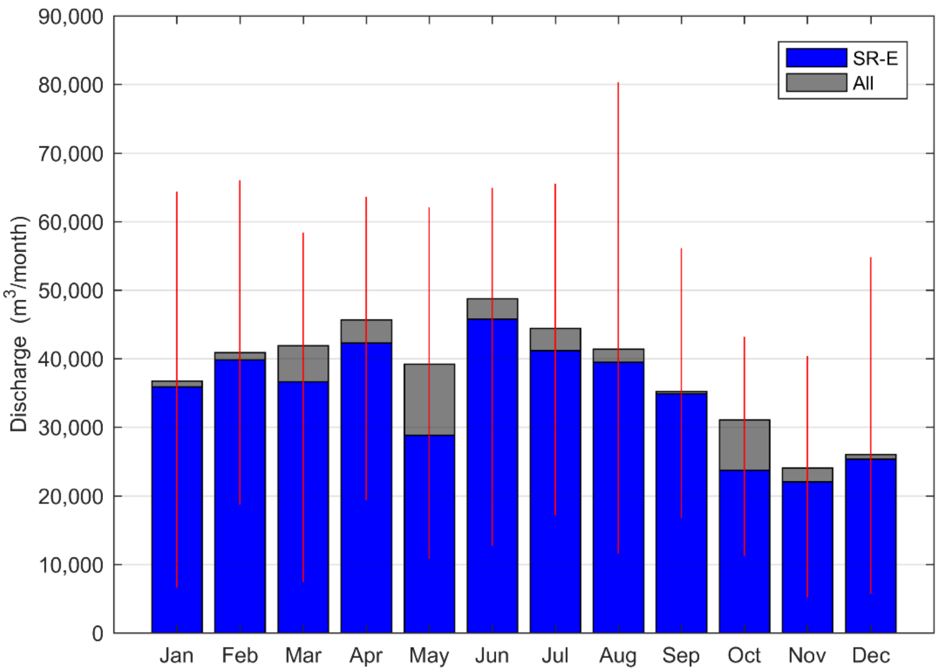

Figure 3.5 Mean monthly discharge rates. Rates are calculated for years after 2008. The vertical lines indicate extent of maximum and minimum discharge rate for each month in the ensemble.

3.2 Conceptual sediment budget

In order to understand the effect of the individual sand discharge points and their effect on the Qld and NSW beaches, a conceptual sediment budget is defined in Figure 3.6. To simplify the description the longshore transport rates are assumed constant.

The sand is continuously reworked by waves and currents, which results in the longshore drift of sand. From previous investigations (Delft, LTA2009, LTA2015) it is estimated that the longshore drift along Letitia Spit is about 500,000 m^3/year. The littoral drift along the downdrift beaches must be of the same size if the beaches are to be stable, i.e. if they do not accrete or retreat over long-term and assuming for simplicity that sand supply from offshore and from rivers is negligible. Other studies further north at e.g. Palm Beach have reported similar transport rates, e.g. DHI (2014). Thus, if all beaches are conceptually in equilibrium, the longshore distribution of the littoral drift would be as indicated by the grey curve (A) in Figure 3.6 (a straight line). The fact that the littoral drift is constant means that all shoreline changes are minimal because each beach compartment receives the same amount of sand from updrift that it lost downdrift – the beach is in equilibrium.

3.2.1 Response to reduced sand supply

With the introduction of the training walls in 1962, the littoral drift was blocked at the Tweed River entrance, which resulted in massive accumulation of sand south of the river. The lack of sand supply past the river entrance meant that Duranbah and the beaches further downdrift had to adjust to the lowered sediment supply. This was initially a strong shoreline retreat where the beach compartments released available sand to be transported further downdrift but over time the beaches will adjust to the lowered supply into a configuration where the transport naturally is lower. For partially embayed beaches or beaches supported by natural or artificial headlands/structures this adjustment will be a turning of the beach normal towards the predominant waves. For an open section such as the one at Snapper Rocks East the only option is further erosion thereby lowering the bed level at the land/water interface which results in a lower transport because waves at some point in time no longer break on a beach but directly on the cliffs/seawalls. In Figure 3.6 the spreading of erosion to beaches further and further downdrift is illustrated by the curves that represent the littoral drift at different stages:

- A: Initial condition before construction of the Tweed River training walls. The transport was about constant along the coast
- B: Supply of sand to Duranbah is reduced, the beach experiences erosion thus resulting in shoreline retreat and clockwise turning of the beach normal
- C: Duranbah has adjusted to the reduced sand supply and is now reducing sand supply to Snapper Rocks. Snapper Rocks is therefore now adjusting by general bed lowering
- D: Snapper Rocks has adjusted to the reduced supply and is now limiting sand supply to Rainbow Beach, which is then adjusting to the reduced supply by eroding the beach and turning the bed contours clockwise
- E: Rainbow Beach has adjusted to the lowered sand supply and limits now supply of sand to Coolangatta. Erosion along Coolangatta causes bed contours to retreat and the bed contours turn clockwise thus reducing the littoral drift along the beach compartment.

The response of the beaches may not in practice be as successive as indicated in the above description. The important point is that the any coastal system will respond to changes in sediment input. The response to a reduced sediment supply will be erosion that continues as long as the transport rate in that system is higher than the updrift sand supply. For smaller embayed beaches the erosion will cause the shore normal to turn thereby reducing the natural sand transport along that beach to match the sand supply from updrift. For long open coasts the erosion will occur more uniformly and result in long-term erosion of the beach, thus maintaining a transport capacity which is above the sediment supply.

Accretion will occur along a sediment cell, in the opposite event, where updrift sediment supply is increased. The bed contours will in a similar manner turn to increase the transport capacity within the cell and thereby increase sediment supply to the cells located further downdrift.

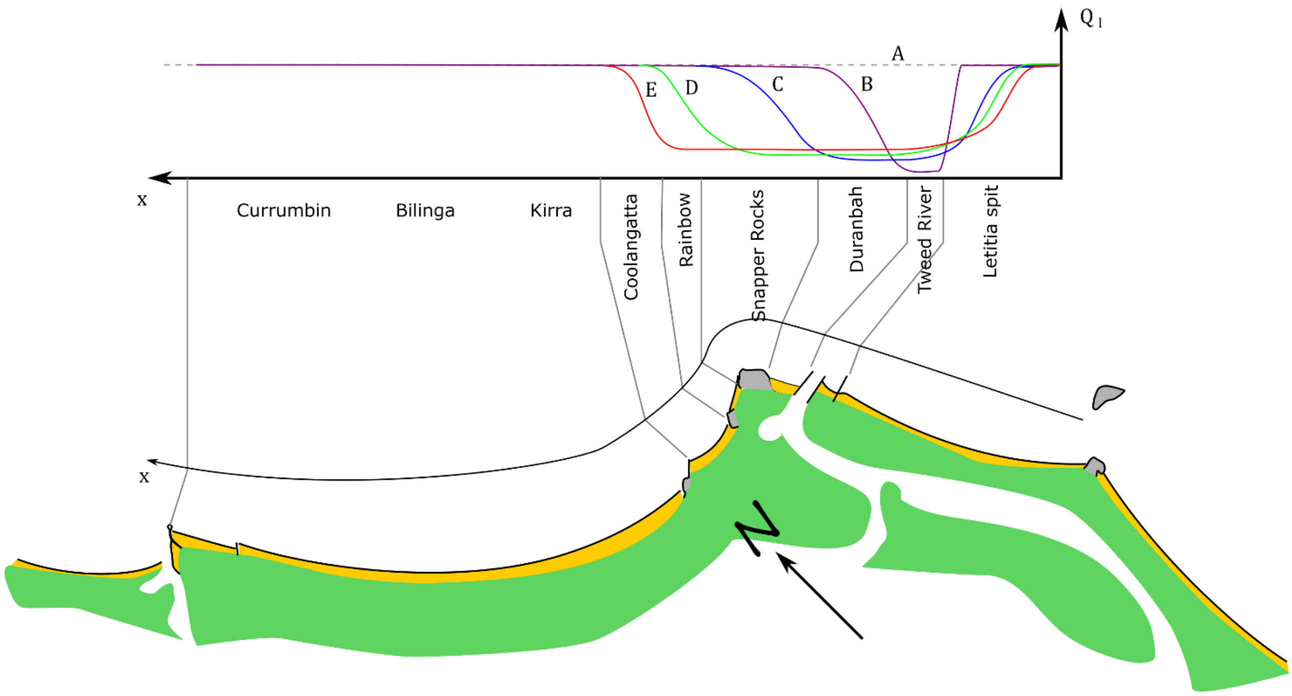

Figure 3.6 Conceptual evolution of the littoral drift in response to decrease sand supply.
A: Prior to 1962, the system is in equilibrium and the transport is constant throughout the system.
B: Construction of Tweed River entrance training walls blocks the transport and causes massive accretion along Letitia Spit. Sediment supply to Duranbah is suddenly lowered.
C: Duranbah has adjusted to the change in sand supply and now delivers a lower sand supply to Snapper Rocks. Snapper Rocks starts to respond.
D: Snapper Rocks has adjusted. Sand supply to Rainbow Beach is lowered.
E: Rainbow Beach has adjusted. Sand supply to Coolangatta is lowered.

3.2.2 Response to artificial bypass from pumping

The emphasis of the following description is put on the response to sand supply from pumping, while in reality the response is similar if the sand is supplied by disposal of dredged sand.

Any external sand supply to a point will initially result in accretion and over longer time the sub-cell will adjust such that the transport capacity in that cell is increased. An anti-clockwise turning of the bed contours will typically result in an increased transport capacity for the compartments at Qld and NSW because the predominant waves are from southeast. Thus, the expected response from these beaches to an increased sand supply will initially be accretion followed by an anti-clockwise turning of the bed contours.

Thus, the littoral drift distribution along the entire coastal system is highly affected by the choice of discharge points used for the bypass of pumped sand. The long-term distributions of the littoral drift are shown in Figure 3.7 for the configurations of the sand bypass by pumping which has been applied more or less since 2008. Note that the cases shown in the figure indicate the long-term trend and does not include the transient evolution, which was described previously.

The upper panel in Figure 3.7 illustrates the ideal long-term equilibrium littoral drift distribution for the coastal system as it has been operated recently, i.e.:

- The bypass pier intercepts most of the natural transport along Letitia Spit and bypasses it north, thus ensuring that captured sand does not interfere with Tweed River entrance while allowing for good surfing conditions on a bypass shoal.
- The sand transport along Duranbah is equal to the combined contribution of sand supply from the bypass shoal and the supply from the intermittent bypass outlet located at the southernmost end of Duranbah Beach.
- The sand transport along Snapper Rocks East (and all the following areas) is equal to the amount captured by the bypass pier and discharged at the Snapper Rocks East outlet plus the supply from Duranbah Beach.

The bypass configuration shown in Figure 3.7 is thus, intended to ensure that the littoral drift along Duranbah is relatively low compared to what it is along Letitia Spit. The low sand transport at Duranbah is motivated by the fact that experience has shown that the surf conditions are improved at Duranbah when the beach is undersupplied and thus forced to have a short beach width.

Discharging the remaining sand at Snapper Rocks East means that the beaches further downdrift are supplied by the full amount of sand. The beaches will respond by having a natural beach width, which in theory should be similar to the conditions before the training walls were constructed.

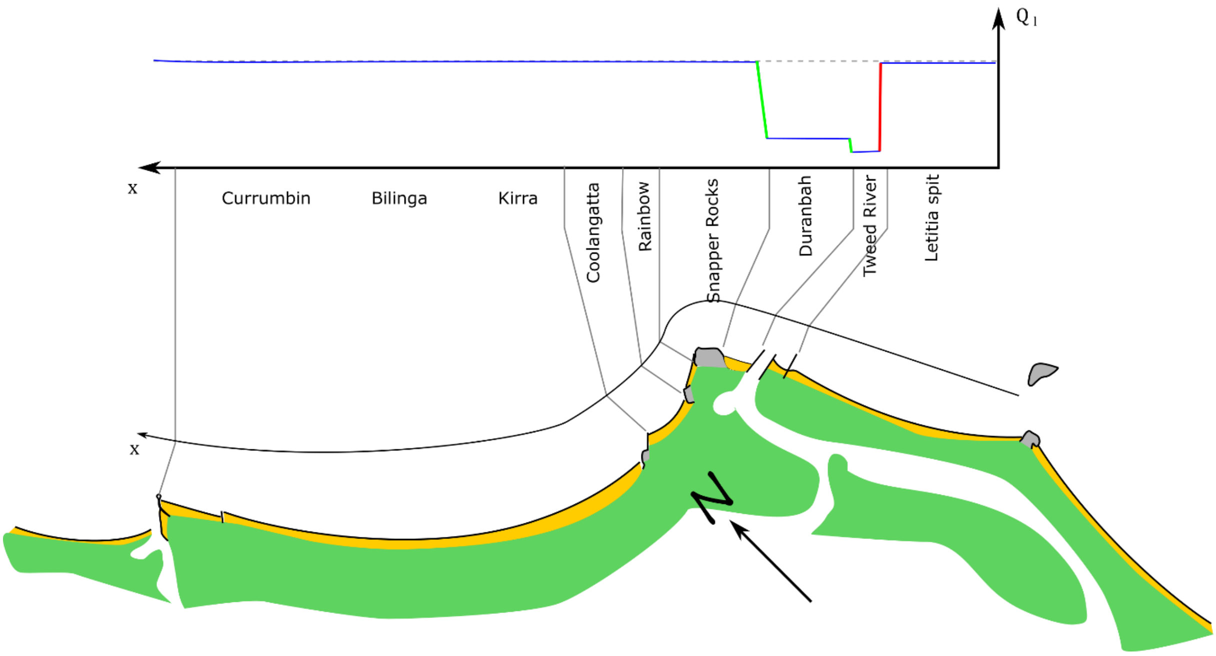

Figure 3.7 Conceptual littoral drift budget for the sand discharge scheme used since 2008 i.e., 90% of the sand removed by the jetty is discharged at Snapper Rocks East, and 10% is discharged at Duranbah. A small amount of sand is assumed to bypass the jetty and feed into Duranbah.
Red column represents the sand removed from the coastal system by the pier.
The green columns indicate sand put back into the coastal system.

Figure 3.8 shows an alternative discharge configuration where 20% of the sand removed by the bypass pier is discharged at Kirra, 70% is discharged at Snapper Rocks East and 10% is discharged at Duranbah. The point of this example is to illustrate how the choice of sand discharge configuration can be used to change the state of the downdrift beaches. The example is not a recommendation.

Discharging some amount of sand at Kirra means that the supply of sand at the updrift discharge points must be reduced; in this case, the discharge at Snapper Rocks East is reduced. The effect of this is that the littoral drift along the beach sections between Kirra and Snapper Rocks now is reduced correspondingly. The beaches will respond by eroding and turning clockwise until the transport along the two beaches corresponds to the supply from updrift. This means effectively that by moving sand discharge points further downdrift, the state of Coolangatta and Rainbow Beach is changed to a case where they are under supplied compared to the situation prior to the construction of training wall at Tweed River.

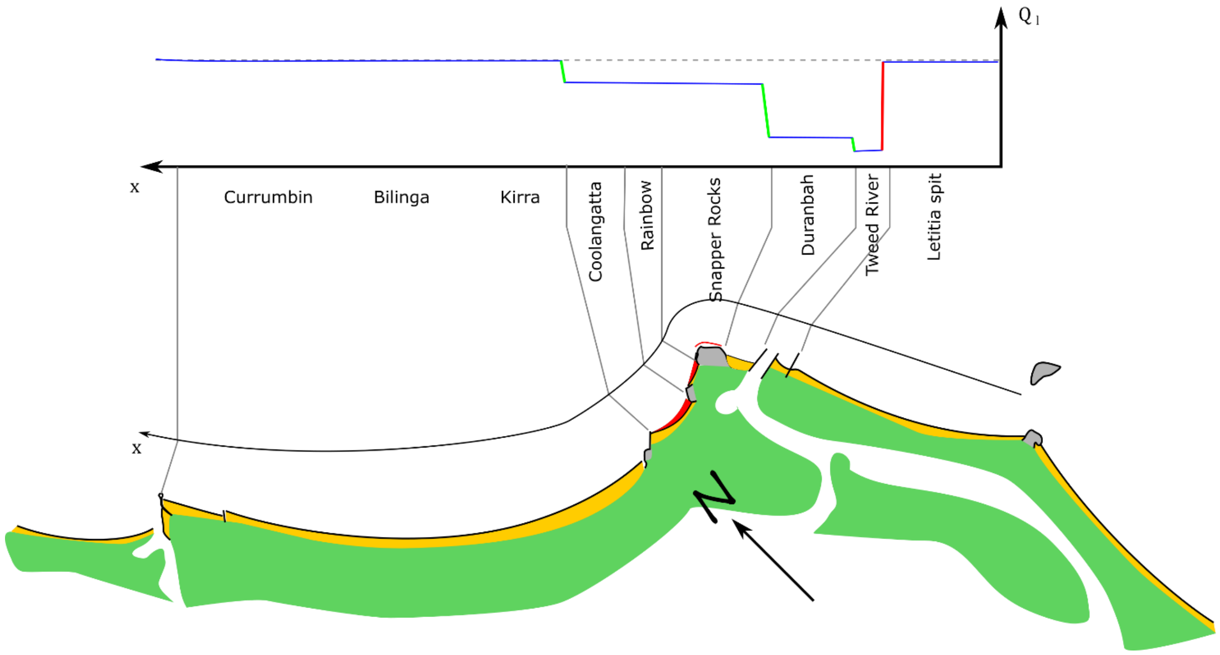

Figure 3.8 Conceptual littoral drift budget for an alternative sand discharge scheme where 20% of the sand removed by the jetty is discharged further downdrift at Kirra, and 70% is discharged at Snapper Rocks East, and 10% is discharged at Duranbah. A small amount of sand is assumed to bypass the jetty and feed into Duranbah.
Red column represents the sand removed from the coastal system by the jetty.
The green columns indicate sand put back into the coastal system.

4 Development and analysis of Key Performance Indicators (KPIs)

In this section we will demonstrate a method for deriving a full suite of Key Performance Indicators (KPIs) based on the sediment volumetric analysis of the local coastal compartments.

4.1 Definitions

For this purpose, the relevant New South Wales beaches and the Gold Coast beaches are sub-divided into compartments. The use of sub-domains follows previous studies of this coast section but with each sub-domain adjusted and further sub-divided into a nearshore and an off-shore domain. The interface between the offshore and the nearshore domains is located near the –6 m AHD depth contours. The sub-domains are illustrated in Figure 4.1 and Figure 4.2 illustrates typical positions of the –6 m AHD depth contour.

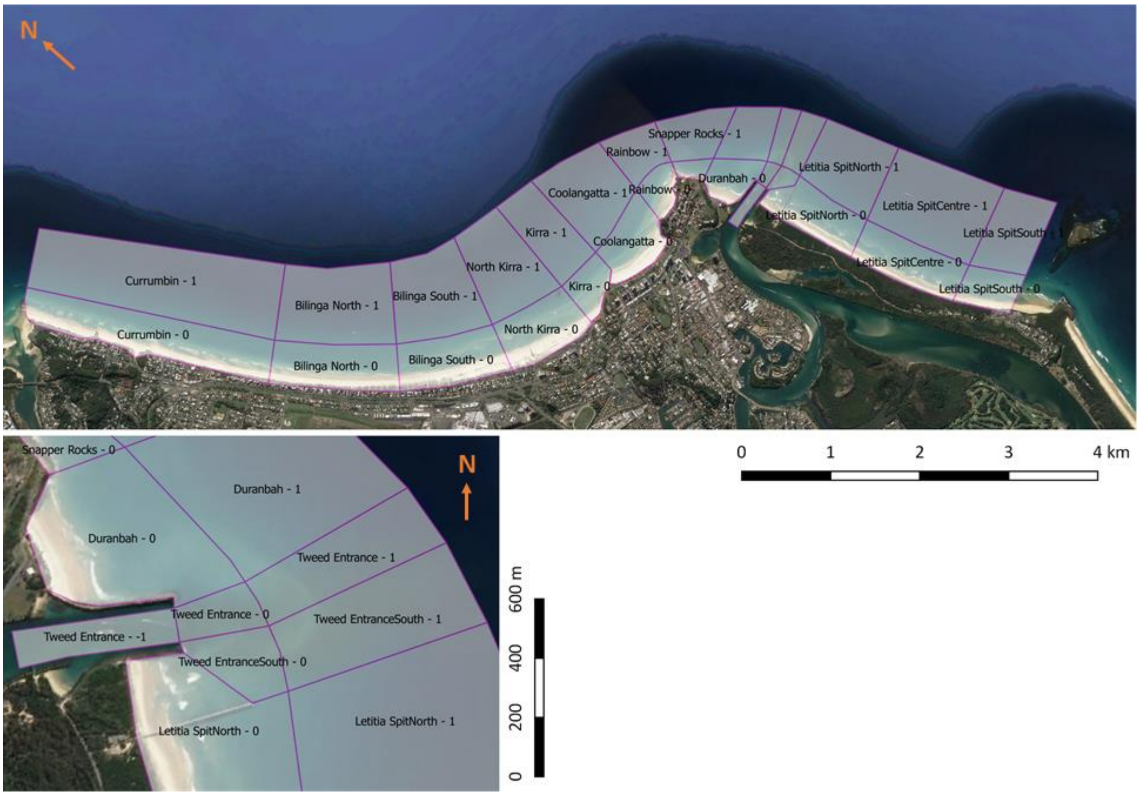

Figure 4.1 The volumetric analysis is based on sub-dividing the NSW and GCC beaches into sub-domains.

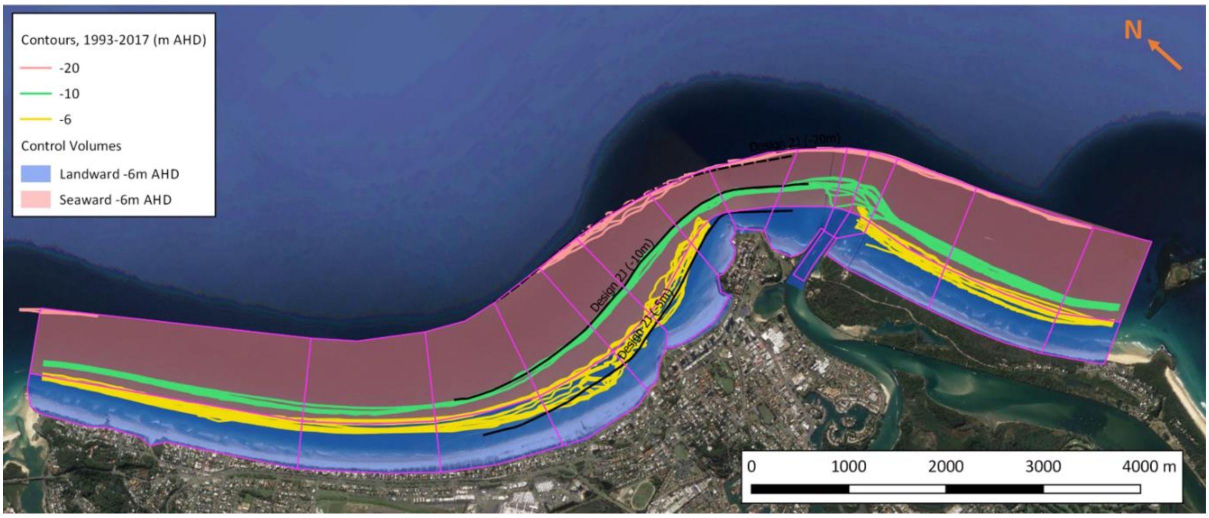

Figure 4.2 Each sub-domain is divided into a compartment seaward and landward of typical position of the -6m AHD depth contour.

For each surveyed bathymetry and for each sub-domain, the following parameters are calculated. The parameters, also referred as **Key Performance Indicators (KPI)** are presented for each sub-domain from Figure 4.3 to Figure 4.17. The KPIs are calculated for all surveys in compartments where at least 50% of the sub-domain is covered by bathymetry data.

- **Coverage** (top panel in figures): Each survey is shown in terms of the data coverage over the sub-domain. The coverage is calculated both for the nearshore and the offshore domain.
- **Sand volume deficit ΔV** (second panel): The sand volume deficit is defined as the volume deficit of a measured bed surface from a baseline surface. The baseline surface is inspired by the 2J bathymetry (see Section 5.1) where it is applicable and extrapolated to cover Letitia Spit and the beaches north of Kirra.
  The sand volume deficit is extrapolated to cover the entire sub-domain under the assumption that the deficit within the measured part is representative for the entire sub-domain. i.e. if only 75% of the sub-domain is covered, the calculated volume deficit will be 1.33 times larger than the calculated volume difference.
  Based on DHI experience, a deviation in sand volume from a fixed surface (similar to the natural bed surface) leads to the most robust definition of sand volume when analysing surveys of poor data coverage and relating sand volume changes to changes in the other key performance indicators.
  The sand volume deficit is calculated for both nearshore and offshore compartments.
  The purpose of the sand volume deficit KPI is an index of how close the compartment is overall to the predefined natural state.
- **Beach width** (third panel): The beach width measured in metres from an origin, presently at the vegetation line or foot of bedrock of the Aug. 2017 aerial mosaic, to the MHWS line (+0.61 m AHD), which is estimated by the centroid of the beach profiles containing bed levels between +2.61 m and –1.39 m AHD (+0.61 m AHD +/- 2 m) in order to take into account non monotonous variations in the profile.
  The purpose of the beach width KPI is to serve as a more direct indicator of general beach amenity and coastal resilience compared to the sand volume deficit.
- **Bank position** (fourth panel): The distance measured in metres from an origin, presently at the vegetation line or foot of bedrock of the Aug. 2017 aerial mosaic, to the –5 m bed contour, which is estimated by the centroid of the coastal profiles containing bed levels between –6 m and –4 m AHD) in order to take into account non monotonous variations in the profile.

- **Bank orientation** (fifth panel): The normal orientation of the –5 m AHD depth contour measured positive as a clockwise rotation from True North. The orientation corresponds to the direction pointing away from the coast.
  The normal orientation of the –5 m bed contour is calculated as an average orientation over the entire sub-domain. This is done in practice by splitting each sub-domain into a northern and a southern sub-domain and calculating the distance to the –5 m contour for each. The purpose of the bank orientation KPI is to serve as an indicator for wave peel angle, which is related to the surf quality along the point breaks of Snapper, Greenmount and Kirra. Unfortunately, this KPI is not very descriptive on its own with regards to surfing amenity at Duranbah and the additional beach breaks. For that reason, the Bank position KPI has been included to support of assessing how close the bathymetry in the compartment is to 2J from a surf quality perspective.

Additionally, for the Tweed River entrance areas, the following indicators are calculated:

- **Crest height**: The maximum bed level within the entrance channel (seaward of the river training walls). The bed level is extracted for different distances to the centreline of the channel. The bed level is given in metres relative to LAT.
  It was found useful to limit the search within certain bands of the centreline of the entrance channel, i.e. +/-35 m +/-50 m.

- **Sediment Volume above threshold**: The sediment volume above a threshold contained in the Tweed River Entrance area. The threshold used in the present analysis is the minimum required navigation depth of –3.5 m LAT.

It is important to note that the crest height KPI is rather sensitive to local areas of accumulation and a more robust KPI is therefore also used, where the volume of sand above a certain threshold within the Tweed River entrance channel is calculated. The sand volume dictates furthermore the minimum volume of sand to be dredged from the entrance.

4.2 Evolution of the KPIs

The Key Performance Indicators are calculated as time series for each sub-domain and discussed in the following section.

For information, the Key Performance Criteria (defined in Section 5) for beach width is indicated in the figures as a green horizontal curve. The KPC for beach width is defined as the average over the years 2008–2017 (both years included).

