Larval dispersal from Te Taonga O Ngati Kere and Te Angiangi Marine Reserve: numerical model simulations

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Larval dispersal from Te Taonga O Ngati Kere and Te Angiangi Marine Reserve: numerical model simulations

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Executive Summary

This report gives details of the development of a hydrodynamic and dispersion model for the Central Hawke's Bay coastline between Cape Turnagain and the Te Angiangi Marine Reserve. The model incorporates the effects of tides, waves and oceanic intrusion of the East Cape Current and the influence of the Wairarapa Coastal Current (WCC). Forcing under weak, average and strong conditions of the WCC combined with average, easterly and southerly storm wave conditions gave a range of realistic forcing conditions to examine the resultant dispersal of a number of larval species from four key locations along the coast. Release sites were Cape Turnagain, the Porangahau River entrance, Blackhead Point and the Marine Reserve itself. The five species of interest were bull kelp *(Durvillaea),* kina *(Evechinus chloroticus),* limpets *(Cellana* spp), paua *(Haliotis iris)* and bubu *(Turbo smaragdus* and *Cookia sulcata)* which are found on the rocky reefs along this stretch of the coast. This report presents estimates of the likely dispersal and settlement range of these species from their spawning sites along the coast between Cape Turnagain and the Marine Reserve.

Residual currents

Residual currents (i.e., the net movement of water over a tidal cycle) under tides alone are small (less than 5 cm/s) and are generally to the south along most of the coast. The exception being Porangahau River embayment. Here symmetrical tidal flows result in virtually no net residual current.

Combined forcing by waves, tides and oceanic intrusion resulted in complex patterns of flows both in the near shore zone (i.e., out to around 30 m water depth) as well as in the deeper waters offshore. At the Marine Reserve residual flows are to the north for average to strong WCC conditions. For weak WCC conditions residual currents at the Marine Reserve are very weak (less than 0.05 m/s). Residual currents flow to the north and south at Cape Turnagain. Residual currents flow to the north and south at Blackhead Point under average and strong WCC conditions. For weak WCC and average wave conditions it is predicted that residual currents at Blackhead Point are to the south. Within the Porangahau River embayment residual flows are directed onshore under weak WCC conditions and to the north under average and strong WCC conditions.

Cape Turnagain

The area to the south of Cape Turnagain consists of a long sandy beach (c. 12 km) with no intertidal rocky reef and few subtidal reefs. The nearest substantial area of intertidal reef is at Akitio (c. 20 km south of the Cape). The modelling suggests that populations of kaimoana along the coast from Cape Turnagain to Porangahau Beach are largely dependent upon self-recruitment. It is only under persistent strong Wairarapa Coastal Current and wave conditions that limited recruitment may occur between Blackhead Point and Porangahau Beach.

Porangahau Bay

Porangahau Bay contains a 14 km sandy beach (c. 6 km north of the river mouth, and 8 km south of the river mouth). The only intertidal reef along this stretch of coast is located off Porangahau River mouth (Taikora Rock). The modelling implies that populations of intertidal and estuarine shell fish in the bay are likely to self-recruiting. Populations on Taikora Rock will receive limited larvae from Blackhead Point and the potential for recruitment from the reefs south of Porangahau Beach is very limited.

Blackhead Point

Intertidal and shallow subtidal invertebrate populations just south of Blackhead Point appear to be relatively isolated, receiving little larval input from the north or the south under most weather conditions. Only under prolonged calm conditions will there limited connectivity with reefs to the north (including Te Angiangi Marine Reserve).

Te Angiangi Marine Reserve

Populations in Te Angiangi Marine Reserve are self-recruiting and receive most external larval inputs from the reefs immediately to the south of Blackhead Beach. Any potential benefits the Te Angiangi Marine Reserve are likely to be greatest on the reefs north of it, and numbers of larvae potentially settling on these reefs from the marine reserve are likely to quite large.

Because of the limited larval duration populations of bull kelp along the Central Hawke's Bay coast may be reproductively isolated from each other and may require careful management to ensure adequate recruitment

1. Introduction

NIWA was commissioned by the Department of Conservation to model larval dispersal from the taiapure Te Taonga O Ngati Kere and Te Angiangi Marine Reserve (Figure 1) in the Central Hawke's Bay. In particular, this study aimed to predict the potential for settlement of larvae populations along the stretch of coast between Cape Turnagain and the Marine Reserve.

