Appendix B – Climate Change

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1 Introduction

This Appendix provides the detailed calculation of beach rotation and beach recession due to sea level rise and climate change at Scotts Head, Nambucca Heads and Valla Beach.

Climate change and its effect on the coast is discussed in Section 2 of the main report.

2 Beach Rotation

2.1 Beach Rotation in Nambucca Shire – General

Studies of embayed beaches on the NSW coast have identified a sensitivity of shoreline alignment to mean wave direction, which has been linked to the Southern Oscillation Index (SOI).

Examination of wave data from Crowdy Head Waverider buoy between 1985 and 2005 was carried out to determine the change in mean offshore wave direction over time. It was found that mean wave direction was increasing over time on average, though the record is too short to remove the effects of inter-decadal variability. It was also found that mean wave direction was related to the Southern Oscillation Index (SOI), with mean wave direction being more southerly during *El-Niño* years and more easterly during *La-Niña* years (Figure B.1). Goodwin *et al.* (2007) identifies conceptual sediment transport processes based on mean wave climate states. A more southerly wave climate consistent with an *El-Niño* event would lead to greater northerly longshore sediment transport (clockwise beach rotation) while a more easterly wave climate would lead to an anti-clockwise translation (Figure B.2). A shift from dominant *La-Niña* to dominant *El-Niño* conditions caused by climate change would enhance northerly longshore drift and therefore increase beach recession. The prevalence of *El-Niño* conditions over the last few years (until 2005) has allowed recovery of the various beaches.

Beach rotation is estimated for Scotts Head, Nambucca Heads and Valla Beach below.

2.2 Rotation and Longshore Drift at Scotts Head

The beaches at Scotts Head are fairly stable in the long term. Medium-term oscillations in sub-aerial beach sand store are noticeably visible on the RL4.0m movement chart (Figure B.3). The measured beach recession which occurred between 1942 and 1973 has been steadily recovering since 1973. Ongoing long term recession is not significant enough at Scotts Head to override the medium term oscillation of the sub-aerial beach sand store that may be induced by beach rotation of the swash zone.

There is no significant evidence of beach rotation taking place at the beach compartment immediately surrounding Scotts Head. The coastline seems to be impacted almost in the same way all along the beach (Figures B.3 and B.4), i.e. changes on the southern side of the beach were positively correlated with changes at the centre of the beach. The planform of Forster Beach and deposition of sand at the mouth of Nambucca River could be an indicator of the net northward longshore drift. The beaches at Scotts Head have on average receded since 1942, in spite of continuous recovery since 1973.

A wave refraction analysis was undertaken for Scotts Head to investigate the impact of change in offshore wave angle on mean wave angle in the nearshore area. This was undertaken using SWAN (acronym for **S**imulating **WA**ves **N**earshore – Cycle III version 40.11). SWAN is a numerical wave transformation program developed at the Delft University of Technology (Holthuijsen *et al.*, 2000). SWAN can be used to describe wave transformation in shallow water and to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bathymetric and current conditions. The background to SWAN is provided in Young (1999) and Booij *et al*., (1999). SWAN has been validated using field data by Nielsen & Adamantidis (2003).

The range of offshore wave angles examined was from 127°TN to 140°TN, corresponding to the annual Mean Wave Direction (MWD) reported by Goodwin (2005). For this range of offshore wave directions, the variation in wave angle in the nearshore area of Scotts Head (at approximately the 5m depth contour, beyond the median wave breaking depth) is around 2° for Little Beach and 1.5° for Forster Beach (see Figure B.5). As the beach planform is typically normal to the MWD, the beach rotation that would be expected would be of the same order (±1°), with the effects seen most greatly at the extreme southern and northern ends of the beach. Assuming that the beach can be approximated by a straight line, the beach fluctuations due to rotation are estimated by the following formula:

$$R = dist \times \tan(r)$$

where *R* = beach fluctuation in metres at the location of interest

dist = distance in metres from the centre of the beach (120 m for Little Beach and 5400 m for Forster Beach)

r = estimated change in nearshore wave angle in degrees.

Beach fluctuations over the 240 m of Little Beach for a ±1° beach rotation may reach 2 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±4 m^3/m which is not significant.

Beach fluctuations over the 10,800 m of Forster Beach for a ±0.75° beach rotation may reach a maximum of 70 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±140 m^3/m. This is significant, due to the length of the beach. However, as the beach is undergoing net northerly longshore drift, the potential for beach rotation would manifest itself as an increase or decrease in the rate of northerly longshore drift.

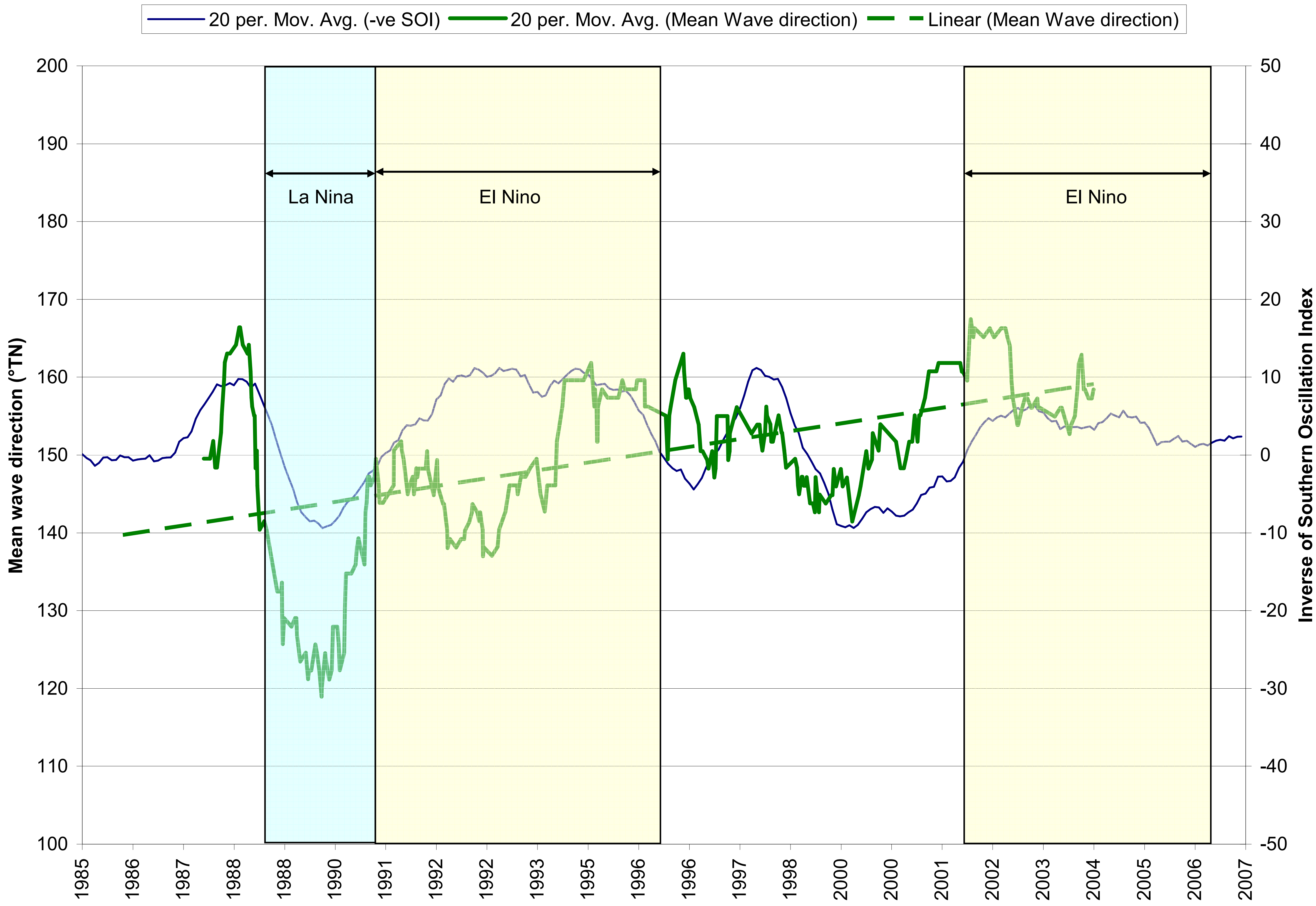

Figure B.1 – Mean Wave direction vs. mean SOI, Crowdy Head wave data

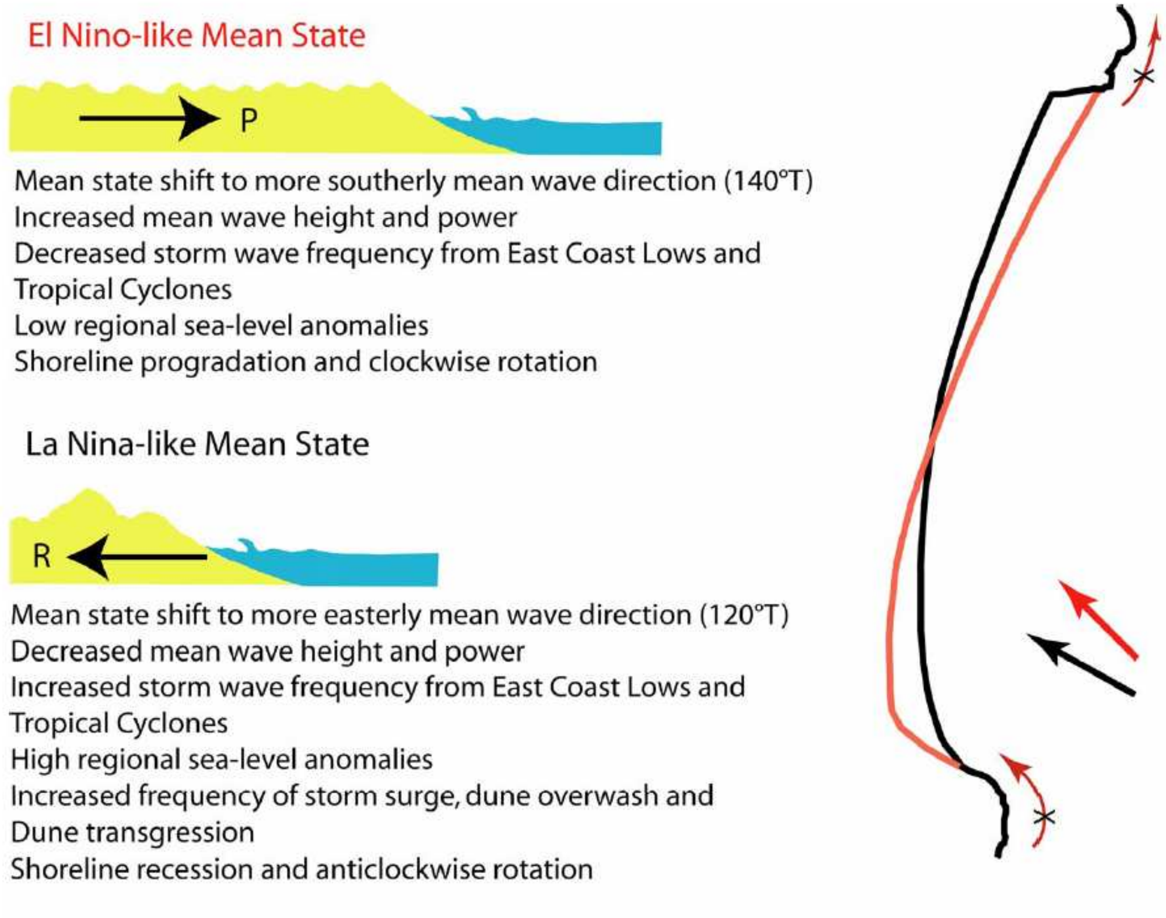

Figure B.2 – Wave rotation caused by *El-Niño* or *La-Niña* mean states (after Goodwin et al. 2007)