4.2.1 New South Wales beaches

Letitia Spit south

The total sediment volume has decreased in this compartment from 1993 to 2013 by about 700,000 m^3. Since 2013 the volume has increased by about 400,000 m^3. The decrease in volume occurs both in the outer and inner part of the sub-domain. The decrease in the outer volume appears however to have occurred since 1993, while the decrease in volume for the inner part appears to start in 2001 when the bypass by pumping was commenced.

The decreasing volumes have resulted in a minimum shoreline of about 50 m in 2013. Since 2013 the shoreline has advanced by about 20 m (2016).

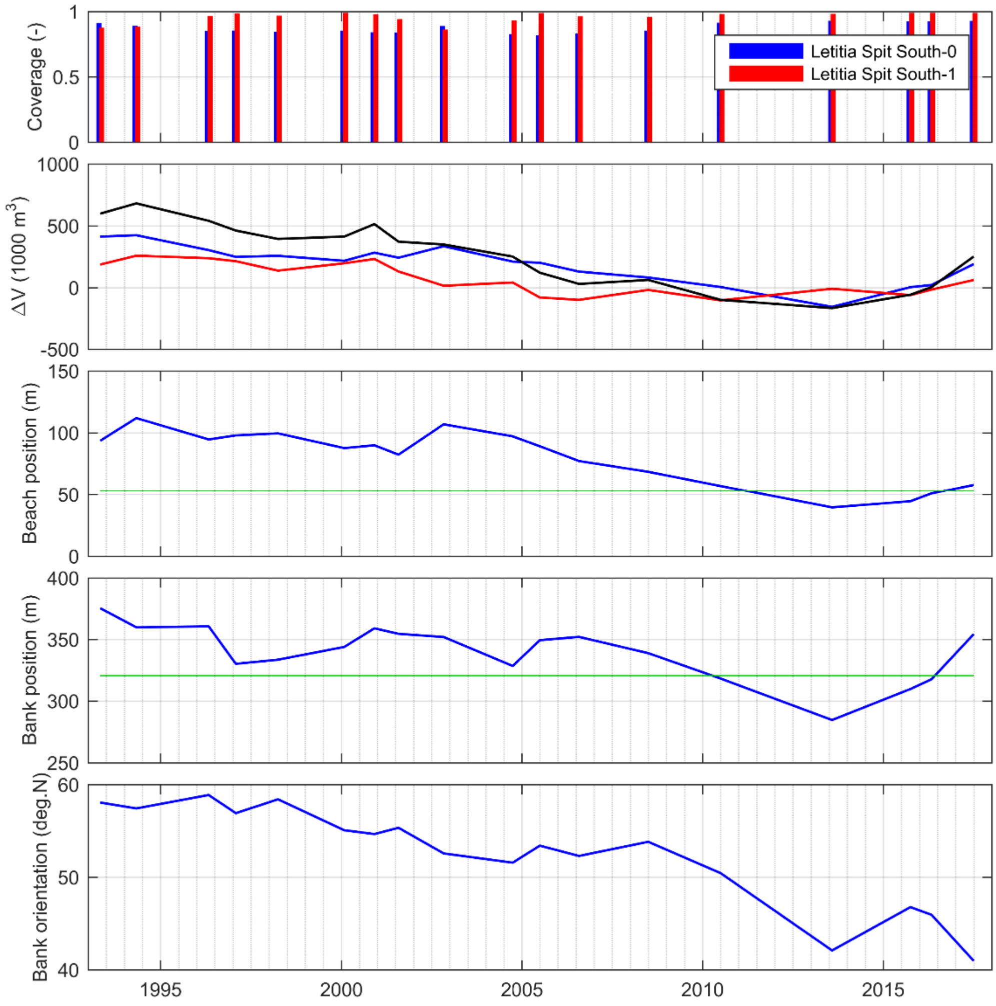

Figure 4.3 Time evolution of key performance indicators for Letitia Spit south.

Letitia Spit centre

The total sediment volume in this sub-domain has decreased by about 2,000,000 m³. The decrease of sand appears to have accelerated with the introduction of the sediment bypass programme in 2001. About 60% of the sand loss has occurred in the inner part of the sub-domain and this has resulted in a shoreline retreat of about 70 m. The shoreline appears relatively stable since 2014.

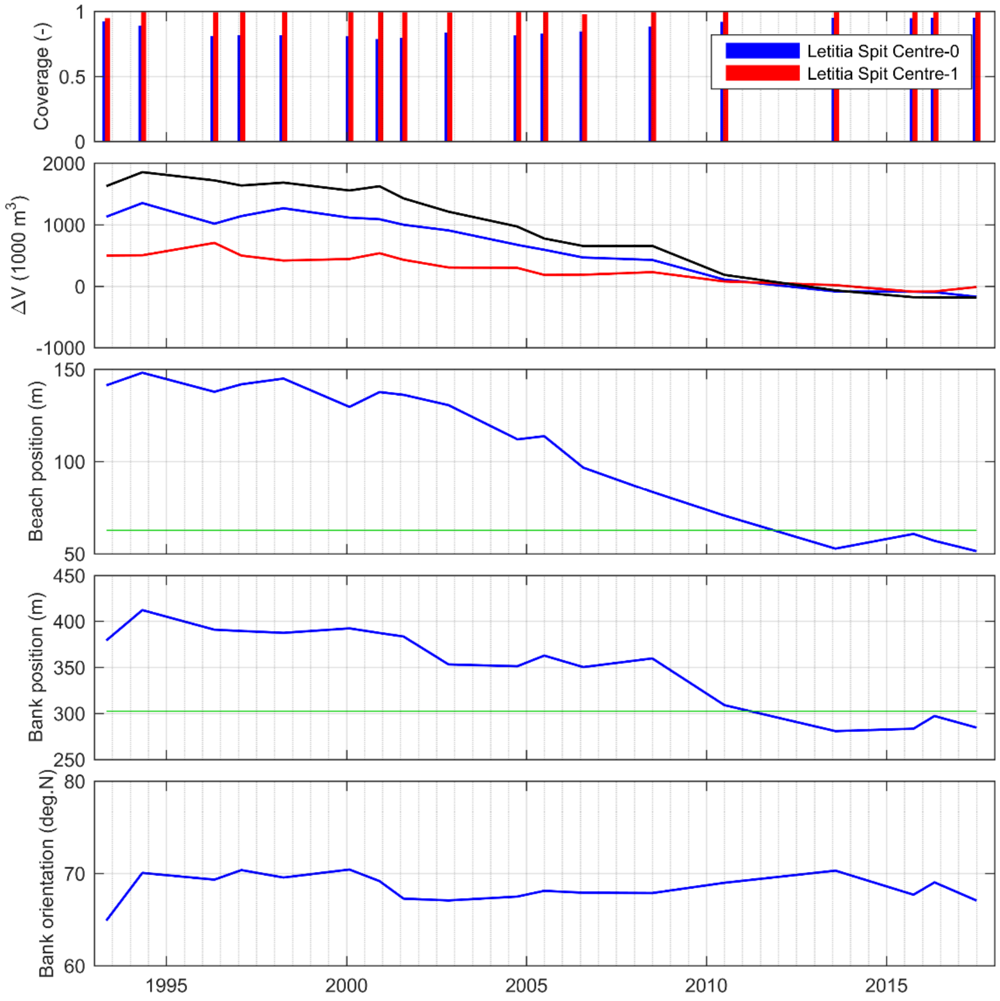

Figure 4.4 Time evolution of key performance indicators for Letitia Spit centre.

Letitia Spit north

The total sand volume has decreased by about 1,000,000 m^3. The sand loss occurs within three years after having introduced the sand bypassing system. The majority of the loss occurs in the inner part of the sub-domain while the sand deficit in the outer part of the sub-domain is relatively constant.

The sand loss has resulted in an overall shoreline retreat of 70–80 m. The shoreline position has remained relatively stable since 2005.

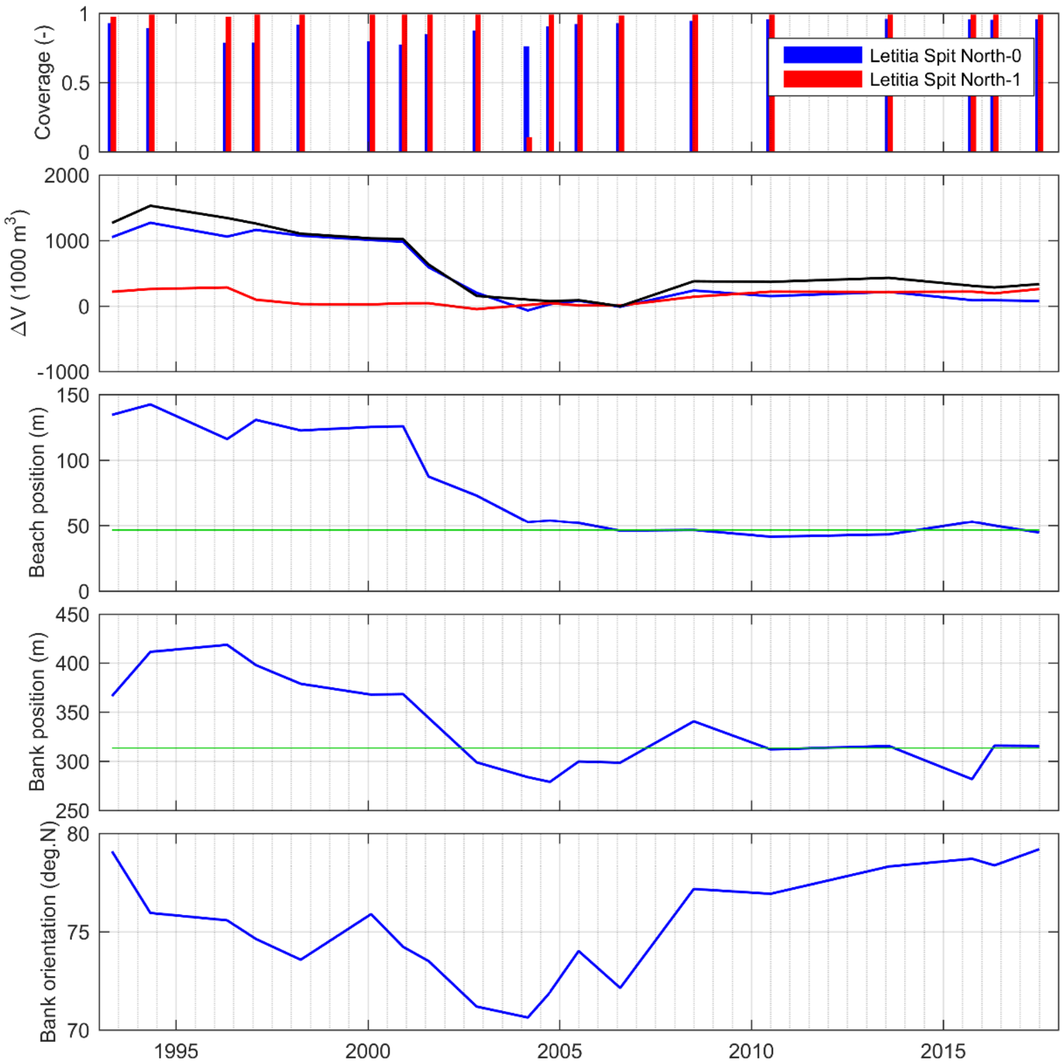

Figure 4.5 Time evolution of key performance indicators for Letitia Spit north.

Tweed River entrance

The total sand volume changes considerably in both of the Tweed River entrance sub-domains in the years prior to implementation of the sand bypassing programme – most likely due to the earlier dredging programmes.

The sand volume has however remained constant in the inner part of the sub-domain after the initiation of the sand bypassing programme while the sand volume in the offshore part has increased gradually by about 800,000 m^3 (sum of the contributions in the southern entrance and in the entrance).

The time evolution of the maximum bed level within the Tweed River entrance and the volume of sand above –3.5 m LAT in the entrance are shown in Figure 4.7. The figure shows that the maximum bed level was generally above –3.5 m LAT in the years prior to implementing the sand bypassing system. During 2000–2008 where large quantities of sand was bypassed, the maximum bed level was generally below –3.5 m LAT. After 2008 when dredging was stopped, the maximum bed level quickly returned to the –3.5 m LAT.

The evolution of the sand volume above –3.5 m LAT shows a similar trend, in the sense that the volume was above 0 m³ in the years prior to implementing the sand bypassing system. The volume was about zero during 2000–2008 when extensive sand bypassing was performed. After 2008 when dredging in the entrance was stopped, the volume started to increase.

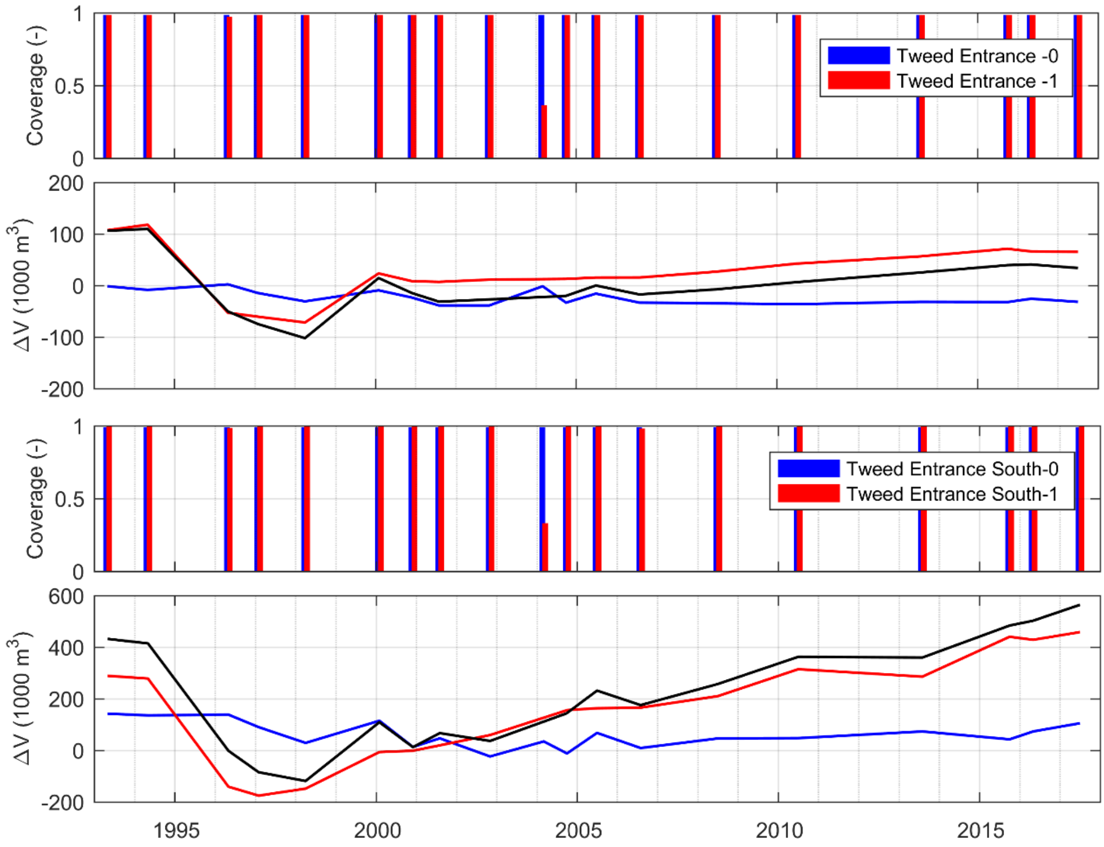

Figure 4.6 Time evolution of sand volume deficit in the Tweed River entrance compartments.

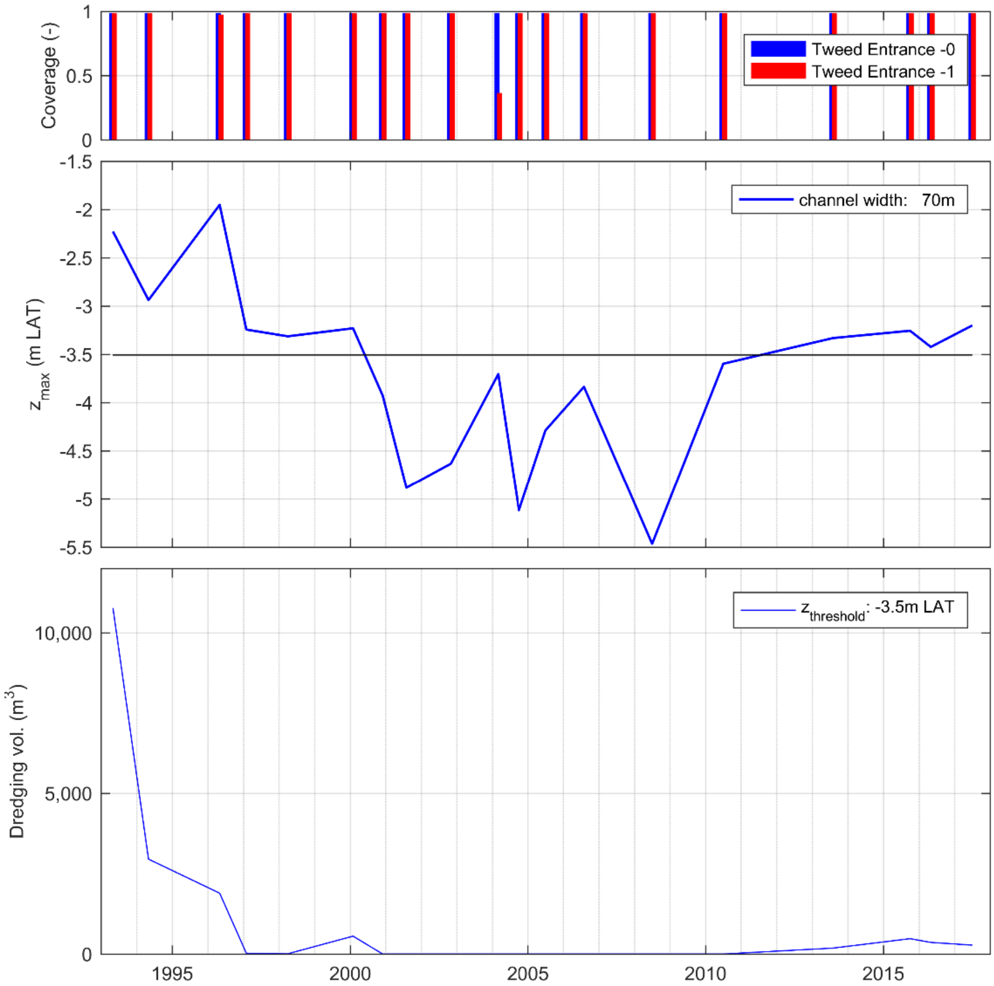

Figure 4.7 Time evolution of the maximum bed level and the volume of sand above –3.5 m LAT.

Duranbah

The total sand volume has decreased by about 500,000 m^3 during 2001 to 2011, mainly along the inner part. After 2012 however, the sand volume has recovered completely. The recovery is likely linked to the recent dredge disposals done at Duranbah in 2016 and in 2017.

The beach retreated by about 25 m between 2001 and 2012 but has since then recovered. The bank position changes in a similar manner, although at greater rates, with changes of about 200 m.

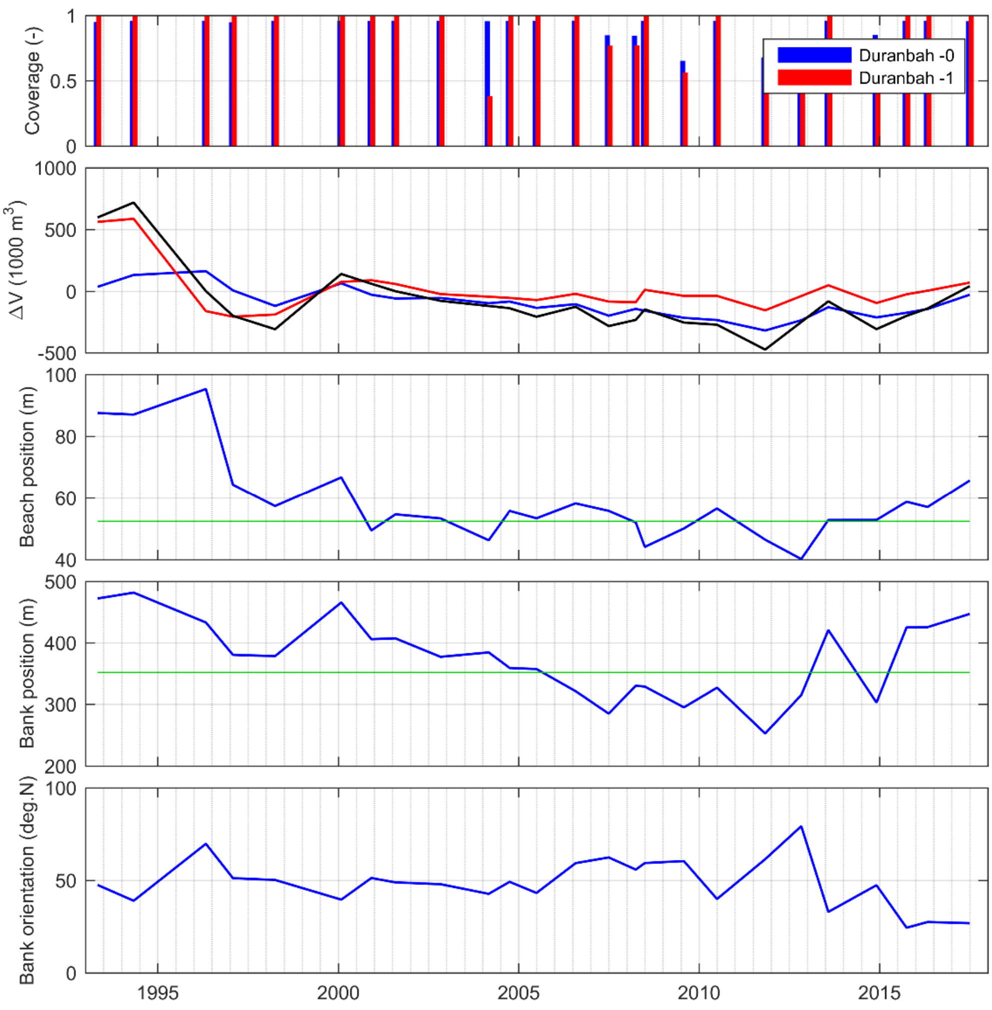

Figure 4.8 Time evolution of key performance indicators for Duranbah.

4.2.2 Gold Coast beaches

Snapper Rocks

The total sand volume has varied moderately over the period covered by the surveys. The sand volume tended to be high during 2000–2005 and has since been lower. The sand volume was also lower in the years before 2000 and as such, the total sand volume is today similar to the level in the 1990s. The increase in volume during 2001–2005 is consistent with the period where the bypass rates were high.

The beach width has followed the volume changes and is thus today similar to the level in the 1990s but about 10 m narrower compared to the years 2000–2005.

The –5 m bed contour retreated about 50 m after 2008–2009 and remained at this level until 2017, where new nourishments from dredge disposal was initiated once more.

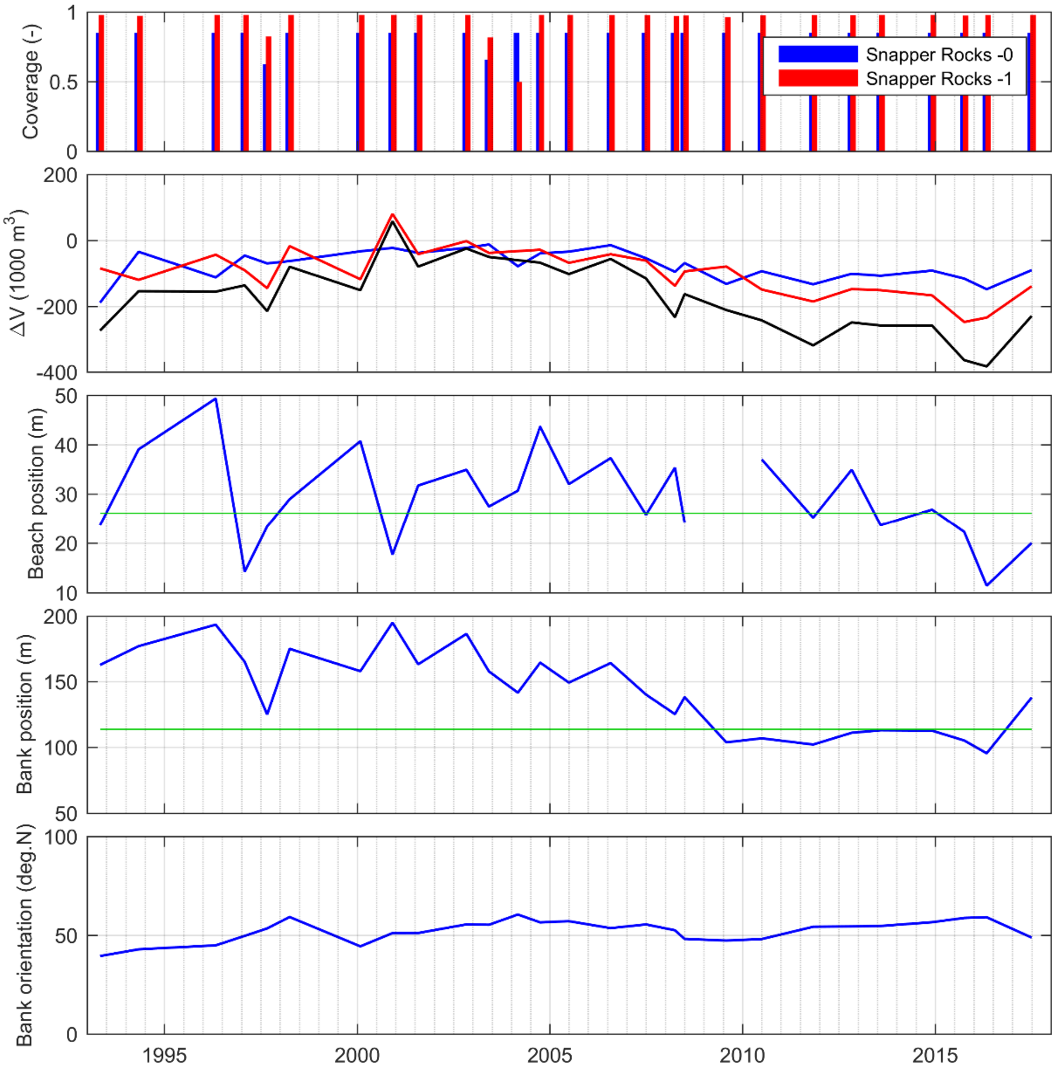

Figure 4.9 Time evolution of key performance indicators for Snapper Rocks.

Rainbow Beach

The total sand volume in front of Rainbow Beach has increased by about 500,000 m³ between the years 1993–2002 and decreased by about 300,000 m³ during the years 2002–2017. The decrease in sand volume after 2002 is limited as most of the loss occurs in the outer part of the sub-domain. This indicates that the dredge disposals carried out along SR-E ONR and SR-W (according to Figure 2.5) before 2005 have maintained the position of the –5 m contour while the lack of dredge disposals in the years after has caused the –5 m contour to retreat.

The survey from 2008 was made during/in between dredge disposal campaigns along SR-E and DBAH. From the variation in the sand volume deficit it appears that the outer part of the sub-domain is unaffected by the nourishments, while there is a clear response on the beach, with the beach width increasing about 20 m.