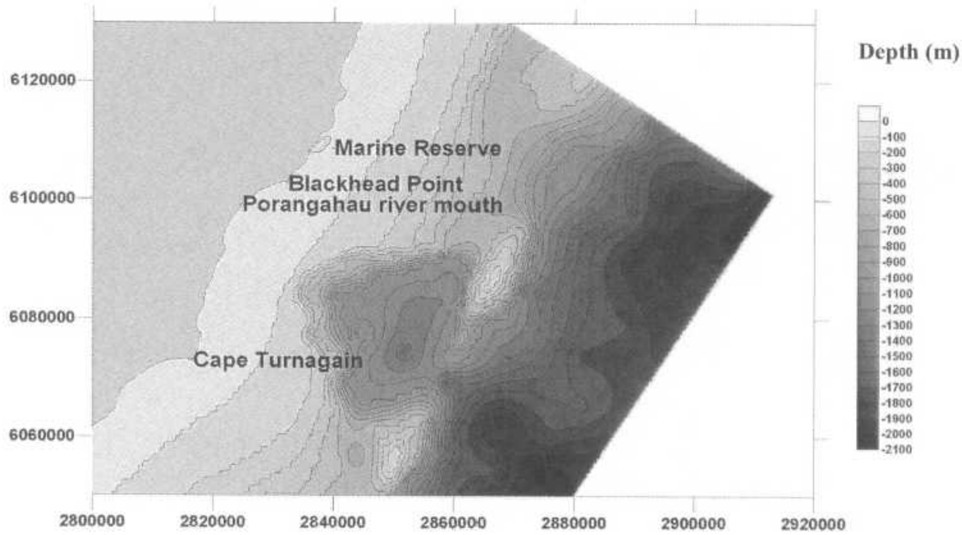

Figure 1: Overview of the area of the study showing the larvae release locations, Te Angiangi Marine Reserve and the offshore depth contours. Coordinate system NZMG and depths relative to Chart Datum.

Numerical models were used to determine the dispersion "footprint" of larvae released from four inshore point sources, based on realistic hydrodynamic forcing over periods of 4, 10, 20 and 30 days.

The five species of interest were bull kelp *(Durvillaea),* kina *(Evechinus chloroticus),* limpets *(Cellana* spp), paua *(Haliotis iris)* and bubu *(Turbo smaragdus* and *Cookia sulcata)* which are found on the rocky reefs along this stretch of the coast. This report presents estimates of the likely dispersal and settlement range of these species from their spawning sites along the coast between Cape Turnagain and the Marine Reserve.

2. Modelling methods

2.1 Modelling overview

Numerical modelling was undertaken using four models. The deepwater wave climate offshore from the marine reserve was extracted from a 20-year WAM hindcast of the New Zealand region (Gorman et al. 2003), and used to calculate mean offshore wave conditions. These mean waves were then propagated inshore accounting for shallow water effects using the wave model SWAN (Booij et al. 1999). Resulting wave radiation stresses were input to a two-dimensional hydrodynamic flow model [1], which simulated the combined flow effects of tides and waves. Tidal boundary conditions were derived from the NIWA EEZ tide model (Goring 2001, Walters et al. 2001), while the ocean forcing boundary conditions were obtained from a NIWA regional ocean model (Rickard et al. 2005) to produce climatological estimates of the flows along the Wairarapa coastline.

A lagrangian particle model[2] was then used to simulate larval dispersal in the predicted flow fields. All models used the same regular square bathymetry grid with cells of 270 x 270 m. The bathymetry grid was created using a combination of data digitised from an existing hydrographic chart, and detailed Navy data supplied by the Department of Conservation. All positions were rotated 33.26 ° clockwise[3] about NZMG origin X = 2787500, Y =6049400 (Latitude -40.715 ° S, Longitude 176.285 ° E) before gridding. Figure 2 shows the resulting bathymetry map. Significant features of the area include the North Madden Bank and South Madden Bank which sit offshore of Cape Turnagain and Blackhead Point respectively. Offshore of these banks depths range between 1500-2000 m. The banks themselves come up to around 170 m below chart datum. Inshore of these banks there is a deep canyon where the average depth is around 550 m (maximum depth -850 m).

