Appendix A – Coastal Hazard Calculations

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1 Introduction

This Appendix describes the derivation of coastal hazards based on analysis of photogrammetry data and modelling.

Photogrammetry is a technique for mapping ground terrain from vertical aerial photography. It allows the surface elevation of the *subaerial* beach (the portion of the beach above the water line) to be measured along transect lines on the beach. The technique has been used for many years to produce topographic maps and is a useful tool for analysing changes to subaerial beach profiles over time, particularly as historical aerial photography often spans many decades. The technique cannot be used, however, to analyse changes to the beach profile below the water line and is thus limited to analysing only part of the total littoral system.

A photogrammetric survey along the Nambucca Shire coast including Little and Forster Beach, the Nambucca Heads coastline and Valla Beach was undertaken by the Department of Environment Climate Change and Water (DECC&W) using various aerial photographs dating from 1942 to 2004.

Tables A.1, A.2 and A.3 list the aerial photographs analysed with photogrammetry for Scotts Head, Nambucca Heads and Valla Beach respectively. Tables A.1, A.2 and A.3 indicate also a measure of the survey accuracy as derived from the orientation of the photography in the stereo restitution instrument. From the Table, it can be seen that earlier photography (1942 and 1973) was at a smaller scale, leading to vertical accuracies from ±0.5 to ±0.7m. Later photography, being clearer and at a larger scale, allowed the technique to bear more accurate results, with vertical and horizontal accuracies of ±0.3m achieved for photographs from 1979 – 2004.

Date of Photography	Scale	Vertical Accuracy	Horizontal Accuracy	Used for Photogrammetry
07/08/2004	1:10000	0.3 m	0.3 m	YES
01/09/2003	1:25000	0.5 m	0.5 m	NO
28/06/1996	1:10000	0.3 m	0.3 m	YES
12/09/1991	1:25000	0.5 m	0.5 m	NO
09/05/1988	1:10000	0.3 m	0.3 m	YES
29/06/1981	1:25000	0.5 m	0.5 m	NO
18/10/1979	1:8000	0.3 m	0.3 m	YES
14/04/1973	1:40000	0.5 m	0.5 m	YES
01/11/1942	1:17000	0.7 m	0.7 m	YES

TABLE A.1 - List of aerial photographs and accuracies used for photogrammetric analysis, Scotts Head

Date of Photography	Scale	Vertical Accuracy	Horizontal Accuracy	Used for Photogrammetry
07/08/2004	1:10000	0.3 m	0.3 m	YES only for block 2 to 6
2003	1:10000	0.3 m	0.3 m	YES only for block 1
12/09/1991	1:25000	0.5 m	0.5 m	YES
04/04/1980	1:16000	0.3 m	0.3 m	YES
14/04/1973	1:40000	0.5 m	0.5 m	YES
16/06/1953	1:40000	0.5 m	0.5 m	YES
17/11/1942	1:17000	0.7 m	0.7 m	YES

TABLE A.2 – List of aerial photographs and accuracies used for photogrammetric analysis, Nambucca Heads

Date of Photography	Scale	Vertical Accuracy	Horizontal Accuracy	Used for Photogrammetry
07/08/2004	1:10000	0.3 m	0.3 m	YES
28/06/1996	1:10000	0.3 m	0.3 m	YES (for Block M-N only)
17/06/1993	1:10000	0.3 m	0.3 m	YES (for Block M-N only)
1991	1:10000	0.3 m	0.3 m	YES (except for Block O)
23/09/1988	1:16000	0.3 m	0.3 m	YES
26/03/1986	1:25000	0.5 m	0.5 m	YES (for Block M-N only)
31/08/1983	1:10000	0.3 m	0.3 m	NO
29/06/1981	1:25000	0.5 m	0.5 m	YES
21/04/1963	1:40000	0.5 m	0.5 m	YES
29/10/1942	1:17000	0.7 m	0.7 m	YES

TABLE A.3 – List of aerial photographs and accuracies used for photogrammetric analysis, Valla Beach

Figures A.1, A.2 and A.3 illustrate the dates of photogrammetry when compared with the occurrence of major storm events offshore of Nambucca Shire, for the Scotts Head, Nambucca and Valla Beach areas.

For the photogrammetric surveys, the coast along Scotts Head was divided into five blocks, delineating the beaches (Little Beach and Forster Beach) from south to north. At

Nambucca Heads, the study area was divided into six blocks. The coast along Valla Beach was divided into four blocks, delineating the beach from south to north. Among these four blocks, the two blocks around Deep Creek entrance have already been studied in the draft report of the Specialist Coast and Flood Services, NSW Department of Land and Water Conservation of “Deep Creek entrance dynamics, Valla Beach, NSW” (May 2000).

Figure A.4 illustrates the block divisions along the coast at Scotts Head, Figure A.5 illustrates the block divisions at Nambucca Heads and Figure A.6 illustrates the block divisions at Valla Beach.

At Scotts Head, profiles from the southernmost Block 1 front 250 metres of Little Beach and the Blocks 2 to 5 front Forster Beach covering approximately 2200m. Figures A.7 and A.8 illustrate Little Beach and its foredune, as it appeared in December 2008 (Block 1). This beach does not seem to be significantly eroding. Figure A.9 shows the southern end of Forster Beach (Blocks 2-3) where some dune erosion is visible at the bottom of the dune. Figure A.10 presents some global views of Forster Beach (Blocks 2-3-4-5). At the southern end, mature trees can be seen on the foredune which indicates that some erosion has taken place there, whereas the northern end appears to have a healthy foredune with grass and shrubs.

At Nambucca Heads, profiles from Block 1 front approximately 1.2 kilometres of the northern extremity of Forster beach south of the Nambucca River entrance. Profiles from Block 2 front a 100m-long pocket beach located at the end of the northern breakwater of the Nambucca River entrance and south of Shelly Beach. Profiles from Block 3 front Shelly Beach car park (Figure A.9). Profiles from Block 4 front approximately 750m of beach including Beilbys Beach and the northern end of Shelly Beach (Figure A.10). The profiles from Block 5 front Main Beach Surf Club (Figure A.11), and profiles from Block 6 front approximately 1.5 kilometres of beach length from Main Beach to Swimming Creek (Figure A.12).