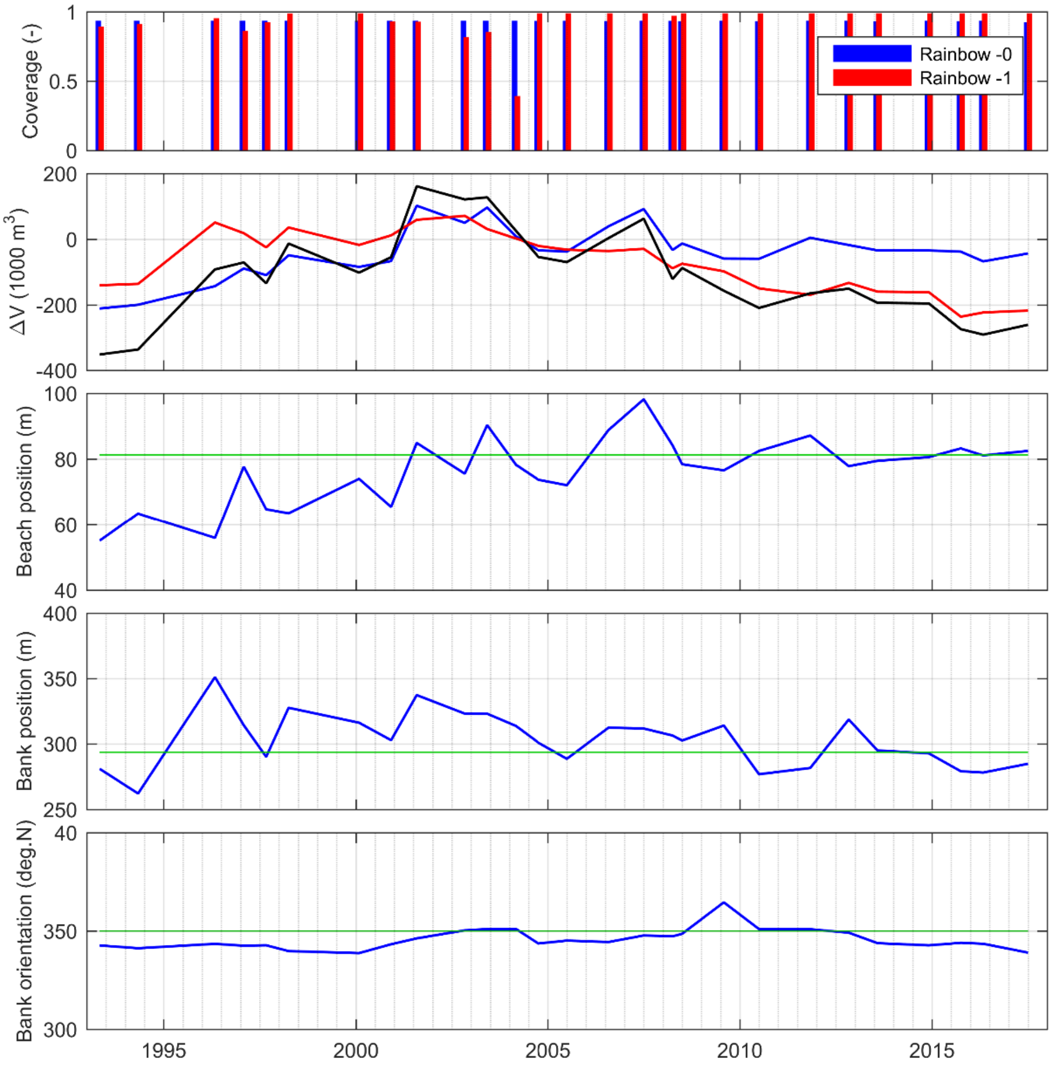

Figure 4.10 Time evolution of key performance indicators for Rainbow Beach.

Coolangatta

The total sand volume at Coolangatta increased by about 1,000,000 m³ from 2001–2003, where the nourishment campaigns along with most of the dredging disposal sites were intensified and led to disposal of about 800,000 m³. However, since 2003 the total sand volume has decreased by little more than 1,000,000 m³. More than half of the decrease has occurred in the nearshore part of the sub-domain.

The increased bypassing of sediment has led to a distinct 100 m advance of the beach in 2002 and 2003. After 2003, the beach appears to be moving back although with some variability from survey to survey. In 2017, the beach width had decreased by about 10–20 m compared to the situation in 2003.

The –5 m bed contour moved about 75 m seaward during 2002 and 2003 and has retreated since then. In 2017 the –5 m bed contour had retreated about 120–130 m compared to the position in 2003.

The campaign with disposal of dredged sediments in 2008 (along SR-E and DBAH) appears to have led to a slight response along the inner part of the sub-domain and a seaward movement of the beach. The –5 m bed contour appears to be less affected by that nourishment.

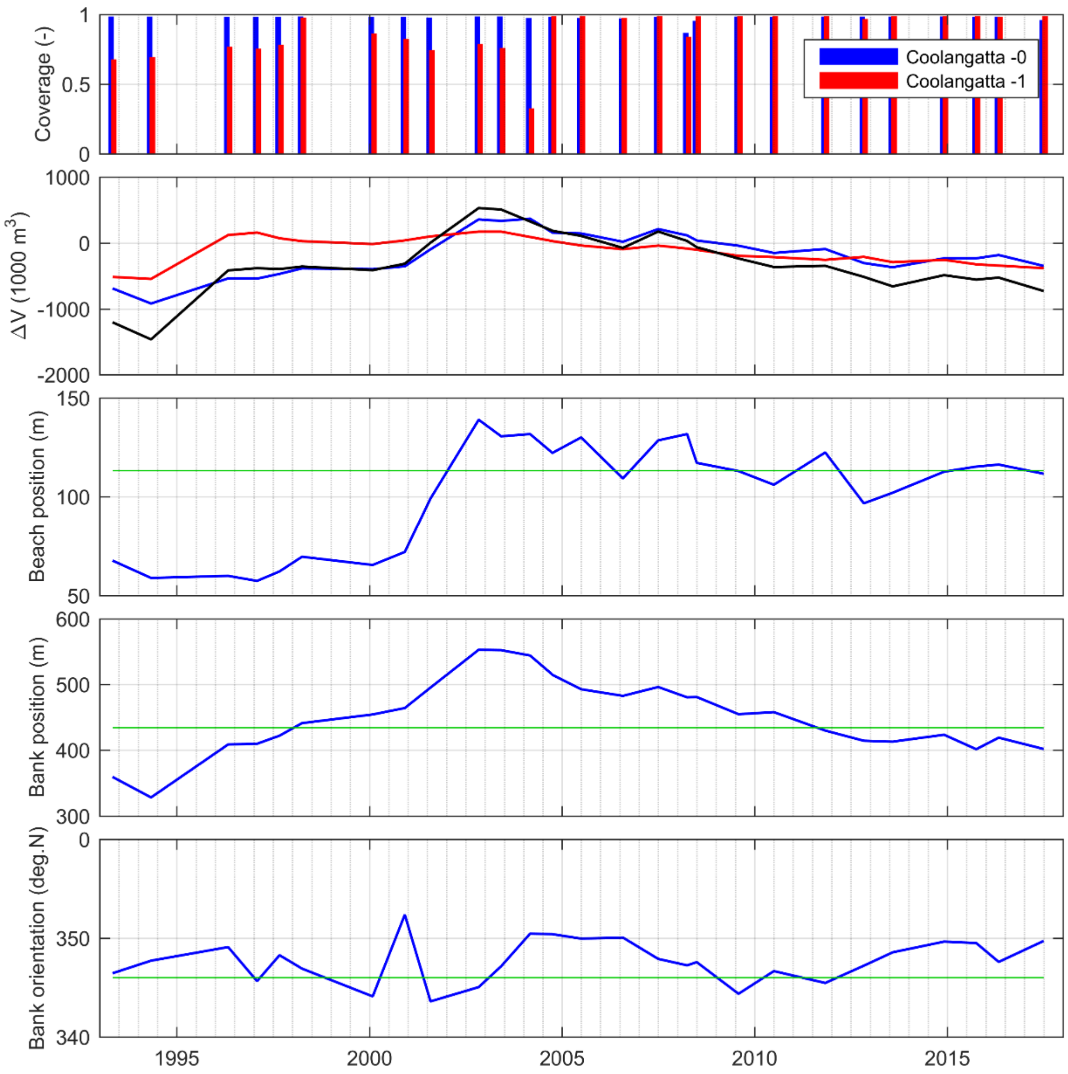

Figure 4.11 Time evolution of key performance indicators for Coolangatta.

Kirra

The sand volume along the inner part of the sub-domain increases by about 500,000 m^3 from 2002 to 2003 in response to the dredging disposal operations carried out in those years. The increased sand volume is maintained only during the years where additional sand is bypassed by dredging, i.e. the volume starts to decrease slowly in 2005 where dredge disposal rates were lowered and the volume decreases suddenly in 2009 where disposal of dredged materials was stopped. The sand volume along the inner part of the sub-domain appears to have levelled out at a constant value for the years after 2009.

The sand volume in the outer part of the sub-domain does not show any clear response to the disposal by dredging and has decreased gradually since 1996.

The variation in beach width at Kirra follows the tendencies observed for the sand volume in the inner part of the sub-domain, i.e. the beach width was increased by about 60 m during 2002 to 2003 due the increased sand bypassing. Since 2003 the beach width has gradually decreased by 20–30 m although a high amount of short term changes in beach width appears to be present.

The –5 m bed contour moved more than 100 m seaward during 2002–2003. The depth contour could not be maintained completely during the years where disposal by dredging occurred thus resulting in slight retreat of the contour. The –5 m bed contour retreats rapidly in 2009 by about 250 m, after disposal by dredging was stopped. The position of the –5 m bed contour has since then remained fairly stable.

The bank orientation at Kirra has changed considerably during this period. The bed contour normal was oriented towards NNW prior to the nourishment operations. During the period where significant amounts of sand was pumped onto the Gold Coast profiles, the normal gradually turned clockwise to face towards NNE, this was in particular due to the significant beach advanced that occurred in the downdrift sub-domain (North Kirra, as indicated in Figure 4.13). The bank orientation started to turn anti-clockwise from 2009 and appears to have levelled off at a northward facing direction since 2015. It is noticed that the effect of the 2013 Kirra Groyne extension is more difficult to see it the data.

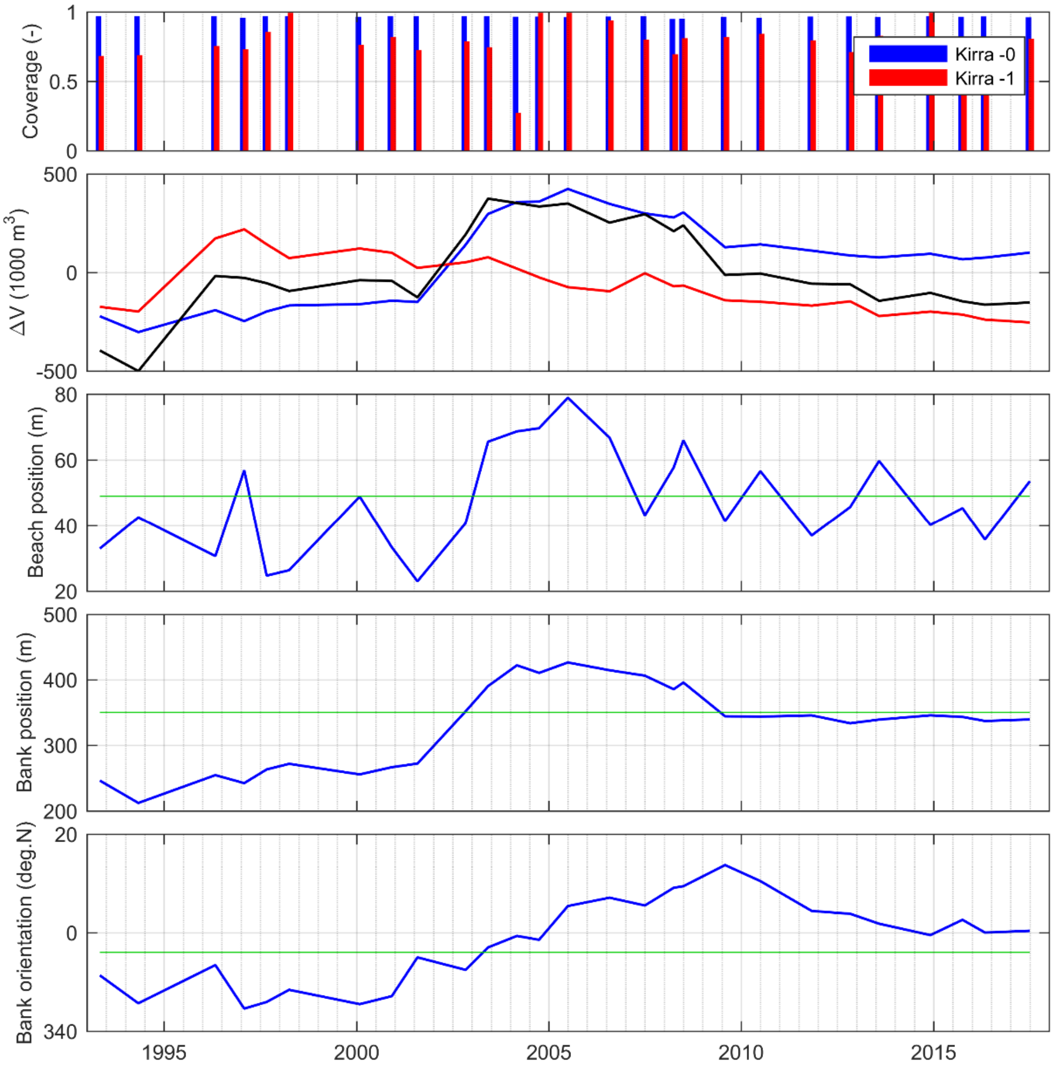

Figure 4.12 Time evolution of key performance indicators for Kirra Beach.

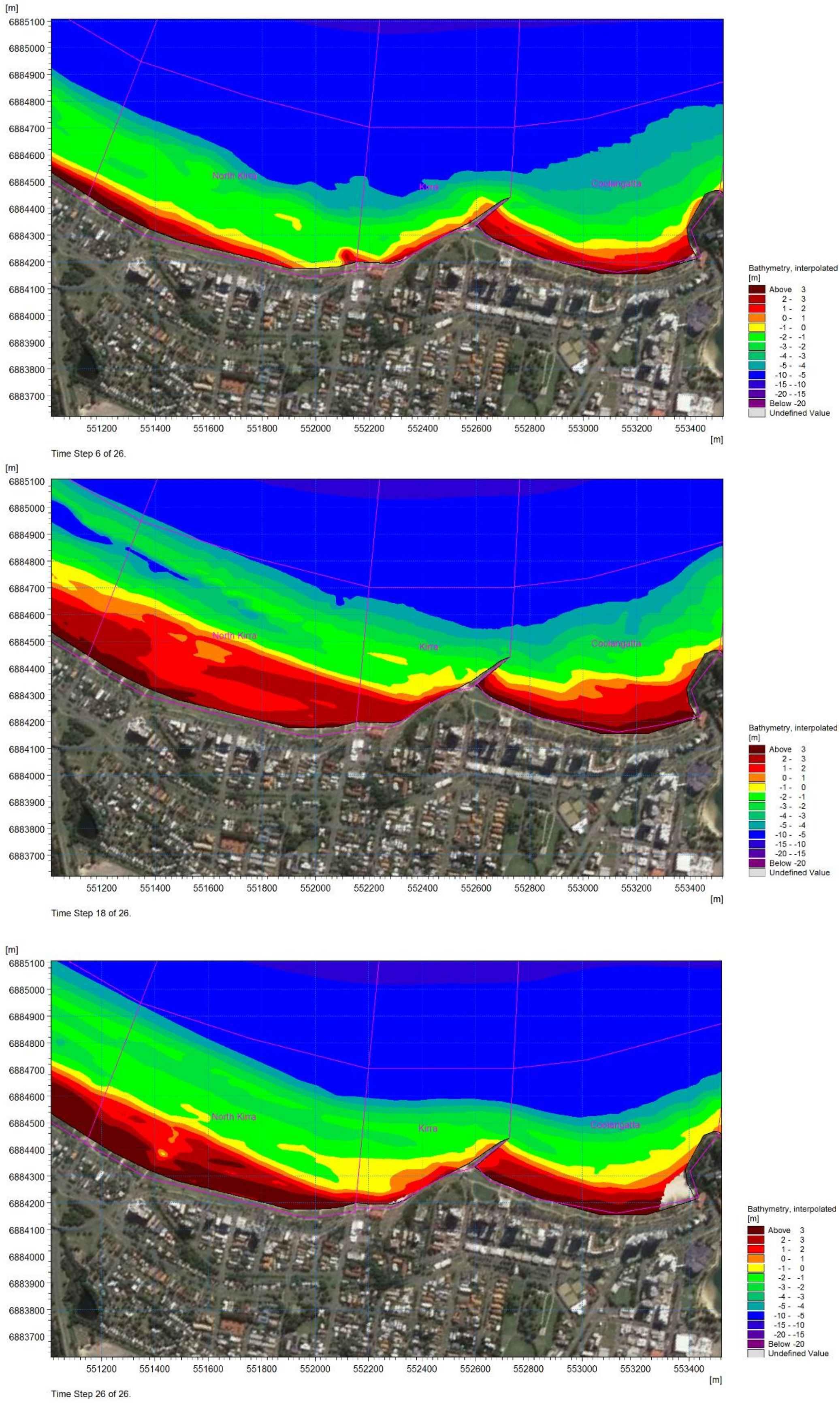

Figure 4.13 Measured bed levels at North Kirra, Kirra and Coolangatta. Top: 2000 Feb., Centre: 2009 Aug., Bottom: 2017 Sep.

North Kirra

The changes in sand volume in the North Kirra sub-domain occur nearly entirely within the nearshore part. The sand volume changes started increasing gradually from 2003/2004 and continued to increase until 2008 when the disposal of dredge material was stopped. In those years the sand volume increased by about 2,000,000 m^3. Since 2008 the sand volume in North Kirra has decreased by about 750,000 m^3.

The beach width increased by 100 m from 2003/2004 to 2010 and has remained relatively stable since then. Only a minor decrease of about 25 m appears to have occurred in 2015.

The seaward displacement of the –5 m bed level contour appears to have occurred relatively fast compared to the movement of the beach itself. The figure below shows that the bank has moved about 250 m seaward from 2003 to 2007. Since then the bank has moved onshore gradually by about 25 m.

The bank orientation has varied considerably. Prior to the years with very high bypass, the normal orientation was about 20 N. In 2004 the orientation had turned to about 5 deg. N, mainly due to the large amount of sand in the upstream compartment (Kirra). Since 2013 the normal orientation has been around 22 N. The changes in bank orientation at North Kirra are entirely caused by the very large variations in sand volume that have passed through the system during the period in question.

Comparing the temporal evolution of the key performance indicators with the evolution of the updrift compartments shows that the parameters are no longer affected as directly by the individual nourishment programmes. This is due to the increased distance between the subdomain and the disposal areas of the dredged sediment. Instead, the evolution of the parameters within the North Kirra sub-domain vary over time scales of years. This type of smoothing out of the beach response and time lag to nourishment works as the distance to the nourished area increases is perfectly normal.

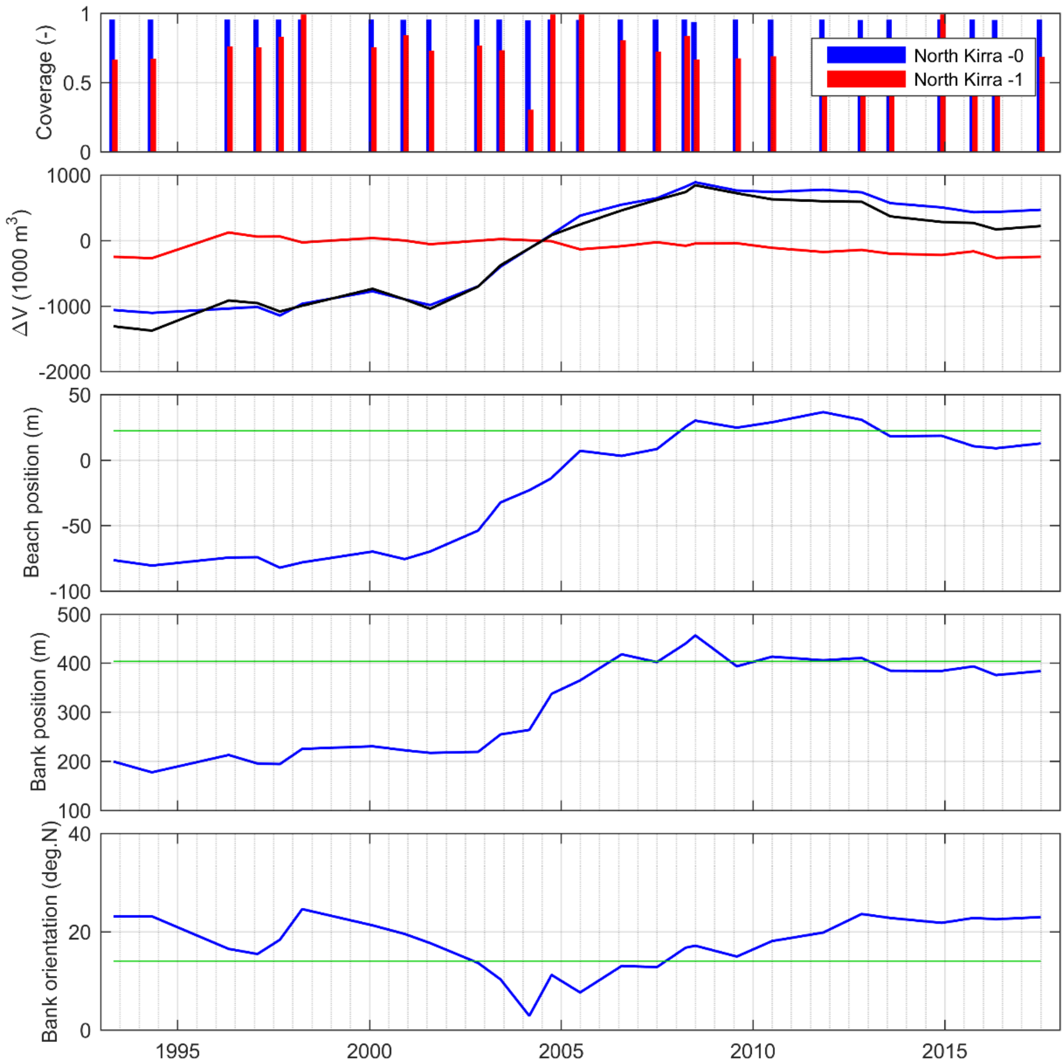

Figure 4.14 Time evolution of key performance indicators for North Kirra.

Bilinga south

The sand volume changes in Bilinga south occur predominantly in the nearshore part of the sub-domain. The increase in sand volume does not start before 2004/2005, thus increasing further to the time lag in response to the many nourishment campaigns that were carried out between 2000 and 2008. The volume change occurs furthermore over a series of years. In 2010 the rate of increase flattens out, but there is still a slight tendency for increasing volume in the sub-domain as of the 2017 survey.

Between 2004 and 2017 the total volume has increased by nearly 2,000,000 m^3. The beach width has increased by about 100 m over this period of time and the bank has moved seaward slightly more, about 150 m. The bank has turned anti-clockwise by about 2 degrees.

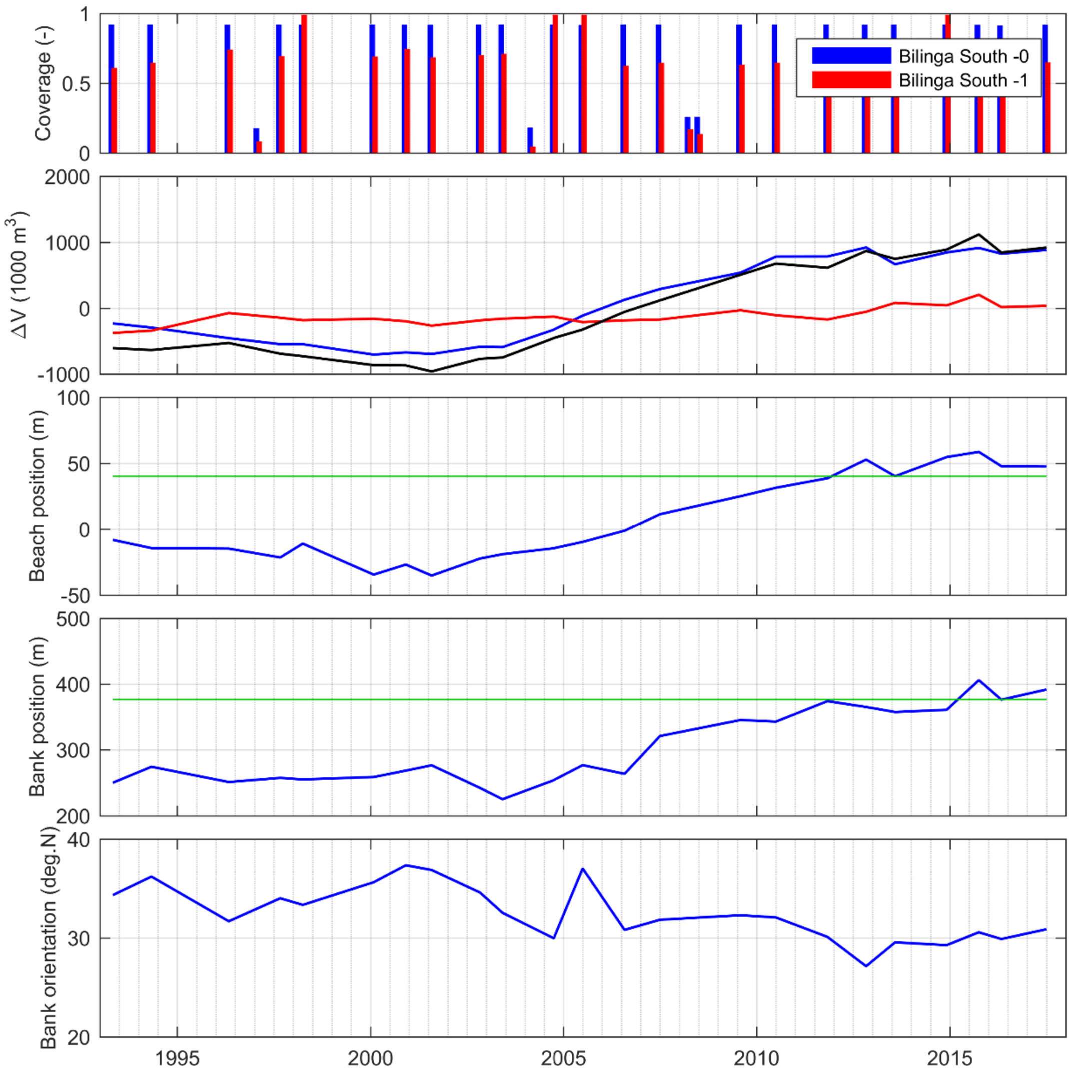

Figure 4.15 Time evolution of key performance indicators for Bilinga south.

Bilinga north

The sand volume in Bilinga north started to increase in from about 2008. The increase in sand volume occurs as such later than in the updrift sub-domains. The increase in sand volume is about the same in the nearshore and in the offshore part of the sub-domain, which is slightly surprising given the fact that the volume changes in the two updrift compartments have been entirely limited to the nearshore parts.

The changes in beach width in Bilinga north are relatively subtle and are about 20–30 m, seaward. The changes in beach width appear to be on an increasing trend still and have not yet been affected by the decreased bypass rates, which have been in effect since 2009.

The –5 m bed contour has moved about 30 m seaward.