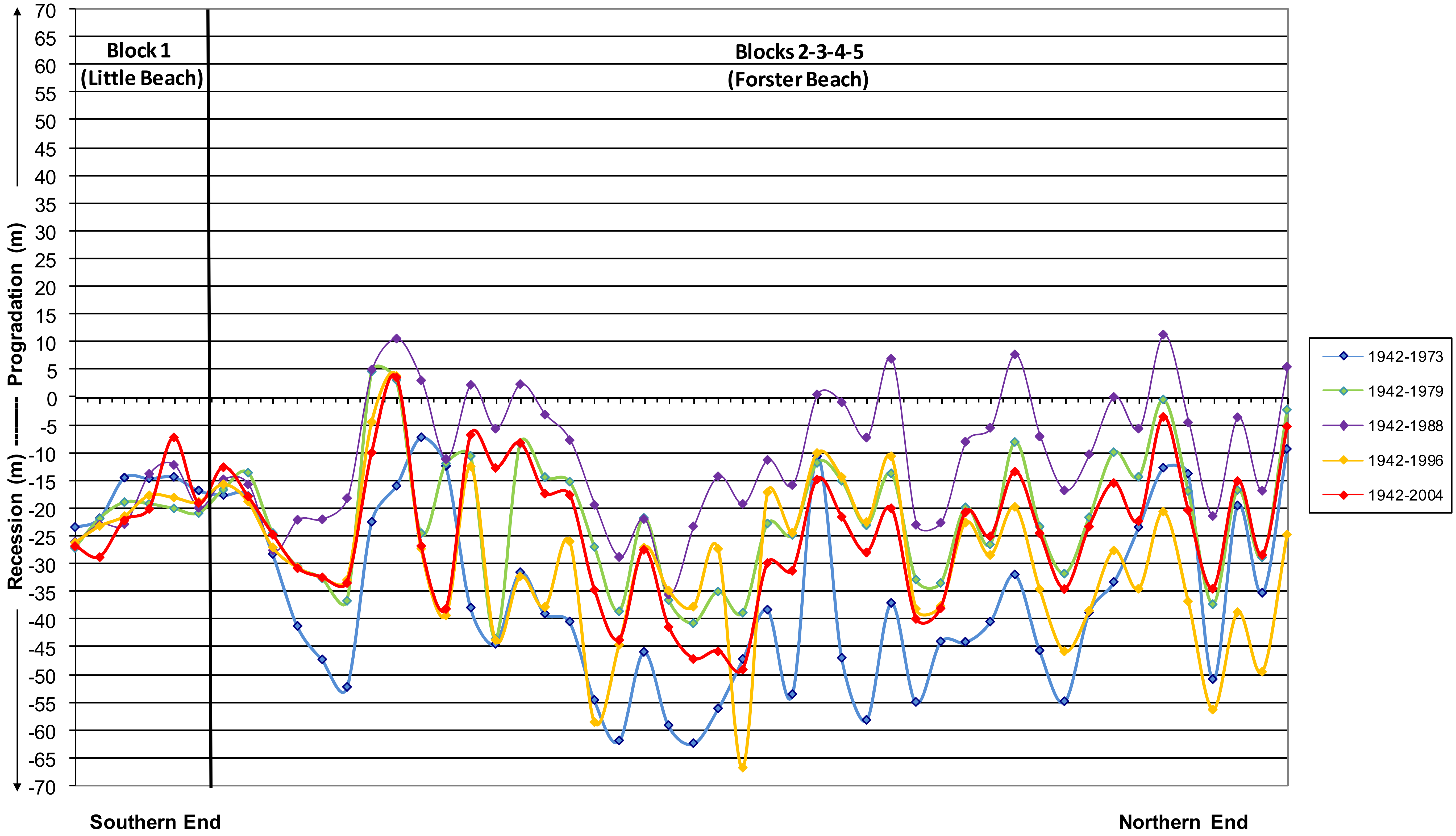

Figure B.3 – RL 4.0m movement between 1942 and 2004 for the different blocks at Scotts Head