At Valla Beach, Figure A.13 illustrates the block divisions along the beach, with profiles from the southernmost Block L fronting 750 metres of beach along Hyland Park, Block M fronting Deep Creek, Block N fronting South Valla Beach and the northernmost Block O fronting 1.05 kilometres along North Valla Beach. Digital files containing the geographic locations and elevations of transects at 50m intervals in each of these blocks for each year of photogrammetry have been provided to Council by DECC&W for analysis for this study.

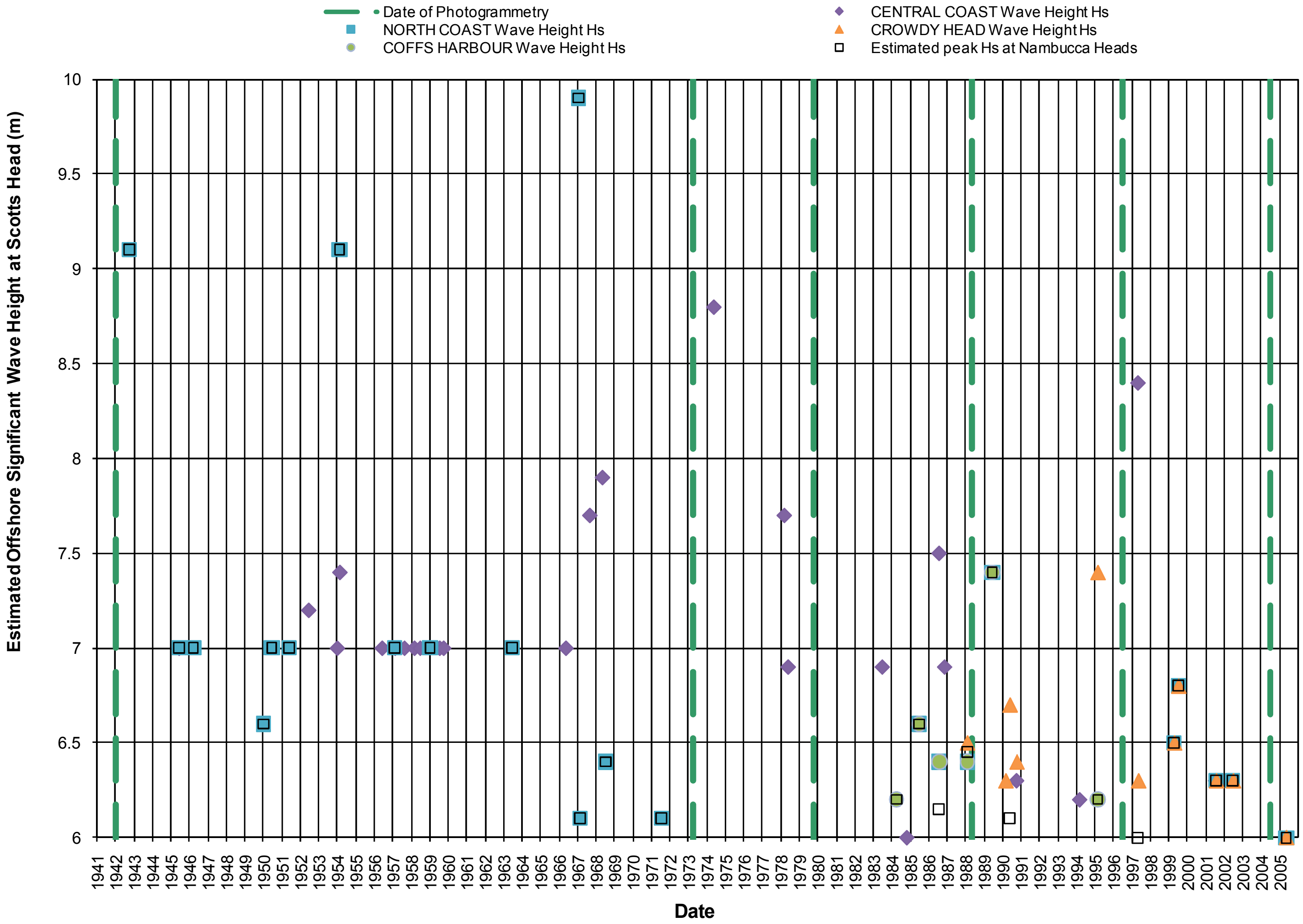


Figure A.1 – Extreme Storm events vs. Photogrammetry Dates, Scotts Head

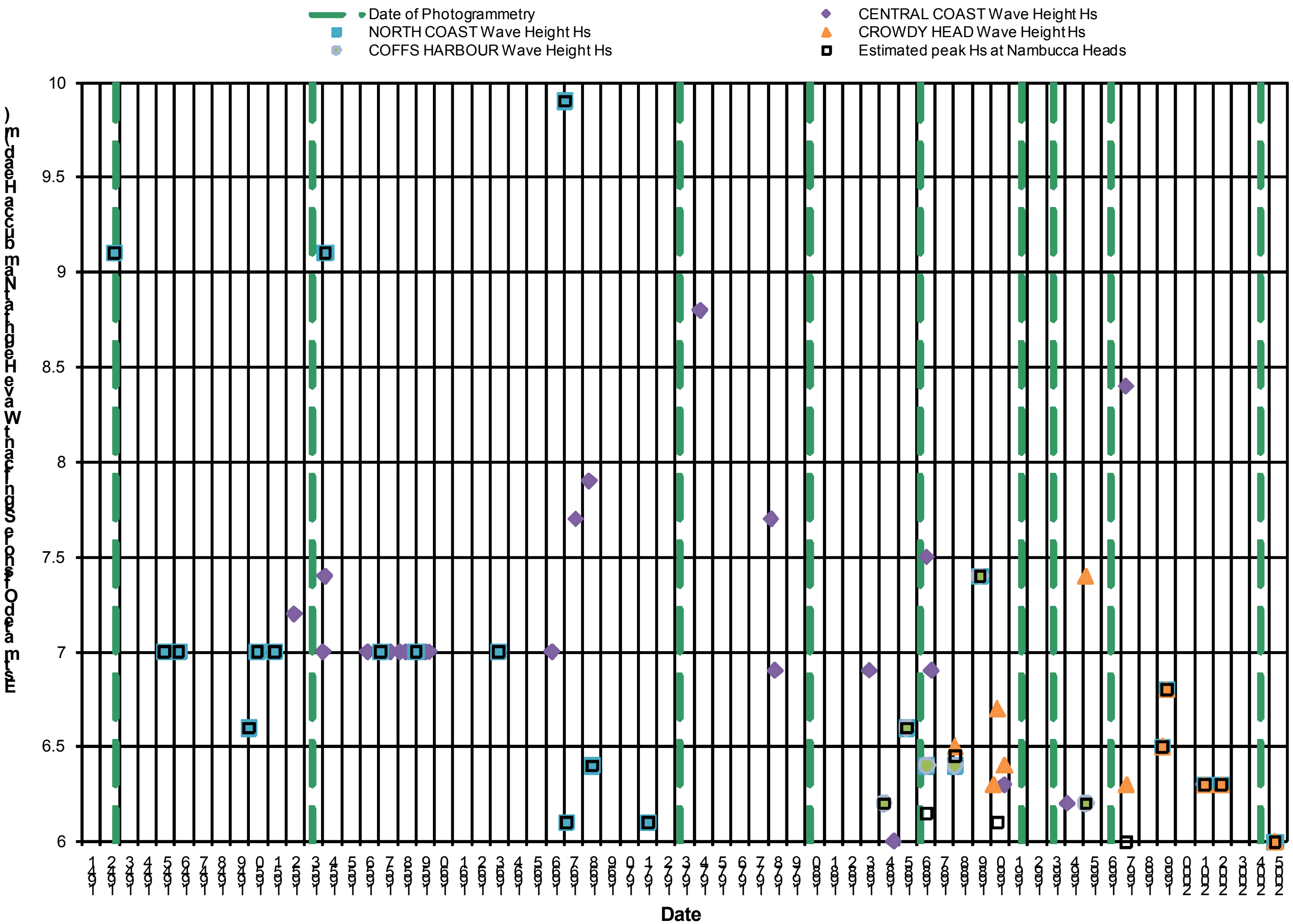


Figure A.2 – Extreme Storm events vs. Photogrammetry Dates Nambucca Heads

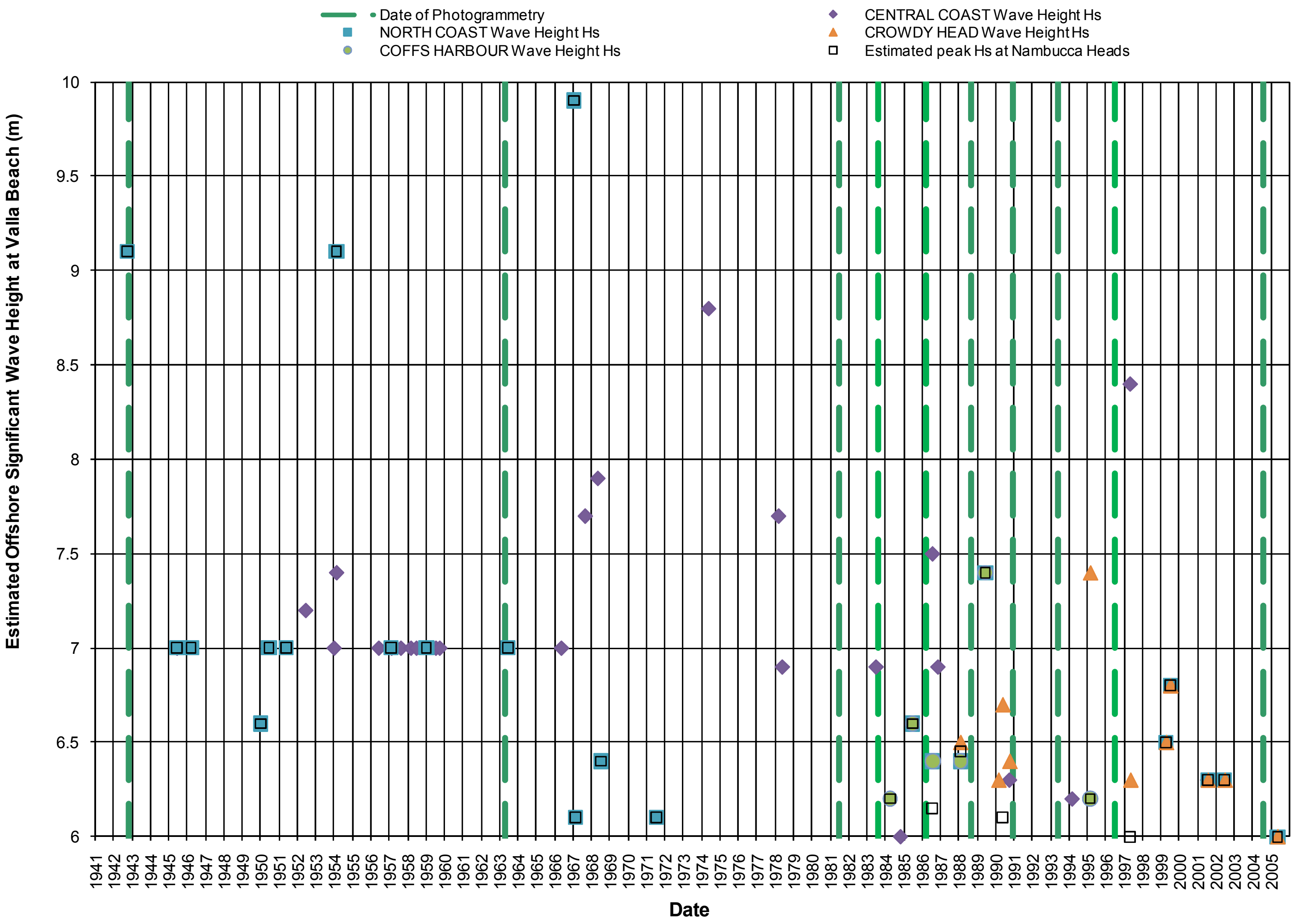


Figure A.3 – Extreme Storm events vs. Photogrammetry Dates Valla Beach

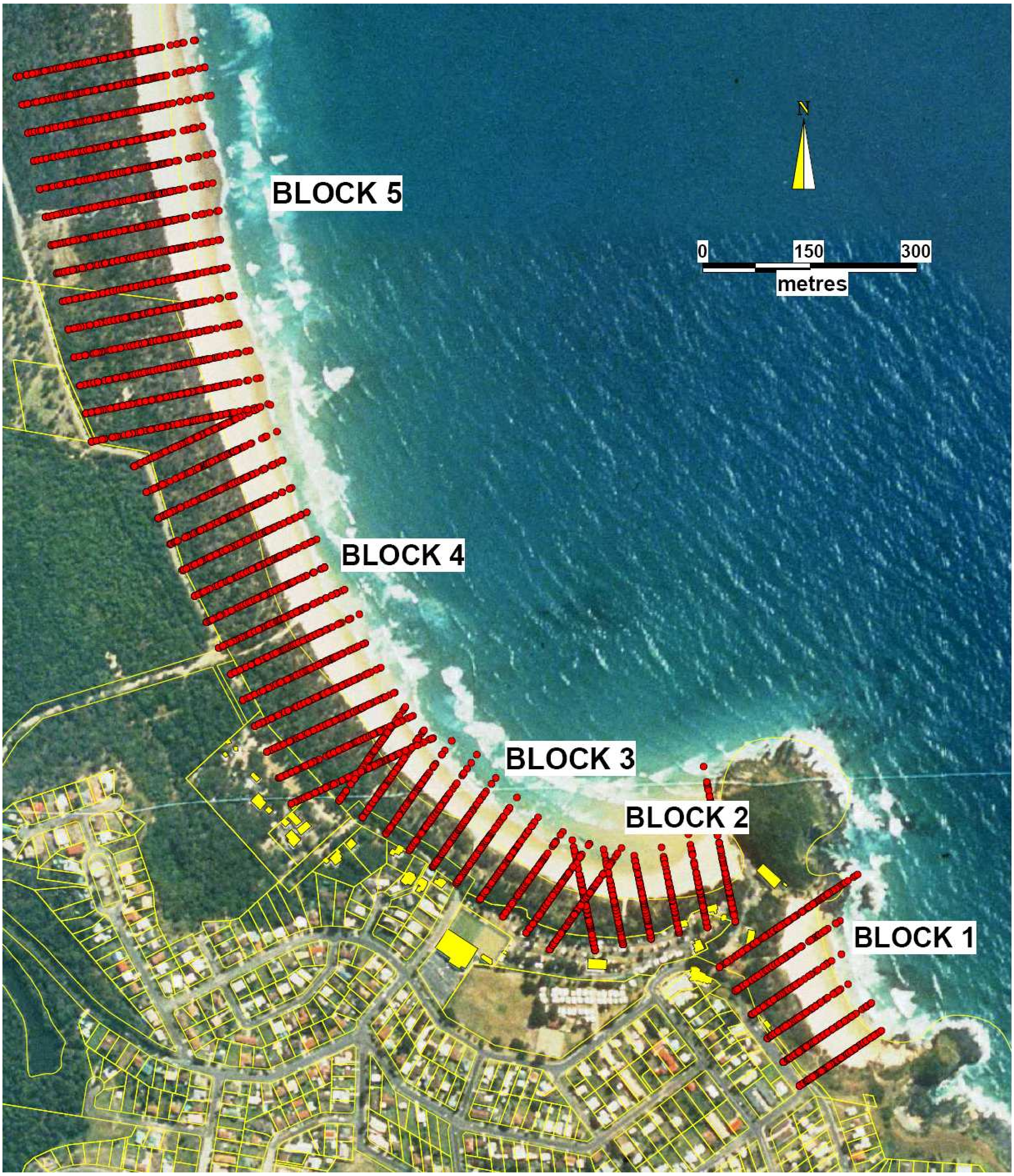


Figure A.4 – Photogrammetry Profiles Scotts Head

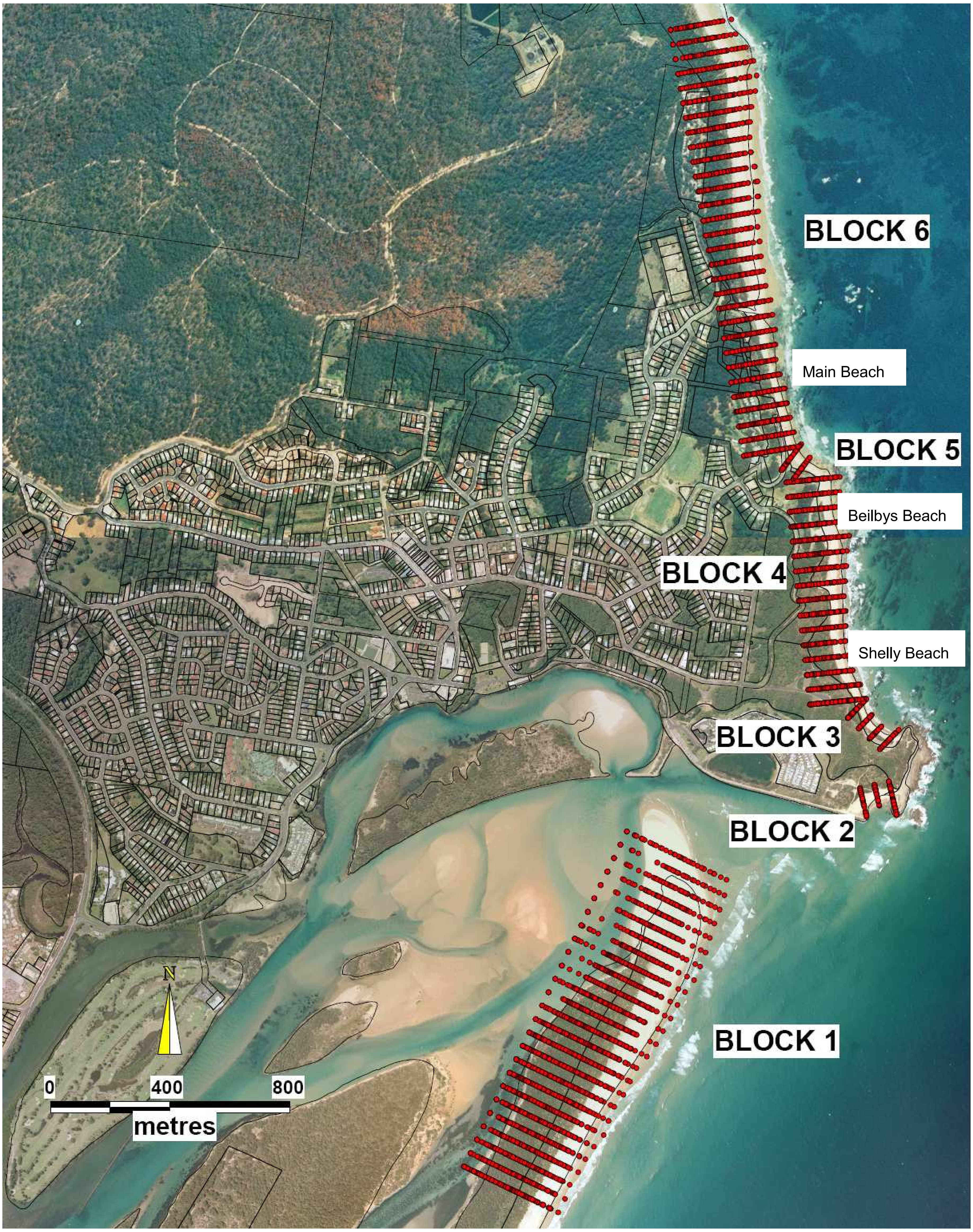