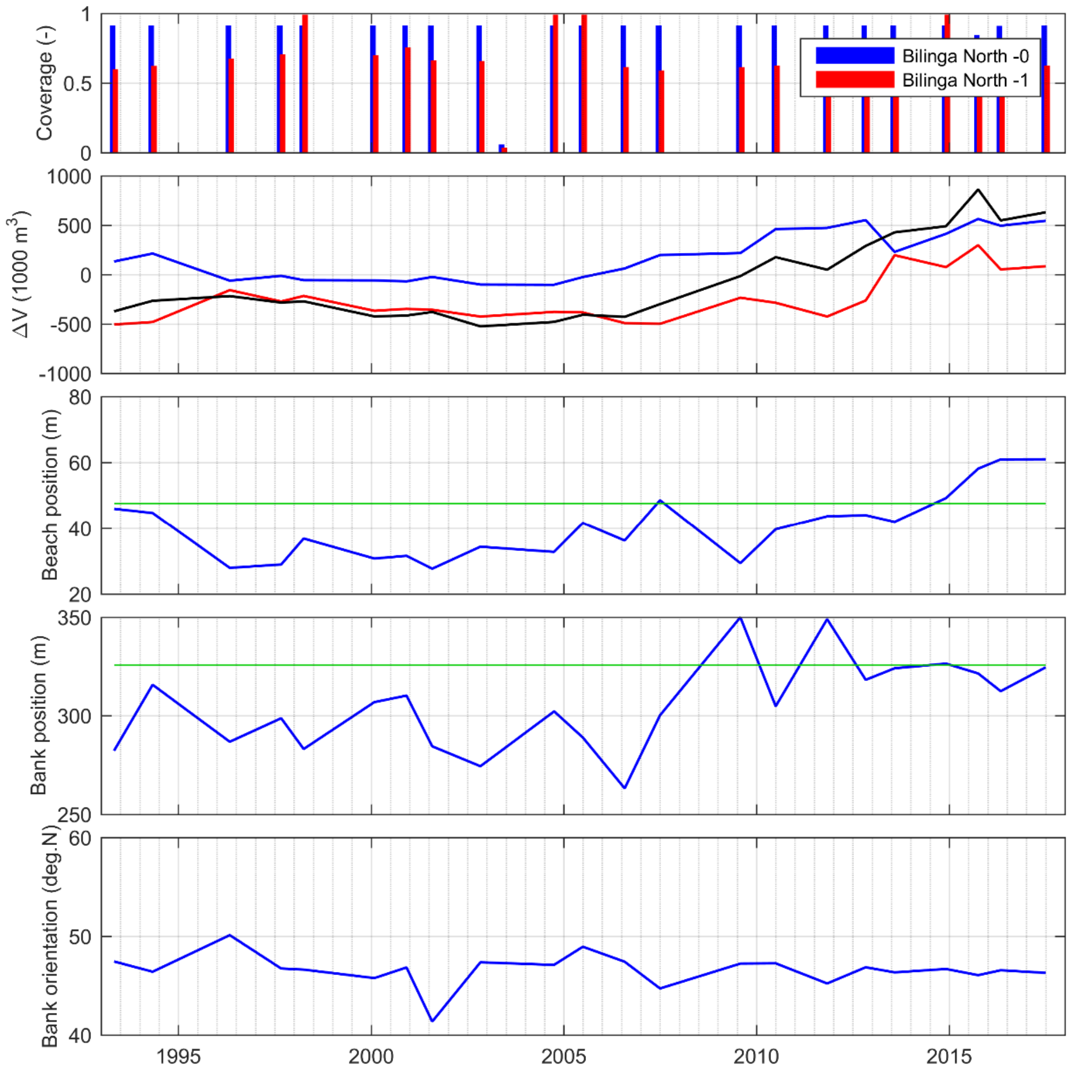

Figure 4.16 Time evolution of key performance indicators for Bilinga north.

Currumbin

The sand volume variations in Currumbin are distinctly different from that of the sub-domains further south in the sense that the total sand volume decreases during 2004–2006 after which the volume starts to increase. The decrease in sand volume in 2004–2006 is most probably the direct result of an offshore dredging campaign at Currumbin where little under 400,000 m^3 were extracted for use in sand nourishment tests along Palm Beach (DHI, 2014).

Thus, the decrease in sand volume is expected to occur as a direct result of the offshore dredging while some of the later changes are likely to be due to the increased bypass rates that were in effect from 2000–2008.

The beach width variations are relatively subtle, with the beach width varying about +/–20 m. The –5 m bed contour varies in a similar manner.

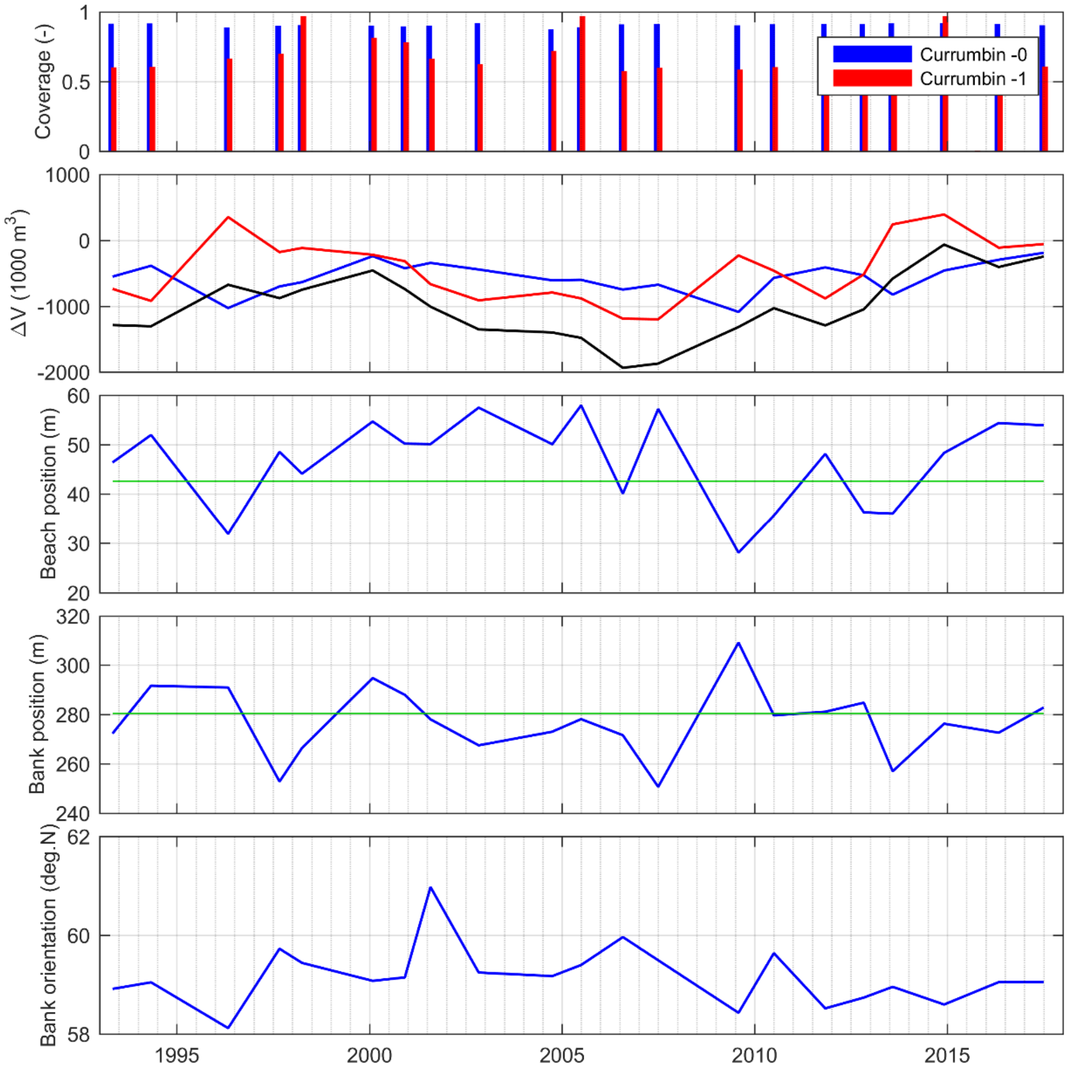

Figure 4.17 Time evolution of key performance indicators for Currumbin.

4.3 KPI evolution summary

Changes to the KPI's are summarised in Table 4.1. The summary is divided into three principal periods:

- 1993–2001: Before commissioning of TRESBP
- 2001–2008: Period with increased bypass (833,000 m^3/year)
- 2008–2017: Period with reduced bypass (440,000 m^3/year)

The table lists the total change in volume for each period and for each sub-domain as well as the change in beach width. For the sub-domains along the 2J contours the change in bank orientation is also given.

Letitia Spit

Prior to the commissioning of TRESP the area was relatively stable. During the second period (2001–2008) massive amounts of sand was removed from the area and the shoreline responded by significant retreat in particular near the Jetty. Over the recent period (2008–2017) volume changes tend to be positive although the coastline itself appears still to be under erosional pressure.

Tweed River entrance

The stage 1 dredging campaigns, which were done prior to commissioning of TRESP lead to a reduction in sand volume in the entrance. However, since commissioning of TRESP, the sand volume has gradually increased. The rate of deposition increased for the latter period (2008–2017) where bypassing was principally reliant on the pumping system, with limited dredging.

Duranbah

The state of Duranbah changed drastically during the first period (1993–2001) with a significant reduction in sand volume and a large retreat of the coastline. During the second period (2001–2008) the area lost additional sand despite the large amount of artificial bypass. The sand volume has increased during the latter period (2008–2017). This is most probably linked to the fact that the majority of the bypassed sand is disposed nearby.

Rainbow – North Kirra

A similar response in volume and beach position is found for the domains Rainbow, Coolangatta, Kirra and North Kirra. The sand volume was increasing during the stage 1 dredging in the first period (1993–2001) while the beach width remained relatively stable. During the second period with increased bypass (2001–2008), the sand volumes increased considerably and the beaches widened. For the latter period with reduced bypass volumes (2008–2017) the sand volumes and beach widths decreased.

Bilinga and Currumbin

The Bilinga and Currumbin areas are located further downdrift and as a result, the response of the sand volumes and beach widths are not as direct to the changing bypass volumes for the three periods and there is a clear time lag between bypass strategies and the morphological evolution. The tendency for increasing sand volumes in the latter period (2008–2017) is as an example the response to the increased bypassing volumes from 2001–2008.

Part of the large decrease in sand volume at Currumbin in the second period (2001–2008) is attributed to the dredging activities carried out in this period for the nourishment tests along Palm Beach.

Table 4.1 Summary of changes to KPIs (Volume change, Change in beach width, change in bank orientation). Volume changes are for the entire profile.

KPI	1993–2001	2001–2008	2008–2017
Letitia Spit South	• –90,000 m^3 • –5 m	• –480,000 m^3 • –15 m	• +220,000 m^3 • –20 m
Letitia Spit Centre	• ~0 m^3 • ~0 m	• –970,000 m^3 • –40 m	• –470,000 m^3 • –45 m
Letitia Spit North	• –250,000 m^3 • –10 m	• –1,020,000 m^3 • –80 m	• +340,000 m^3 • ~0 m
Tweed Entrance	• –540,000 m^3	• +160,000 m^3	• +410,000 m^3
Duranbah	• –540,000 m^3 • –40 m	• –340,000 m^3 • ~0 m	• +320,000 m^3 • +15 m
Snapper Rocks East	• +330,000 m^3 • ~0 m	• –170,000 m^3 • +20 m	• –110,000 m^3 • –15 m
Rainbow Beach	• +300,000 m^3 • +10 m • +1 deg.	• +120,000 m^3 • +20 m • +5 deg.	• –320,000 m^3 • ~0 m • –9 deg.
Coolangatta	• +890,000 m^3 • ~0 m • –2 deg.	• +490,000 m^3 • +60 m • +4 deg.	• –550,000 m^3 • –15 m • +2 deg.
Kirra	• +350,000 m^3 • ~0 m • –4 deg.	• +340,000 m^3 • +25 m • +22 deg.	• –450,000 m^3 • –5 m • –9 deg.
North Kirra	• +410,000 m^3 • ~0 m • –3 deg.	• +1,640,000 m^3 • +70 m • –7 deg.	• –520,000 m^3 • +5 m • +10 deg.
Bilinga South	• –260,000 m^3 • –20 m	• +990,000 m^3 • +35 m	• +800,000 m^3 • +35 m
Bilinga North	• –40,000 m^3 • –15 m	• +120,000 m^3 • +15 m	• +930,000 m^3 • +10 m
Currumbin	• +550,000 m^3 • –5 m	• –1,130,000 m^3 • +5 m	• +1,630,000 m^3 • ~0 m

5 Key Performance Criteria (KPCs)

In this section, a suite of Key Performance Criteria (KPC) is developed. KPCs are operational targets for the KPIs (defined in the previous section) aiming at guiding the ISDMP for sand supply legislative requirements, navigational safety, beach health and surfing amenity.

5.1 Target bathymetry surface review

In recent times, a target bathymetry has been used to guide in the sand placement and sand pumping from Tweed River. The target bathymetry has been named 2J and consists of four bed contours (–5 m, –10 m –15 m and –20 m AHD) mainly in the area around Snapper Rocks. The four contours are based on the 1960 bathymetry which is considered as a "Natural "configuration of the system which was unaffected by the many sand bypassing works that have since then been carried out. The 2J contours (in particular the –5 m AHD contour) are smoothed out to result in a more optimal configuration concerning surf quality. It is important to note that the 2J Bathymetry does not take into account shoreline management changes since 1960 like the construction of Kirra Groyne (1972) and Miles St. Groyne (1975).

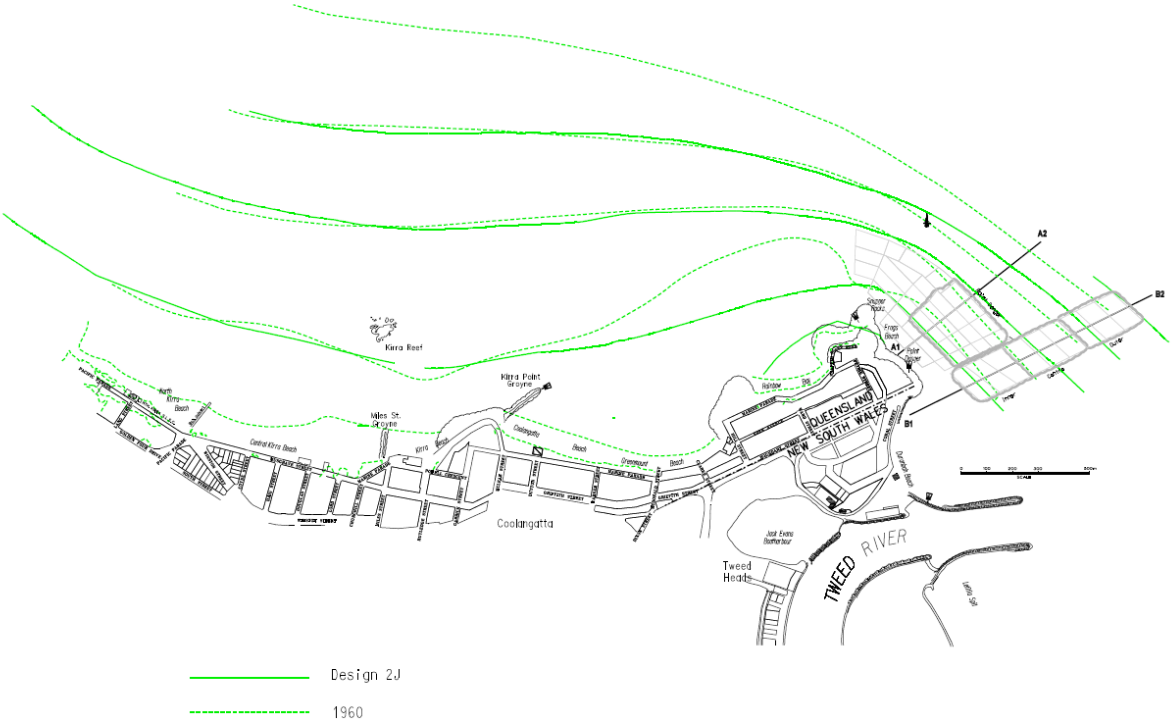

Figure 5.1 A target bathymetry (2J) has been used to guide sand placement from dredging and pumping. The bed contours for the 2J are the following: –5 m, –10 m, –15 m and –20 m AHD.

Sand placement is currently guided by comparing the deviation of a recently measured bathymetry from the 2J bathymetry. Subsequently sand placement is then being favoured in areas where the recently surveyed bathymetry inside the Snapper rocks and Duranbah disposal areas is lower than the 2J bathymetry.

The purpose of this sand placement selection method is that coastal profiles in the disposal areas are maintained at a level similar to conditions in 1960. The approach is built on the assumption that this type of placement will cause equivalent adaptation to 2J in the remainder of the domain.

The 2J contours are compared against bed contours extracted from the available surveys. The extracted bed contours are for the bed levels –6 m, –10 m and –20 m AHD. The measured bed contours at –6 m AHD should therefore be located slightly seaward of the –5 m AHD 2J contour as is in fact the case.

The figure shows that the variability of the –6 m AHD contour is relatively high compared to the variability of the bed contours on deeper water. In general, variations in the upper part of the active profile are expected to be higher, but as is shown in Section 4.2, a large amount of the variability is caused by the variations in sand placement. The –5 m contour has for example retreated about 100 m between 2006 and 2009 due to the change in sediment supply from the artificial bypassing.

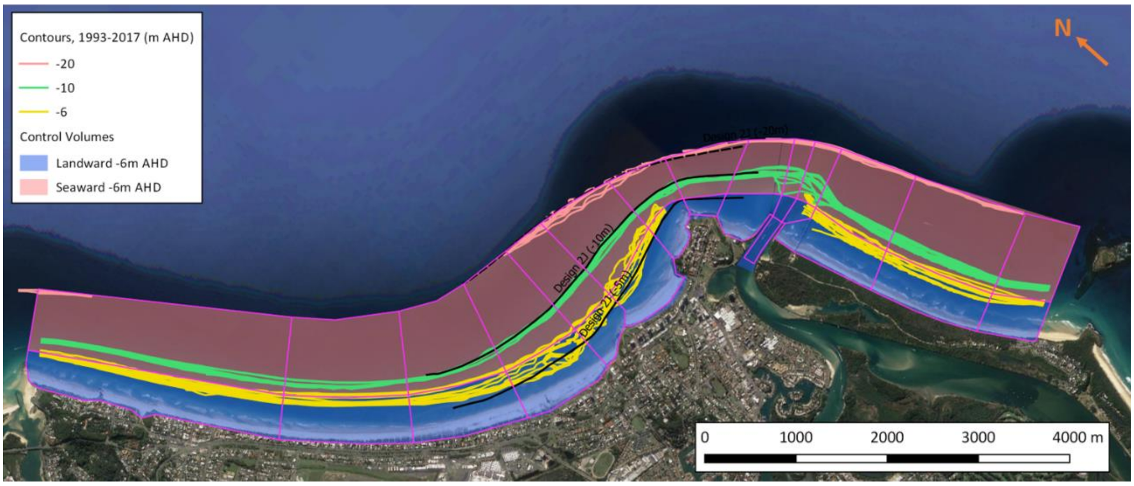

Figure 5.2 Comparison between the 2J contours and bed contours extracted from the surveys.

The use of a fixed bed surface for assessing where sand is required and where there is a surplus of sand is straightforward and useful. However, it does not provide an ideal guideline for how beach amenity and surf amenity targets are directly affected and accommodated.

Furthermore, it does not take into account how the disposed sand disperses through the system and the time scales associated to the movement of the disposed sand into adjacent beach compartments.

In the following section we will describe a proposed improvement of the sand placement strategy using 2J bathymetry to guide the definition of KPCs but adopting a more robust and agile approach for making sure that all stakeholder and legislative requirements are incorporated into one integrated framework.

5.2 Recommended values for Key Performance Criteria (KPCs)

The historic evolution of KPIs (see Section 4.2) for each compartment and their comparison to 2J values provides a robust platform for selection of associated key performance criteria (KPC) that can be used to inform the prioritizing decision logic of an Integrated Sand Delivery Management Plan (ISDMP).

In addition to values that can be determined through volume analysis, there are fixed pre-existing KPCs that are linked to the legislative requirements between Qld and NSW with regards to sand by-passing and placement volumes that are also included in this section for completeness.

The following KPCs derived from volume analysis have been selected to inform the ISDMP. Within the limits optimizing to achieve KPCs, by-passing and sediment placement volumes must comply with legislation.

1. Minimum dredge volume requirements in Tweed (both Compartments).
2. Minimum Beach Width (all Compartments).
3. Optimum Bank Orientation.

It is considered a strict requirement that navigational safety to the Tweed River is maintained. If the bed level in the channel is above minimum declared thresholds it means that an equivalent minimum volume from associated areas must be dredged and placed in another designated compartment. Any additional dredging in the Tweed compartments is tentatively considered beneficial as it would be likely to delay the need for re-dredging, but at the cost of potentially increased sedimentation rates.

It is concluded that the dry beach width provides a strong indicator for quantifying beach amenity and coastal erosion resilience. From a beach amenity point of view, the ideal beach width is considered to be a range. If too narrow, it cannot support the number of visitors that is required (sun bathers, beach walkers, etc.) and might be unsafe during high wave events. If too wide, it is considered less aesthetically appealing and might make access to the water difficult by some users. For erosion resilience, a minimum beach width is considered to be required to sustain a base level protection against erosion, with a wider beach always being considered beneficial to mitigate extreme events.

As a result, it has been chosen to select, for the beach width KPC, a minimum value that should be satisfied in all compartments, with the option to change the minimum width between compartments.

From the analysis of the Bank Orientation indicator from Rainbow to Kirra (see Section 2.6), it is concluded that it provides a fair indication of surfing quality in particularly the Kirra compartment and to lesser degree in Coolangatta and the Rainbow Bay Compartments. As previously discussed, the surfing quality in the open beach compartments are much less sensitive to overall changes in bank orientation. Surfing quality along the open beaches is more susceptible to ongoing bank undulations, which are not picked up by average values. Sand placement in most of these open beach compartments are considered to potentially temporarily beneficial if using a rainbow discharge in concentrated areas in the surf zone. Surf quality at Duranbah is considered closely linked to the local beach volume not exceeding specific thresholds and is considered an exception to this rule.

In addition to the above KPCs it is a requirement through NSW/Qld legislation that.

- The combined dredged and pipeline pumped volume of sediment to Qld must be within the target volume 500,000 m^3/year +/–200,000 m^3 (Figure 3.4).
- Maximum combined sand placement volume of 50,000 m^3/year in Duranbah placement boxes through dredge placement or pipeline pumping.
- Maximum combined sand placement volume of 75,000 m^3/year in Kirra placement boxes through dredge placement or pipeline pumping.

summarizes the implemented KPCs used for the ISDMP. These values are implemented in the Decision Aid Tool. The beach width criteria is defined as the average value over the years 2008–2017. The bank orientation criteria is extracted from the 2D contours. As the surf conditions at Snapper Rocks have not been assessed in this project, no orientation is indicated in the table below for this compartment.

Table 5.1 Key performance criteria.

Coastal Compartment	Minimum Beach Width [m]	Bank Orientation [ºN]
Letitia Spit South	Not implemented	-
Letitia Spit Centre	Not implemented	-
Letitia Spit North	Not implemented	-
Tweed River entrance South	-	-
Tweed River entrance	-	-
Duranbah	52	-
Snapper Rocks	26	-
Rainbow	81	350
Coolangatta	113	346
Kirra	49	356
North Kirra	22	14
Bilinga south	40	-
Bilinga north	48	-
Currumbin	43	-

6 Integrated Sand Delivery Management Plan

The aim of the Integrated Sand Delivery Management Plan (ISDMP) is to deliver a robust and achievable plan for the future management of the TSB system and associated supplementary dredging and sand placement.

The objective for the ISDMP is to:

1. Comply with Qld/NSW legislation for sand bypassing from NSW to Qld
2. Maintain safe navigational access to the Tweed River
3. Optimize sand placement to maintain adequate beach amenity
4. Optimize sand placement to maintain and potentially improve surfing amenity

It is proposed that the ISDMP uses the framework of KPIs listed in Section 4 to monitor current system status. As previously demonstrated the KPIs only relies on regular bathymetry surveys.

The proposed ISDMP uses advanced 2D MIKE21 ST SM numerical modelling simulations to calculate the time dependent sand volume transfer through the domain based on an extensive matrix of sand placement scenarios. Subsequently the volume change in each beach compartment can be evaluated. Using this method each potential sand placement option can be directly converted to changes in the suite of KPIs for each compartment.

In order to vastly reduce computational time, the detailed morphological simulations will be batched into of an extensive matrix of pre-defined sand disposal operations (combination of volume and location) where the associated response in each beach compartment is tracked.

These results are subsequently normalised into so-called transfer functions, which can be used to predict the time varying volumetric impact in any beach compartments.

The analysis is independent of the disposed sand volume and can therefore be used to describe the impact of any disposal placement volume. Furthermore, the effect of disposal placement within a single area is expanded to cover also the effect of disposing in several areas by the principle of super-position. This is reasonable under the assumption, that the disposed sand volumes are relatively small compared to the natural transport. The analysis is independent on the volume of the disposed sand volume and can therefore be used to describe the impact of any placement volume. Simple examples on how the transfer functions are formulated and how they are combined are given in section 6.2.2, and the actual transfer functions are shown in Section A.5.

Subsequently the effect on beach width and bank orientation can be assessed for all potential placement options.

A significant advantage for using transfer functions, as opposed to direct ad-hoc numerical simulations, is that a very large matrix of sand placement combinations and their impact on KPIs can be evaluated at virtually no computational overhead.

The scenario matrix is then subjected to logical flowchart where KPIs will be benchmarked against target KPCs resulting in a ranked prioritization of sand placement options.

Please note that current framework has only considered optimization of 5 placement boxes and only includes detailed morphological response to beaches north of the Tweed River training walls. In the future, the following improvement could be considered within an extended framework:

- Additional placement boxes could be included by running additional simulations of placement scenarios (see Section 6.1).
- Simulation of the active morphology around the river and south of the training walls could be considered. However, the model developed within the current framework is not suitable for this task and would require the calibration of an extended model in order to describe the seabed evolution around the piers and south of the Tweed River entrance.

6.1 Sand placement optimization decision aid logic

This section presents the proposed logical flowchart used to assess the dredging requirements from the Tweed River entrance and identify the most optimal sand placement options based on the status of current KPIs.

The decision aid logic based on the following core principals.

1. A recent bathymetric survey of the entire domain is required to provide up to date status of KPIs.
2. It is assumed that any excess sand volume in the Tweed River compartments must be dredged to secure navigational safety. The volume is added to the total sand placement volume.
3. Combined pumping and sand placement in Qld compartments placement boxes must not exceed the Deed of Agreement (accumulated budget requirements must be maximum +200,000 m^3 from target). Additional sand will have to be back-passed to Letitia Spit.
4. If the accumulated budget combined with dredge volume requirement from Tweed River compartments is less than –200,000 m^3 from target, then additional volume must be dredged from the Tweed compartments to meet minimum threshold (see Deed of Agreement, clause 13.7).
5. Combined placement in Duranbah boxes and pumping at Duranbah beach must not exceed 50,000 m^3 in a single year (see Deed of Agreement, clause 12.2.7).
6. Sand placement in Kirra placement boxes must not exceed 75,000 m^3 in a single year
7. KPI response to placement scenarios are based on a yearly average from the time of placement commences (see Deed of Agreement, clause 12.2.7).
8. For scenarios fulfilling the Deed of Agreement, scenarios satisfying the beach amenity KPC for all compartments will be short-listed. If none complies then the placement scenarios will be ranked, based on how close they are at satisfying the beach amenity KPC.
9. For scenarios fulfilling the beach amenity KPC, rank the placement options based on which cause the bank orientation KPI to be as close as possible to 2J for designated beach compartments (Snapper, Rainbow Bay, Coolangatta, Kirra, North Kirra).

