ACOUSTIC DOPPLER CURRENT PROFILING FROM KIRRA BEACH TO COOK ISLAND – FIELD EXERCISES UNDERTAKEN BY THE TWEED RIVER ENTRANCE SAND BYPASSING PROJECT

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Abstract

The dynamic ebb-shoal bar at the entrance of the Tweed River adjacent to the NSW/QLD border has historically been a navigational hazard for the local commercial and recreational boating community. To improve the navigability of the Tweed River entrance, the training walls were extended in the 1960s. However over time, longshore sediment transport resulted in a sand build-up on the southern side of the training walls and the reformation of the ebb-shoal bar across the river entrance. Concurrently, extensive erosion occurred on the southern Gold Coast beaches located to the north of the river entrance.

To remedy this problem, the Tweed River Entrance Sand Bypassing Project (TRESBP) was established as a joint venture between the NSW and QLD State Governments. The objectives of the Project are; to establish and maintain a navigable entrance to the Tweed River, and to provide an ongoing supply of sand to the southern Gold Coast beaches consistent with the natural rate of longshore drift. The mechanical bypassing of sand from south of the river entrance to the southern Gold Coast beaches commenced in 2001.

As part of the project's ongoing monitoring program, a series of nearshore Acoustic Doppler Current Profiling (ADCP) exercises have been undertaken between Kirra Beach (QLD) and Cook Island (NSW). The objective of this work is to measure ocean current magnitudes and directions over varying tidal cycles to assist in determining the local current regime and sediment transport pathways in this complex coastal environment.

This paper will present the results from several ADCP exercises recently undertaken by the TRESBP and compare results to historical studies that were undertaken prior to the implementation of the bypassing system. The resulting information will provide a better understanding of sediment transport pathways in the project area and thereby assist in making more informed operational decisions.

Introduction

The study area for which the ADCP current monitoring exercises were undertaken is located on the east coast of Australia in the vicinity of the Queensland and New South Wales state border, between Kirra Beach to the northwest and Cook Island to the southeast (Figure 1). This small stretch of coastline is morphologically and bathymetrically complex due to its discontinuity and complex topography; with the inclusion of headlands (Point Danger, Fingal and Greenmount), Cook Island, and reef systems (the Danger Reefs and Fido's Reef). These features, as well as the Tweed River Entrance result in complex current characteristics within the study area.

As part of the project's evolving monitoring program, three nearshore Acoustic Doppler Current Profiling (ADCP) exercises were undertaken between Kirra Beach and Cook Island in 2009, 2010 and 2011 by the Department of Environment and Resource Management (DERM) on behalf of the Tweed River Entrance Sand Bypassing Project (TRESBP). The objective of this work was to measure ocean current magnitudes and directions over varying tidal cycles to investigate the current dynamics and sediment transport pathways in the project area. This information is useful when considering sand bypass operations and making decisions regarding sand pumping regimes and dredge placements.

This paper will present some of the key observations from the limited ADCP monitoring undertaken to date. This includes the influence of the East Australian Current (EAC) on the nearshore current regime; circulation cell development within the Letitia Embayment; and the deflection of littoral currents caused by the Tweed River ebb jet.

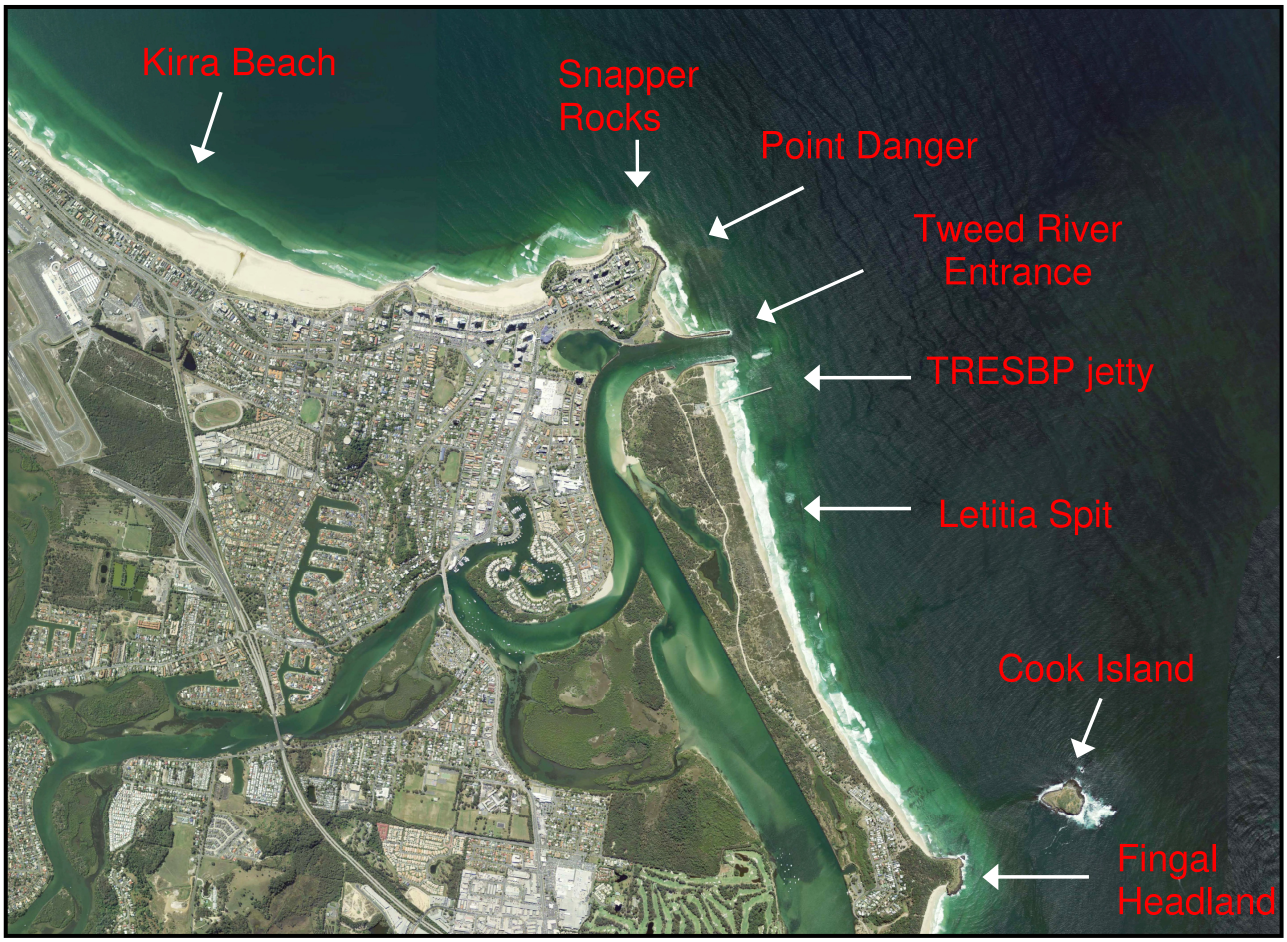

Figure 1: Tweed River Entrance and surrounds

Methodology

The ocean current profiling was conducted using a Sontek RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP). ADCP instruments work by emitting acoustic pulses of a constant frequency into the water column. As the pulses travel away from the instrument they collide with particles in the water column causing a backscatter signal to be returned to the instrument, the return signal is processed based on Doppler Shift theory. In all three field exercises carried out to date (Table 1), the instrument was side-mounted on the vessel, utilising a wooden boom and graduated alloy arm with the instrument attached to the bottom of the arm shown in Figures 2-3.

The ADCP instrument also incorporates a GPS signal from an external GPS antenna, which provides geo-referenced coordinates for the recorded data. Following calibration of the internal compass, each transect is slowly traversed whilst the ADCP makes continuous measurements.

Figure 2: ADCP vessel mount

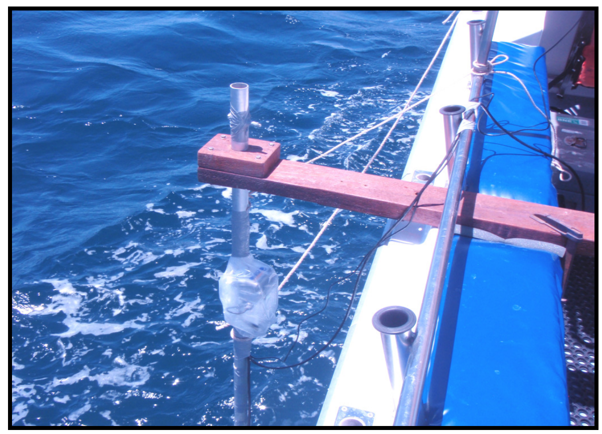

Figure 3: ADCP vessel mount

The details of each of the exercises, carried out on 13 November 2009, 20 December 2010 and 2 & 3 August 2011, respectively, are summarised in Table 1 below. All three exercises were conducted during calm weather, with low wave energy (<0.5m significant wave height), in order to maximise data quality.

Following each field exercise, the collected data was processed and plotted using Sontek RiverSurveyor software. For this study, some simple analysis was undertaken to determine the average current magnitude and direction for each survey, which was then used to produce average current velocity vector plots overlayed onto aerial imagery. It should be noted that these plots are representative only as they are based on the average current magnitude and direction for large sections of the entire water column, and therefore do not capture smaller scale currents or represent changes in current direction or magnitude through the water column. Therefore the plan view average velocity vector plots should be viewed in conjunction with the current profiles.