Figure A.5 – Photogrammetry Profiles Nambucca Heads

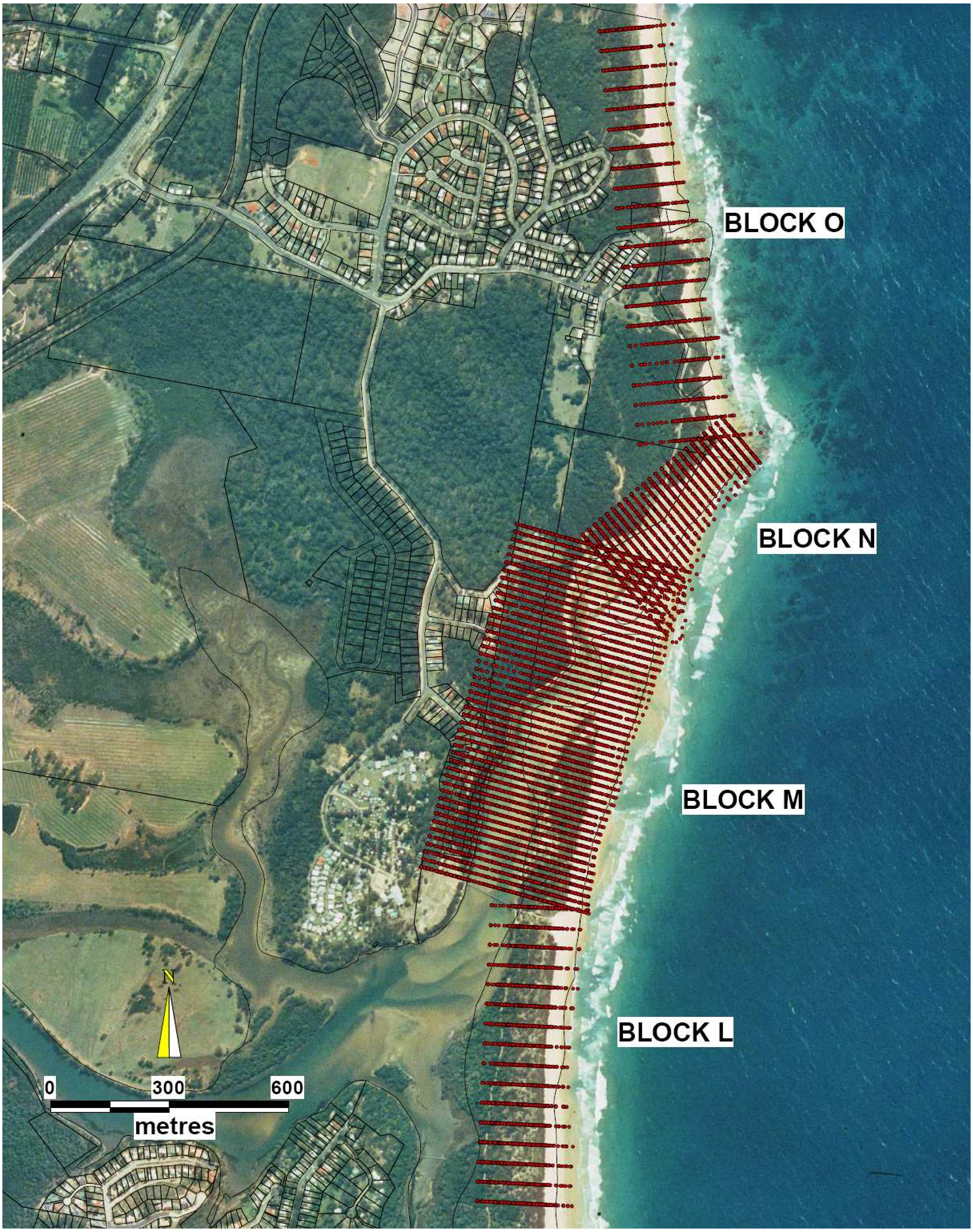


Figure A.6 – Photogrammetry Profiles Valla Beach

Figure A.7 – Looking north from the middle of Little Beach

Figure A.8 – Looking south from the middle of Little Beach (top) and from the SLSC (bottom)

Figure A.9 – Top – Forster Beach car park (Block 2).
Bottom – Forster Beach dune visible erosion (Block 2-3)

Figure A.10 – Top – Forster Beach looking north from car park (Block 2-3-4)
Bottom – Northern end of Forster beach (Block 5)

Figure A.14 includes two views of North Valla Beach showing that there are some rock outcrops along the beach. This indicates that there may be some bedrock below the sand layer which could reduce the erosion of the beach. Figure A.15 illustrates two views of South Valla Beach showing the erosion at the former picnic area. Figure A.16 shows a general view toward the entrance of Deep Creek, taken from the footbridge.