The vertical grid datum is lowest astronomical tide (LAT), which corresponds to the datum of navy chart NZ57. Both the wave model (SWAN) and the ocean model assume a fixed water level. For consistency, the hydrodynamic model was run with a mean sea level of 0.87 m above datum.

Unlike the previous study carried out for the Te Tapuwae O Rongokako Marine Reserve (Stephens et al. 2004) only a single grid was used for this study. This was primarily because the spatial scale of this study is much larger. As the release points were such large distances apart, it would not have been possible to model all of the

[1] DHI Water and Environment MIKE21 hydrodynamic model.
[2] DHI Water and Environment MIKE21-PA particle analysis model.
[3] This rotation was derived from the alignment of the local coastline.

release points with a single higher-resolution m grid. The alternative, and more complex approach, is to use one large grid (of cell size 270 m), nest down to a 90 m cell size grid and then nest to several smaller grids with cell size of 30 m. The complexities of using this approach and the time constraints of this study meant this was not possible. Furthermore the lack of calibration data at inshore sites meant that models at greater resolution were not warranted. Importantly, comparisons carried out at Te Tapuwae O Rongokako Marine Reserve (Stephens et al. 2004) showed that the overall patterns of larval dispersal are captured using a 270m grid.

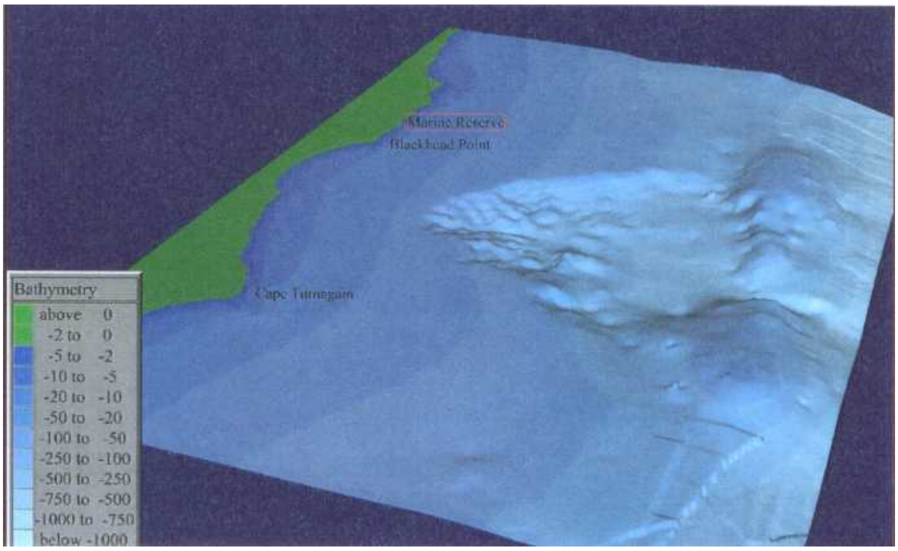

Figure 2: Bathymetry map derived from Navy and bathymetric charts. Vertical datum is lowest astronomical tide (LAT) which corresponds to NZ57 Chart Datum.

2.2 Offshore wave climate

Historically, wave data coverage of New Zealand's coast has been poor, particularly for directional records. With very few data sets available of more than one year's duration, it has been difficult to establish accurate wave climatologies. To help fill in the gaps in our wave records, the WAM wave generation model has been implemented over a domain covering the Southwest Pacific and Southern Oceans. The model has been used to hindcast the generation and propagation of deep-water waves incident on the New Zealand coast over a 20-year period (1979-98), using winds from the European Centre for Medium Range Weather Forecasting (ECMWF).