Table 1: Exercise details

Exercise	Date	Vessel	Wind	Tide	Waves	Number and Location of Transects
Exercise 1	13-11-2009	7m Shark-Cat. "this way up"	0700-1400: NW-NE >25km/h	Ebb tide High: 0517 Low: 1121	<0.5m ENE	9: North Letitia Spit; Tweed River Entrance; Duranbah; Point Danger 7 x shore normal to 20m depth 2 x River entrance
Exercise 2	20-12-2010	11m Stebercraft Cat. "Reef Hunter"	0600: SW<10km/h 1000: N<25km/h 1200: NE <25km/h	Ebb tide High: 0714 Low: 1349	<0.5m E	15: Fingal Head-Cook Island; Central-North Letitia; Duranbah; Point Danger; Snapper Rocks
Exercise 3a	02-8-2011	11m Stebercraft Cat. "Reef Hunter"	0900: S 4km/h,	Flood – high tide Low: 0348 High:0945	<0.5m E	11: Fingal Head-Cook Island; Letitia Spit; Duranbah; Point Danger; Snapper Rocks; Greenmount; Coolangatta; Kirra
Exercise 3b	02-8-2011	11m Stebercraft Cat. "Reef Hunter"	1500: ESE 20km/h	Ebb – low tide High:0945 Low:1535	<0.5m E	9: Fingal Head-Cook Island; Letitia Spit; Duranbah; Point Danger; Snapper Rocks; Greenmount
Exercise 3c	03-8-2011	11m Stebercraft Cat. "Reef Hunter"	0900: SW 6km/h 1500: ESE 19km/h	Flood – high - ebb tide Low: 0428 High: 1033 Low: 1626	<0.5m ENE	13: (5 extended): Fingal Head-Cook Island; Letitia Spit; Duranbah; Point Danger; Snapper Rocks; Greenmount; Coolangatta, Kirra, Currumbin

Results

Three ADCP monitoring exercises were conducted between 2009 and 2011 in an area extending from Cook Island to Kirra Beach with over 57 surveys completed. Given the extensive range of surveys undertaken; the results presented will focus on specific areas which displayed current observations of interest such as changes in current magnitude and direction over varying tidal cycles, as well any anomalies. Four smaller geographical areas have been chosen to present the results based on their bathymetric and morphological features. These are Point Danger, Tweed River Entrance, Letitia Spit North (adjacent to the TRESBP jetty) and Cook Island. The results of these surveys have been presented in plan view with averaged current velocity vectors to display the indicative current movement within each geographical area over each of the 5 survey events (Figures 27-31). In addition, a selection of survey transects have been presented for each region in profile view (Figures 4-26). It should be noted that the current velocity descriptions follow the oceanographic convention of describing the direction in which the current is flowing. All directions are given in respect to True North.

Point Danger ADCP Surveys

A total of 16 surveys were conducted in the vicinity of Point Danger, three in 2009, four in 2010 and nine in 2011. The 2009 surveys were conducted at Duranbah Beach just prior to low tide. The current velocities closer to shore, in depths of less then 6m were highly mixed, but tending northward, for all three surveys. Beyond a depth of 6m, the current shifted to a stabilised SE flow at average speeds of 0.35 – 0.39m/s which can be seen in Figures 4-5. When the North velocity bin plot is examined in Figure 6, it is apparent that a northward flowing bottom current existed below the SE flowing current at the time of the survey.

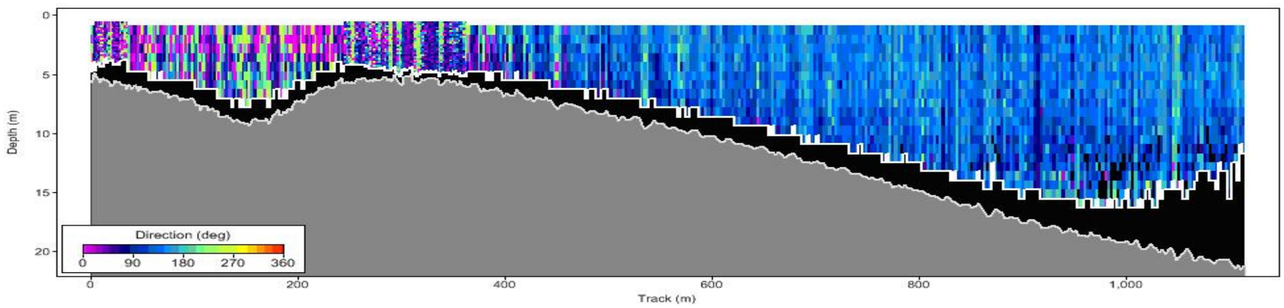

Figure 4: Current direction Duranbah Beach 13/11/2009

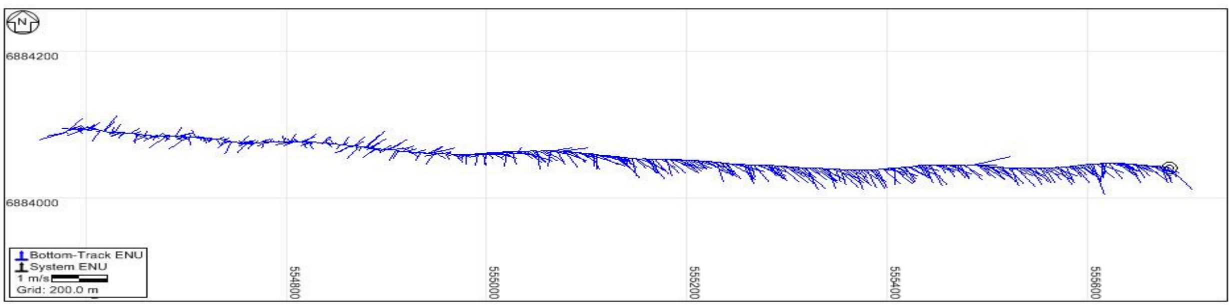

Figure 5: Average current velocity vector plot Duranbah Beach 13/11/2009

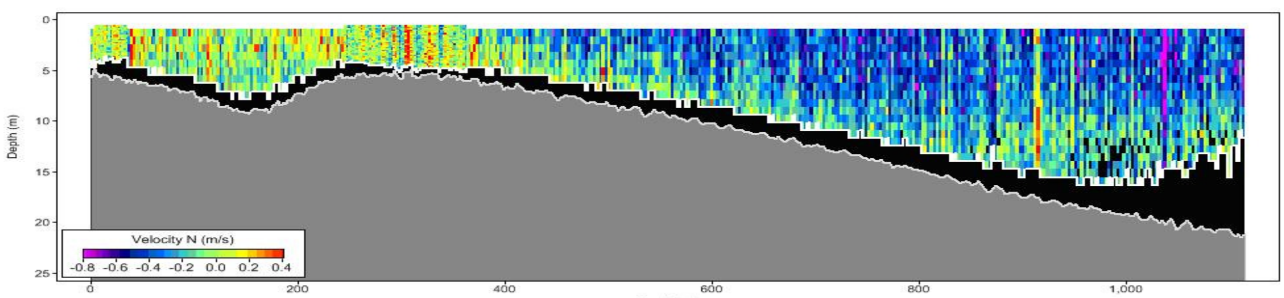

Figure 6: North Velocity Bins (m/s) Duranbah Beach 13/11/2009

In 2010, four surveys were conducted off Duranbah Beach / Point Danger. All four surveys were conducted on the ebb tide, close to low tide. The first transect was orientated east-west from Duranbah Beach. Close to the shoreline, the current velocity was slightly mixed, stabilising beyond a depth of 6m where the current velocity increased to 0.33m/s and shifted SE. The two subsequent surveys, both orientated NE from Point Danger, revealed similar results with SE currents beyond a depth of 6m averaging at a speed of 0.31m/s. The final survey was orientated north from Point Danger where beyond 6m depth, the current speed averaged 0.26m/s, however flowing in an ESE direction instead of SE, as the current moved around the Point Danger Headland from Coolangatta Bay.

Three ADCP surveys including Duranbah Beach, Snapper NE and Snapper NW were conducted three times each between 2-3 August 2011 (Table 1). During the first 2011 exercise, the current velocities observed to the northwest of Snapper Rocks were fairly consistent throughout the transect averaging between 0.21-0.23m/s in an easterly to ESE direction as the current flowed around the Point Danger Headland. Further to the east, the Snapper NE survey current velocity averaged 0.31m/s in a SE direction offshore and 0.23m/s closer to Snapper Rocks. Further south at Duranbah Beach beyond a depth of 10m, the current stabilised to a SE flowing current with average speeds of 0.28m/s (Figures 7-8). The second and third 2011 exercises yielded similar results with the current transitioning from ESE to SE as it moved around the headland at average speeds ranging 0.17-0.25m/s.

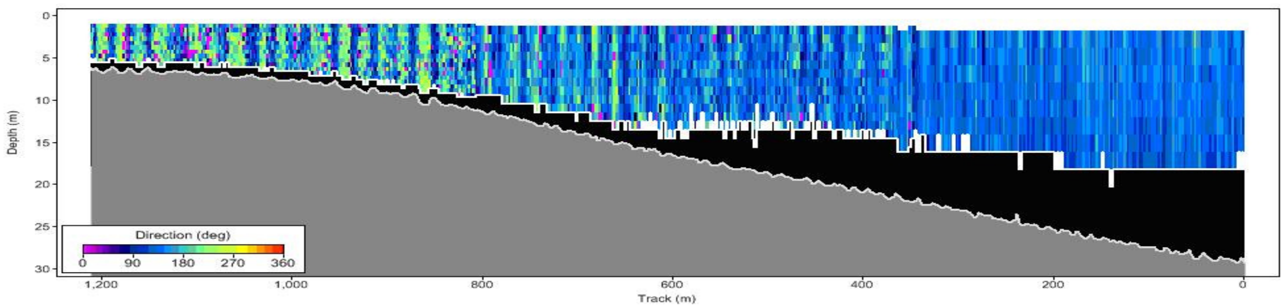

Figure 7: Current direction Duranbah Beach 02/08/2011

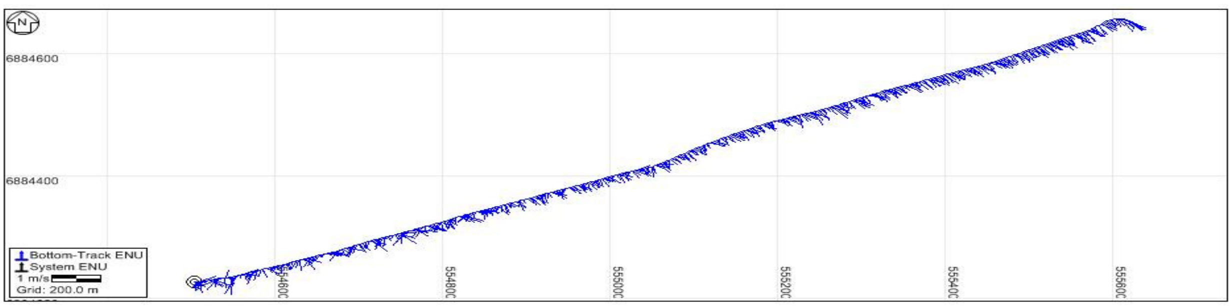

Figure 8: Average current velocity vector plot Duranbah Beach 02/08/2011

Tweed River Entrance

A total of six surveys were conducted over the Tweed River Entrance, two in 2009, one in 2010 and three in 2011. The two 2009 surveys were conducted beyond the river training walls on an ebb tide, recording a swift ebb jet flowing eastward at an average speed of 0.78m/s out to a depth of approximately 10m and reaching speeds of up to 1.5m/s. Immediately seaward of the ebb-shoal bar, the current speed reduced to an average of 0.43m/s flowing in a SE direction.