The results and comment are detailed separately for every beach as the morphology of the different beaches within this area are governed by different coastal processes. For example, the zone south of Nambucca Heads is directly influenced by the river entrance dynamics, while the areas to the north form a separate beach compartment.

Historical aerial photographs from 1942 to 2007 have been examined to observe the various changes occurring along the Nambucca Shire coastline over the years. This appendix documents the observations made on the photography and two techniques used to quantify subaerial beach changes using the digital data files:

1. Carrying out a volumetric analysis of the profiles to determine beach response over time, and
2. Plotting the location of the main dune face along the beach with time.

Figure A.11 - Shelly Beach (Block 3) looking South

Figure A.12 – Beilbys Beach (Block 4) looking South

Figure A.13 – Main Beach looking South (Block 5)

Figure A.14 – Main beach looking North (Block 6)

Figure A.15 – Top – Looking south from North Valla Beach

Bottom – Looking north from North Valla Beach

Figure A.16 – Top – Looking north from South Valla Beach
Bottom – Looking south from South Valla Beach

Figure A.17 – Looking in direction of Deep Creek entrance from the footbridge

2 Short Term Fluctuations

2.1 Storm Erosion

The amount of sand eroded from the beach during a severe storm will depend on many factors including the state of the beach when the storm begins, the storm intensity (wave height, period and duration), direction of wave approach, the tide levels during the storm and the occurrence of rips. Storm cut is the volume of beach sand that can be eroded from the subaerial (visible) part of the beach and dunes during a *design* storm. Usually, it has been defined as the volume of eroded sand as measured above mean sea level (~ 0 m AHD datum). For a particular beach, the storm cut (or storm erosion demand) may be quantified empirically with data obtained from photogrammetric surveys, or it may be quantified analytically using a verified numerical model.