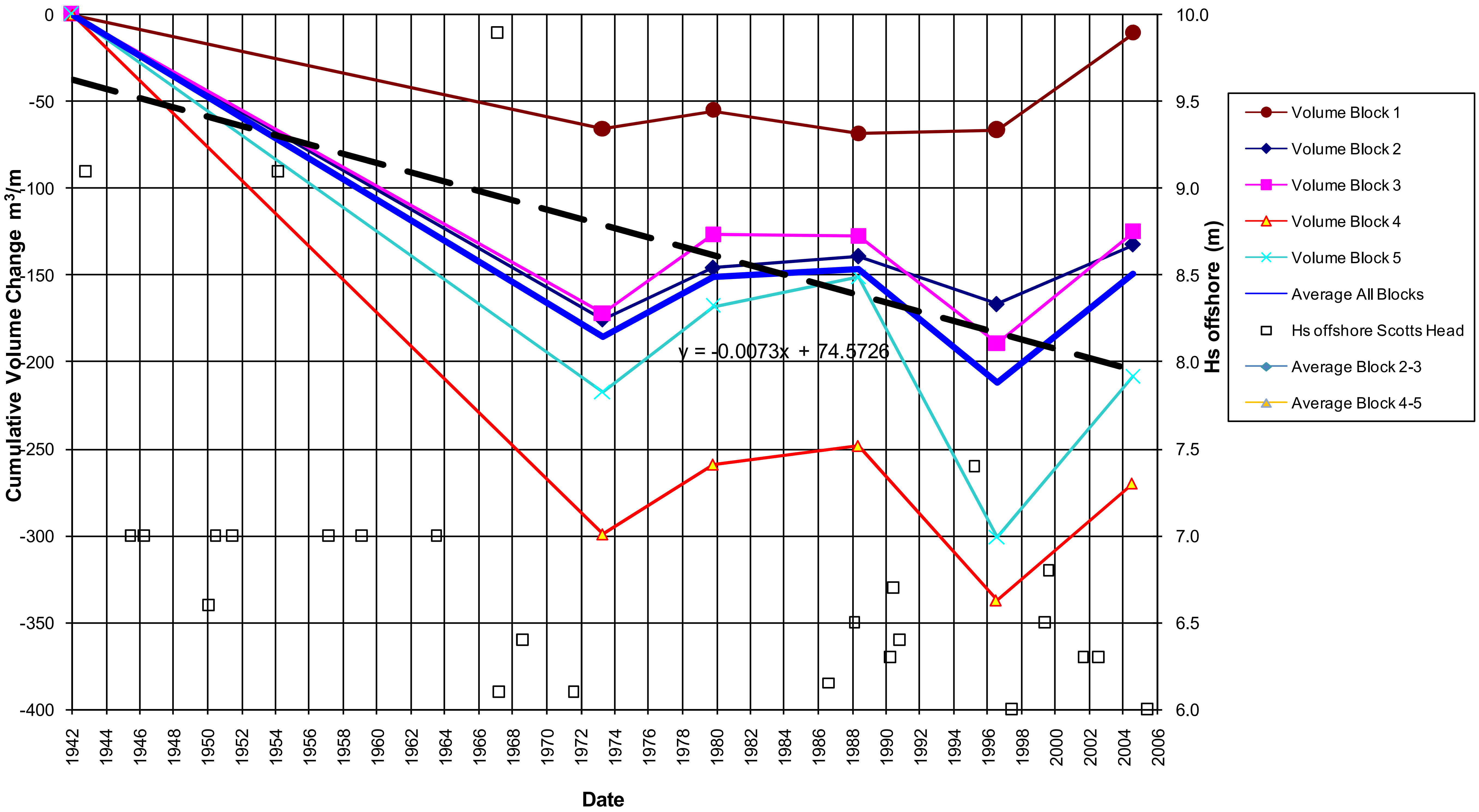

Figure B.4 – Scotts Head Beach Volume Change for the different blocks

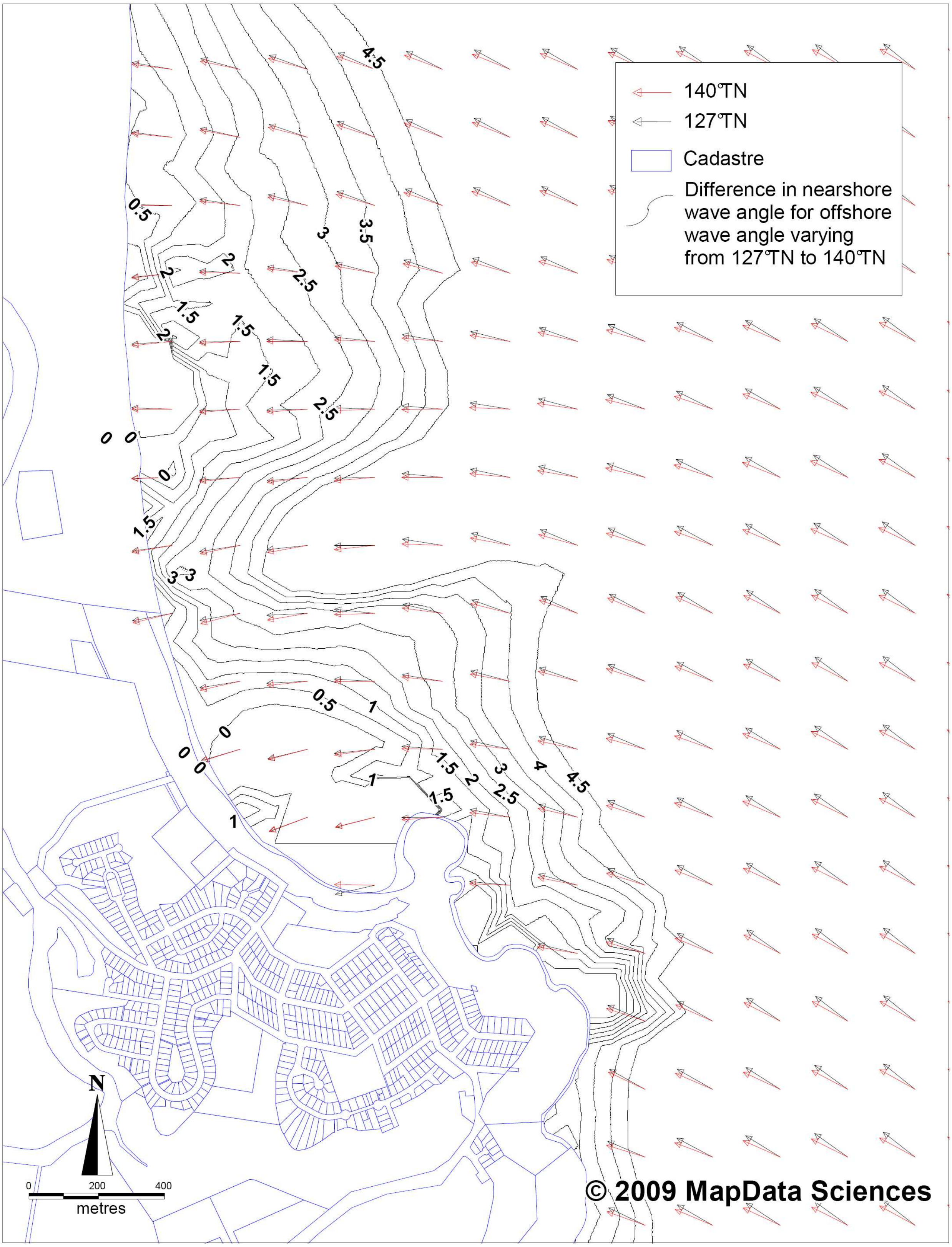

Figure B.1 – Change in nearshore angle caused by change in offshore wave approach angle from 127°TN to 140°TN, Scotts Head

2.3 Rotation and Longshore Drift at Nambucca Heads

The beaches at Nambucca Heads are fairly stable and medium-term oscillations in sub-aerial beach sand store are noticeably visible on the RL4.0m movement chart (Figure B.6). The beach recession which occurred between 1942 and 1980 is recovering at most of the beaches along the Nambucca Shire coast.

There is no real evidence of beach rotation at the entrance berm to Nambucca River, or at the small beach adjacent to the northern breakwall. The sand transport at the Nambucca entrance area is dominated by local estuarine processes, as is the case with the small beach adjacent to the northern breakwall.

There is also little evidence of beach rotation taking place at Main, Shelly and Beilbys beaches. Shelly and Beilbys beaches are undergoing long term recession at a low rate, while Main Beach is accreting. These beaches are flanked by considerable expanses of offshore rocky reefs, which have shaped the plan-form of the coastline and form natural boundaries between the beaches. This is evident at the southern end of Main Beach, which is held in place by the rocky reef immediately adjacent to the Main Beach Surf Club. This reef acts as a natural groyne, trapping the northward transport of sand. This is evident by examining aerial photographs, with a significant dune at the northern end of Beilbys Beach, but reduced sand stores in front of Main Beach Surf Club.

The observed recession at the southerly beaches (Shelly, Beilbys) compared to the observed accretion at the northerly beaches (Main Beach) could be an indicator of beach rotation (Figure B.7). However, this is more likely an indicator of a mean northerly longshore drift occurring; if the coast is considered as a whole, a longshore drift is perceptible.

A wave refraction analysis was undertaken for Nambucca Heads to investigate the impact of change in offshore wave angle on mean wave angle in the nearshore area. This was undertaken using SWAN (described in Section 2.2 above).

The range of offshore wave angles examined was from 127°TN to 140°TN, corresponding to the annual Mean Wave Direction (MWD) reported by Goodwin (2005). For this range of offshore wave directions, the variation in wave angle in the nearshore area of Nambucca Heads (at approximately the 5 m depth contour, beyond the median wave breaking depth) is around 0.5° (see Figure B.8). As the beach planform is typically normal to the MWD, the beach rotation that would be expected would be of the same order (±0.5°), with the effects seen most greatly at the extreme southern and northern ends of the beaches. Assuming that the beach can be approximated by a straight line, the beach fluctuations due to rotation are estimated by the following formula:

$$R = dist \times \tan(r)$$

where *R* = beach fluctuation in metres at the location of interest

dist = distance in metres from the centre of the beach (450 m for Beilbys and Shelly Beaches, 700 m for Main Beach and Swimming Creek)

r = estimated change in nearshore wave angle in degrees.

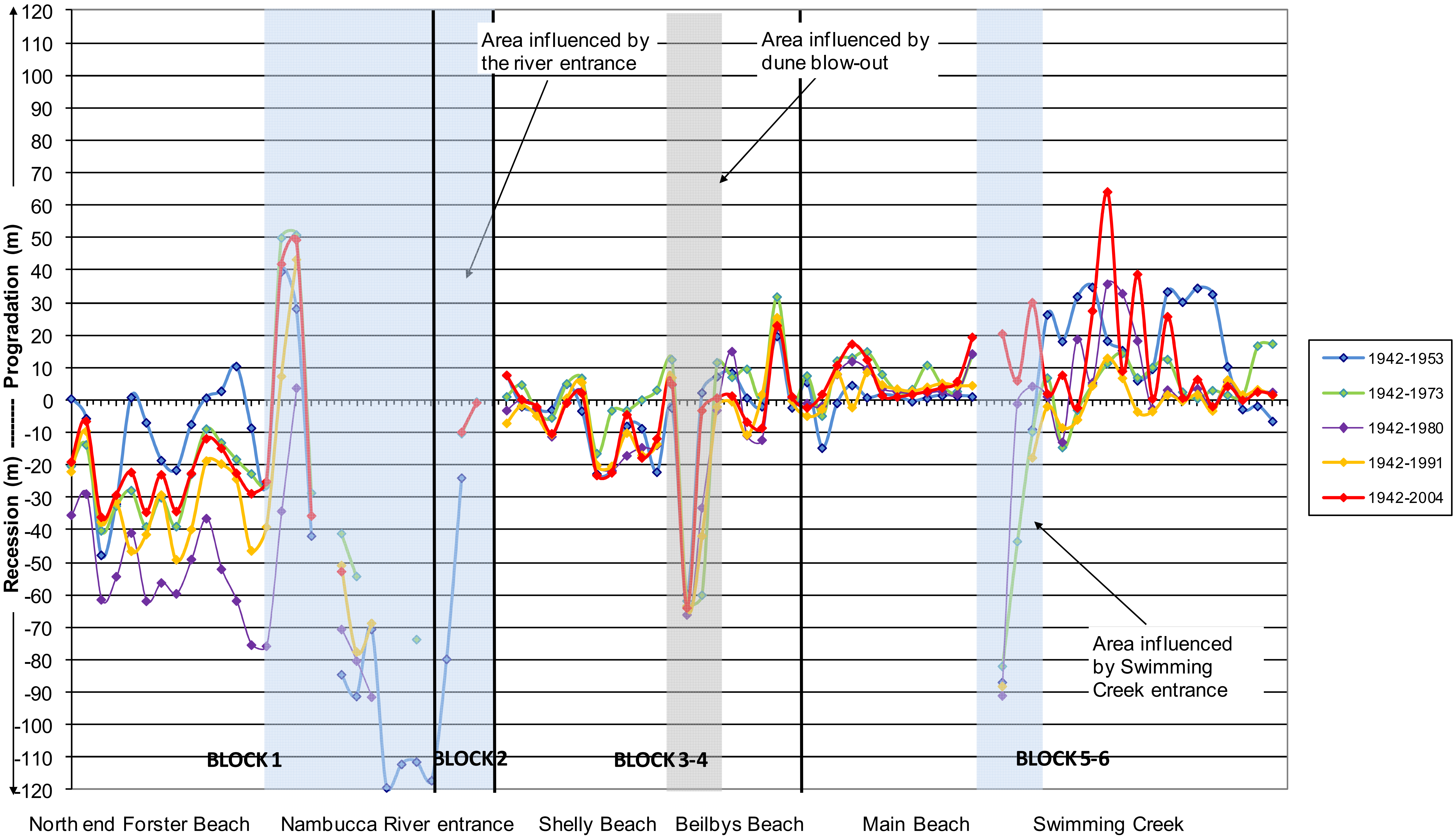

Figure B.6 – RL 4.0m movement between 1942 and 2004 for the different blocks, Nambucca Heads