During the 2010 survey, the Tweed River Entrance was monitored on an ebb tide, approximately two hours prior to low tide. The velocity inside the river entrance adjacent to the Jack Evans Boat Harbour averaged at 1.4m/s in the direction of the entrance. 200m beyond the river entrance, the ebb jet velocity dramatically decreased and shifted southward as it met the EAC-induced SE current. This intersection occurred over the ebb-shoal bar at a depth of 5m. Further offshore, the SE current reached average speeds of 0.36m/s.

Similar results were observed in the surveys conducted on 2-3 August 2011, the first of which was conducted during the flood tide. Velocities within the river entrance adjacent to Jack Evans Boat Harbour reached an average of 0.91m/s in the direction of the estuary, with decreased values between the river training walls (average of 0.51m/s). Despite the flood tide, the southerly flowing EAC-induced current was observed immediately beyond the ebb-shoal bar flowing at an average speed of 0.18m/s SE - SSE direction (Figures 9-11).

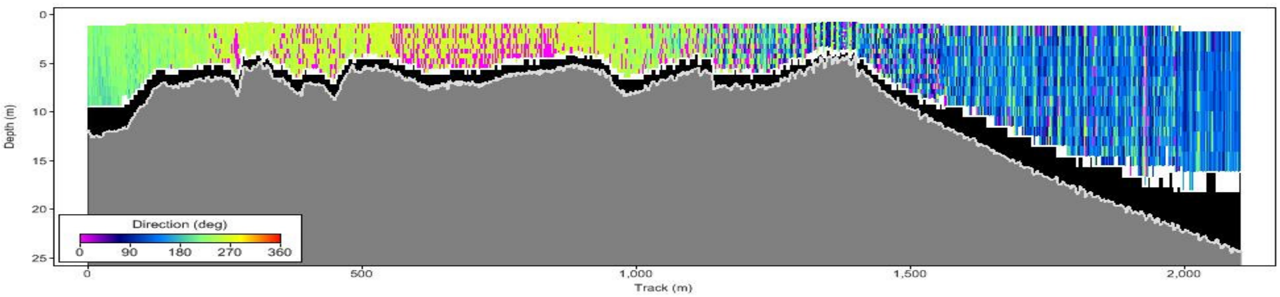

Figure 9: Current direction Tweed River Entrance 02/08/2011

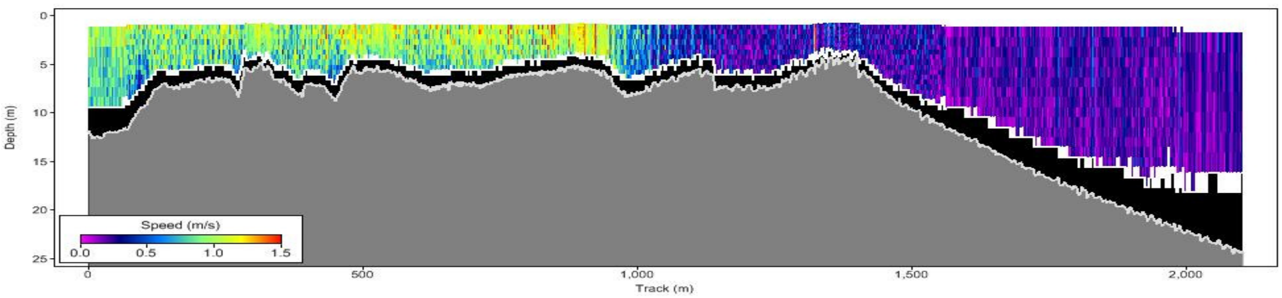

Figure 10: Current speed (m/s) Tweed River Entrance 02/08/2011

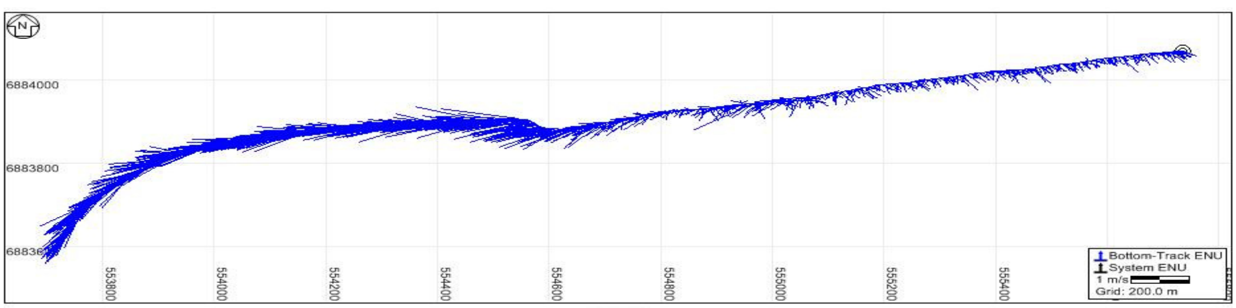

Figure 11: Average current velocity vector plot Tweed River Entrance 02/08/2011

The second 2011 Tweed River Entrance survey was conducted shortly after the low tide. The current magnitude within the river reached an average of 0.42m/s in the direction of the entrance. The ebb jet met the EAC-induced southerly current several hundred meters beyond the ebb-shoal bar at depth of 10-15m, approximately 500-600m offshore from the river entrance groynes. The SE flowing current seaward of this point flowed at an average speed of 0.17m/s.

The last of these surveys was conducted on mid flood tide and was extended further offshore. The current velocities within the river reached an average of 0.72m/s in the direction of the estuary. Over the ebb-shoal bar, velocities decreased to 0.21m/s and were mixed. Immediately beyond the bar and for several hundred meters offshore from the entrance to a depth of 10m, the current velocity remained mixed and reduced to an average speed of 0.12m/s. The SE flowing current was not clearly observed until 1.5km offshore well beyond the ebb-shoal bar, at depth of 25m where it flowed at an average speed of 0.21m/s. These results can be seen in Figures 12-13.

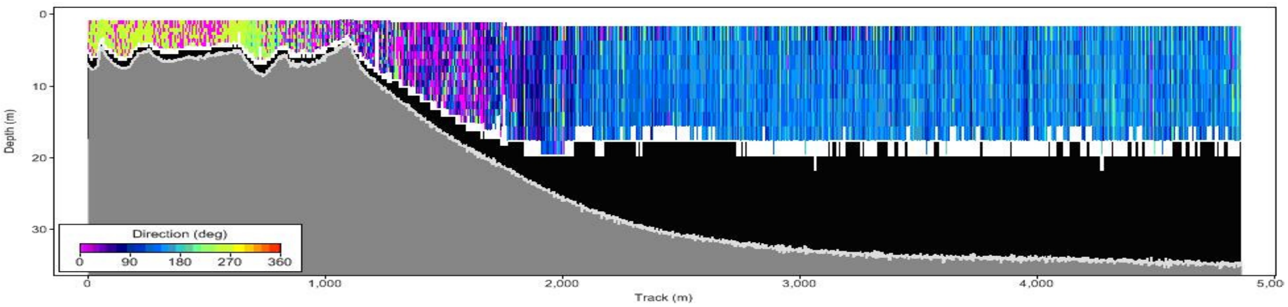

Figure 12: Current direction Tweed River Entrance 03/08/2011

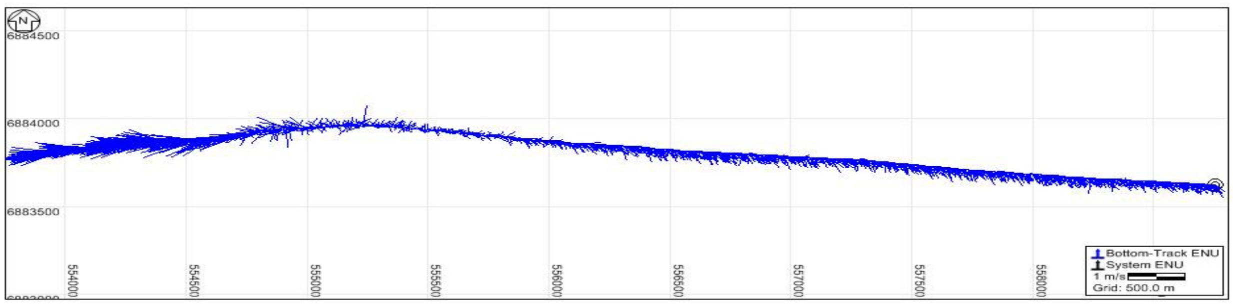

Figure 13: Average current velocity vector plot Tweed River Entrance 03/08/2011

Letitia Spit North ADCP Surveys

A total of seven surveys were conducted in the vicinity of Letitia Spit North adjacent to the TRESBP jetty, one in 2009, three in 2010 and three in 2011. The 2009 ADCP survey was conducted on an ebb tide commencing in a water depth of 4m between the TRESBP jetty and southern Tweed River training wall. Current velocities observed close to shore were mixed but tended north with an average speed of 0.2m/s. Beyond a depth of 15m the current stabilised and increased in magnitude to an average speed of 0.52m/s, flowing in a SE direction. These results can be seen in Figures 14-15.