2.1.1 Storm Erosion / Dune Stability Schema

A generalised dune stability schema relating to storm erosion is presented schematically in Figure A18. The following four stability zones (*Zone of Wave Impact*, *Zone of Slope Adjustment*, *Zone of Reduced Foundation Capacity* and *Stable Foundation Zone*) have been delineated as follows (after Nielsen *et al*., 1992):

1) The *Zone of Wave Impact* delineates an area where any structure or its foundations would suffer wave attack during a severe storm. It is that part of the beach that is seaward of the dune erosion escarpment.

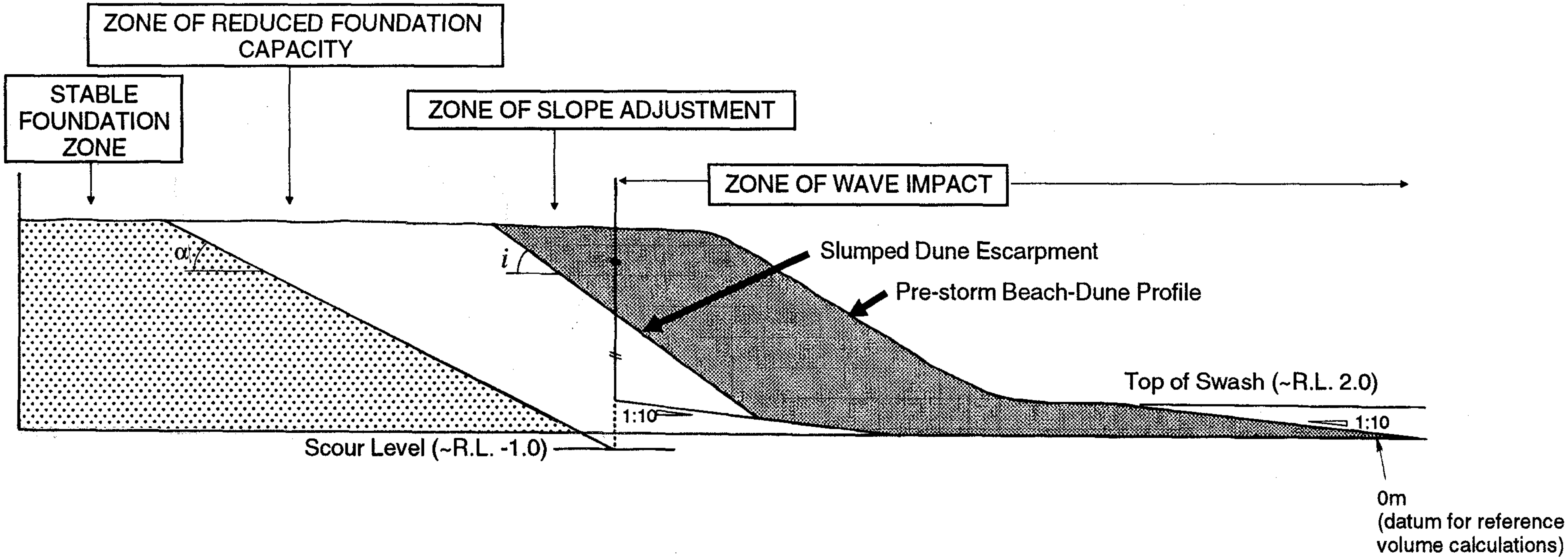
2) A *Zone of Slope Adjustment* was delineated to encompass that portion of the seaward face of the dune that would slump to the natural angle of repose of the dune sand following removal by wave erosion of the *Design Storm Erosion Demand*. That presents the steepest stable dune profile under the conditions specified.