The decision aid flow logic above is summarised in the flow chart shown in Figure 6.1

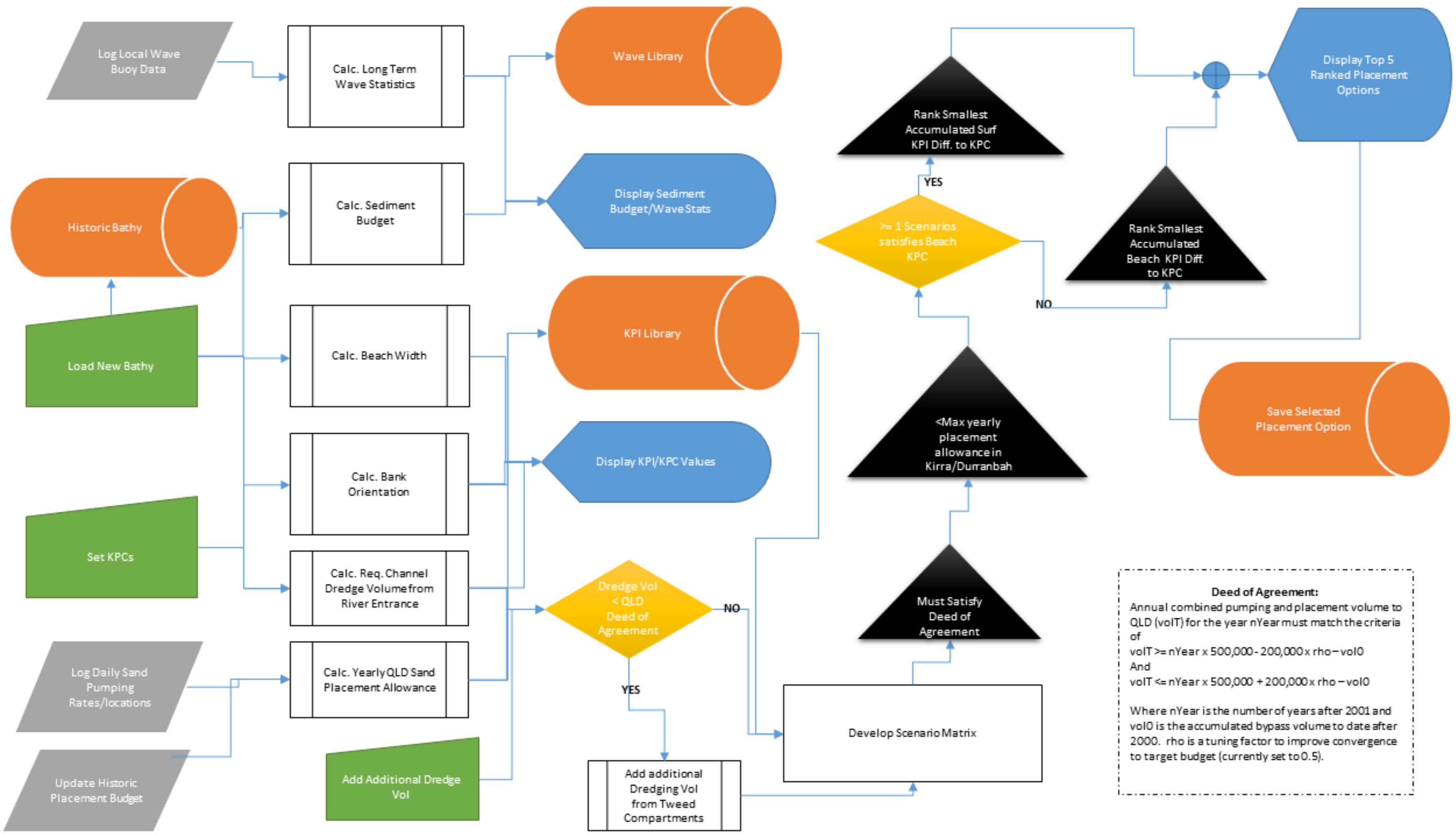

Figure 6.1 Decision logic flow chart for the ISDMP.

Requirements to dredge volumes

The minimum required volume to be dredged from the Tweed River entrance is defined either to ensure safe navigation or to ensure that the minimum required sand volume is bypassed to Queensland, i.e.:

- The minimum volume dredged from the Tweed River entrance is defined as the volume of sand above the minimum allowed depth, i.e. the volume of sand located above –4.4 m AHD (–3.5 m LAT)
- The minimum volume of dredged sand from the Tweed River entrance is increased if the bypassed sand volume is below the minimum requirement imposed by the Concession Agreement.

Restrictions to total bypass volume

According to the Deed of Agreement between Queensland and New South Wales, TRESBP is required to bypass 500,000 m^3/year and the cumulated bypass should not deviate more than ±200,000 m^3 at any time.

As part of the Deed of Agreement it has been decided that while sand placement in some placement boxes are considered to only supply Qld beaches (for instance, the Duranbah Centre-nearshore box), three of the designated placement boxes are considered to partially supply sand to the NSW beaches. The location of these three placement boxes is indicated in Figure 6.2 and their contribution is presented below:

- 50% of the sand pumped to Duranbah beach will enter Queensland
- 50% of the sand disposed in the Duranbah Inner-nearshore box will enter Queensland
- 75% of the sand disposed in the Duranbah Outer-nearshore box will enter Queensland
- 0% of the sand back-passed to Letitia Spit will enter Queensland

Please note that the list above does not indicate the placement boxes contributing to Qld only, such as the Duranbah Centre-nearshore box. However, these boxes have been considered in the model.

Thus the required 500,000 m^3/year of sand required to be supplied to Queensland are termed Deed of Agreement (DoA) volumes thus emphasizing that the volume is an adjusted quantity which takes into account that some of the disposed sand actually reaches NSW beaches rather than the Qld beaches.

Constructing the placement scenario matrix

This current work only considers the placement in the following 5 active placement boxes listed in Table 6.1 and plotted in Figure 6.2. The definition of an active placement box means that a suite of transfer functions has been developed to calculate the coastal response involving any type of placement in this location. Additional boxes can be added at a later stage by simply extending the suite of transfer functions. All placements are considered to cover a conical area with a diameter of 200 m.

Letitia north has been included as a passive placement box. Sand placed in a passive placement box will not include a coastal response.

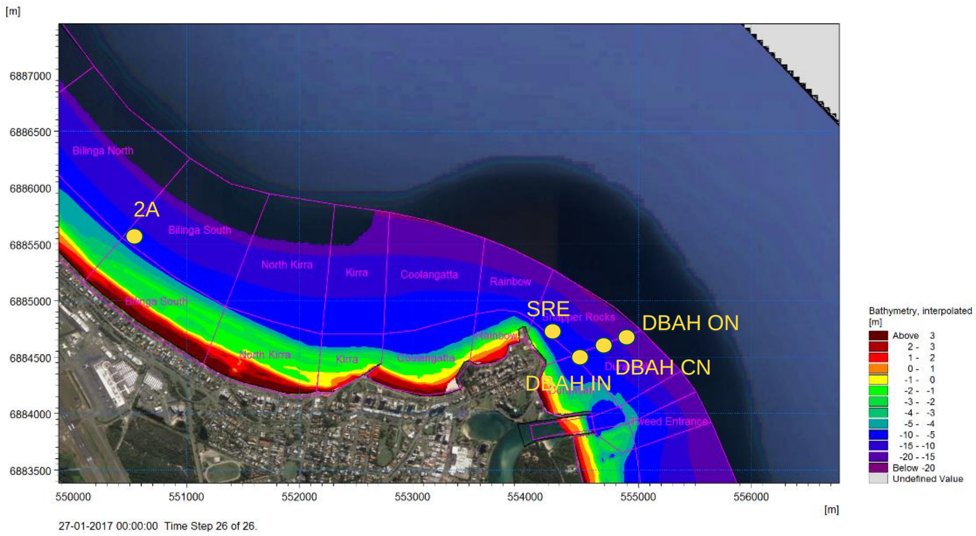

Figure 6.2 Active Placement Box locations

Table 6.1 List of 5 active placement locations (X,Y)

Name	Compartment	MGA-56 X	MGA-56 Y
SRE	Snapper Rocks	554,245	6,884,750
DBAH IN	Duranbah	554,485	6,884,495
DBAH CN	Duranbah	554,690	6,884,595
DBAH ON	Duranbah	554,900	6,884,700
2A	Billinga south	550,545	6,885,590

The standard scenario matrix contains all possible combinations of the six placement locations (SRE, DBAH-IN, DBAH-CN, DBAH-ON, 2A and Letitia North) for cases where up to three different disposal sites can be used simultaneously. Nourishment volumes in each dredge disposal sites are multiples of 10% of the total dredge volume with a restriction that minimum 30% is placed in a single disposal area. The standard scenario matrix contains potentially 141 combinations of sand placement. Among the 2568 combinations of placements in the six placement boxes (using multiple of 10%), only 141 combinations fulfil the restriction of a minimum of 30% in a single disposal area.

Restrictions in required/allowed total sand bypass volumes and disposal volumes within the Duranbah pumping and dredge disposal areas will reduce the number of relevant scenarios before assessing the recommended sand placement.

6.2 Basis for the transfer functions

6.2.1 Morphological modelling of nourishment scenarios

A 2D morphological shoreline model is setup for the area between Tweed River and Currumbin rock groyne. The model simulated transformation of waves over a 2D bed and generation of wave driven depth averaged currents. The combined action of waves and currents is used to calculate the sand transport, which in turn affects the bed through gradients in the transport field, see Appendix A for details on the model setup.

The nourishment operations are modelled as deposition of sand at a constant rate over a certain time inside each of the dredge disposal dump boxes. Additionally, 500,000 m^3/year on a long term average is disposed by pumping along Snapper Rocks East, continuously.

Figure 6.3 shows snapshots of simulation results where the colours indicate the distribution of the nourished sand in terms of the layer thickness. The left column shows snapshots from a case where sand is disposed in the SRE compartment and the right column shows snapshots from a case where sand is disposed in the DBAH-ON compartment. The nourishment scenarios involve in both cases disposal of 50,000 m^3 over a period of 2 months during the spring period. The top panels show the layer thickness right after finishing the nourishment operations (after 2 months), the middle panel shows the distribution 5 months after finishing the nourishment operation (7 months after model start) and the bottom panel shows the distribution 10 months after finishing the nourishment operation (12 months after model start).

The figure shows clearly how differences in water depth at which the nourishment operation is carried out, affects the dispersion of the nourished material through the coastal system:

- Material disposed in the SRE compartment is transported downdrift quickly to the Qld beaches further downdrift, thus leaving no sand in the area after one year
- A large part of the material disposed in the DBAH-ON compartment remains near the dump site also after a year

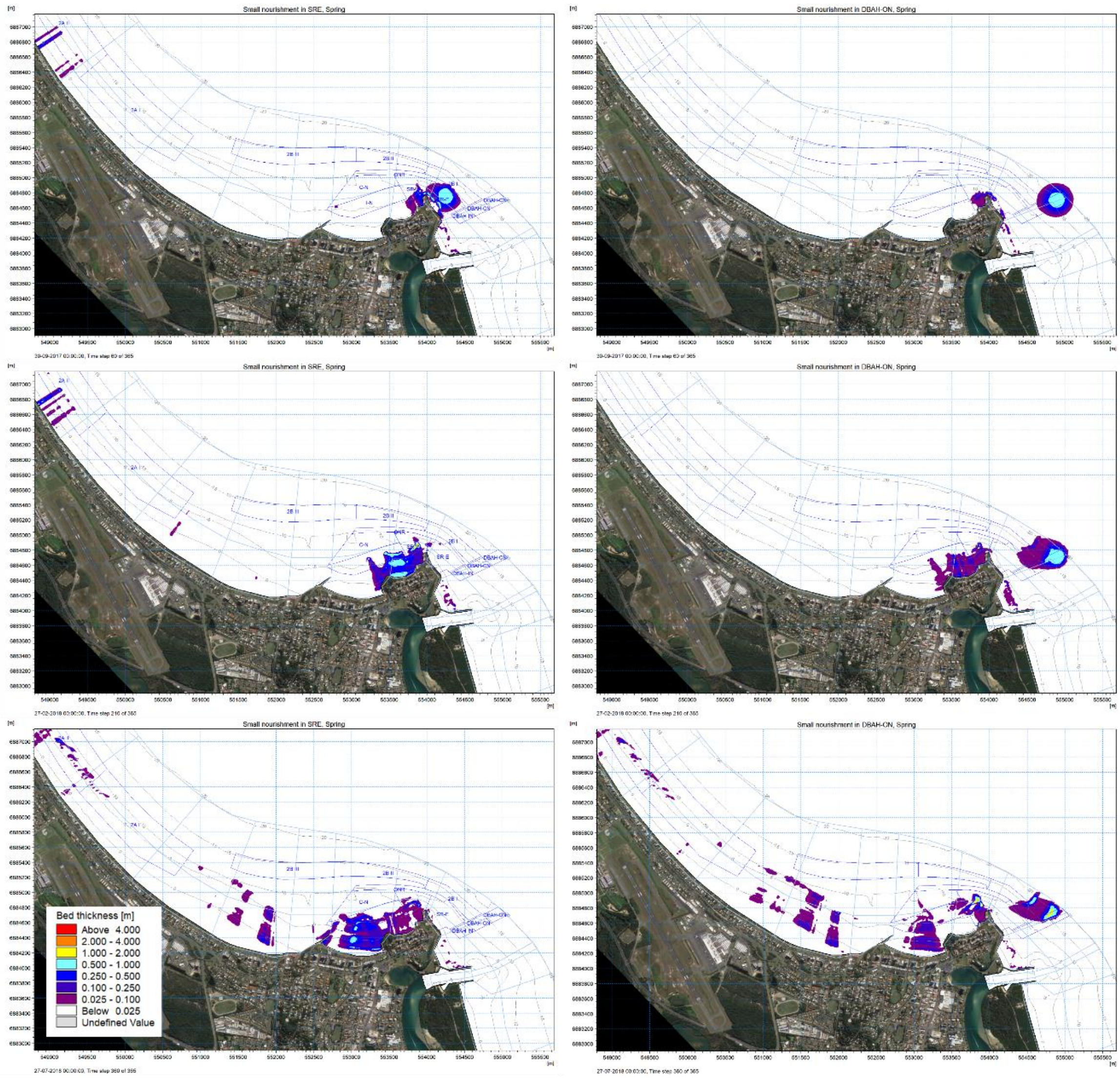

Figure 6.3 Snapshots of calculated distribution of nourished sand (shown as a layer thickness). Left column: Nourishment in SRE. Right column: Nourishment in DBAH-ON. From top to bottom: After 2 months, 7 months and after 12 months.

Time series of volume change within the sub-domains introduced in Section 4 and 4.2 are derived by integrating the bed level changes of each simulation. The resulting time series of volume changes is shown in Figure 6.4. The time series shown in the figure are created by subtracting the zero order solution from the simulated response of the dredge disposal. The zero order solution is in this case the situation where the dredging disposal is not carried out. This is a standard method to distinguish the response of a relatively small perturbation to a larger system.

The figure shows both how the volume change within each of the nearshore sub-domains varies and the total sum of sand from all sub-domains (black dashed curve). The values are normalized with respect to the nourishment volume.

The total nourished sand volume will in most cases be below one, either because the nourished sand remains outside the inner zone of the coastal profile or because part of the nourished sand travels out of the beach system – further downdrift.

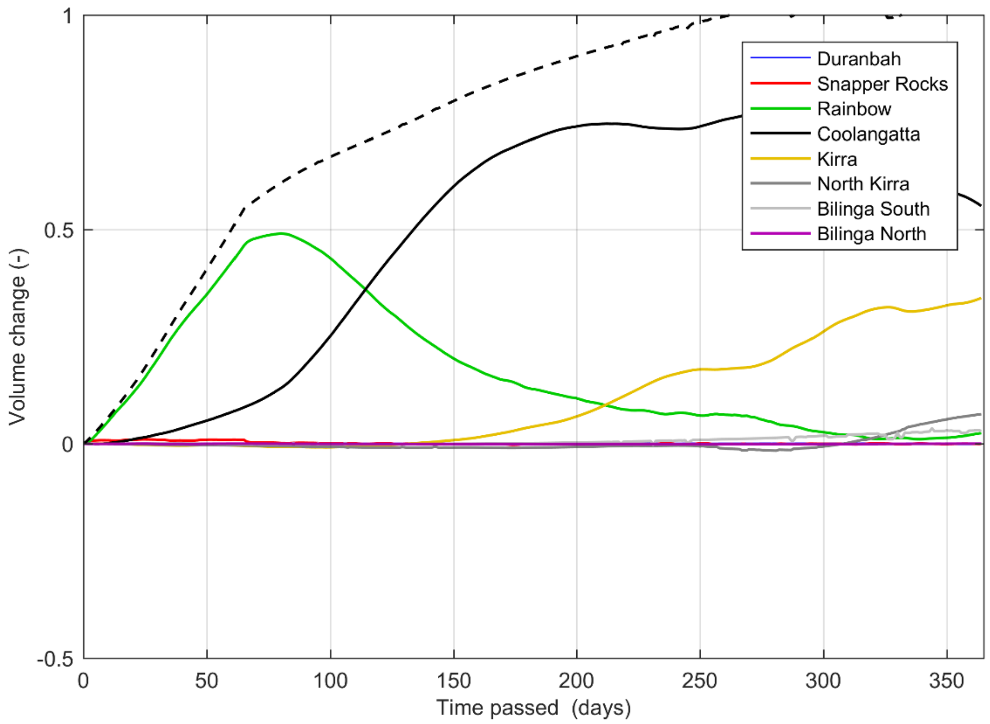

Figure 6.4 Transfer function for sand volume to a 50,000 m³ disposal operation at Snapper Rocks East. The volume changes are normalized.

The volume changes are transformed to changes in beach width by use of a cross-correlation derived in Section 4.2. The relationship between the volume change and a change in beach width are also shown in Appendix B.

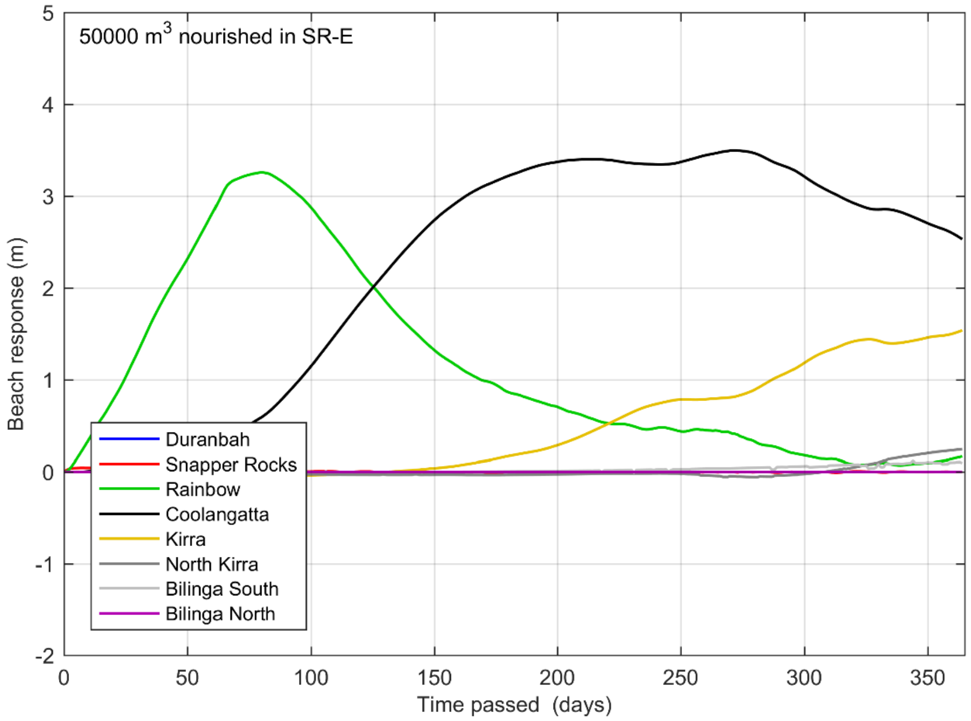

Figure 6.5 Beach response to a nourishment in Snapper Rocks East.

6.2.2 Using and combining transfer function for arbitrary disposal volumes

The transfer functions are formulated such that any disposal volume can be incorporated as long as the impact from the disposal is relatively similar to the disposal volume used to create the transfer function. Transfer functions for a small volume (50,000 m^3) and a large volume (200,000 m^3) are calculated for the active placement boxes listed in Table 6.1.

All the transfer functions are presented in Appendix A.5. An illustration of the transfer functions is shown below in Figure 6.6. Basically, the transfer functions indicate the relative volume distribution of the disposed sand onto the NSW and Qld beaches. For the case shown in the figure, the transfer function specifies that 8% of sand disposed in DBAH-IN ends up at Duranbah, 9% affects Snapper Rocks, 34% affects Rainbow, and 15% affects Kirra (when averaged over 1 year). The sum of this is 66%, i.e. 66% of the sand disposed in DBAH-IN is recognised along the downdrift beaches. The rest either remains in the disposal area or is moved further seaward or further downdrift.

The fact that the transfer functions are formulated using this relative volume distribution allows the transfer functions to be used to calculate the volume distribution for an arbitrary sand volume. Assume as an example that 10,000 m^3 is disposed in DBAH-IN. The transfer function predicts that the disposal operation will increase the sand volume at Duranbah by 800 m^3 (i.e. 8% of 10,000 m^3).

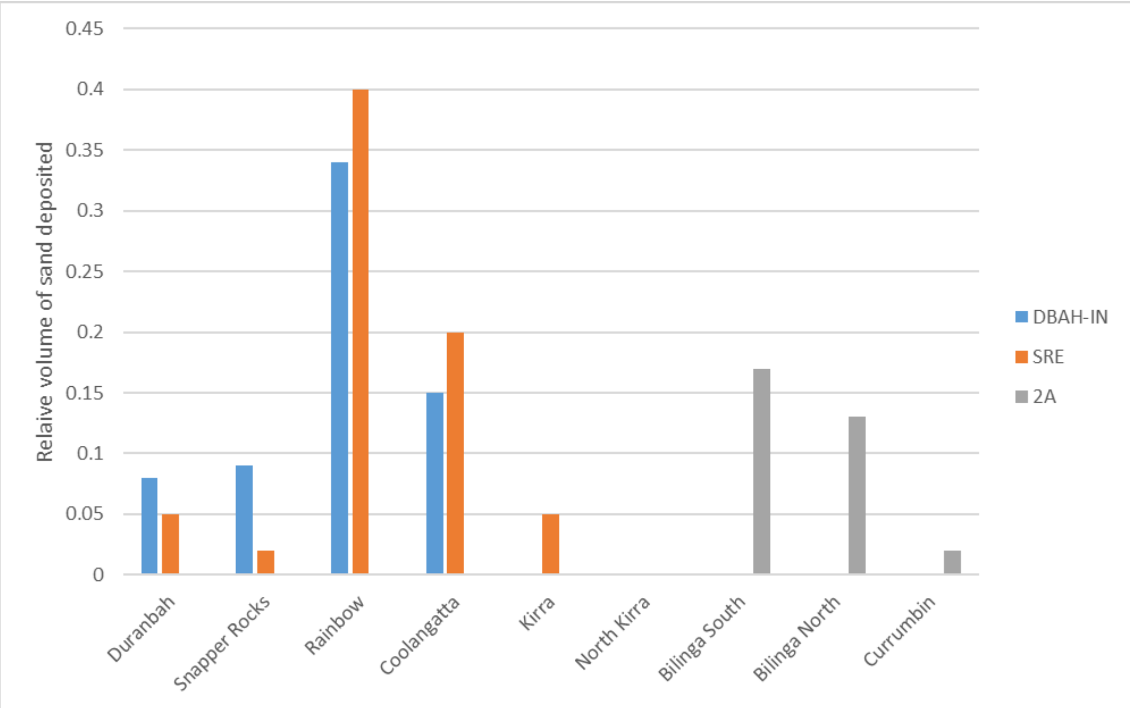

Figure 6.6 Illustration of the transfer functions obtained for a small nourishment during spring (for three different placement areas).

Scenarios with dredge disposal in multiple disposal areas are handles by adding the volume contribution obtained from each set of transfer functions. This is also known as the principle of super-position. The assumption that the combined effect of multiple disposal operations is equal to the sum of the individual operations is a simplification which is generally considered valid as long as the perturbation imposed by the dredge disposal is small. This is generally the case for the considered dredge disposal volumes (that should be compared to the natural net transport, which is about 500,000 m^3/year).

Assume for instance that 10,000 m^3 is disposed in each of the three disposal areas. The total sand supplied to the beaches is then indicated in Figure 6.7. As an example, sand volumes at Duranbah are increased by 1300 m^3, which cover over the following contributions:

- 800 m^3 from the DBAH-IN disposal operation (8% of 10,000 m^3)
- 500 m^3 from the SRE disposal operation (5% of 10,000 m^3)
- 0 m^3 from the 2A disposal operation (0% of 10,000 m^3)

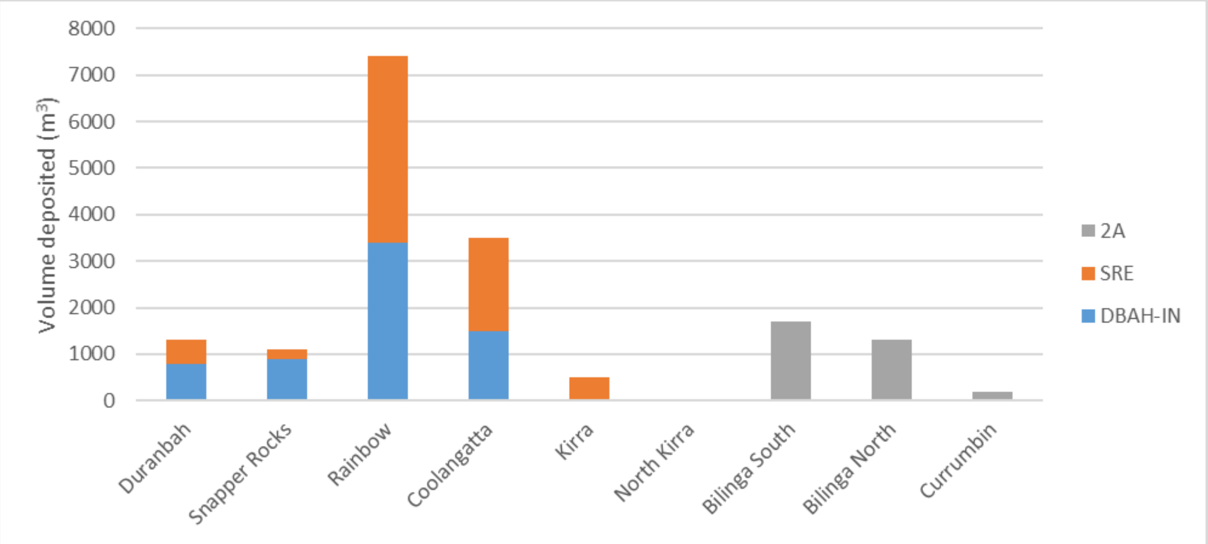

Figure 6.7 Example of added sand volume from a scenario where 10,000 m3 is disposed in each of the three disposal areas.

6.3 Decision Aid Tool (DAT)

In order to effectively execute the proposed ISDMP plan the Figure 6.1 decision logic will be incorporated into an online web-based Decision Aid Tool (DAT). The User manual prepared for the project (see Ref. /8/) details the features provided by the DAT, a step-by-step guide and a FAQ section.