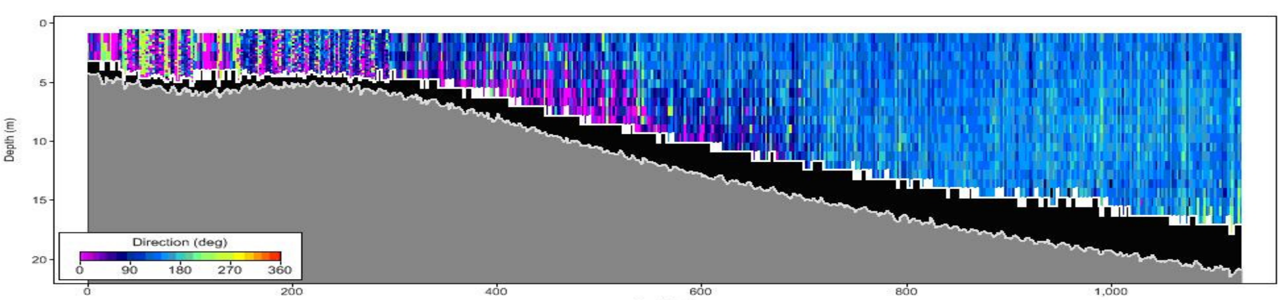

Figure 14: Current direction Letitia Spit North 13/11/2009

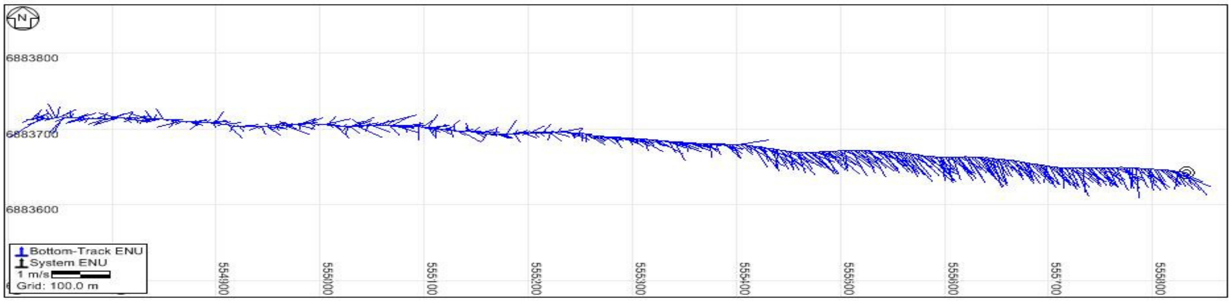

Figure 15: Average current velocity vector plot Letitia Spit North 13/11/2009

The 2010 surveys were all conducted during an ebb tide. The second survey undertaken recorded a stable NNW flowing current adjacent to the shore in depths of 2-5m, at average speeds of 0.35m/s (Figures 16-17). Beyond a depth of 10m, several hundred meters offshore, the current transitioned 180° from NNW to SSE, flowing at an average speed of 0.46m/s. When the north velocity bin plot for the entire water column is examined in Figure 18, it is evident that the SSE current magnitude was strongest at the surface of the water column approaching speeds of 1.0m/s and lowest along the seafloor. Current magnitude was more consistent over the bar and trough, reaching speeds of up to 0.5m/s.

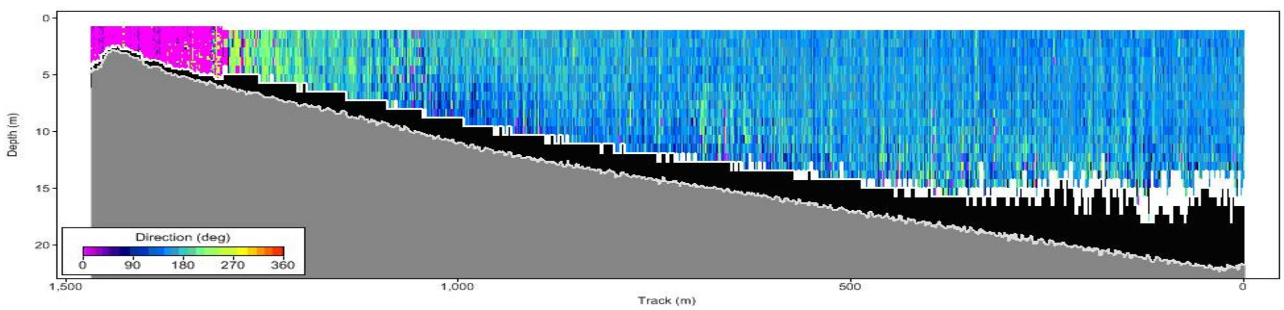

Figure 16: Current direction Letitia Spit North 20/12/2010

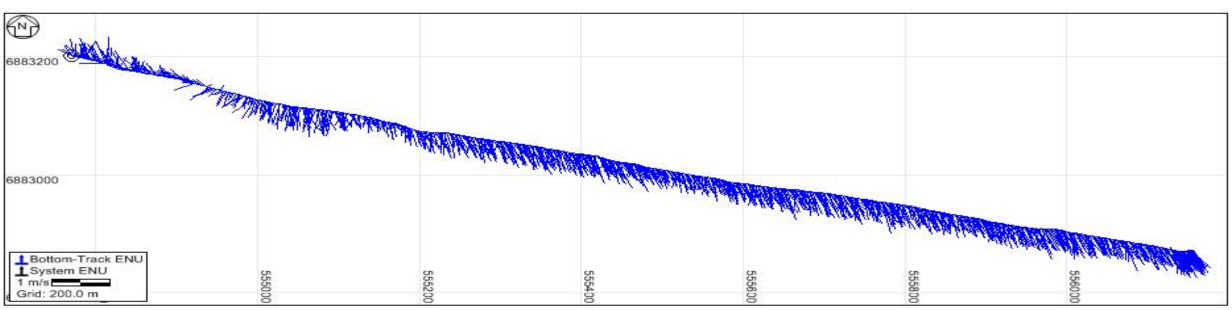

Figure 17: Average current velocity vector plot Letitia Spit North 20/12/2010

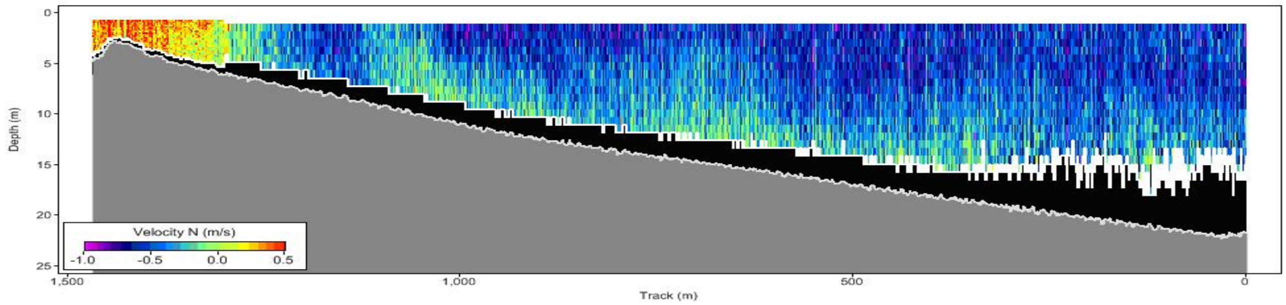

Figure 18: North Velocity Bin (m/s) Letitia Spit North 13/11/2009

The third 2010 ADCP survey was conducted further north, closer to the TRESBP jetty, where the current velocity observed out to a depth of 6m was 0.42m/s in an ENE direction. Beyond a depth of 10m the current increased to an average speed of 0.62m/s and swung to a SE direction. A stream of faster moving water was observed within the SE current, most probably due to the influence of the ebb tide from the Tweed River.

Three ADCP surveys off Letitia Spit North were conducted to the south of the TRESBP jetty from a depth of 5m, during the 2-3 August 2011 surveys. The first survey was conducted during the high tide on 02/08/2011. The current observed closer to shore in shallower water was mixed in direction and moved at average speeds of 0.3m/s. Further offshore from a depth of 10m, the current began to stabilise to a SE direction and decreased to an average of 0.15m/s. The second 2011 survey was conducted at low tide on the 02/08/2011 and the current observed during this transect was mixed, tending towards the north at an average speed of 0.21m/s decreasing to 0.16m/s further offshore . These results can be seen in Figures 19-20.