For this study, the 20-year hindcast was extracted for location 177.402 ° E, -40.638 ° S (WGS84), a deepwater site corresponding with the outer edge of the model grid. Of the 58440 3-hourly wave statistics, the mean significant wave height H_s (average of the highest $1/3^{rd}$ of waves), mean wave approach direction D (coming from) and mean wave period T_m were 1.9 m, 170° and 6.9 s respectively. About 70% of all waves approach from ESE through SSW (Table 1). Figure 3 can be used to estimate the frequency of occurrence of deepwater waves near the marine reserve, and Figure 4 shows their relative height and direction distribution.

Storm waves were selected using a peaks-over-threshold method with a 2-day threshold. We define southerly storm waves as those storm waves approaching from south of east, and these make up 73% of storm waves, or 2.4% of all waves. Of these waves the mean significant wave height H_s, mean wave approach direction D and mean wave period T_m were 2.6 m, 184° and 6.8 s respectively. We define easterly storms as those storm waves approaching from east or north of east, and these make up 27% of storm waves, or 0.9% of all waves. Of these waves the mean significant wave height H_s, mean wave approach direction D and mean wave period T_m were 2.1 m, 22° and 6.9 s respectively.

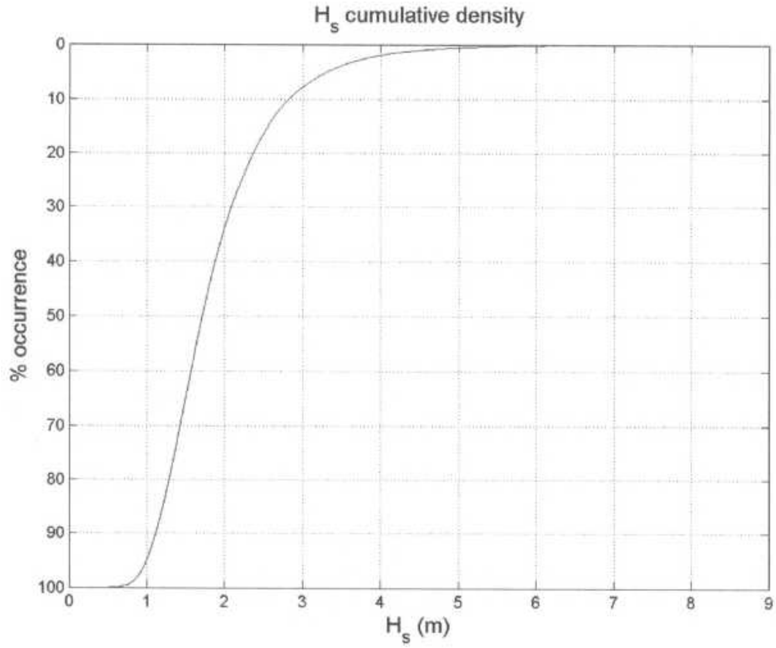

Figure 3: Cumulative density curve of significant wave height H_s from the 20-year wave hindcast offshore from the marine reserve.

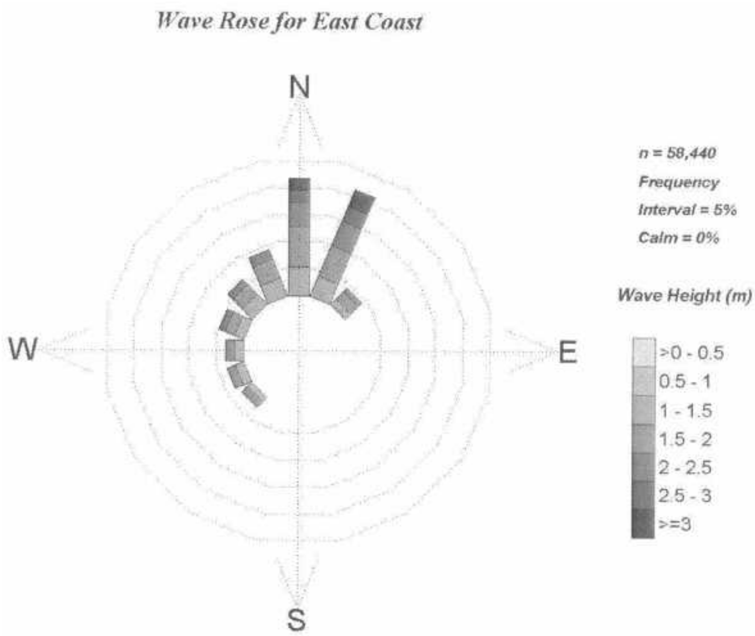

Figure 4: Wave rose of significant wave height and mean wave direction from the 20-year wave hindcast offshore from the marine reserve. Directions shown are the direction of wave travel.