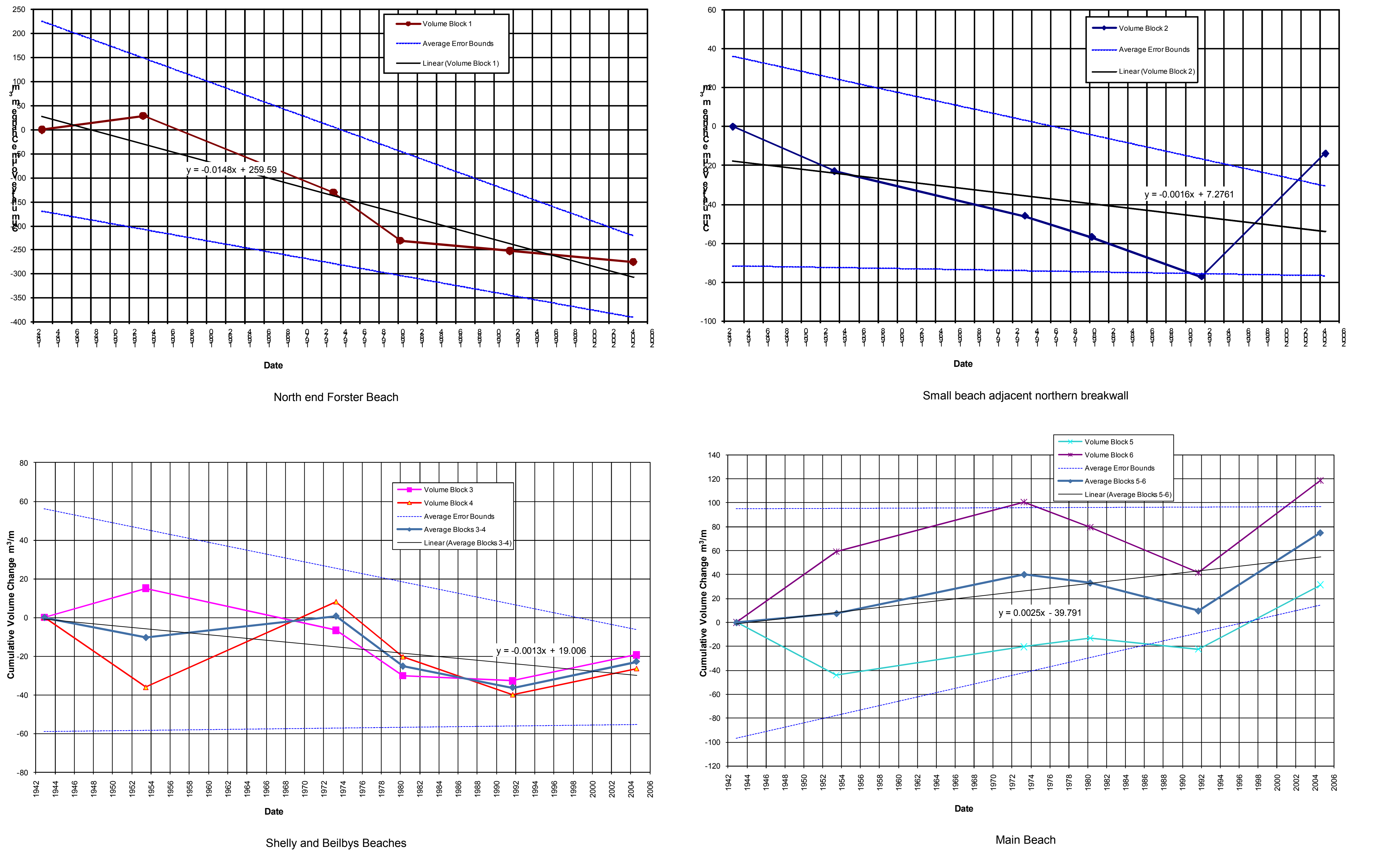

Figure B.7 – Long term recession volume analysis for the different blocks

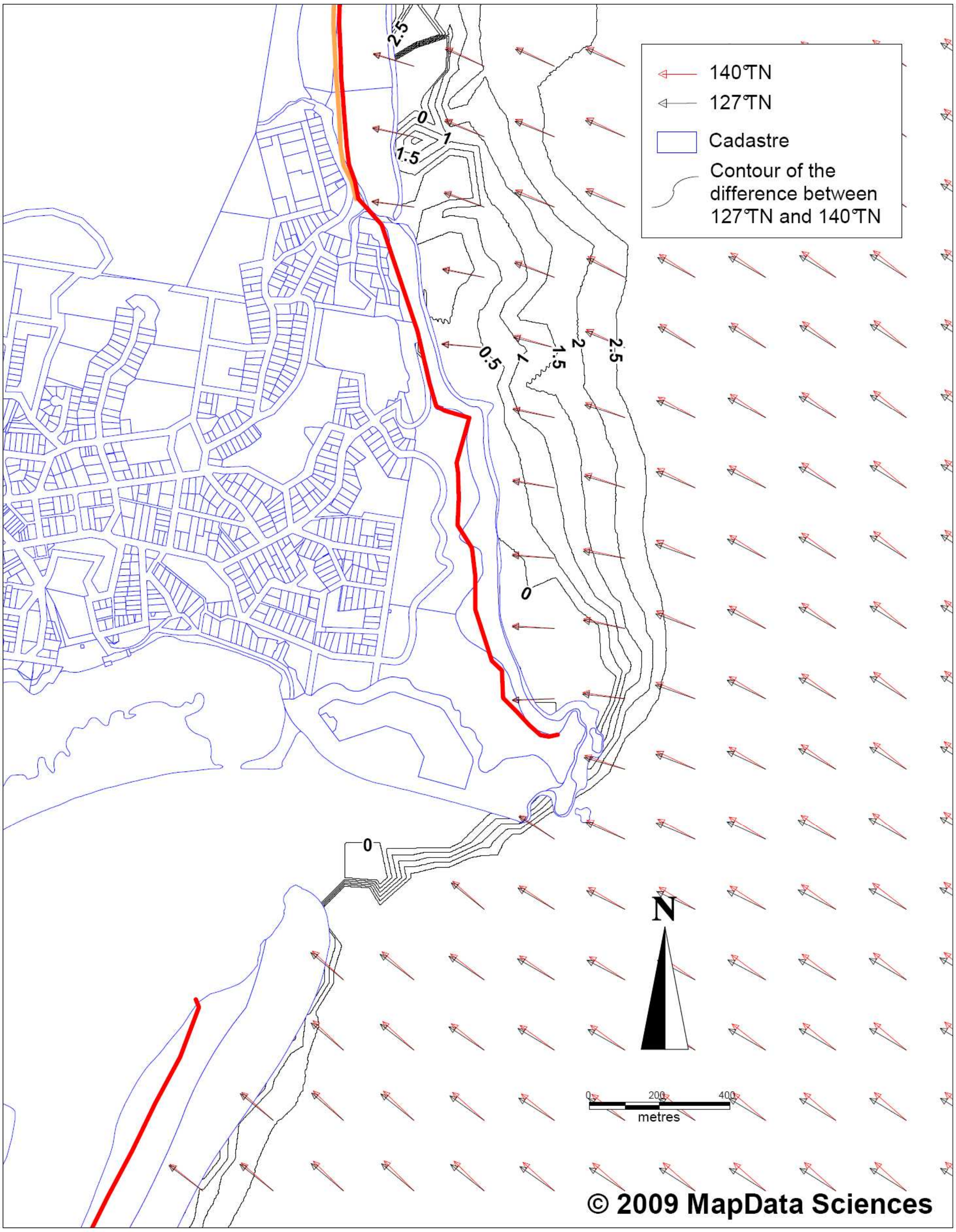

Figure B.8 – Change in nearshore angle caused by change in offshore wave approach angle from 127°TN to 140°TN, Nambucca Heads

Beach fluctuations over the 450 m distance including Beilbys and Shelly Beaches for a ±0.5° beach rotation may reach 4 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±8 m^3/m.

Beach fluctuations over the 700 m distance including Main Beach and Swimming Creek for a ±0.5° beach rotation may reach 6 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±12 m^3/m.

Beach rotation would be limited by the presence of the rock outcrops along the beach which control the beach plan-form.

2.4 Rotation and Longshore Drift at Valla Beach

The beaches at Valla Beach are accreting on average. The application of the storm erosion hazard protocol herein (Nielsen *et al*., 1992) is to apply the design storm erosion demand to the average beach profile to provide a conservative assessment, taking account of medium medium-term oscillations in sub-aerial beach sand store caused by decadal variations in the SOI and the fluctuations resulting from minor storm events. Around the entrance to Deep Creek, these fluctuations are not seen. This is because the ongoing river entrance influence overrides any medium term oscillation of the sub-aerial beach sand store that may be induced by beach rotation of the swash zone.

There is little evidence of beach rotation taking place at the beach compartment immediately surrounding Valla Beach, with beach fluctuations generally correlated positively with changes along the entire region where photogrammetry is available (Figure B.9).

A wave refraction analysis was undertaken for Valla Beach to investigate the impact of change in offshore wave angle on mean wave angle in the nearshore area. This was undertaken using SWAN (described in Section 2.2).

The range of offshore wave angles examined was from 127°TN to 140°TN, corresponding to the annual Mean Wave Direction (MWD) reported by Goodwin (2005). For this range of offshore wave directions, the variation in wave angle in the nearshore area of Valla Beach (at approximately the 5m depth contour, beyond the median wave breaking depth) is around 1.5° (see Figure B.10). As the beach planform is typically normal to the MWD, the beach rotation that would be expected would be of the same order (±0.75°), with the effects seen most greatly at the extreme southern and northern ends of the beach. Assuming that the beach can be approximated by a straight line, the beach fluctuations due to rotation are estimated by the following formula:

$$R = dist \times \tan(r)$$

where *R* = beach fluctuation in metres at the location of interest

dist = distance in metres from the centre of the beach (1250m for Main-South Valla Beach south of Deep Creek, 250m for the southern end of North Valla Beach and 2500m for the rest of North Valla Beach)

r = estimated change in nearshore wave angle in degrees.