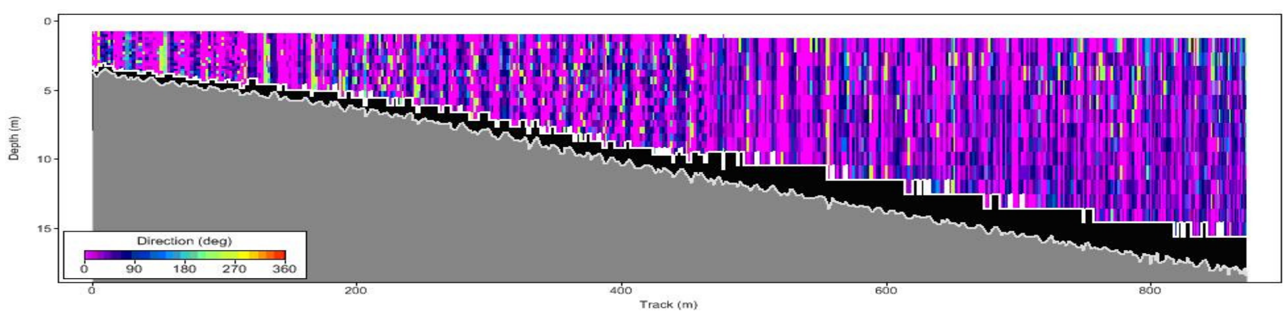

Figure 19: Current direction Letitia Spit North 02/08/2011

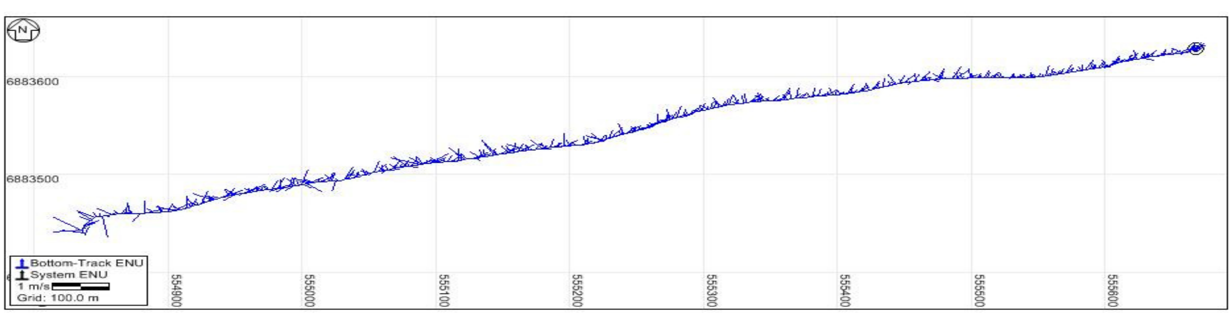

Figure 20: Average current velocity vector plot Letitia Spit North 02/08/2011

The final 2011 Letitia Spit North survey was conducted on the high tide the following day (03/08/2011), showing similarities with the current observed during the low tide on the previous day during which a northward flowing current was observed throughout the water column. The current flowed at an average speed of 0.2m/s out to a depth of 10m. Beyond this depth the average current speed decreased slightly to 0.17m/s.

Cook Island ADCP Surveys

A total of eight ADCP transects were conducted in the vicinity of Cook Island adjacent to Fingal Headland. Two were undertaken in December 2010 and the other six were undertaken in August 2011. During the 2010 monitoring exercise, a survey was conducted in a NE orientation to the north and south of Cook Island during the low tide. The current observed seaward of the island and its rocky shelf reached an average of 0.4m/s flowing in a stable SE direction. Towards Fingal Headland, the current was more mixed, tending northward at speeds of 0.1–0.2m/s, with the exception of a stream of faster moving current flowing in a SE direction between Cook Island and Fingal Headland at speeds of up to 0.6m/s. The results from this survey are seen in Figures 21-23.

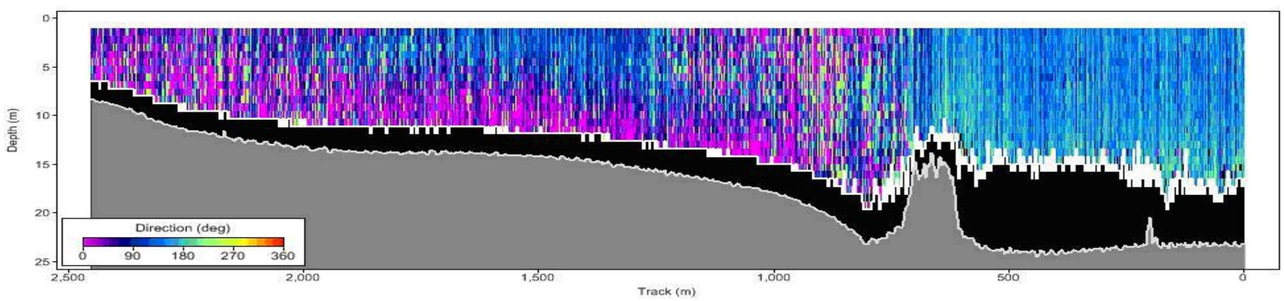

Figure 21: Current direction Cook Island South 20/12/2010

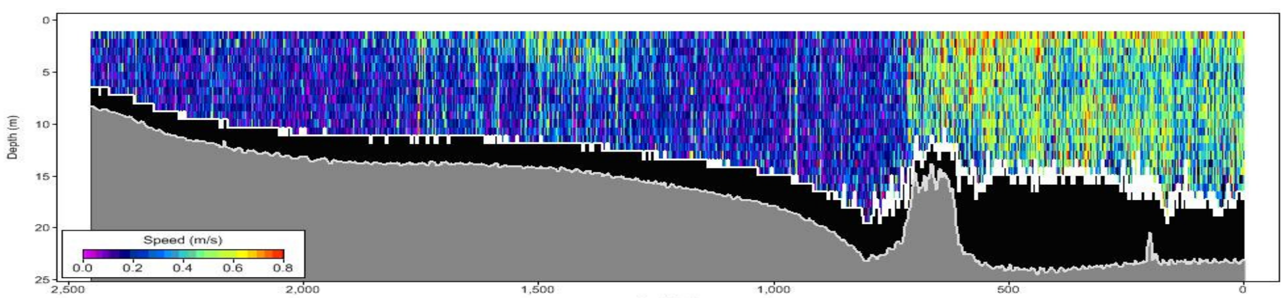

Figure 22: Current speed (m/s) Cook Island South 20/12/2010

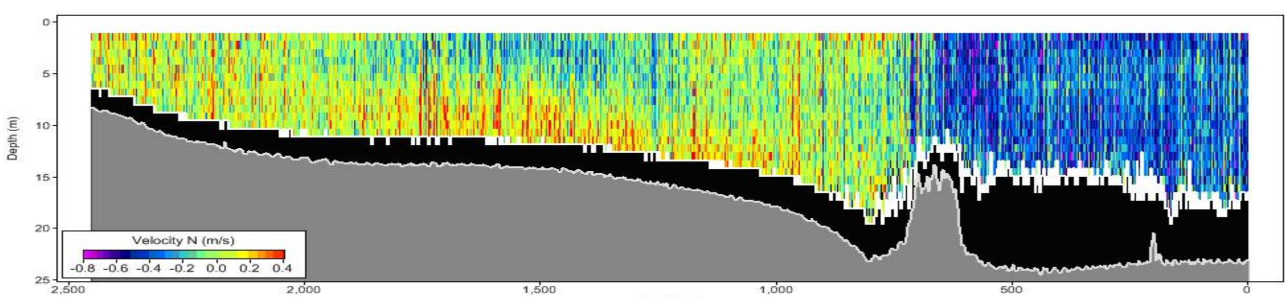

Figure 23: North current velocity bin Cook Island South 20/12/2010

Three pairs of ADCP surveys were conducted to the north and south of Cook Island on 2-3 August 2011. These surveys generally showed mixed current direction to the west of the island adjacent to Fingal Headland; and a stable flowing SSE current seaward of the island, averaging 0.18 – 0.25m/s. The last pair of Cook Island surveys was conducted on the high tide on 03/08/2011 and included an extension to the southern survey for several kilometres offshore. The survey extension traversed Fido's Reef over which the current speed increased up to 0.6m/s and became mixed in direction. Beyond Fido's Reef, the offshore current flowed SE at an average speed of 0.19m/s. To the west of the reef, the current flowed in a more southerly direction. The results from this survey are seen in Figures 24-26.