Table 1: Percent approach direction (coming from) of waves predicted by the 20-year WAM hindcast. Storm waves were selected using a peaks-over-threshold method with a 2-day threshold. Percentages are given to the nearest percent.

Approach Direction	**S**	**SSW**	**SW**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**
All (n = 58440)	22	22	5	2	4	5	5	6	8	11
Storm (n = 1907)	19	28	5	4	6	5	4	4	5	9

2.3 Nearshore wave conditions

The propagation of the deep water waves into shallow water was assessed using the model SWAN (acronym for Simulating WAves Nearshore). SWAN is a numerical wave model developed to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind-, bottom-, and current conditions. The model is based on the wave action balance equation (or energy balance in the absence of currents) with sources and sinks. Further details of the model are provided by Young (1999) and Booij et al. (1999).

The SWAN model was forced by applying wave conditions extracted from the WAM model hindcast to all open boundaries of the model grid. SWAN was run using default physical parameters that included third-generation mode physics, wave breaking, bottom friction, and quadruplet and triad wave-wave interactions in deep and shallow water respectively. Figures 5a-c show the predicted wave heights for the average, southerly and easterly storm waves respectively.

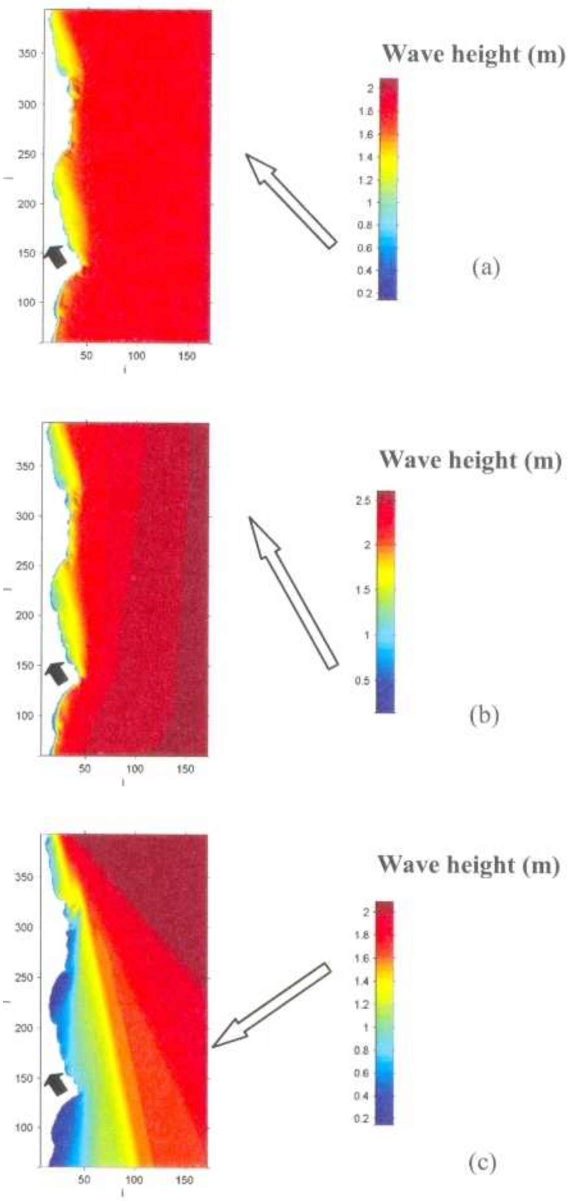

Figure 5: Predicted wave heights for the (a) mean wave conditions (average of the highest 1/3rd of waves 1.9 m, mean wave approach direction (coming from) 170° and mean wave period 6.9 s), (b) southerly storm waves (average of the highest 1/3rd of waves 2.6 m, mean wave approach direction (coming from) 184° and mean wave period 6.8 s) and (c) easterly storm waves (average of the highest 1/3rd of waves 2.1 m, mean wave approach direction (coming from) 22° and mean wave period 6.9 s). Arrows indicate the offshore wave direction with the length being proportional to deep water significant wave height. (Note - True north is indicated by solid arrow).