3) A *Zone of Reduced Foundation Capacity* for building foundations was delineated to take account of the reduced bearing capacity of the sand adjacent to the dune erosion escarpment. It was considered that structural loads should be transmitted only to soil foundations outside the zone within which the *Factor of Safety* was less than 1.5 during extreme scour conditions at the face of the dune. This allows for the design assumption that the soil may develop its full bearing capacity.

4) The *Stable Foundation Zone* is that portion of the dune that is unaffected by the wave erosion processes and within which no special foundation requirements need to be made.

To determine the impact of storm erosion on a homogeneous sand dune, the *design storm erosion demand* is subtracted from the available sand storage on the beach. The slumped storm erosion profile is idealised as comprising a steep dune escarpment at a slope (i) equal to the natural angle of repose of dune sand (φ) to the top of the swash zone at low tide, taken to be RL 2 m (approximately on AHD), then a steep nearshore beach face of slope 1:10 down to RL 0 m (AHD − the datum for the reference volume calculations; see Figure B.7). A flatter slope (α) extending landward from the limit of beach scour and incorporating a Factor of Safety of 1.5 ($\tan\alpha = \tan\varphi/1.5$) defines the limit of the *Zone of Reduced Foundation Capacity* beyond which surface footings can be used safely.

For the assessment of slope stability of eroded dunes, a value of 35° has been adopted for the angle of internal friction for dune sands.



Angle of repose of dune sand: $i \sim \phi \approx 34^{\circ}$

Safe angle of repose of dune sand: $\alpha = \tan^{-1}\{(\tan\phi)/1.5\} \approx 24^{\circ}$

All levels to AHD

Figure A.18 - Dune stability schema (after Nielsen *et al.*, 1992)

For Scotts Head, Nambucca Heads and Valla Beach, details of the empirical analysis are given below.

2.2 Scotts Head - Quantifying Storm Erosion Demand from historical storms

Photogrammetric data for Scotts Head were not entirely suitable for analysing dune volume changes induced by storm erosion, because the photographs were not taken immediately before and after a storm event. Several large storms occurred during the period between 1963 and 1983, as shown in Figure A.1. These storms included the June 1967 storms which impacted greatly on the NSW north coast, and the storms of May-June 1974 whose impacts were greatest felt on the NSW central coast. Nevertheless, the photogrammetric record does not show the impact of these storms, possibly due to long period of time between the storm occurrence and the next post-storm aerial photograph. However, the storms which occurred between 1988 and 1996 can be seen more clearly in the photogrammetry and seem to have had a significant impact at Forster Beach.

In the current investigation, photogrammetric data from 1967 or 1974 was not available and a measurable storm bite is most noticeable after cyclone VIOLET which occurred in March 1995. This cyclone lasted five days and had a pressure of approximately 980hPa with a wind speed of around 54 knots, when it was less than 200 kilometers north-east of Scotts Head. The significant wave height reached 7.4 m during this period. It is possible that because the beach at Scotts Head faces north-east, it would have been impacted more greatly by Cyclone Violet than other beaches within Nambucca Shire. For this reason, volume changes between the photogrammetric data of 1988 and 1996 were analysed to estimate a storm bite recession.

Examination of the beach profiles revealed that dune accretion continued throughout the period of the photogrammetric data. The beach berm below 2.0m AHD was found to be most accreted in the 2004 photography. For empirical measurement of short-term dune recession, it was found that the most appropriate photogrammetric profiles to compare were the 1988 and 1996 photogrammetric profiles. An *equivalent* storm erosion has been estimated empirically using data from 1988 and 1996 and by applying the protocol described in Nielsen *et al.* (1992) and shown in Figure A.16.

2.2.1 Scotts Head - Estimation of Storm Erosion Volumes

From the 1996 photogrammetry data, the location of the top of the scarp feature resulting from the 1995 storms is clearly visible, as the post-storm photogrammetry data has been taken the year after the storm event. At most locations, the dune face had not had enough time to recover from the storm. Although the dune scarp was clearly visible, some beach berm recovery had occurred and the storm erosion demand that may be measured by comparing these two profiles would be less than the “actual” storm bite as a result of this storm.

Figure A.19 illustrates the procedure used to estimate the *equivalent* storm erosion volume. This storm erosion demand consists of the sum of the measured volume difference between pre and post-storm photogrammetric profiles (Volume 1) and the assumed post-storm recovered volume (Volume 2) obtained by applying the protocol from Nielsen *et al.* (1992). This equivalent storm erosion demand corresponds to the *Zones of Wave Impact and Slope Adjustment* illustrated in Figure A.18.