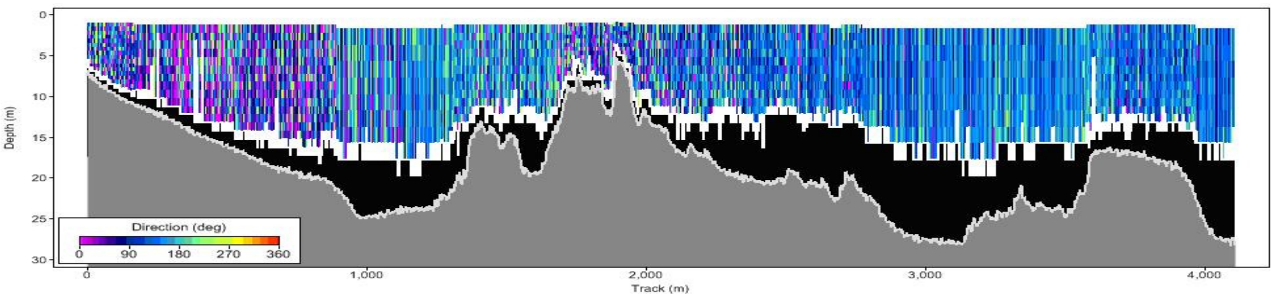

Figure 24: Current direction Cook Island South 03/08/2011

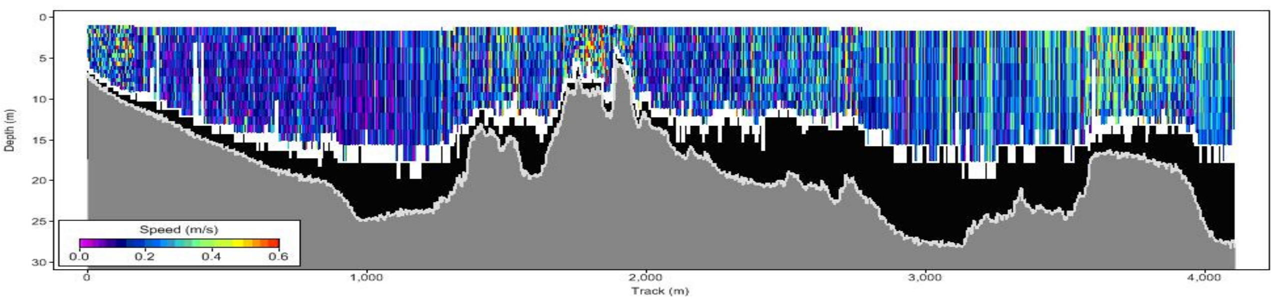

Figure 25: Current speed (m/s) Cook Island South 03/08/2011

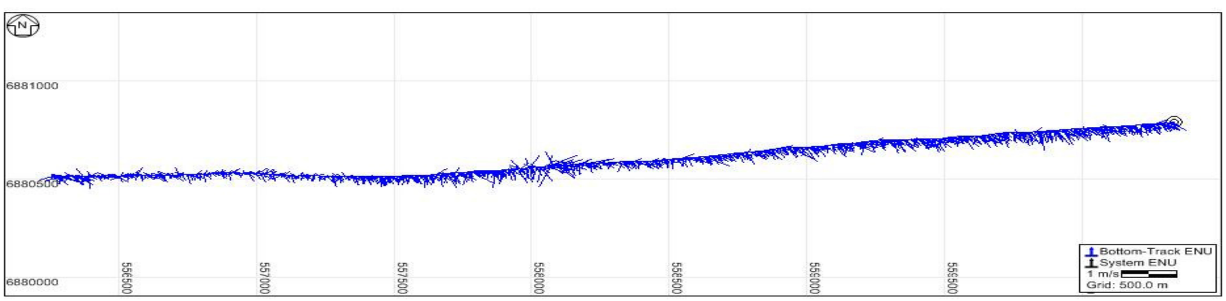

Figure 26: Average current velocity vector plot Cook Island South 03/08/2011

Average Current Velocity Vector Plots

The average current direction and magnitude has been calculated for each survey in order to provide a useful overview of the large scale current movements in the study area. As previously mentioned, the vector plots are based on the average current magnitude and direction for large selections of the entire water column and do not reflect smaller scale changes in current velocity or changes through the water column. As such the plan view plots should be viewed in conjunction with the current profiles.