2.4 Hydrodynamic model

MIKE21 was used to simulate the depth-averaged hydrodynamics of the study area. Results from the previous study (Stephens et al. 2004) indicate that density driven currents do not significantly contribute to larval dispersal patterns but the inclusion of wave radiation stress is important (Stephens et al. 2004). The littoral currents set up by inshore wave radiation stress are very effective in ejecting larvae spawned in shallow inshore waters out into the broad-scale tidal and wind-induced flows. The inclusion of wave radiation stresses is limited to a stationary forcing field for the duration of the simulation, such as the mean wave radiation stresses over the deployment period. For this study the hydrodynamic model included forcing by tides, ocean currents and wave radiation stresses.

2.4.1 Tidal forcing

Boundary conditions for the tidal model were derived from the NIWA EEZ model (Goring 2001). Tidal constituents at the northern and southern offshore boundary cells were extracted from this model (Table 2) and used to derive a time-series of water levels (Figure 6). Rather than apply the full tidal range to each boundary just the boundary slope was applied about a mean sea level (0.87 m). That is, half of the predicted slope was added to the northern boundary and half the predicted slope was subtracting at southern boundary. This results in the slope across the boundaries being the same as shown in Figure 6b with water levels ranging from 0.81-0.93 m. This is then consistent with both the wave and ocean forcing models which run using a fixed water level of 0.87 m.

	Northern offshore site		Southern offshore site	
	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)
M2	163.300	0.603	156.800	0.597
N2	133.000	0.134	126.500	0.133
K1	315.400	0.056	307.900	0.054
MU2	101.300	0.027	95.400	0.027
S2	256.600	0.026	246.500	0.017
NU2	135.700	0.026	129.500	0.026
01	239.800	0.023	231.900	0.028
2N2	97.100	0.023	91.200	0.024
P1	310.100	0.017	300.400	0.017
L2	174.400	0.011	167.000	0.011
Q1	253.700	0.007	244.900	0.009
K2	322.400	0.006	343.900	0.005
T2	209.800	0.002	192.600	0.002

Table 2: Tidal constituent data from the EEZ model for the northern and southern offshore boundary cells used to drive the tidal model.

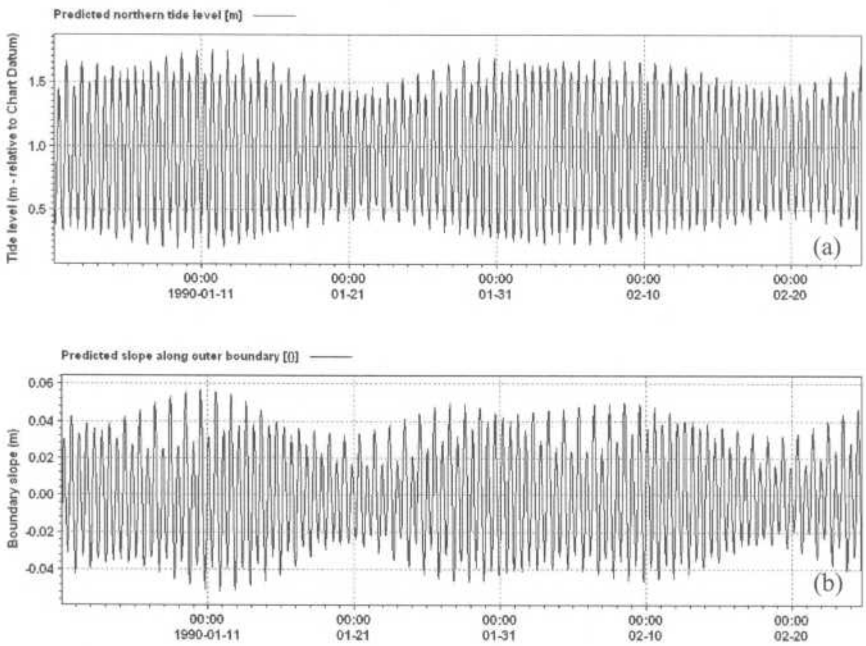

Figure 6: Predicted tide level (a) and slope along the offshore boundary (b) of the tidal model.