7 References

/1/ RHDV (2017): Tweed River Entrance Sand Bypassing Project, Sand Transport Information System (STIS), Development – Stage 1. Final, March 2017. Prepared for NSW Department of Industries – Lands

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/6/ BMT WBM (2017): Currumbin Coastal Processes Assessment, Rev. 1 June 2017 (Confidential). Prepared for NSW Department of Lands

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/8/ DHI (2018), NSW DoI STIS, User Manual. July 2018. Prepared for NSW Department of Industries

APPENDICES

APPENDIX A – Model setup

Short description of the MIKE 21 Shoreline Morphology setup

A Model setup – Morphological response

A.1 Short model description

The model used for calculating the morphological response to dredge disposal is DHIs in-house model: MIKE 21 Coupled FM. The model is a suite of coupled sub-modules, which are solved on an unstructured (triangular) mesh also known as a Flexible Mesh (FM). The sub-modules used in the present application are:

- Spectral Wave module (SW): Transformation of offshore waves into the near-shore. The module is used to calculate driving forces from waves (wave setup, wave-driven currents) and for quantifying the wave impact on sand transport.
- Hydrodynamic module (HD): Solves the non-linear shallow water equations taking into account forcing from tides and waves.
- Sand transport module (ST): Calculates the sand transport under action of waves and currents.
- Shoreline morphology module (SM): Morphological module used calculate shoreline changes in response to gradients in the longshore and cross-shore transport. In the present application, the shoreline module is applied inside the –6 m AHD contour and traditional 2D morphology is used outside the –6 m AHD depth contours (out to about –20 m AHD).

A.2 Model extent and spatial maps

The extent of the coastal model is shown in Figure A.1. The colours in the figure show the bathymetric variation inside the model domain. The model covers thus an alongshore extent of about 15 km and extends about 5 km into the sea (bed levels around –50 m AHD).

The model resolution varies within the domain as indicated in Figure A.2 and Figure A.3. The distance between two neighbouring mesh elements is about 5 m in the surf zone and up to about 100 m on deeper water. The mesh composes of 125,000 mesh elements.

Adding morphological feedback to a coastal model complicates the requirements to model setup and calibration greatly. The morphology is therefore restricted in the present application to the nearshore area between the northern Tweed River entrance training wall and Currumbin Creek groyne and the –20 m AHD depth contour. The area with active morphology is shown in Figure A.4. The figure indicates also the placement boxes for dredge material by use of blue polygons. Both historical placement boxes, presently used placement boxes and proposed placement boxes have been included in the figure.

Bedrock is exposed in certain areas (e.g. Point Danger and Kirra Reef) which limits erosion depths and reduces sand supply to the downdrift areas. The transport capacity around Point Danger is as an example significantly higher than 500,000 m^3/year, but the transport around Point Danger is limited by the sand supply from south. Thus, in order to include this in the model an initial sand layer thickness map is created. The sand layer thickness map is created synthetically and is not supported by actual measurements of the sand layer thickness. Figure A.5 shows the synthetic sand layer thickness map. In the simulations with different seasons, different sand layer thickness maps are used to initialise the model thereby reflecting the fact that the area has recently been subject to relatively harsh conditions or relatively calm conditions.

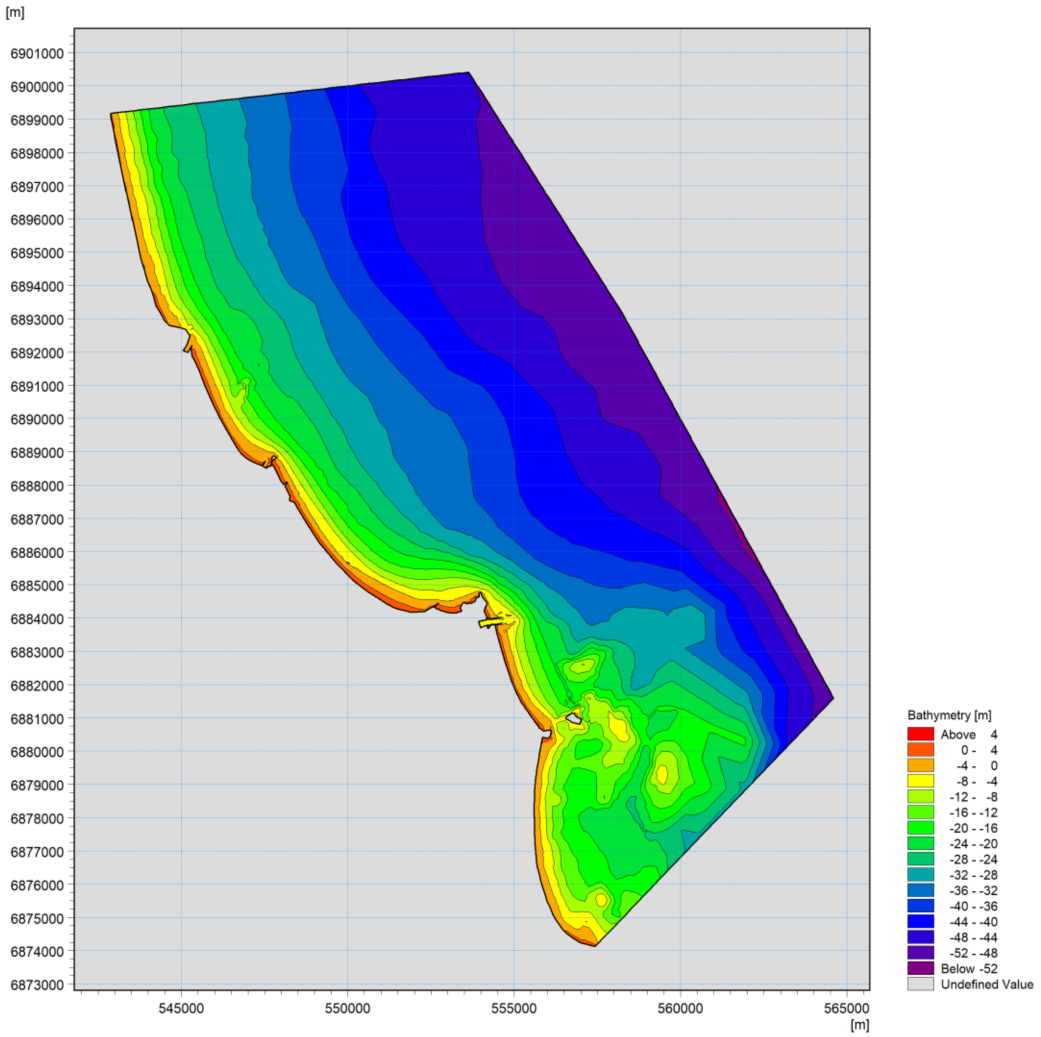


Figure A.1 Model extent of the coastal model used to calculate transfer functions. Colours indicate the bed level relative to metres AHD. Horizontal coordinates are given in metres relative to MGA-56.

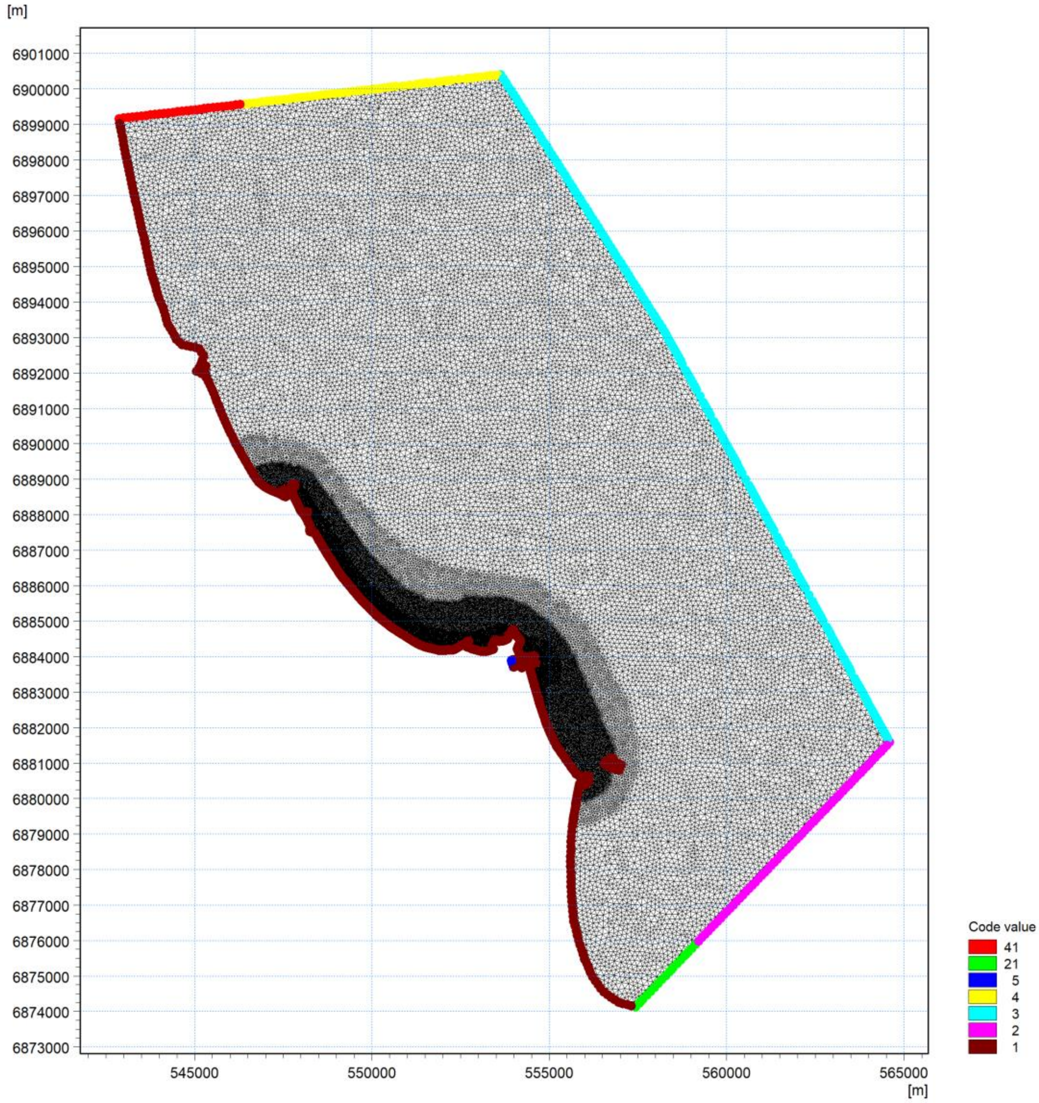


Figure A.2 Mesh resolution.

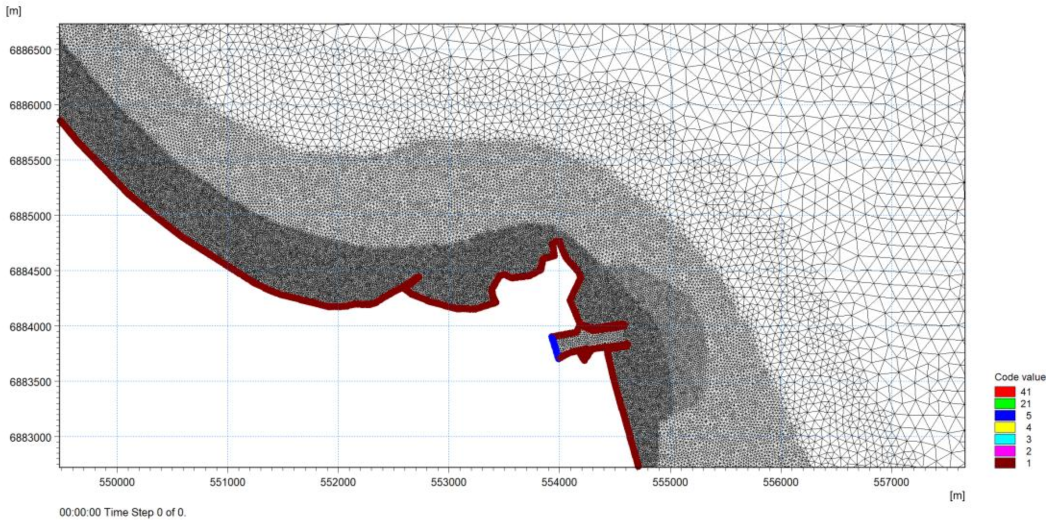


Figure A.3 Detail of mesh resolution near the beach.

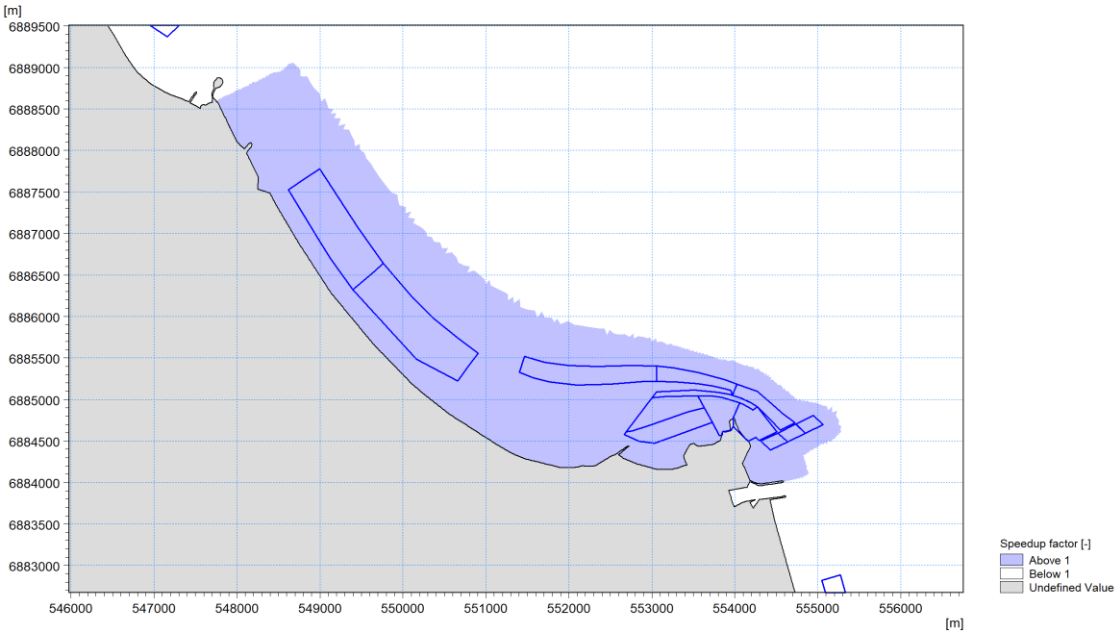


Figure A.4 Morphological evolution is constrained within the blue shaded area. The blue polygons show the location of historic, present and planned dredge disposal areas.

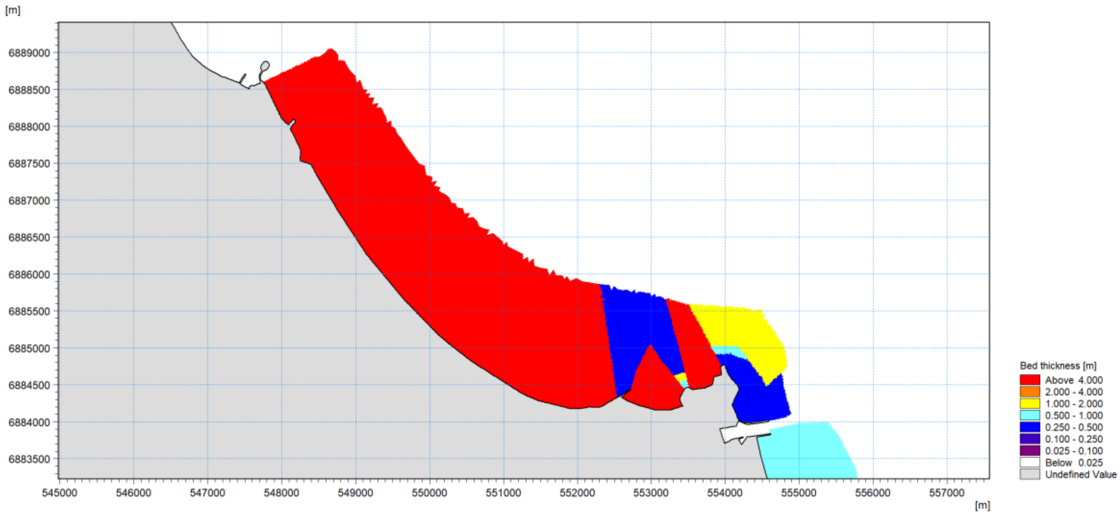


Figure A.5 Initial sand thickness layer. Used to restrict erosion around headlands.

A.3 Simulation periods

The morphological impact of dredge disposal is simulated for a full year. In order to take into account the effect of dredging in different periods of the year, three different starting points are incorporated. Table A.1 summarises the start date of the three seasons.

All three seasons are based on the calendar year 2012, which from a sediment transport point of view in Ref. /2/ was found to be a characteristic year for the southern Gold Coast beaches.

Time series of the offshore wave parameters (significant wave height, mean wave direction and peak wave period) during 2012 are shown in Figure A.6. The starting dates of the three seasons are also indicated in the figure.

Table A.1 Starting date used for the three seasons.

Season	Starting date
Cyclone	1. Jan.
Winter	1. Apr.
Spring	1. Aug.

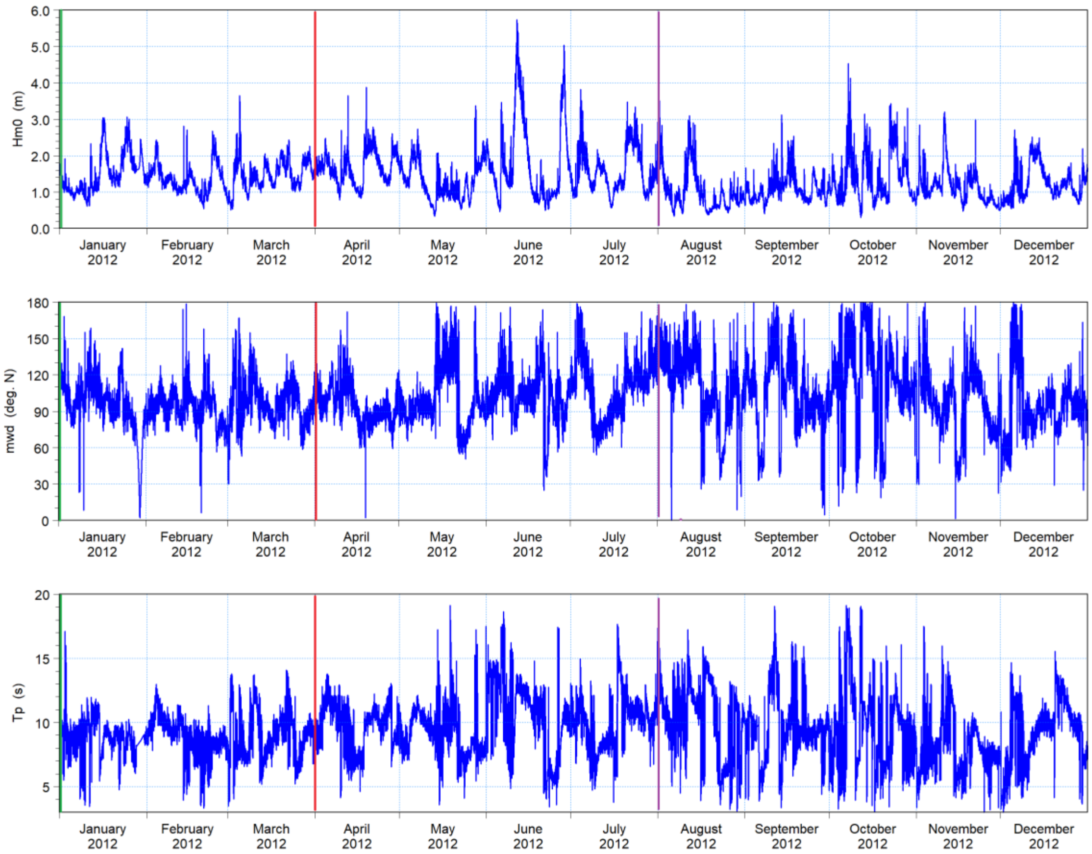


Figure A.6 Wave forcing applied along the offshore boundary. The starting dates of the three seasons are indicated by the vertical lines. Green: Cyclone, Red: Winter and Purple: Spring.

A.4 Snapshots of simulation results

A.4.1 Spatial distribution of waves and currents – Selected events

Three snapshots from the simulation results are presented in the following. The dates are chosen in order to document model results for some characteristic events. Two of the events contain moderate wave conditions (around H_{m0}: 3 m) at the offshore point with wave approaching from East and South. One event contains severe storm conditions (H_{m0}: 5 m) with waves approaching from ENE. Table A.2 summarises the dates and wave conditions.

The snapshots are shown in the following three figures. The top panel indicates the wave height distribution in colours and the wave direction with the vector overlay. The bottom panel shows the intensity of the depth averaged wave-driven current in colours and the direction of the current with the vector overlay. Flow conditions are for all three snapshots towards NW.

The figures show that waves are generally smaller near North Kirra and Bilinga due to shadow effects from Point Danger. What is more interesting is the strong reduction in wave height, which occurs along the entire nearshore area for conditions where waves in the offshore point approach from South (compare differences in wave height fields for Event 1 against Event 3).

Table A.2 Overview of dates used to show snapshots from model results.

ID	Date (dd-mm-yyyy)	H_{m0} (m)	MWD (deg.N)	Comments
1	25-01-2012	3.0	93	Summer event, moderate waves from ESE
2	12-06-2012	5.2	85	Severe storm, large waves from ENE
3	06-12-2012	2.7	178	Spring event, moderate waves from S

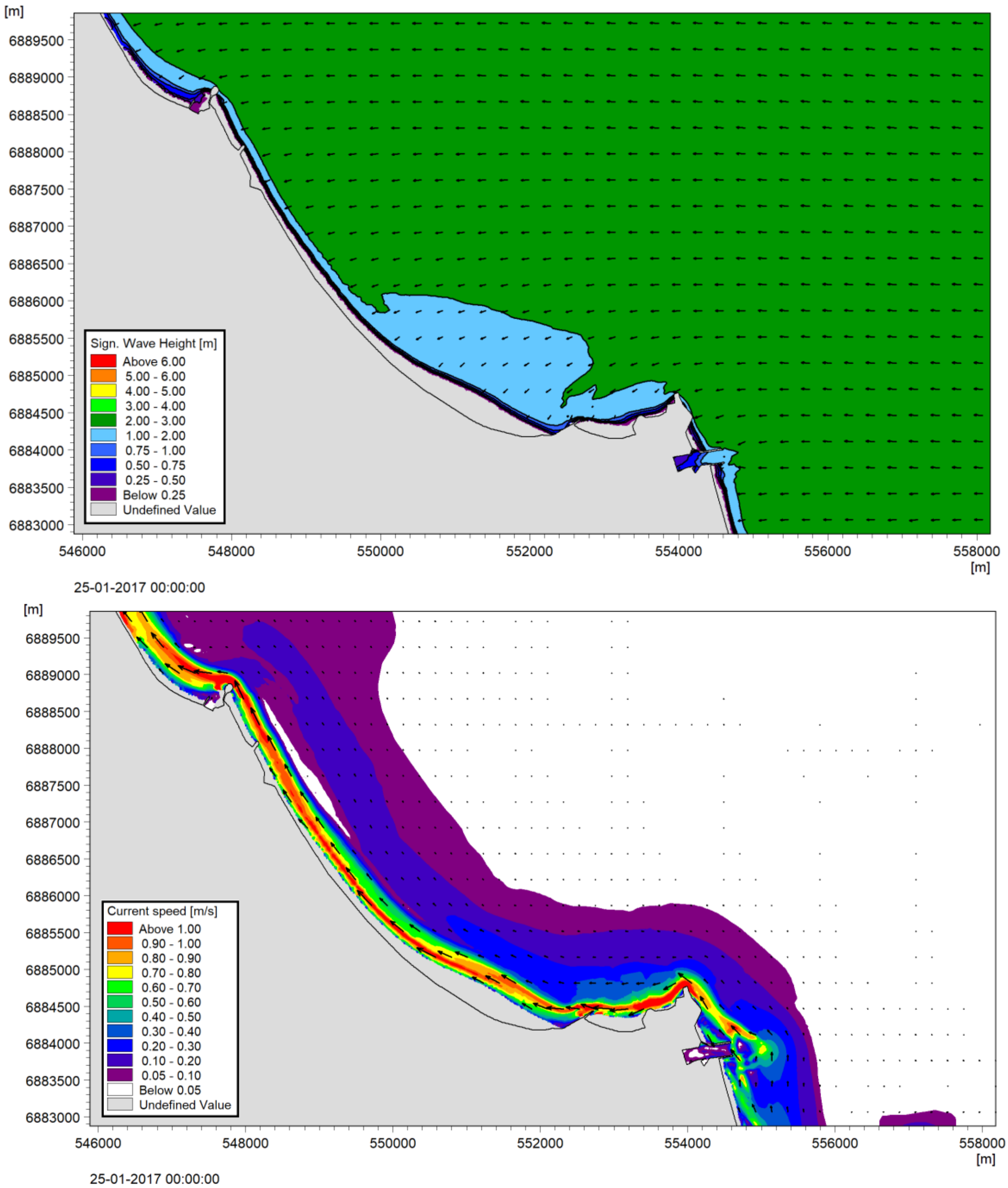


Figure A.7 Wave height distribution and distribution of wave-driven currents during an event with waves from East.

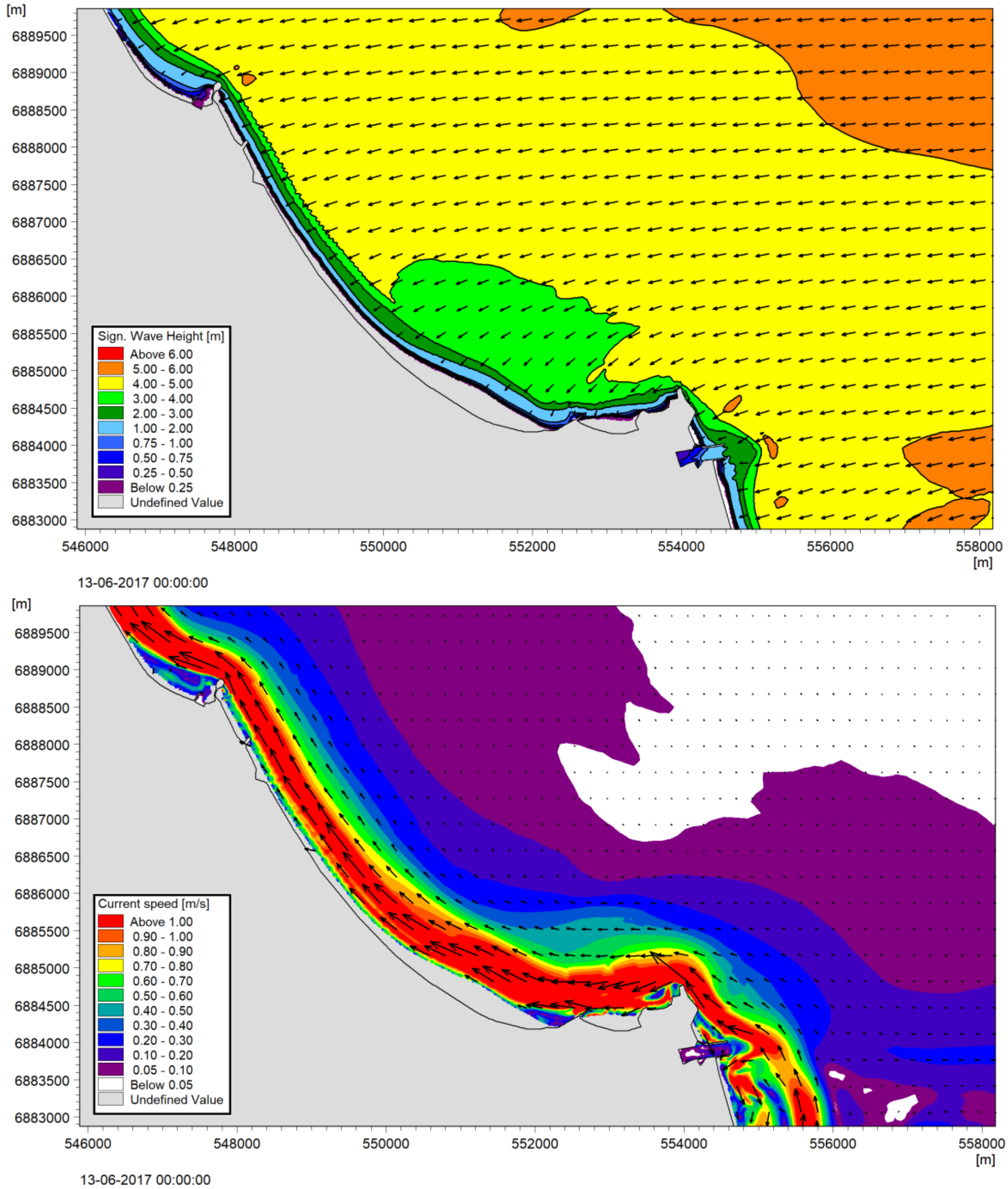


Figure A.8 Wave height distribution and distribution of wave-driven currents during a severe event with waves from East.