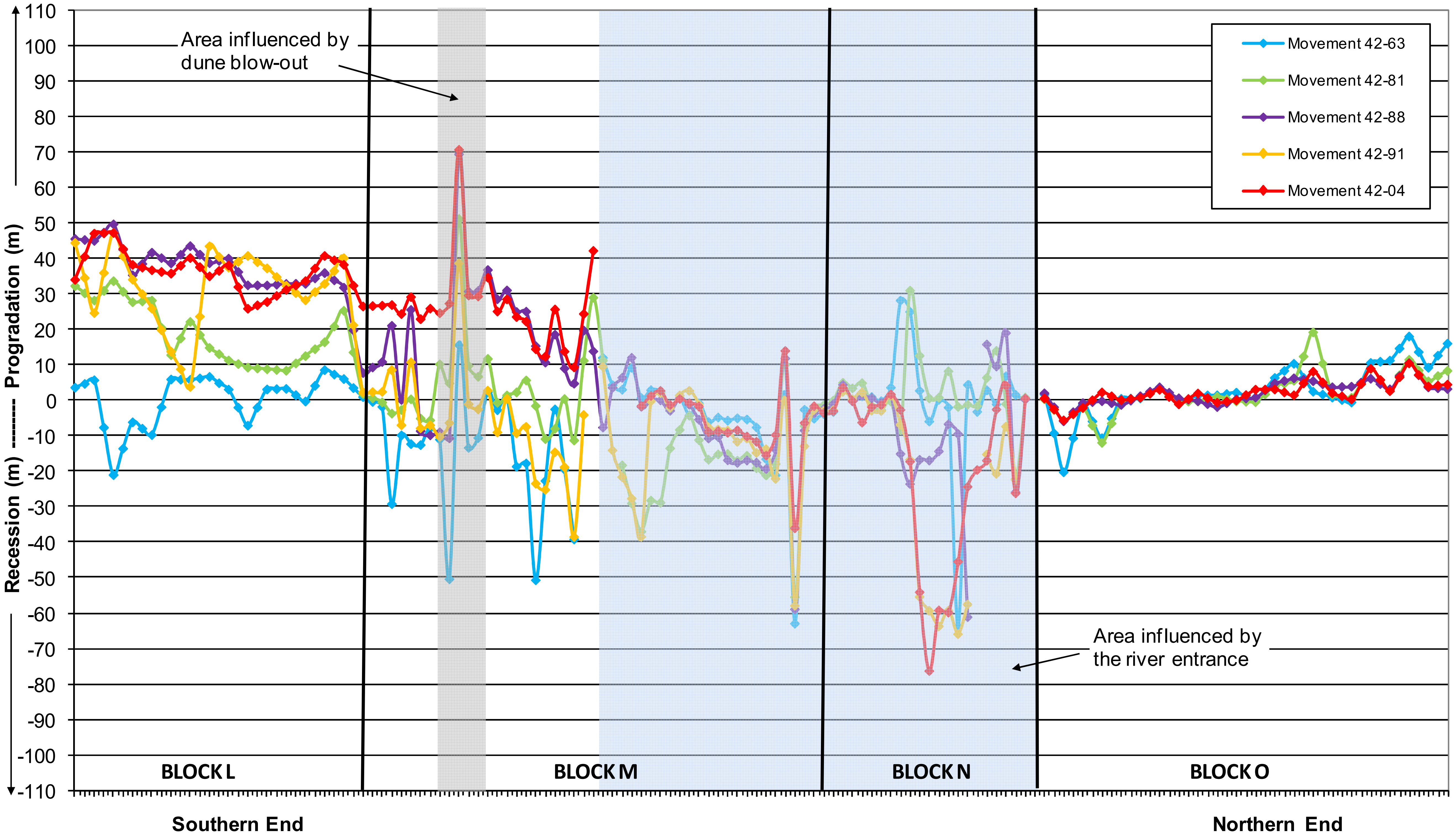

Figure B.9 - RL 4.0m movement between 1942 and 2004 for the different blocks, Valla Beach

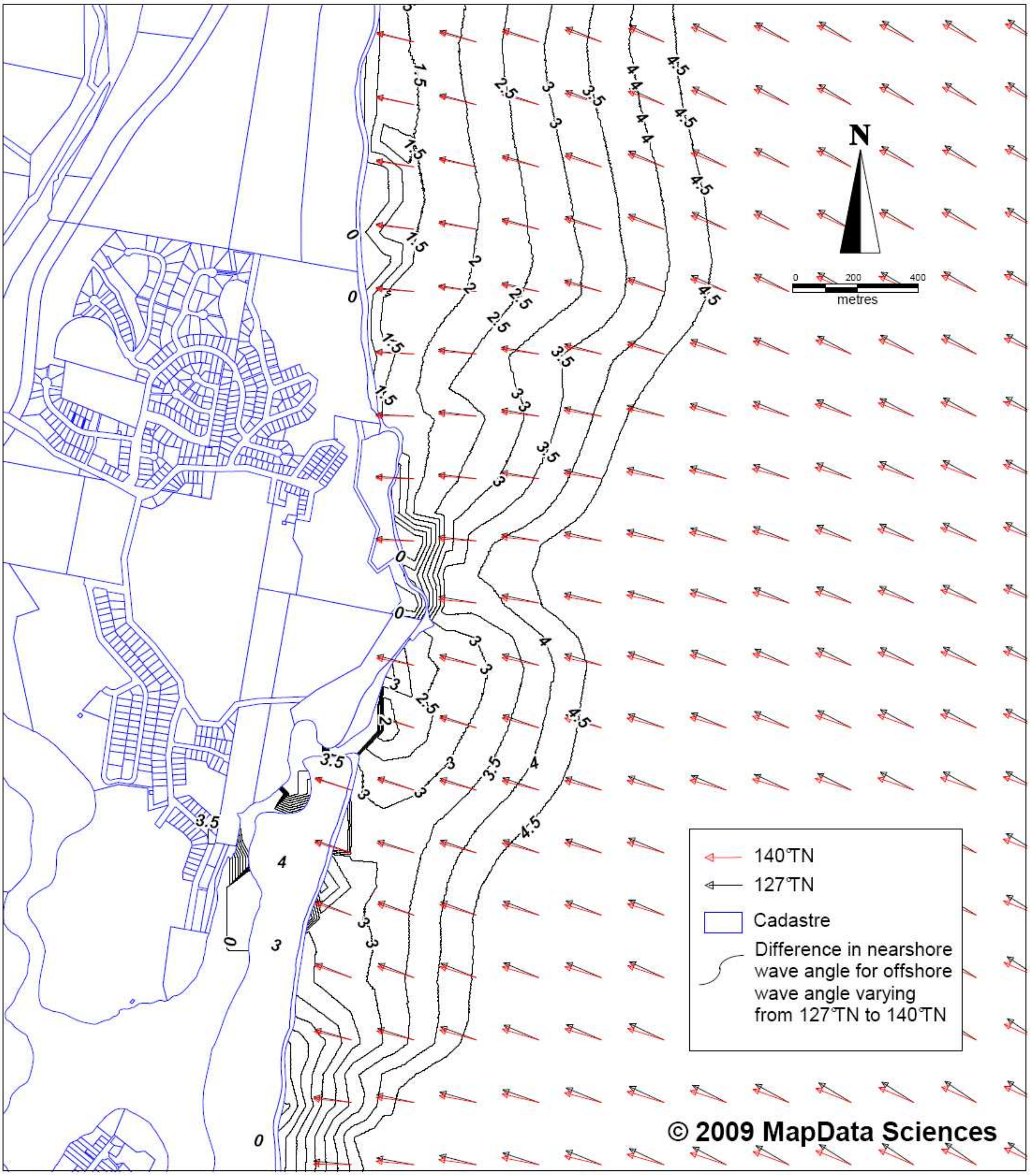

Figure B.10 – Change in nearshore angle caused by change in offshore wave approach angle from 127°TN to 140°TN, Valla Beach

Beach fluctuations over the 1250 m including Main and South Valla Beach for a ±0.75° beach rotation may reach 16 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±32 m^3/m.

Beach fluctuations over the 250 m at the southern end of North Valla Beach for a ±0.75° beach rotation may reach 3 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±6 m^3/m.
Beach fluctuations over the 2500 m distance between Valla Beach and Wenonah Head for a ±0.75° beach rotation may reach 32 m over the sandy portion of the beach – for a beach berm height of 2.0m AHD, this represents a sand volume fluctuation of approximately ±64 m^3/m.

Beach rotation would be limited by the presence of the rock outcrops along the beach, which control the beach planform.

3 Sea Level Rise

3.1 Impacts of Sea Level Rise

3.1.1 Bruun Rule

The most widely accepted method of estimating shoreline response to sea level rise is the Bruun Rule (Bruun, 1962; 1983). Bruun (1962, 1983) investigated the long term erosion along Florida's beaches, which was assumed to be caused by a long term sea level rise. Bruun (1962, 1983) hypothesised that the beach assumed an *equilibrium profile* that kept pace with the rise in sea level without changing its shape, by an upward translation of sea level rise (S) and shoreline retreat (R).

Figure B.11 illustrates the concept of the Bruun Rule. The Bruun Rule equation is given by:

$$R = \frac{S}{(h_c + B)/L}$$

where: *R* = shoreline recession due to sea level rise;

S = sea level rise (m)

h_c = closure depth

B = berm height; and

L = length of the active zone.

The Bruun model assumes that the beach profile is in an equilibrium state.

Berm height is taken to be the average height of the dune along the beach, and closure depth is the depth at the seaward extent of measurable sand movement. The length of the active zone is the distance offshore along the profile in which sand movement still occurs.

3.1.2 Determination of Bruun Rule Parameters

Several schemas exist, based on analytical and laboratory studies, to determine closure depth and length of the active zone, including those of Swart (1974) and Hallermeier (1981, 1983).

Hallermeier (1981, 1983) defines a simple zonation of an onshore-offshore beach profile consisting of a *littoral* zone, *shoal* zone or buffer zone, and offshore zone where surface wave effects on the bed are negligible.

Based on an analytical approach, supported by laboratory data and some field data, the two water depths bounding the shoal zone, defined by d_s and d_o are given by:

$$d_s = \frac{2.9H}{(S-1)^{0.5}} - \frac{110H^2}{[(S-1)gT^2]}$$

where d_s	=	water depth bounding the littoral and shoal zones
H	=	significant wave height *exceeded 12 hours per year*
T	=	associated wave period
S	=	specific gravity of the sediment, and
G	=	acceleration due to gravity; and

$$d_o = 0.018 H_{med} T_{med} \left[\frac{g}{(S-1)D_{50}} \right]^{0.5}$$

where d_o is the depth at the boundary of the offshore zone and H and T are the median *significant* wave height and period parameters and D_{50} is the median grain size. For Nambucca Heads, H_{med} = 1.5 m; T_{med} = 9.5 s; H_s = 7 m and T_p = 12 s (Kulmar et al, 2005).

Typical beach sand characteristics give S = 2.65, and grain size at Nambucca Heads is around 0.25mm. Use of these values gives:

d_s = 13.49 m and

d_o = 39.60 m.

Nielsen (1994) reviewed these, and other analytical methods and a large body of field data to define subaqueous fluctuations of open coast beaches in NSW. Nielsen (1994) found that the absolute limit of offshore sand transport under cyclonic or extreme storm events occurred at a depth of 22m. Use of the Hallermeier (1981, 1983) formulation for estimating the closure depth gives an inner limit for the depth of closure of around 13 m and an outer limit of around 40 m.

Bruun (1954) proposed a simple power law to describe the relationship between water depth, *h*, and offshore distance, *x*, measured at the mean sea level:

$$h = Ax^{\frac{2}{3}}$$

where *A* is a dimensional shape factor, mainly dependent on the grain size. Figure B.12 (from Dean, 1987) gives an empirical relationship between *A* and grain size, D. This gives a value of *A* for the different beaches along Nambucca Shire coast, based on an assumed median grain size of around 0.25 mm, of approximately 0.1 to 0.15.

The closure depths and the equilibrium profile lengths have been assessed from the shape of the nearshore beach profiles. These two characteristics are the coordinates of the seaward limit of the equilibrium profile.