Predicted tidal currents for northbound and southbound flows are shown in Figure 7. Offshore tidal currents are predicted to be low with localised higher flows on either side of the entrance to the offshore canyon. During the north bound phase of the tide (Figure 7a) flows are deflected offshore and decelerate as they enter the canyon area and as flows exit the canyon, acceleration occurs with flows moving onshore. This spatial phase differences in the velocity patterns, leads to the formation of what was termed a "phase" eddy (Black & Gay 1987, Black et al. 2005) inshore of the canyon area. It can be seen that the scale of the eddy leads to flows inshore of the canyon which are opposed to the general northward pattern of flow. A similar pattern of flows develops during the south bound phase (Figure 7b) of the tide although the strength of the eddy is much reduced. The influence of the eddy can be seen by examining the net current over a tidal cycle (Figure 8). Within the deeper waters to the north and south of the residual currents are generally very low. However inshore of the canyon residual currents are to the south and north - essentially moving water away from the coast and into the deeper water.

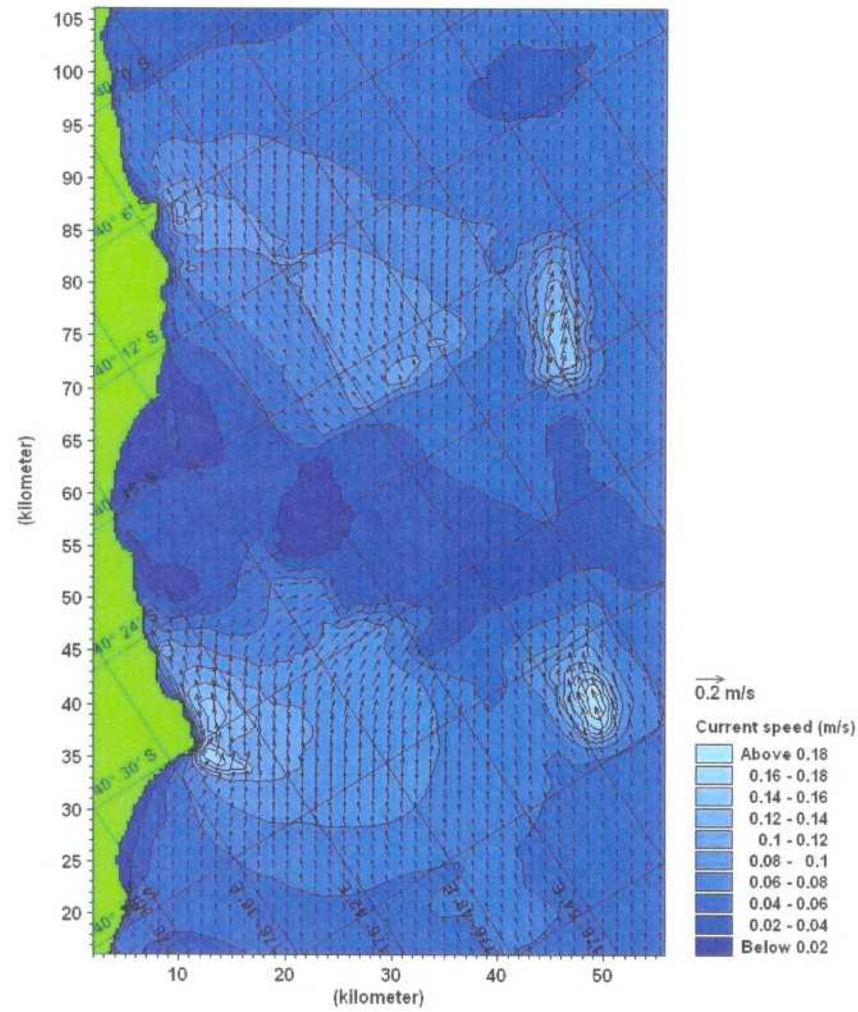

Figure 7a: Predicted peak north bound tidal currents.

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