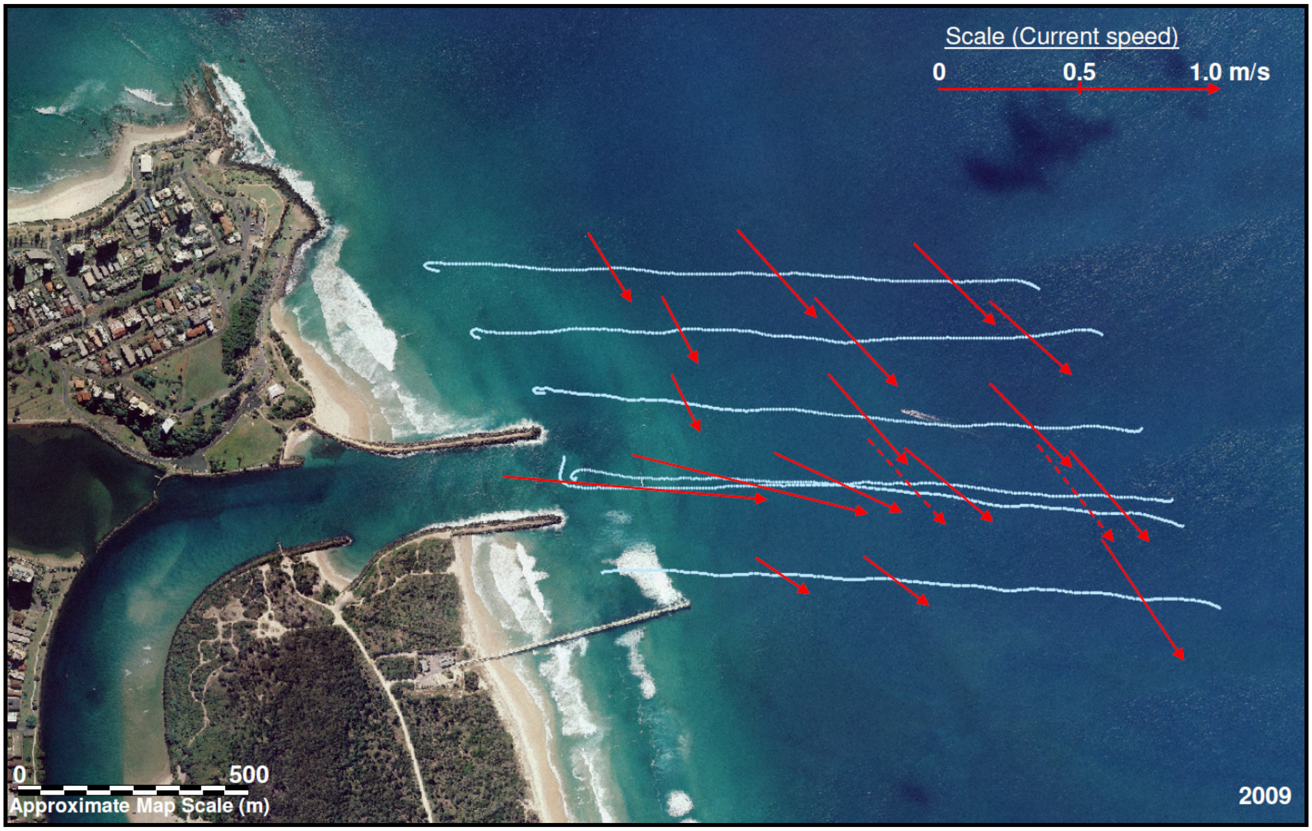

Figure 27: Exercise 1 - Average current velocity vector plot 13/11/2009

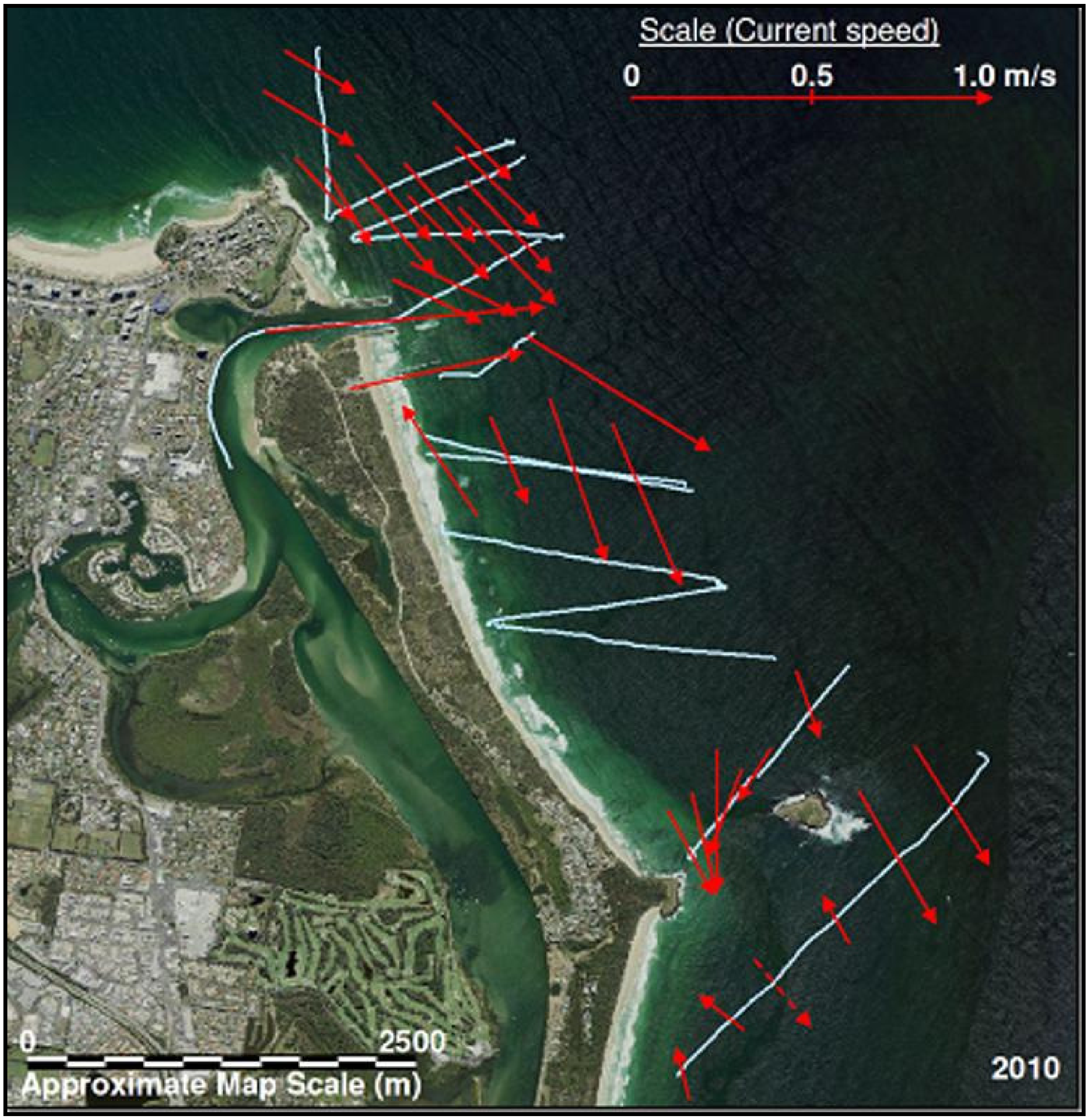

Figure 28: Exercise 2 - Average current velocity vector plot 20/12/2010

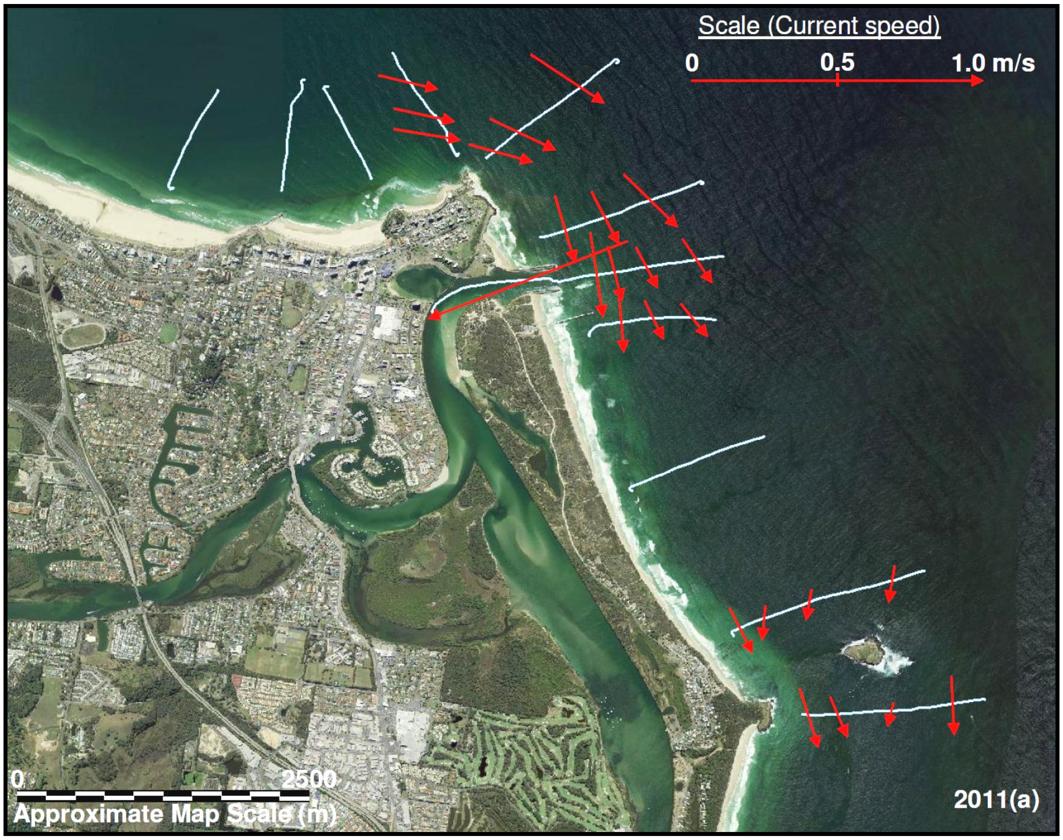

Figure 29: Exercise 3a - Average current velocity vector plot 02/08/2011 (a.m.)

Figure 30: Exercise 3b - Average current velocity vector plot 02/08/2011 (p.m.)

Figure 31: Exercise 3c - Average current velocity vector plot 03/08/2011

Discussion and Key Findings

Currents Influencing the Study Area

The ocean current regime within the study area is controlled by a complex interaction of meteorological conditions, tides, shelf currents, offshore currents, wind and waves. The relative influence of each of these components will vary at different depths and is dependant on their proximity to topographical features such as reefs, headlands, islands and river entrances.

Numerous current monitoring studies have been undertaken to assess current and sediment transport processes in the study area and include studies undertaken by Delft (1970), Tomlinson and Foster (1986), Wyllie and Tomlinson (1991), Haradasa, *et al* (1991), PWD (1991), MHL (1996) and Hyder *et al* (1997), Allen, (1998), amongst others. These studies determined several key factors contributing to the current characteristics within the study area including the East Australian Current (EAC), tidal and wind induced currents, wave induced longshore currents and coastal trapped waves.

Many of the findings from these studies have assisted in interpreting the recent data collected by DERM's Coastal Impacts Unit during the recent current profiling exercises and the results will be discussed in the following sections.

Recent Observations - Point Danger

The EAC is a key influencing factor within the study area, exhibiting seasonal, interannual and decadal changes and is typically stronger in the months between December to April (Ridgway and Hill, 2009). The EAC generally flows southward along the edge of the continental shelf at peak speeds of up to 2.5m/s (Allen, 1998); however, its position is highly variable and impinges on the coast where it has considerable influence on the current characteristics in the study area. Previous current studies have determined that the southward flowing EAC current is deflected away from the coast at Point Danger resulting in SE flowing nearshore currents, flowing at speeds of up to 0.5m/s (PWD (1991), Wyllie and Tomlinson (1991), Hyder *et al*, (1997). At times, these deflections produce large clockwise circulation cells in the coastal embayment to the immediate south of the headland creating northward flowing currents along the shore (Hyder *et al*, 1997). These 'reverse flow' circulation cells in Letitia Embayment may have the effect of enhancing northerly littoral drift (PWD (1991), Haradasa *et al* (1991)).

The EAC-induced SE flowing current appeared to be topographically controlled by the Point Danger headland during all three years of ADCP monitoring exercises, following the 5m depth contour and increasing in velocity as it moves east from Coolangatta Bay around the headland to the south. During all of the Point Danger surveys, the current velocities within the shallower waters adjacent to the headland were mixed, most with elements of north velocity movement attributed to littoral currents.

The data collected between 2009 and 2011 shows a reduced velocity of the nearshore EAC-induced current. In 2009, the SE current observed at Duranbah Beach from depths of 5m at average 0.35-0.4m/s. The surveys in 2010 revealed an easterly current flowing to the north of Point Danger, transitioning to a SE flowing current as the current moved around the headland to the south, flowing at average speeds of 0.26-0.33m/s. In 2011, the SE current flowing to the northeast of Snapper Rocks averaged 0.23-0.31m/s during the high tide and 0.2-0.25m/s during the low tide on the same day, and 0.19-0.2m/s on the high tide the following day. The SE current was observed to also have diminished in magnitude in the waters just adjacent to Cook Island from an average speed of 0.4m/s in 2010 to 0.18-0.25m/s in 2011.

It is likely that this decrease is attributed to the weakening of the EAC over the winter period, evidence of which can be seen in the Integrated Marine Observing System (IMOS) images from the 2009 and 2011 survey dates (Figures 32-33). The water surface temperature recorded by the ADCP in the vicinity of Point Danger during the November 2009 (22.9-23.5℃) and December 2010 (24.6-25.0℃) surveys, both conducted in the 'summer' period, was noticeably higher then that observed in August 2011 (20.2-20.6℃) which was conducted during the winter period.

It is worth noting the difference in current velocity of the SE moving current between the high tides on two consecutive days during the August 2011 surveys. The average velocity approximately 1km off Duranbah Beach reduced from 0.28m/s on the 02/08/2011, reducing to 0.18m/s on 03/08/2011. Whilst this reduction may be as a result of tidal influences, it is also possible that northward current observed flowing in the Letitia Embayment, thought to be a clockwise circulation cell caused by a large scale eddy, may have negated or deflected the effect of the SE current moving past Point Danger. The current velocity in the shallow waters of Duranbah Beach was also more mixed during the period of northward flowing current along Letitia Spit, possibly indicating an area of northward and southward current convergence.

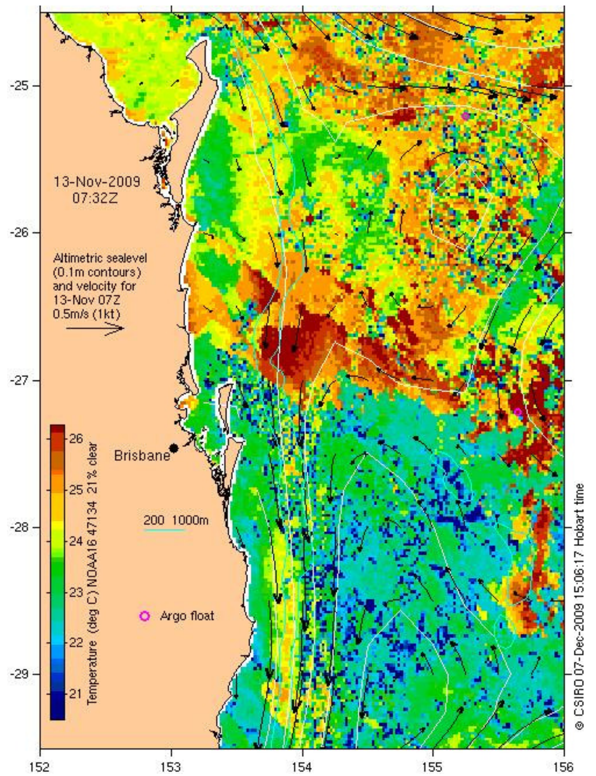

Figure 32: Ocean surface current and temperature 07:32Z 13/11/2009 - Integrated Marine Observing System (IMOS)

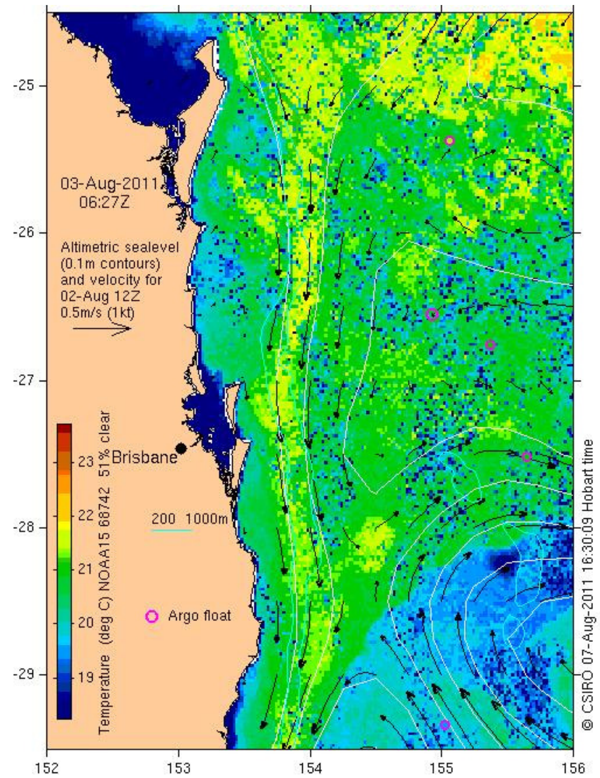

Figure 33: Ocean surface current and temperature 06:27Z 03/08/2011 - Integrated Marine Observing System (IMOS)

Recent Observations - Tweed River Entrance

From the field exercises undertaken and the results presented it was found that a southeast flowing current prevailed adjacent to the Tweed River Entrance on all tide cycles. This current is attributed to the EAC which can manifest itself on to the continental shelf, impacting as a secondary flow directly on the coastline (PWD, 1991). Previous studies have determined that within the study area, the EAC is most prevalent at Point Danger, the Tweed River Entrance and Letitia Spit where it reaches speeds of up to 0.3m/s and may significantly influence sediment transport in these areas (Hyder *et al*, 1997). The ADCP monitoring undertaken recently by DERM's Coastal Impacts Unit has recorded even faster flowing EAC-induced currents in the study area.