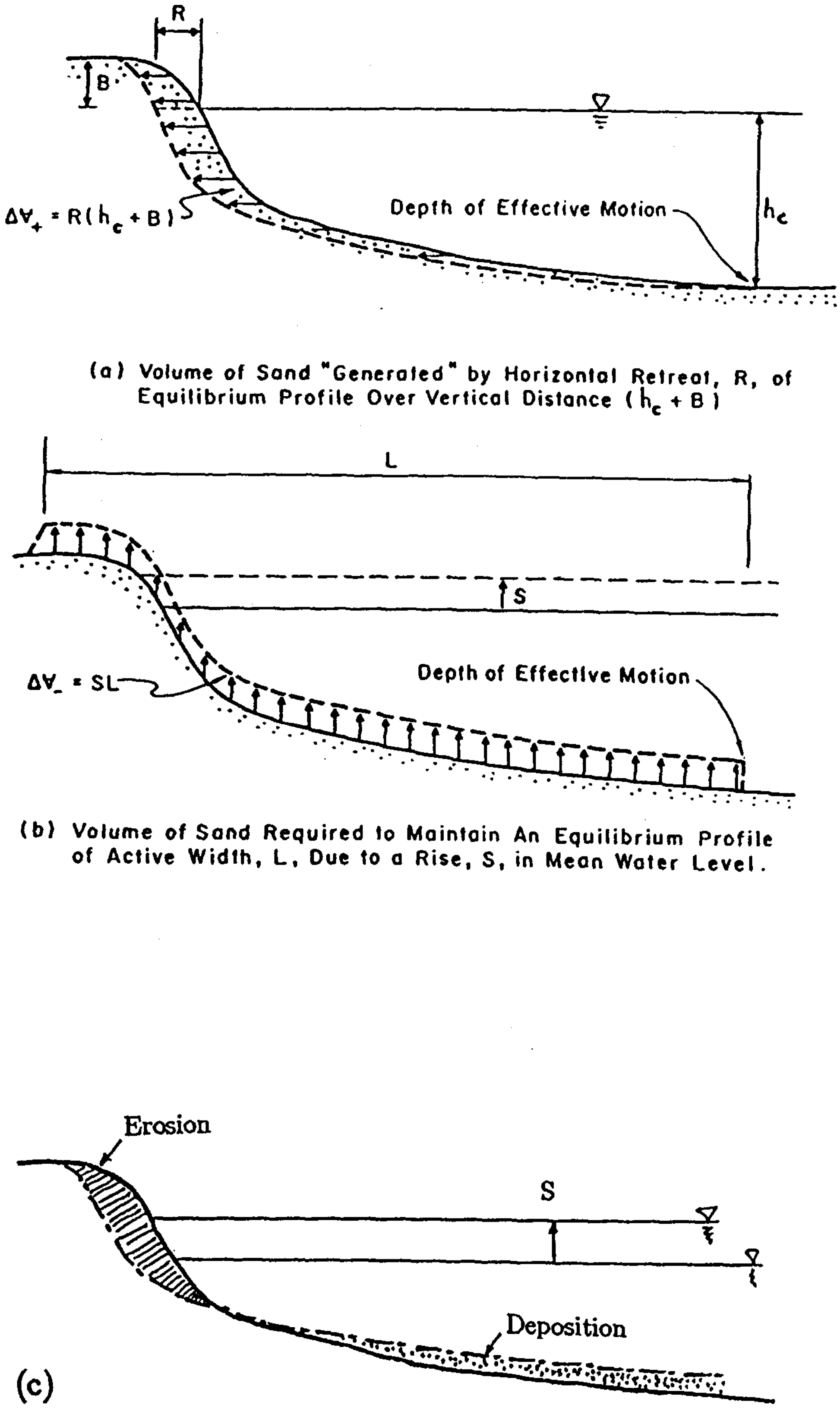

Figure B.11 - Concept of shoreline recession due to sea level rise

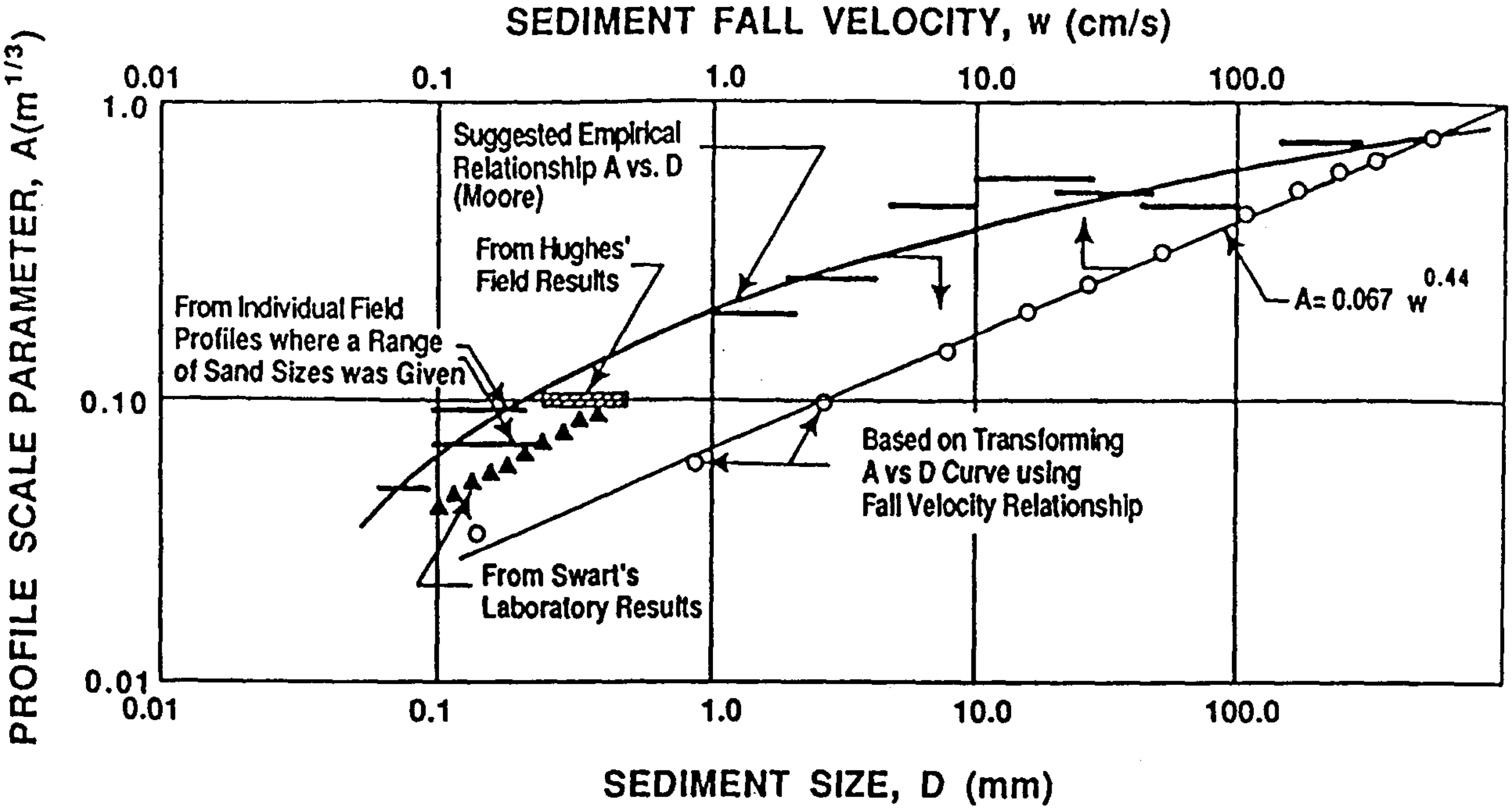

Figure B.12 – Suggested relationship for shape factor A vs. grain size D (Dean, 1987)

3.1.3 Scotts Head Bruun Rule Parameters

Examination of data from digitised soundings on a 1 km grid as provided by Geoscience Australia (Petkovic & Buchanan, 2002) showed that the nearshore profile was in equilibrium down to a depth range from 30 to 33m depth, and a profile length varying between 2100 and 3200m (Table B.1).

<table>
<tr><th>Block number</th><th>Location</th><th>Av. Dune height B (m)</th><th>Av. Closure depth h_c (m)</th><th>Av. Profile length L (m)</th><th>Average slope per block (1:X)</th></tr>
<tr><td>1</td><td>Little Beach</td><td>6</td><td>-30</td><td>2100</td><td>60</td></tr>
<tr><td>2</td><td rowspan="2">Southern end Forster Beach and surf club</td><td rowspan="2">7</td><td rowspan="2">-32</td><td rowspan="2">2675</td><td rowspan="2">70</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="2">Mid-northern end Forster Beach</td><td rowspan="2">11</td><td rowspan="2">-33</td><td rowspan="2">3150</td><td rowspan="2">70</td></tr>
<tr><td>5</td></tr>
</table>

Table B.1 – Determination of the dune height, closure depth and profile length per block from Geoscience Australia bathymetric data.

The depths calculated from the Geoscience Australia bathymetry data are of the same order as the depth calculated with the Hallermeier formula. These results have been used to determine the recession due to sea level rise along the Little and Forster beaches, as the application of the Bruun Rule is limited to the portion of the profile in equilibrium. The computed nearshore profile slope is within the range of around 1:60 to 1:70, which is within the range common to many open coast beaches along the New South Wales coast.

A comparison plot of the shore-normal profile at Forster Beach and the estimated equilibrium profile is given in Figure B.13. It should be noted that the nearshore profile is based on limited data. As the application of the Bruun Rule is limited to the portion of the profile in equilibrium with the wave climate, taking the nearshore slope out to a depth of 30 to 33 m for use with the Bruun Rule was considered appropriate. Addition of the average dune height to the depth of closure gives a nearshore slope which ranges from 1:60 to 1:70 for use with the Bruun Rule. The computed nearshore profile slope is within the range of 1:50 – 1:100 that is common to many of the world's coastlines (Ranasinghe *et al.* 2007).

Results of the Bruun analysis are given in Table B.2.