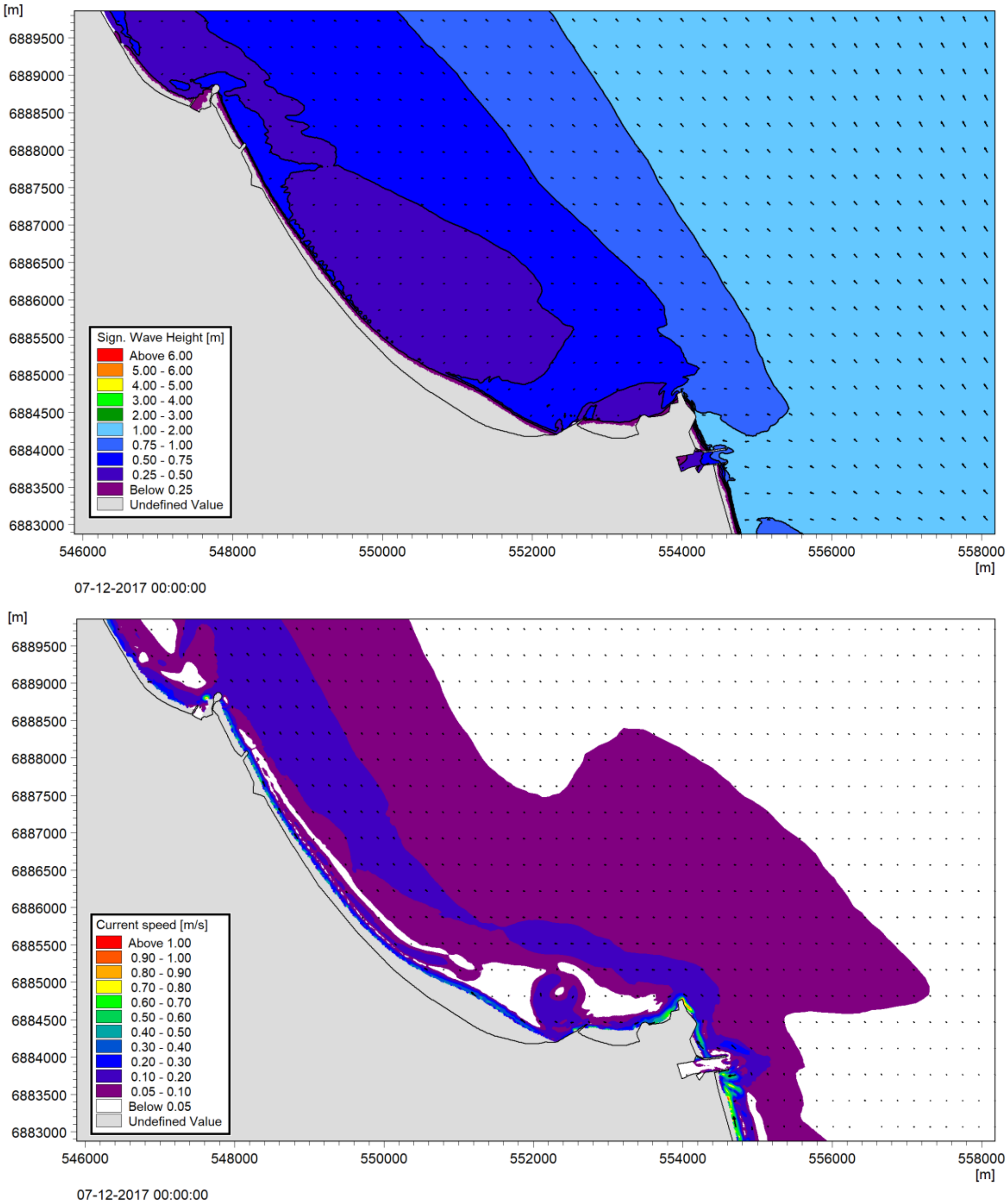


Figure A.9 Wave height distribution and distribution of wave-driven currents during an event with waves from South. The wave height nearshore is significantly reduced due to depth refraction.

A.4.2 Morphological evolution of nourished sand – Spring season

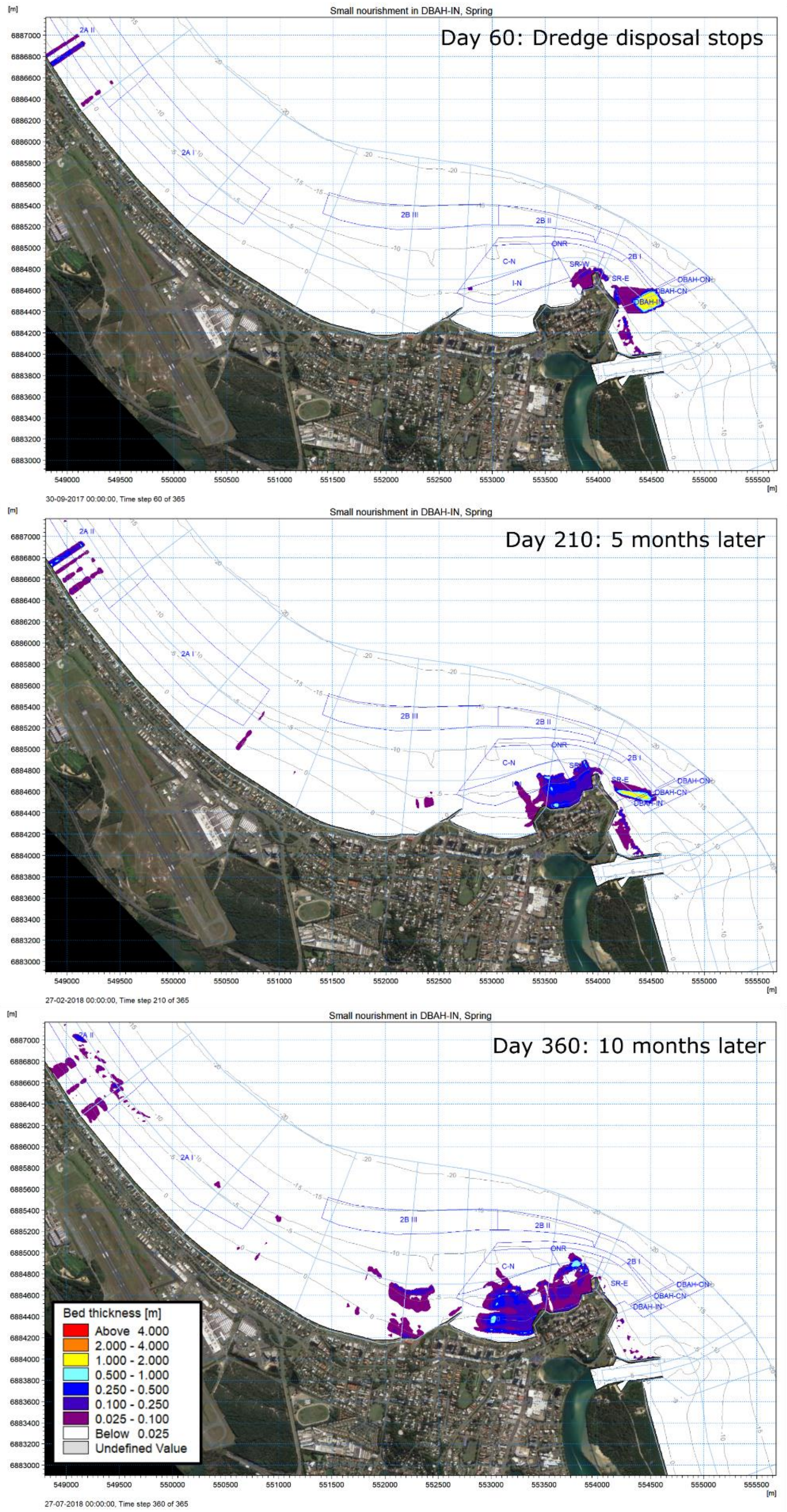


Figure A.10 Spreading of dredge disposal at DBAH-IN. Volume: 50,000 m^3, disposed over two months starting from 1. Aug.

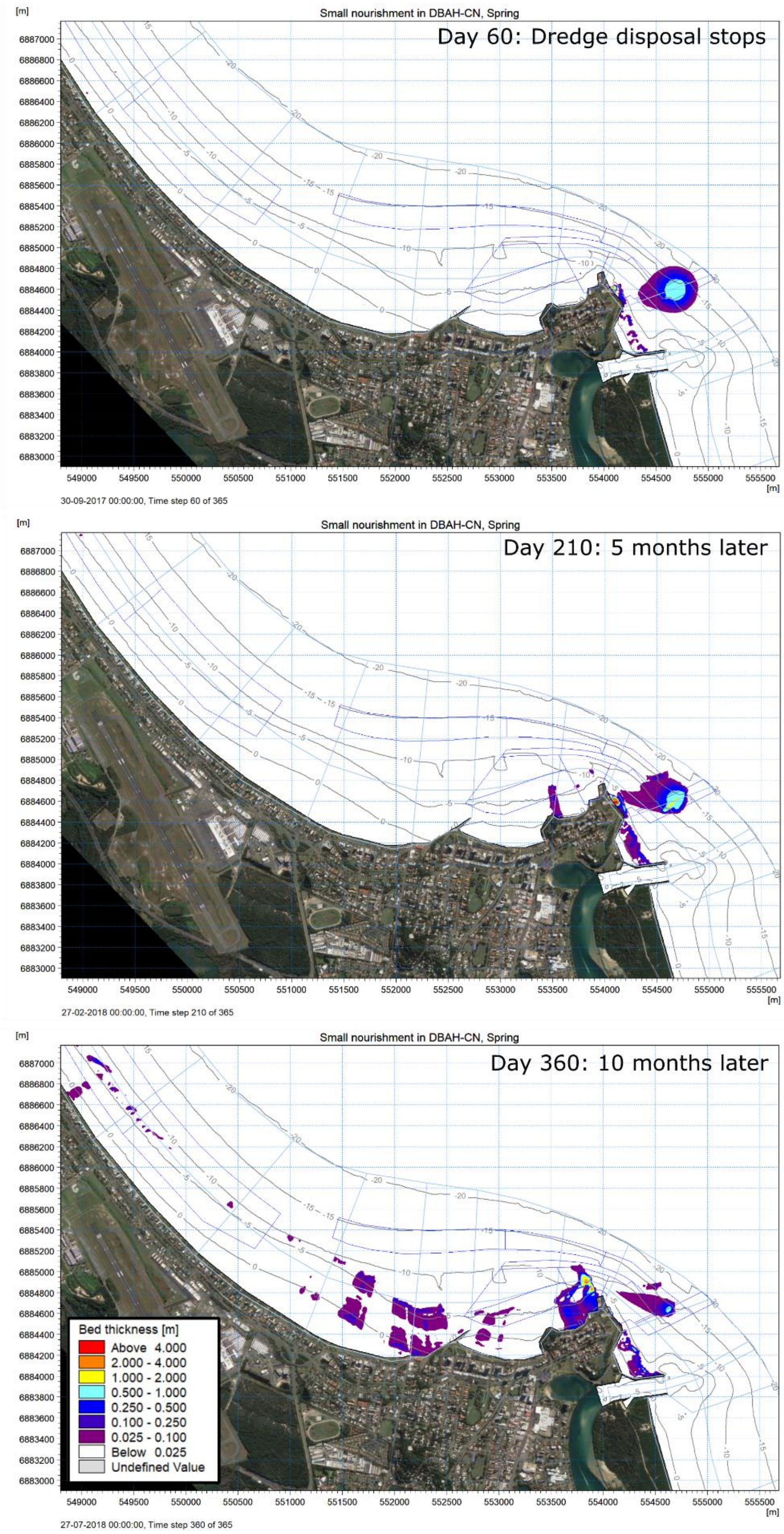


Figure A.11 Spreading of dredge disposal at DBAH-CN. Volume: 50,000 m^3, disposed over two months starting from 1. Aug.

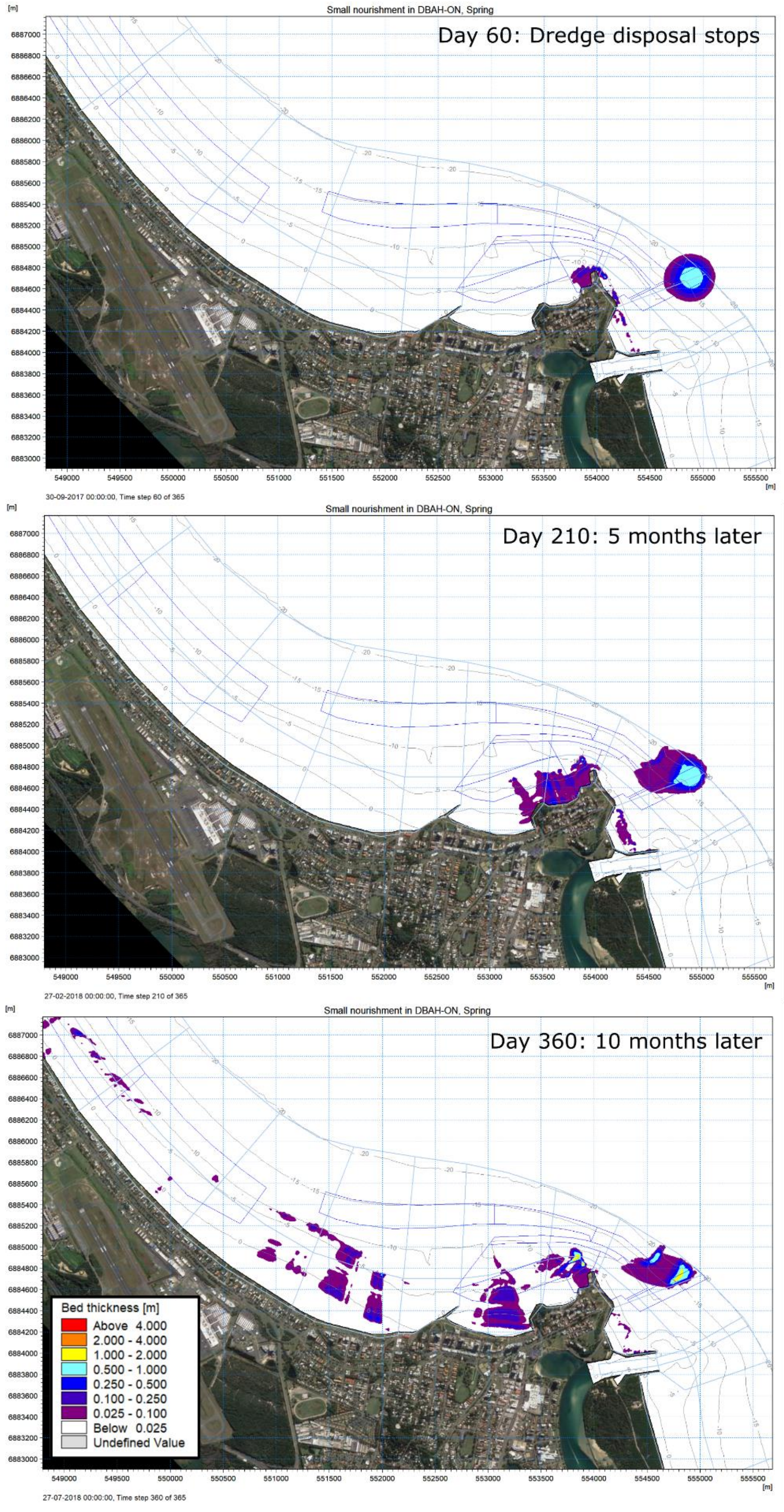


Figure A.12 Spreading of dredge disposal at DBAH-ON. Volume: 50,000 m^3, disposed over two months starting from 1. Aug.

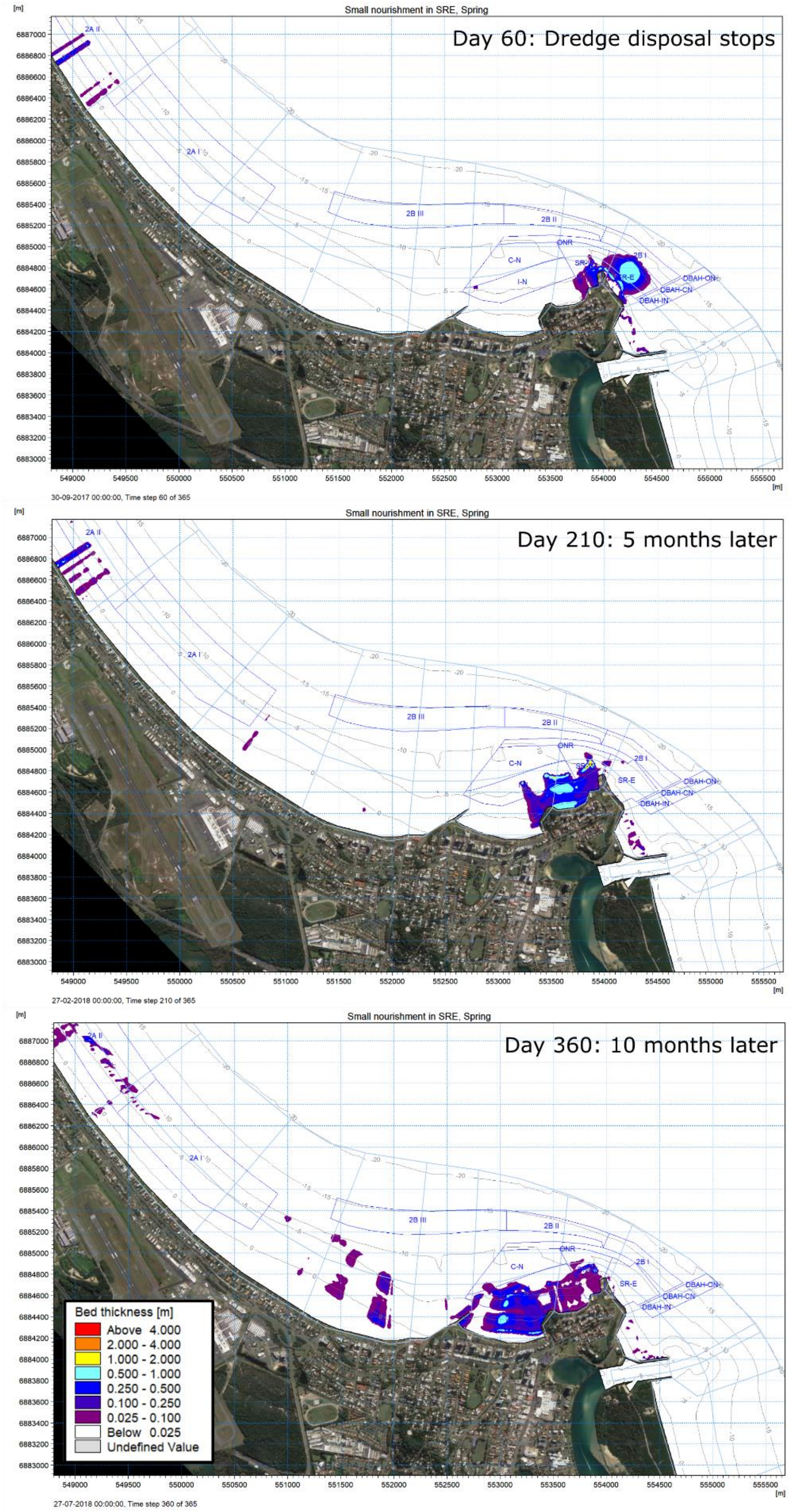


Figure A.13 Spreading of dredge disposal at SRE. Volume: 50,000 m^3, disposed over two months starting from 1. Aug.

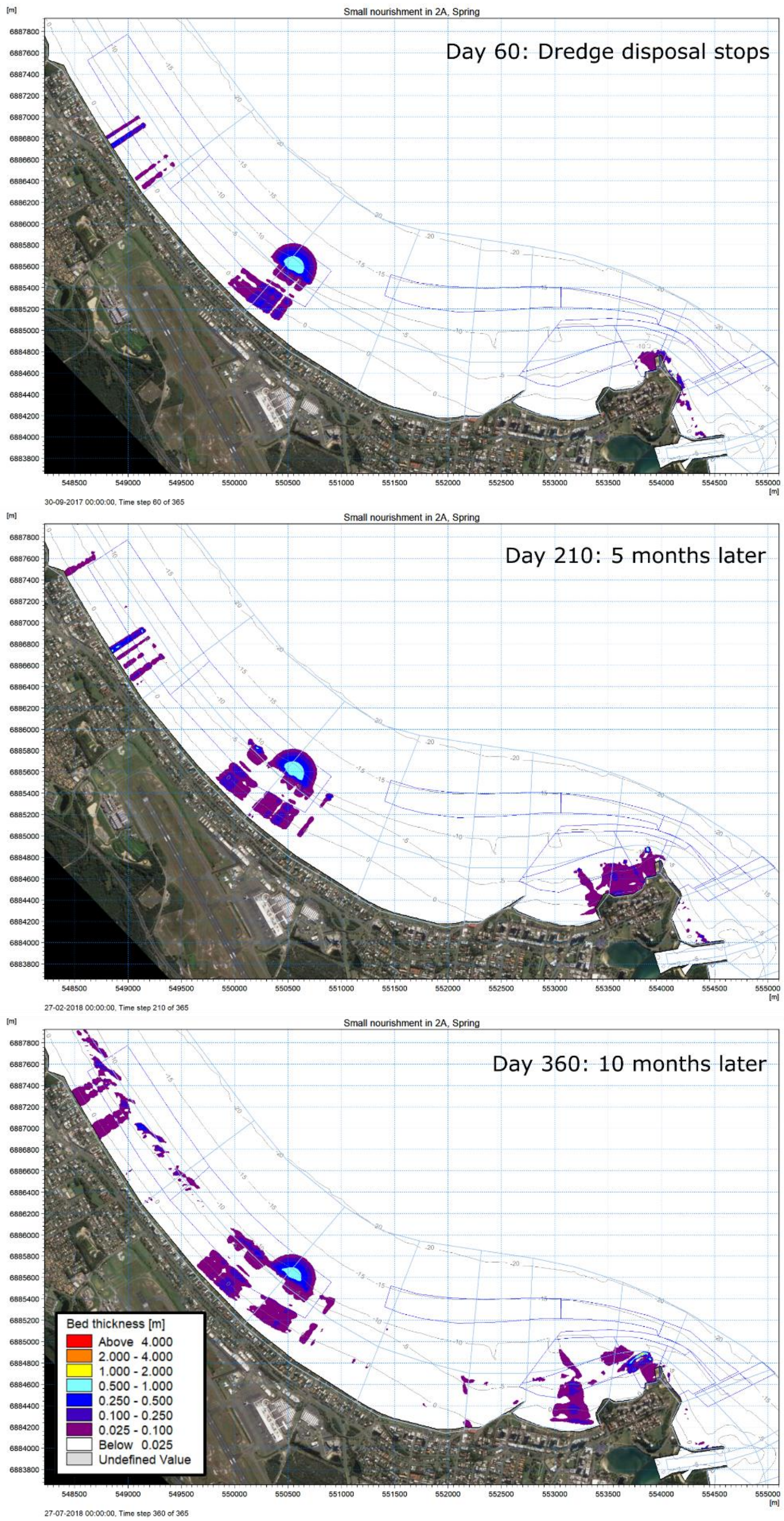


Figure A.14 Spreading of dredge disposal at 2A. Volume: 50,000 m^3, disposed over two months starting from 1. Aug.

A.5 Transfer functions

The simulated dispersion of the dredge-disposed sand is aggregated into one-year averaged volume changes for each compartment. The volume changes are normalized with respect to the disposed sand and are presented as so-called transfer functions.

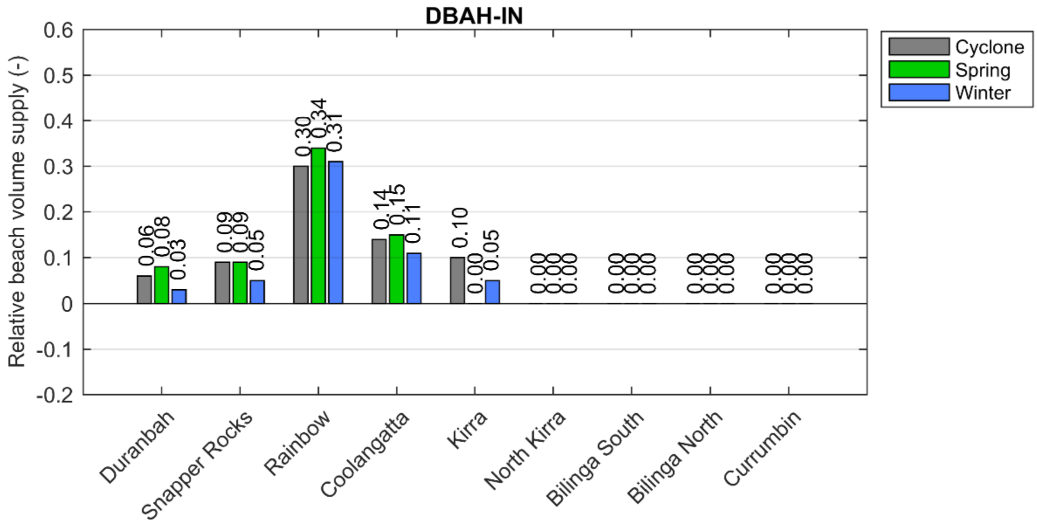
Transfer functions have been calculated for five different disposal areas, each for three different seasons (cyclone, spring and winter), each for two different disposal volumes (large: 200,000 m^3 over 4 months and small: 50,000 m^3 over 2 months).