The location and strength of the EAC-induced current adjacent to the river entrance was found to depend on the stage of the tide at the time of the survey, appearing to intersect or flow just beyond the ebb-shoal bar, being especially conspicuous on the ebb tide. The SE current adjacent to the Tweed River Entrance was observed to flow at average speeds of 0.4m/s in 2009, 0.36m/s in 2010, and 0.17-0.21m/s in 2011.

Based on data collected during the flood tide on 03/08/2011, it appears that the incoming radial tidal flow can conflict with the SE current adjacent to the river entrance. As a result, the SE current appeared 'masked' and was observed 1.5km offshore during this survey. However, the same degree of 'masking' was not observed on the flood tide on the previous day, during which the SE current was located only several hundred meters offshore and therefore cannot be attributed to tidal influence alone. It is likely that another factor was influencing the SE current during the flood tide monitored on the 03/08/2011 and when the broader area is examined, a northward flowing current was detected within the Letitia Embayment. This northward current was also detected on approach of the low tide on the previous day, thus discounting tidal flow as the sole contributing factor to the northward flow.

It is probable that a clockwise circulation cell, caused by the deflection of the EAC off Point Danger (Hyder *et al*, 1997) had developed during the afternoon of 02/08/2011 and continued the following day. These circulation cells have the ability to create northward flowing currents along the shoreline of Letitia Spit which may expedite sediment transport. As this northward flowing current approached the river entrance, it converged with the incoming flood tide and southerly EAC-driven current creating an area of current mixing surrounding the river entrance.

Interestingly, the hydrodynamic computer modelling conducted for the TRESBP EIS indicated that during the flood tide, the EAC-induced south flowing current runs alongshore close to Point Danger and Duranbah beach and contributes to the radial inflow into the river entrance. During the ebb tide, the EAC is deflected further offshore by the ebb jet, reducing its nearshore influence at point Danger and Duranbah (Hyder *et al*, 1997). Whilst the recent monitoring supports that the flood tide does allow the EAC to flow close to Point Danger, the SE flowing current was observed to be at its most conspicuous during an ebb tide as opposed to the flood tide.

Recent Observations - Letitia Spit North

The surveys conducted at Letitia Spit North adjacent to the TRESBP jetty yielded varying results. The 2009 survey was conducted on the ebb tide in between the jetty and southern training wall. Approximately 450m seaward of the jetty, a swift SE flowing current was detected moving at average speeds of 0.52m/s. The SE current during this survey can be attributed to the EAC-induced southerly flow, as well as the ebb jet current from the Tweed River Entrance. These results are similar to those found by MHL in 1996.

The 2010 surveys were also conducted during the ebb tide approximately 500m south of the jetty, in this instance recording some northward littoral current movement along the bar and trough running parallel to the shoreline. As this northward flowing current intercepted the ebb-jet from the river mouth just south of the jetty it was deflected SE flowing at average speeds of 0.62m/s close to the river entrance and 0.46m/s further south. Under the low wave conditions and during an ebb tide, it is possible that northward littoral currents do not pass the entrance as flow is deflected southward as it reaches the ebb jet, however more research would be required to substantiate this supposition.

When the north velocity bin plots for the 2010 surveys are examined, the observed current speed was fastest in the upper water column and slowest along the sea floor. This finding could be supported by the bed current monitoring conducted by Wyllie and Tomlinson (1991) who recorded predominantly shore parallel currents in both a north and south direction in the study area except for the Tweed River Entrance where tidal flows generated a strong offshore component. The bed current reversal recorded is attributed to the influence of longshore currents driven by the predominant wave direction for the northward flowing currents, and the influence of the EAC-driven southward moving current. Near bottom current speeds were found to vary in magnitude and reached speeds of up to 0.2m/s, averaging less then 0.1m/s.

The three Letitia Spit North 2011 surveys showed almost no similarities with those conducted in 2009 and 2010. The first survey was conducted on a high tide and recorded a weak mixed southerly current flowing at average speeds of 0.15m/s. The second survey was conducted at low tide, with an ebb-jet still flowing from the river entrance. Despite the ebb tide, a northward flowing current was observed throughout the entire survey, out to a depth of 15m, flowing at an average speed of 0.16-0.21m/s with decreasing speed seaward. Similarly, the third survey conducted on the high tide the following day also recorded this northward flowing current throughout the entire survey at average speeds of 0.17-0.2m/s with decreasing speed seaward.

During all 2011 three surveys, the EAC-induced SE current was observed to the north of Point Danger and to the south of Cook Island supporting the theory that the northward flowing current detected was a result of a clockwise circulation cell within Letitia Embayment. The surveys conducted at mid Letitia Spit confirm that the northward flowing current was confined to the embayment. As the northward flowing current was observed on differing tidal cycles, it cannot be attributed to tidal influence. This 'current reversal' has been detected during previous current studies undertaken in the area and were attributed to a circulation cell within the Letitia Embayment caused by a deflection of the EAC-induced southerly current off the Point Danger headland or an eddy forming off the southern training wall during an ebb tide.

Recent Observations - Cook Island

As discussed in previous studies, Cook Island creates a point of divergence for the EAC-induced south flowing current in the study area. Seaward of Cook Island and its rock shelves, the observed current was consistently southward flowing. Whilst surveys have detected a predominantly SE flowing current in the study area, it appears that the current begins to shift more southward from Cook Island as water moves into the Dreamtime Embayment to the south. The water movement in between Cook Island and the Fingal Headland appeared to be more complex.

During the 2010 survey conducted on an ebb tide, a slow (0.0-0.2m/s) northward flowing current was observed between the headland and island, with the exception of a faster moving stream of south flowing current (~0.5m/s). Immediately seaward of the island's rocky shelf, the SE current flowed at average speeds of 0.4m/s. The 2010 Cook Island surveys show that the EAC-induced south flowing current does indeed diverge at Cook Island, flowing to either side of this feature. Importantly, despite this brisk southerly flow, northward current movement was also detected moving around the headland attributed to littoral currents.

The 2011 surveys revealed a less distinct pattern with mixed current velocities between the island and headland. Immediately seaward of the island, the current flowed in a SSE direction at speeds of 0.1-0.13m/s to the northeast and 0.18-0.25m/s to the immediate southeast of Cook Island. To the immediate south of the island, a slow northward flowing current was detected, likely to be attributed to eddies forming due to the divergence of the south flowing current around this feature. Previous current monitoring studies have revealed similar results with some deflection of the southerly current around the spur reef inshore of Cook Island, accelerating as it moved past the Fingal Headland, and the majority of the southerly current deflecting seaward of the island at speeds of up to 0.5m/s (Wyllie and Tomlinson, 1991).

The final 2011 Cook Island South survey was extended 4km seaward over Fido's reef and beyond. During the survey, the current velocity increased over the reef to speeds of up to 0.6m/s. Similar observations were made by Wyllie and Tomlinson during surveys undertaken in 1989 where the current speed over the Danger Reef systems was detected at 0.82m/s (Wyllie and Tomlinson, 1991). In between Cook Island and Fido's Reef, the current flowed predominantly southward, however seaward of the reef the current shifted SE demonstrating how the offshore reef features in the study area can influence current direction.

It is worth noting that the distinct northward flowing current observed in Letitia Embayment during the low tide on 02/08/2011 and high tide on 03/08/2011 was not observed at Cook Island, further supporting the theory that the northward flowing current was a circulation cell limited to the Letitia Embayment. Previous detection of such circulation cells have been limited by the topography of Cook Island (Tomlinson and Foster, 1986).

Conclusions

From the recent monitoring, it can be concluded that the EAC is a strong influencing factor to the local nearshore and offshore current regime, generating southerly flows which are deflected by the Point Danger Headland and causing circulation cells within Letitia Embayment. These circulation cells have the ability to enhance longshore littoral transport and are therefore worth investigating during future monitoring exercises. The weakening of the EAC over the winter period results in a reduced magnitude of the southward flowing current within the study area. Further studies into the impact this reduction has on the local current regime would also be useful.

Substantial northward littoral currents along Letitia Spit were observed during the 2010 exercise despite the low wave energy at the time. During the ebb tide, this northward flowing current appeared to be deflected southward before reaching the TRESBP jetty due to the influence of the Tweed River ebb jet. It would be beneficial to the operation of the TRESBP infrastructure to determine over what conditions this southward deflection occurs and whether sand is delivered to the jetty infrastructure by littoral currents under these conditions.

During the 2011 monitoring exercise, the circulation cell in Letitia Embayment converged with the EAC southerly flow and radial flood tide resulting in a highly mixed current environment surrounding the river entrance. On other occasions, the southerly EAC-induced flow was seen to intersect the ebb-shoal bar, especially during the ebb tide. It may be that under certain conditions, very little sediment bypassing occurs around the river entrance during an ebb tide due to the close proximity of the southward flowing EAC-induced current within the local area. However sediment bypassing may be increased during the presence of a circulation cell, which instigates northward flowing currents along Letitia Spit. Further investigation into the current velocity surrounding the river entrance during differing tidal cycles, as well as during the presence of circulation cells is needed to determine the implication of these currents on sediment transport pathways.

Overall, the recent exercises have been a useful learning exercise for TRESBP and similar such monitoring is anticipated to occur over varying tidal cycles, seasons, wave and wind conditions in the near future. Once a substantial amount of data has been collected, it is hoped that DERM's Coastal Impacts Unit will collate the recent data, along with historical data to undertake a more rigorous assessment of the ocean current regime in this complex coastal environment.

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