Table B.2 – Scotts Head - Predicted beach erosion due to sea level rise

BLOCK 1						
Total Predicted Sea Level Rise (m)			**Total Beach Recession (m)**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	14.6	32.1	87.5	192.5
High	0.40	0.90	23.3	52.5	140.0	315.0
BLOCK 2-3						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	17.6	38.7	123.2	271.0
High	0.40	0.90	28.2	63.4	197.1	443.5
BLOCK 4-5						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	18.0	39.5	197.5	434.5
High	0.40	0.90	28.7	64.6	316.0	711.0

For an upper-range sea level rise scenario in line with the NSW Sea Level Rise Policy Statement (DECC 2009a, DECC 2009b), the total beach recession expected would be from **23.3 – 28.7 metres by 2050** and **52.5 – 64.6 metres by 2100**. This equates to annual erosion rates between **3.5 and 7.9 m^3/m/year by 2100**.

It should be noted that these recession rates assume that the dune is composed of erodible material. Where a superficial layer of sandy beach overlies bedrock, such as at Little Beach, the rates of beach recession that would actually occur due to sea level rise may be less than what is estimated above.

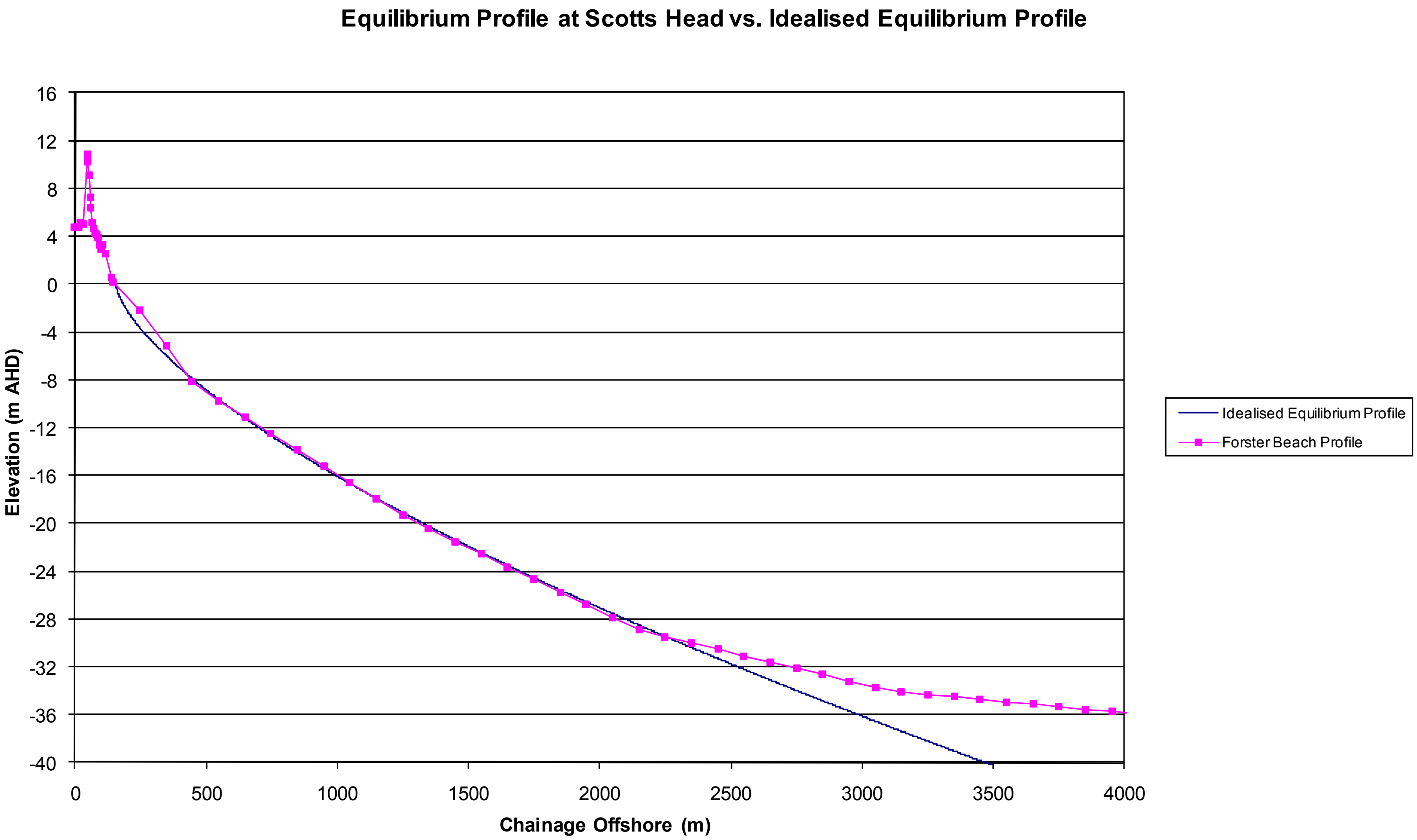

Figure B.13 – Idealised Equilibrium Profile vs. measured profile at Scotts Head

3.1.4 Nambucca Heads Bruun Rule Parameters

Analysis of data from the digitised soundings on an approximately 1 km grid as provided by Geoscience Australia (Petkovic & Buchanan, 2002) showed that the nearshore profile was in equilibrium down to a depth range from 21 to 34m and a profile length varying between 2500 and 4010 m (Table B.3).

Table B.3 – Determination of the berm height, the closure depth and the profile length per block and per continuous beach from the Geoscience Australia data.

Block number	Location	Av. Dune height B (m)	Av. Closure depth h_c (m)	Av. Profile length L (m)	Average slope per block (1:X)
1	North end Forster Beach	9	-35	4012	91
2	Northern breakwater	4	-34	3250	87
3	Shelly and Beilbys Beach	5	-28	3189	97
4					
5	Main Beach and Swimming Creek	7	-21	2642	93
6					

The depths calculated from the Geoscience Australia bathymetry data are of the same order as the depth calculated with the Hallermeier formula. These results have been used to determine the recession due to sea level rise along the Nambucca Shire coast, as the application of the Bruun Rule is limited to the portion of the profile in equilibrium. The computed nearshore profile slope is within the range of around 1:90 to 1:100, which is within the range common to many open coast beaches along the New South Wales coast.

A comparison plot of the shore-normal profile at Nambucca Heads and the estimated equilibrium profile is given in Figure B.14. It should be noted that the nearshore profile is based on limited data. As the application of the Bruun Rule is limited to the portion of the profile in equilibrium with the wave climate, taking the nearshore slope out to a depth of 21 to 35 m for use with the Bruun Rule was considered appropriate.

Results of the Bruun analysis are given in Table B.4.

Table B.4 - Predicted beach erosion due to sea level rise Nambucca Heads

Northern end Forster Beach (BLOCK 1)						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	22.8	50.3	205.6	452.3
High	0.40	0.90	36.5	82.2	328.9	740.0
Northern breakwater (BLOCK 2)						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	21.4	47.0	85.5	188.2
High	0.40	0.90	34.2	77.0	136.8	307.9
Shelly and Beilbys Beach (BLOCK 3-4)						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	24.2	53.2	120.8	265.8
High	0.40	0.90	38.7	87.0	193.3	435.0
Main Beach and Swimming Creek (BLOCK 5-6)						
Total Predicted Sea Level Rise (m)			**Total Beach Recession**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	23.7	52.1	165.6	364.4
High	0.40	0.90	37.9	85.2	265.0	596.3

For an upper-range sea level rise scenario in line with the NSW Sea Level Rise Policy Statement, the total beach recession expected would be **34.2 - 38.7 metres by 2050** and **77.0 - 87.0 metres by 2100**. This equates to annual erosion rates **between 3.4 and 8.2 m^3/m/yr by 2100**.

It should be noted that these recession rates assume that the dune is composed of erodible material. Where a superficial layer of sandy beach overlies bedrock, such as at Main and Shelly beaches, the rates of beach recession that would actually occur due to sea level rise may be less than what is estimated above.

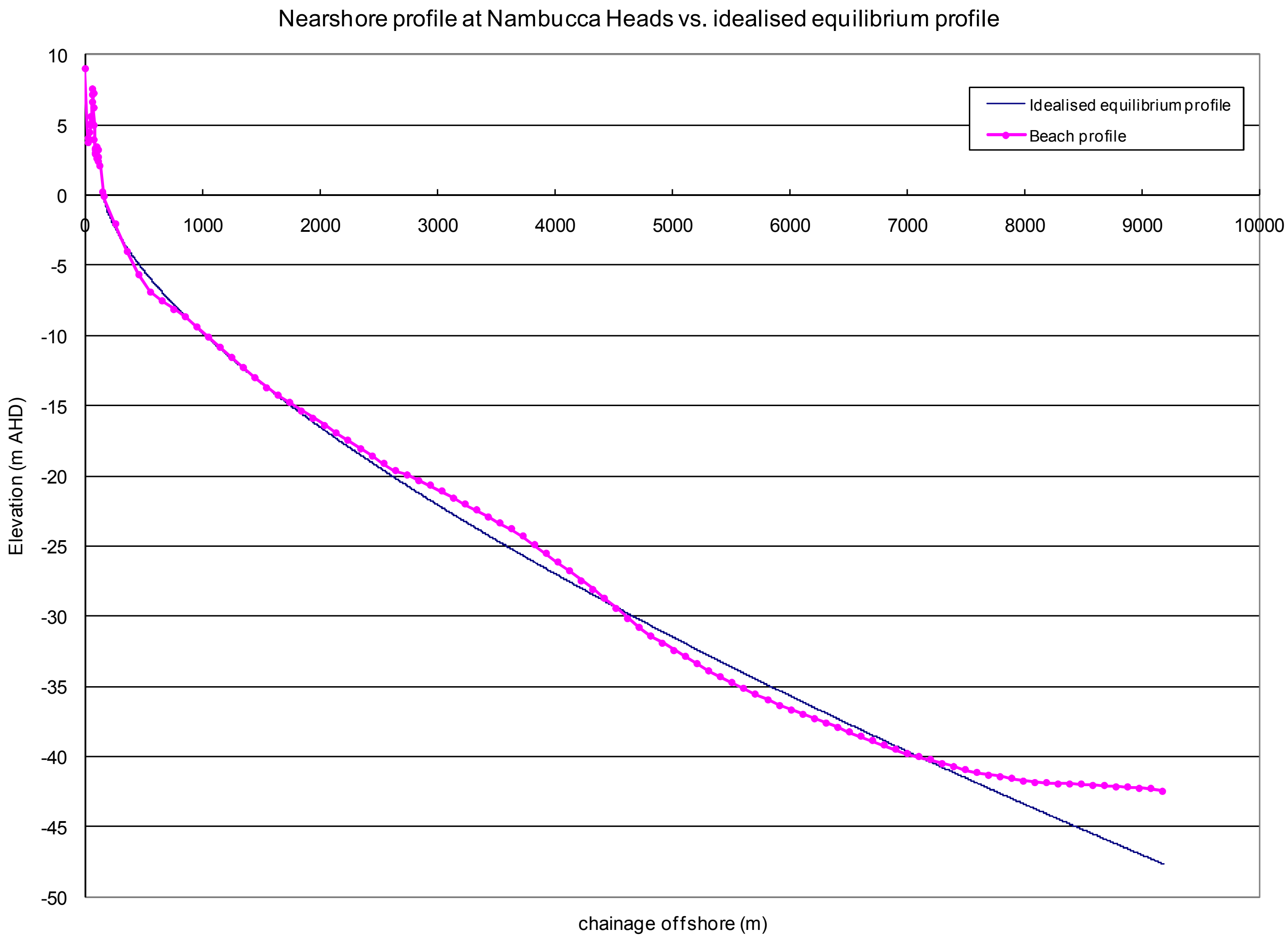

Figure B.14 – Idealised Equilibrium Profile vs. measured profile at Nambucca Heads

3.1.5 Valla Beach Bruun Rule Parameters

Examination of data from the digitised soundings on a 1 km grid as provided by Geoscience Australia (Petkovic & Buchanan, 2002) showed that the nearshore profile extended to a depth of 18 to 30 metres, and a profile length of around 1930 to 4590 metres (Table B.5). Beyond these depths there is a discontinuity in the profile indicating that it is not in equilibrium with the wave climate.