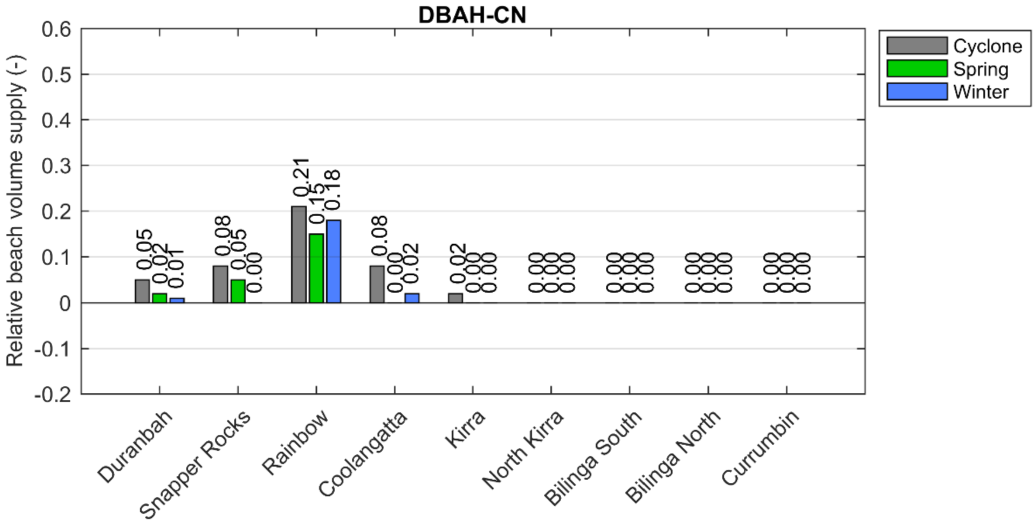
A.5.1 General observations

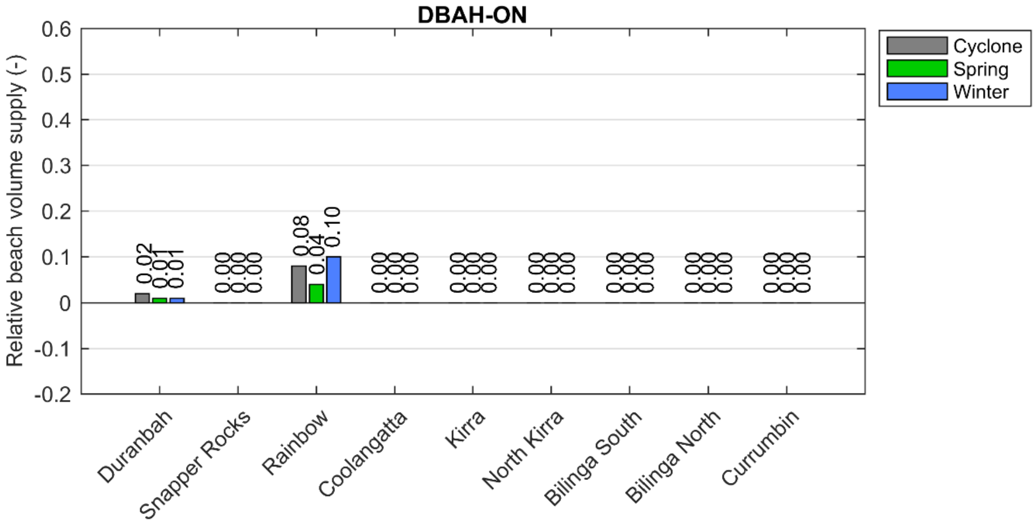
- DBAH-IN: Sediment placed in DBAH-IN is redistributed to the beaches effectively. The disposed sand affects the beaches from Duranbah to Kirra.
- DBAH-CN: Less than half of the sand placed in DBAH-CN affects the beaches within a year due to the larger depths at which the sand is disposed on.
- DBAH-ON: About 10% of the disposed sand affects the beaches within a year. The very large water depth at which sand is disposed on causes the sand to remain fixed except during severe storms.
- SRE: The transport capacity in this area is extremely high. Thus, sand disposed in this area is swiftly moved further downdrift. The sand does not affect the beach compartment at SRE itself because of the strong currents.
- 2A: About 50% of the sand disposed in 2A reaches the beaches within a year. The disposed material remains in the disposal area for a long time due to the relatively weak waves in the area.

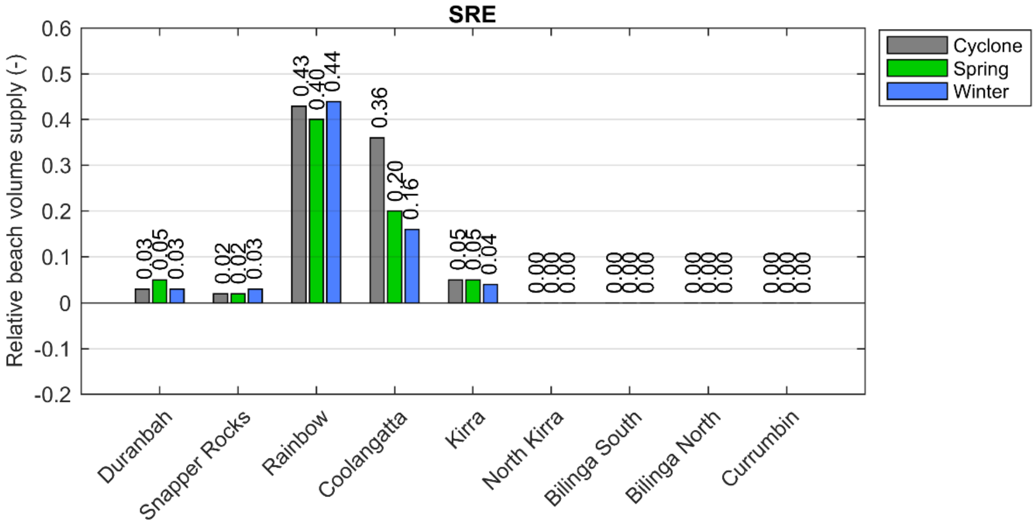
Comparing the transfer functions for small and large volumes shows that the difference is relatively small. The transfer functions for the large volumes tend to appear less effective (smaller values). However, this is because the transfer functions are normalised by the disposal volume. Thus, larger disposal operations will have a greater effect on the beach.

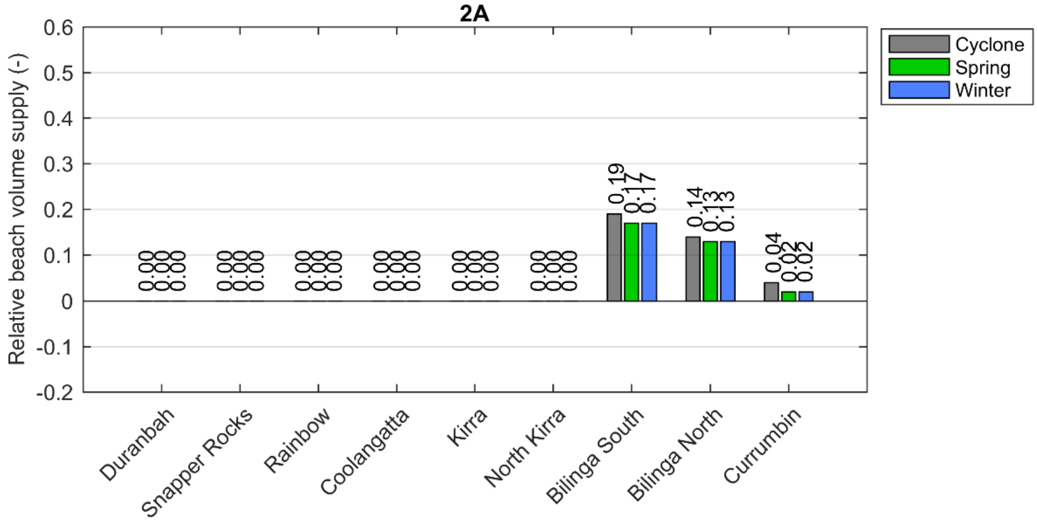
A.5.2 Transfer functions for small disposal volumes



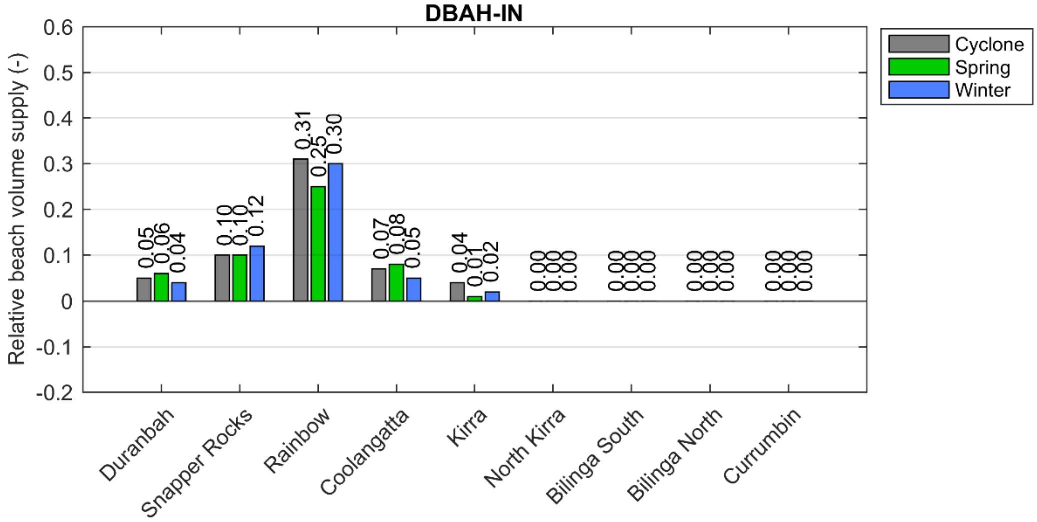

DBAH-CN
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin

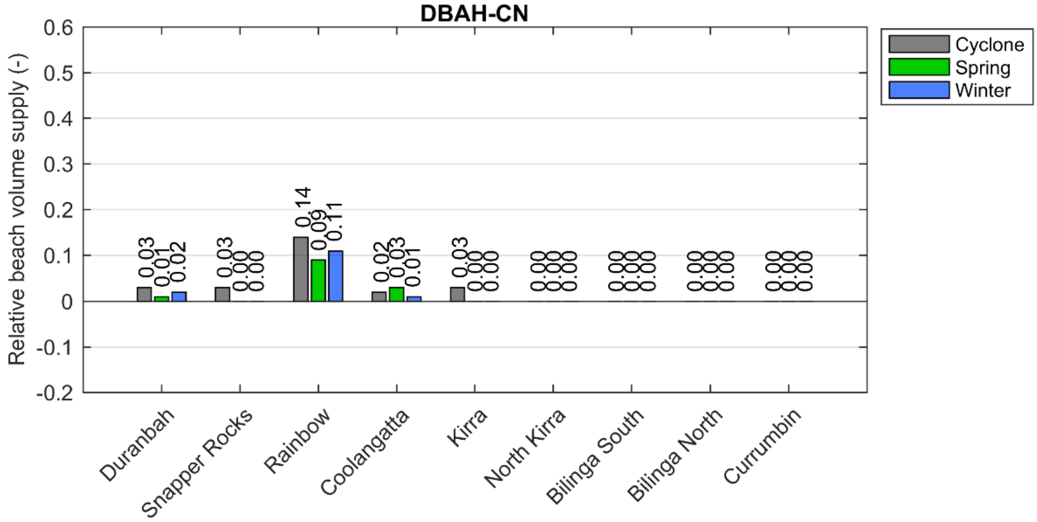

DBAH-ON
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin

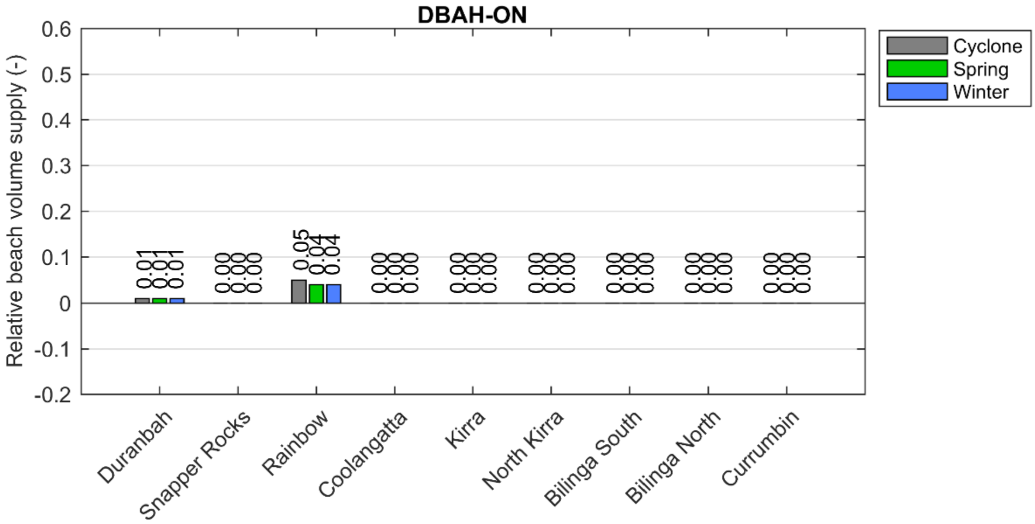

SRE
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin



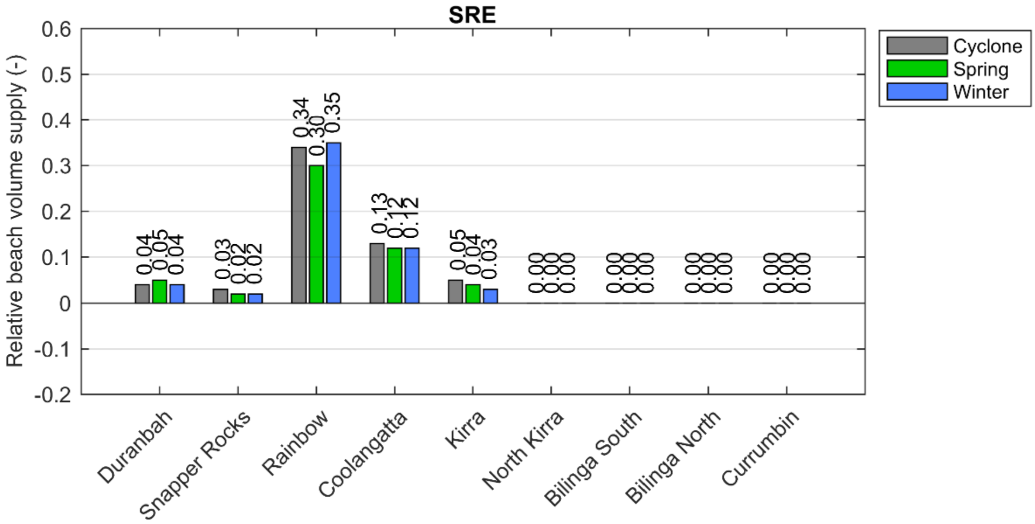
A.5.3 Transfer functions for large disposal volumes



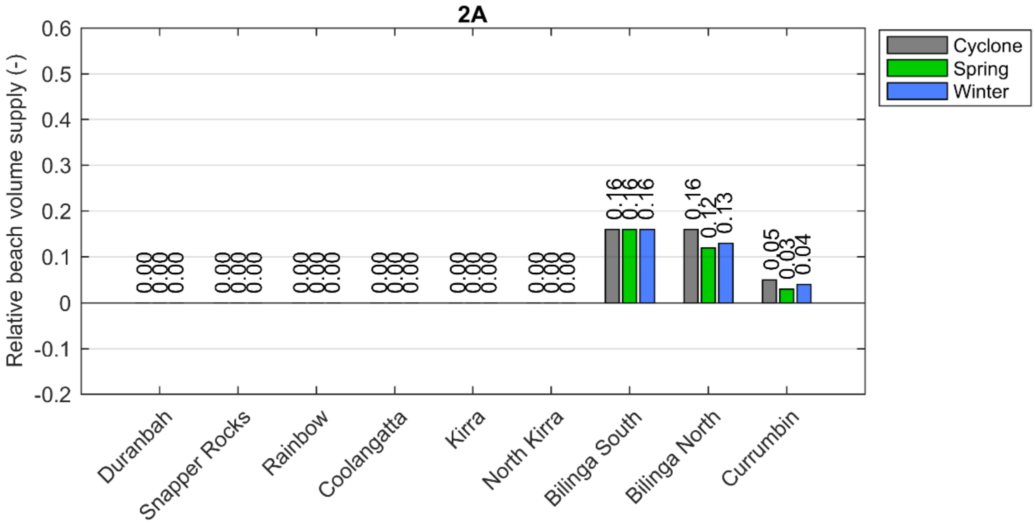




DBAH-ON
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin



SRE
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin



2A
Relative beach volume supply (-)
Cyclone
Spring
Winter
Duranbah
Snapper Rocks
Rainbow
Coolangatta
Kirra
North Kirra
Bilinga South
Bilinga North
Currumbin

APPENDIX B – Correlation of sand volumes and KPIs

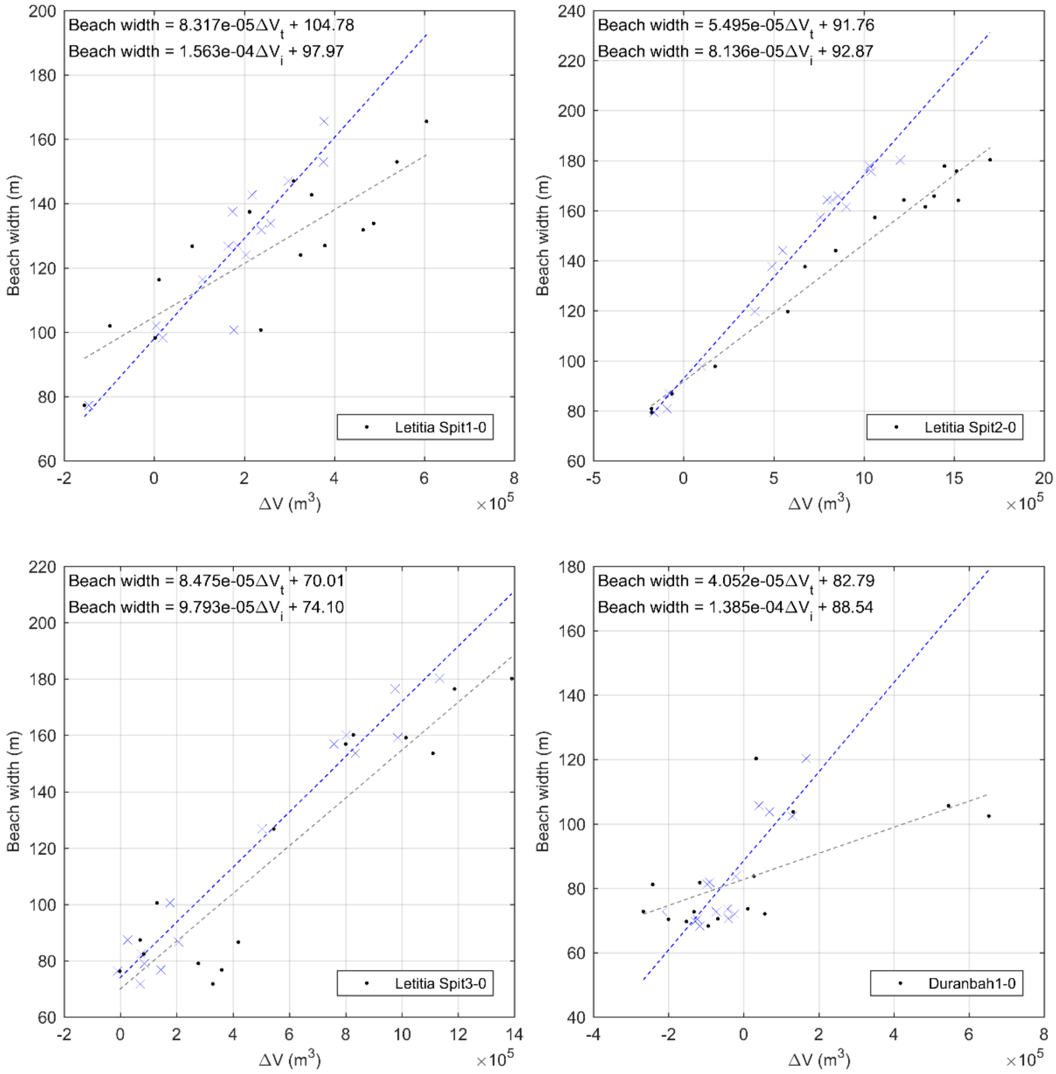
Sensitivity of beach width and position of –5 m bed contour

B Cross-correlation between KPI and sand volume

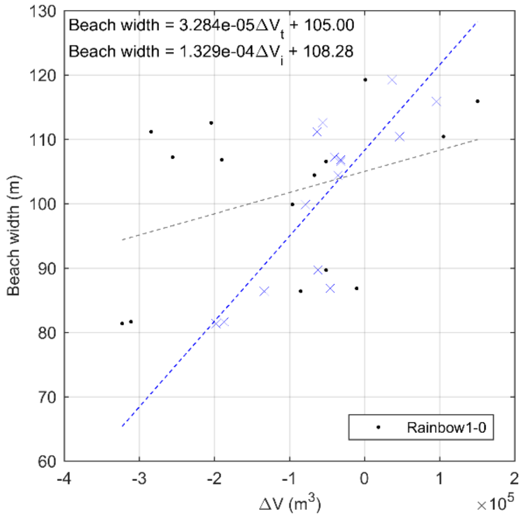
B.1 Correlation between beach width and sand volume

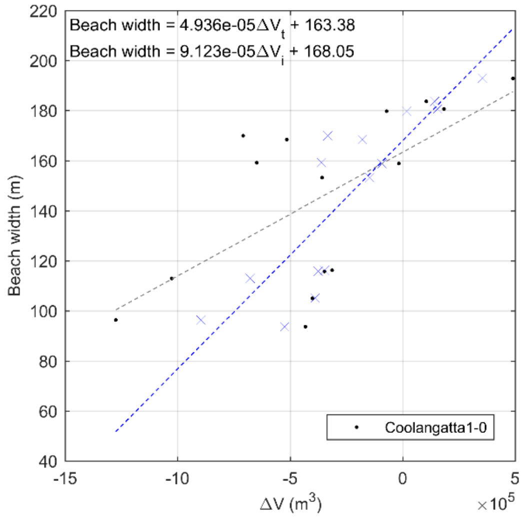
	Sub-domain	Slope [m/m^3]
NSW sections	Letitia Spit south	15.630 E-5
	Letitia Spit centre	8.136 E-5
	Letitia Spit north	9.793 E-5
	Duranbah	13.850 E-5
Gold Coast sections	Snapper Rocks	-
	Rainbow Beach	13.290 E-5
	Coolangatta Beach	9.123 E-5
	Kirra	9.044 E-5
	North Kirra	7.101 E-5
	Bilinga south	6.499 E-5
	Bilinga north	5.176 E-5
	Currumbin	3.962 E-5

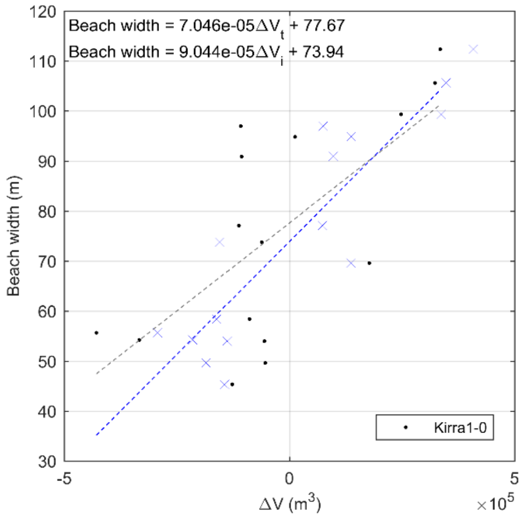
B.1.1 NSW coast sections

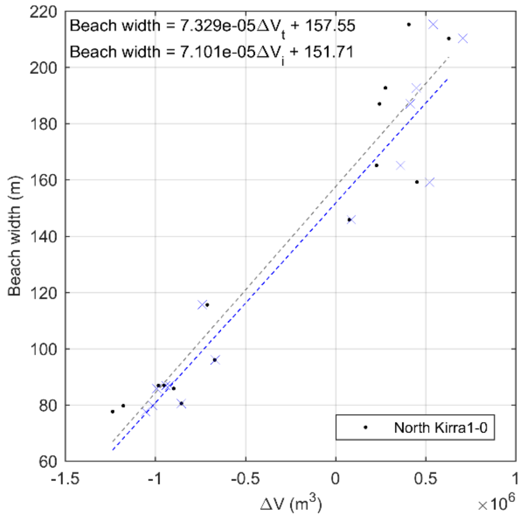


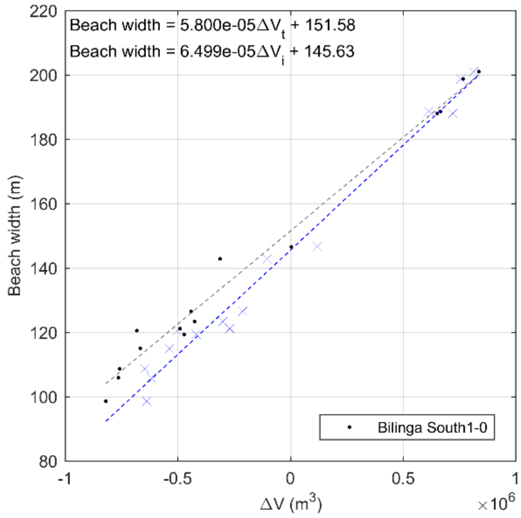
B.1.2 Gold Coast sections

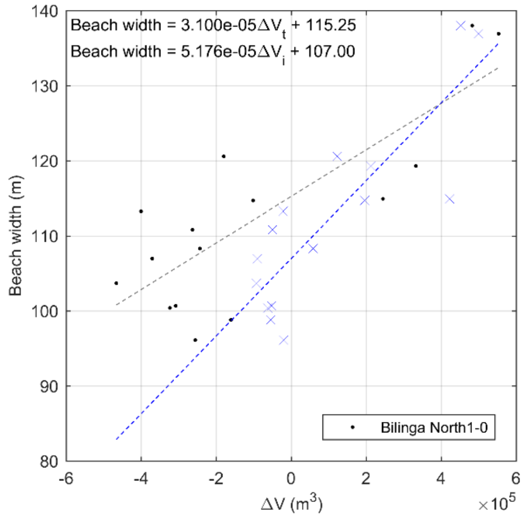


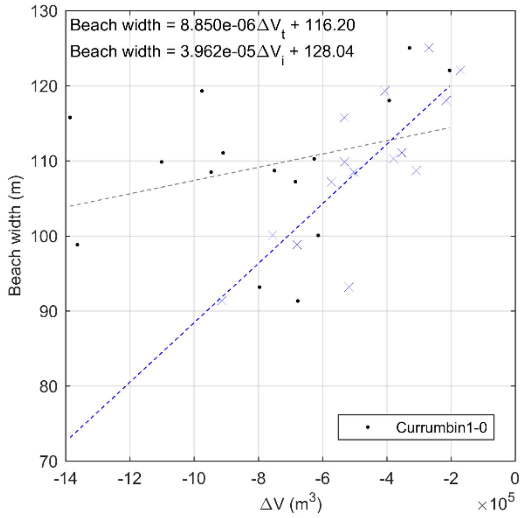







Beach width = 5.800e-05ΔVt + 151.58
Beach width = 6.499e-05ΔVi + 145.63
Beach width (m)
ΔV (m3)
×10^6
Bilinga South1-0


Beach width = 3.100e-05ΔVt + 115.25
Beach width = 5.176e-05ΔVi + 107.00
Beach width (m)
ΔV (m3)
×10^5
Bilinga North1-0


Beach width = 8.850e-06ΔVt + 116.20
Beach width = 3.962e-05ΔVi + 128.04
Beach width (m)
ΔV (m3)
×10^5
Currumbin1-0

B.2 Correlation of position of –5 m bed contour with sand volume

B.2.1 Gold Coast sections