Table B.5 – Determination of the berm height, the closure depth and the profile length per block from the Geoscience Australia data

Block	Av.Dune height (m)	Av. Closure depth (m)	Av. Profile length (m)	Average slope per block (1:X)
L	11	-18	4585	100
M	7	-23	3200	107
N	3	-15	1930	107
O	6	-30	3640	100

The closure depths and the equilibrium profile lengths have been assessed from the shape of the nearshore beach profiles. These two characteristics are the coordinates of the seaward limit of the equilibrium profile. It should be noted that this assessment is based on relatively coarse nearshore data. Aerial photography of the area shows that the nearshore zone is composed of rocky reef, which indicates that the nearshore profile may not be in equilibrium with the wave climate.

A comparison plot of the shore-normal profile at Forster Beach and the estimated equilibrium profile is given in Figure B.15. It should be noted that the nearshore profile is based on limited data. As the application of the Bruun Rule is limited to the portion of the profile in equilibrium with the wave climate, taking the nearshore slope out to a depth of 18 to 30 m for use with the Bruun Rule was considered appropriate. Addition of the average dune height of 6 to 11 m to the depth of closure gives a nearshore slope which ranges from 1:100 to 1:107 for use with the Bruun Rule. The computed nearshore profile slope is consistent with the range of 1:50 – 1:100 that is common to many of the world's coastlines (Ranasinghe *et al.* 2007).

Results of the Bruun analysis are given in Table B.6.

Table B.6 - Predicted beach erosion due to sea level rise Valla Beach

BLOCK L						
Total Predicted Sea Level Rise (m)			**Total Beach Recession (m)**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	25.0	55.0	275.0	605.0
High	0.40	0.90	40.0	90.0	440.0	990.0
BLOCK M						
Total Predicted Sea Level Rise (m)			**Total Beach Recession (m)**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	26.7	58.7	186.7	410.7
High	0.40	0.90	42.7	96.0	298.7	672.0
BLOCK N						
Total Predicted Sea Level Rise (m)			**Total Beach Recession (m)**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	26.8	59.0	80.4	176.9
High	0.40	0.90	42.9	96.5	128.7	289.5
BLOCK O						
Total Predicted Sea Level Rise (m)			**Total Beach Recession (m)**		**Total Beach Erosion (m^3/m)**	
Scenario	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Central	0.25	0.55	25.3	55.6	151.7	333.7
High	0.40	0.90	40.4	91.0	242.7	546.0

For an upper-range sea level rise scenario in line with the NSW Sea Level Rise Policy Statement, the total beach recession expected would be **from 40.0 to 42.7 metres by 2050** and from **90 to 96 metres by 2100**. This equates to annual erosion rates **between 7.5 and 11 m^3/m/yr**.

It should be noted that these recession rates assume that the dune is composed of erodible material. Where a superficial layer of sandy beach material overlies bedrock, rates of beach recession that would actually occur due to sea level rise would be less than what is estimated above. Moreover, the beach at Block O is underlain by bedrock which will limit the erosion of the beach there.

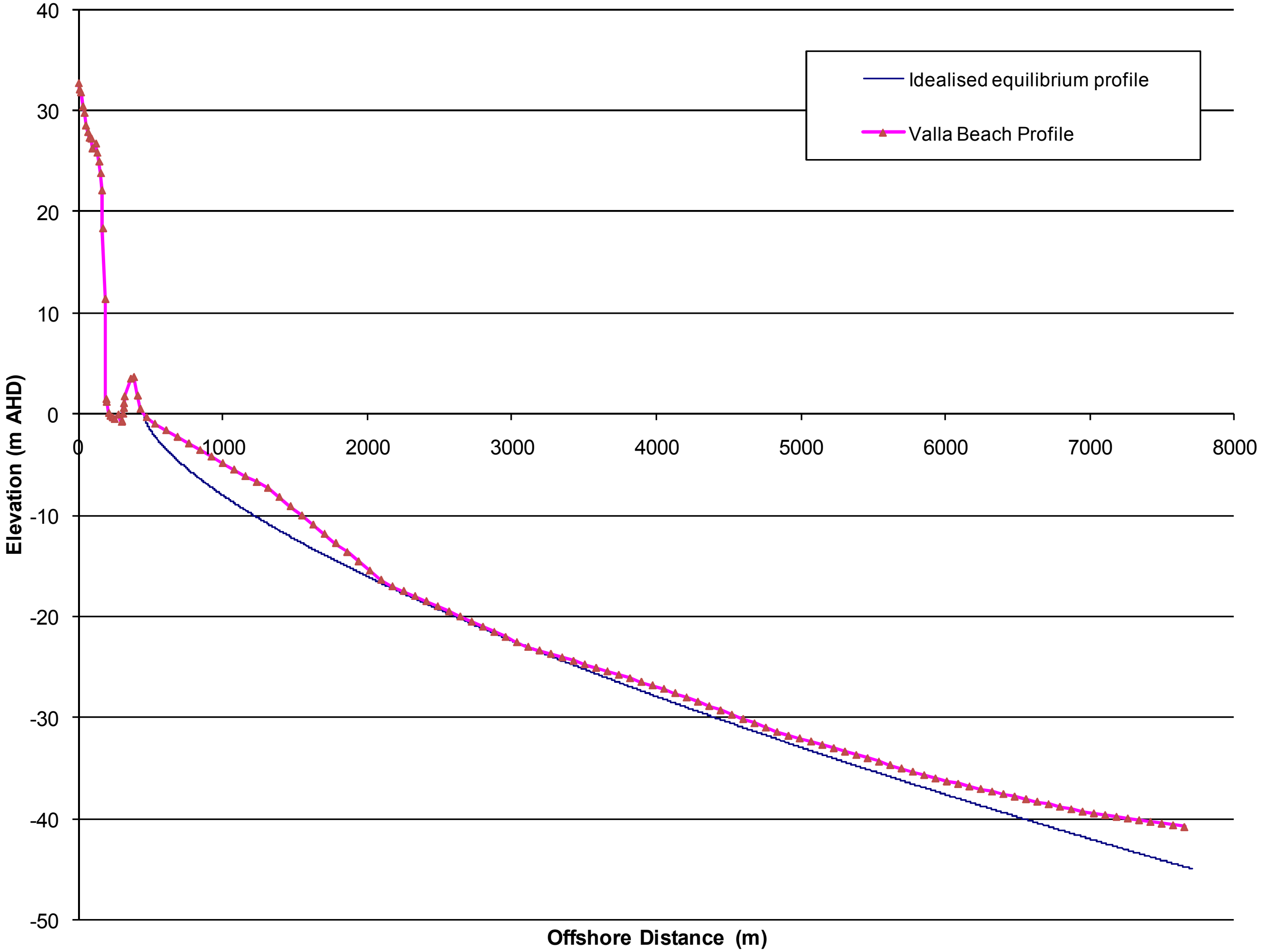

Figure B.15 - Idealised Equilibrium Profile vs. measured profile at Valla Beach

4 Summary and Conclusions

Climate change has the potential to affect the beaches along the Nambucca Shire coastline in two ways:

- erosion/recession resulting from beach rotation, longshore drift and river entrance behaviour at decadal time scales; and

- overall beach recession resulting from sea level rise.

At Scotts Head, it was found that beach rotation related to the Southern Oscillation Index may result in decadal fluctuations of beach berm sand volumes of up to +/- 4 m^3/m for Little Beach and +/- 140 m^3/m for Forster Beach, as the nearshore wave approach angle can vary respectively by as much as ±1° and ±0.75°. Beach rotation at Little Beach is insignificant, and at Scotts Beach, beach rotation would manifest as changes in the net rate of northerly longshore drift.

At Nambucca Heads, beach rotation related to the Southern Oscillation Index may result in decadal fluctuations of beach berm sand volumes of less than 12 m^3/m at Shelly, Beilbys and Main beaches, which is not significant. Due to the influence of wave refraction, nearshore wave approach angles vary only within ±0.5°, and beach rotation is further limited by the presence of rocky outcrops along the beaches.

At Valla Beach, beach rotation related to the Southern Oscillation Index may result in decadal fluctuations of beach berm sand volumes of up to 30 m^3/m along South Valla Beach and 60 m^3/m along North Valla Beach, as the nearshore wave approach angle can vary by as much as ±0.75°. However, beach rotation would be limited by the presence of rock outcrops along the beaches.

The estuary entrance dynamics and local sediment budgets would also be impacted by changes to the mean wave climate brought about by climate change. A change in the frequency of *El-Niño* and *La-Niña* events would change the mean offshore wave direction and thus influence longshore sediment transport. A change toward dominant *El-Niño* conditions would lead to a more southerly wave climate, enhanced northward sediment transport and a clockwise beach rotation (with recession at the southern ends of the beaches). In addition, an increase in the tidal prism of the estuary caused by sea level rise could lead to beach erosion, reduced sediment bypassing of the entrance by longshore drift, and increased sediment infilling of the lower estuary.

The IPCC (2007) projections for sea level rise caused by climate change have been synthesised with tectonic changes relevant for the NSW coast. The predicted shoreline response due to sea level rise at Nambucca Shire has been examined using a Bruun analysis.

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