From the analysis of dune face locations undertaken in this appendix, it can be seen that there was a general movement of the RL 4.0m and RL 5.0m contours landward between the dates of the 1942 and 2004 photography, and that this landward translation varies along the beach, with a mean value of around 25 metres (Figure A.20). The data indicate some periodic variation and it is considered that the local maxima of the landward movement of the RL 4.0m contour could correspond to the location of rip-heads that would have formed during the 1995 storms. It is noted that very high values of beach recession can be seen in the photogrammetry between 1942 and 1973 and since this second date, the beach has mainly been accreting (refer Figure A.21). As the 1942 photography was of small scale and was subject to significant spatial errors, it is possible that the long term trend is better defined by the photogrammetric data since 1973. It is also possible that wind erosion of the dune led to the large changes in dune volumes seen between 1942 and 1973.

For the analysis of equivalent storm erosion volumes, the values at the local maxima of the landward movement of the RL 4.0m contour have been calculated and applied to the whole beach, in order to take account of the formation of rip-heads and to arrive at a conservative estimate of storm erosion demand for the beach.

The estimated storm erosion demand for the 1995 storm for these locations is plotted in Figure A.22. It can be seen that these values range from less than 100 m^3/m (in the well protected zones, such as the southern corner of Forster Beach which is held in place by a seawall) and 250 m^3/m in the more exposed areas. These sand volume losses represent approximately 14 – 22 m of dune loss. It should be noted that the typical values of storm erosion that have been measured on other open-coast beaches along the NSW coast are around 200 – 250 m^3/m. Therefore, Scotts Head beaches appear to have a storm bite erosion typical of open coast beaches on the NSW coast.

From this analysis, an envelope value of erosion volume between 1988 and 1996 was obtained for the various blocks at Scotts Head. These values are given in Table A.4.

Block	Maximum loss of sand volume (m^3/m)
1	120
2	120
3	190
4	200
5	250

TABLE A.4 – Storm erosion and long term recession volume for each block

Except for Blocks 1 and 2, these values are close to the typical values that have been measured at open coast beaches that consist of unconsolidated sands elsewhere in NSW.

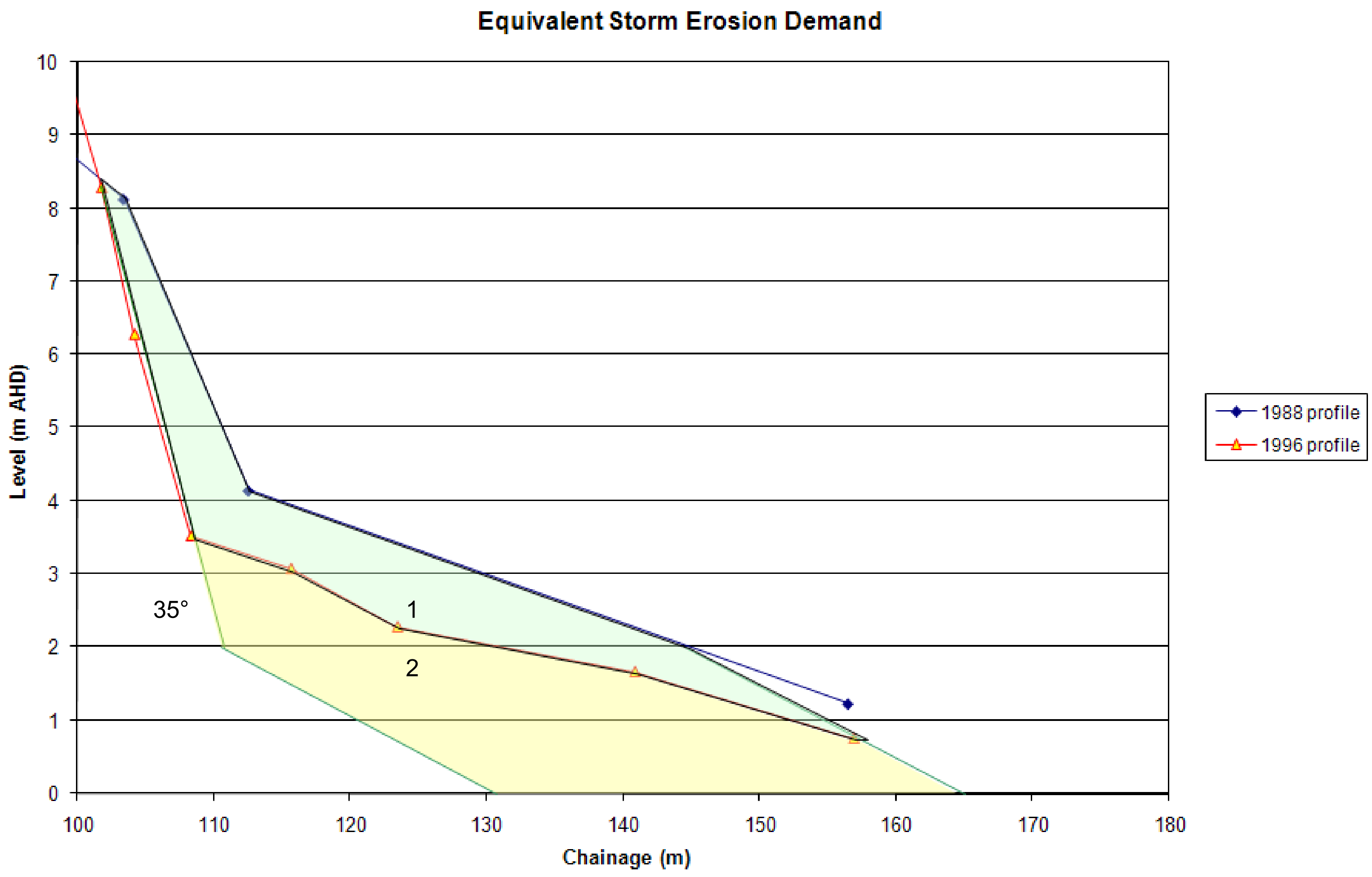


Figure A.19 – Determination of Equivalent storm erosion, Scotts Head 1988 – 1996

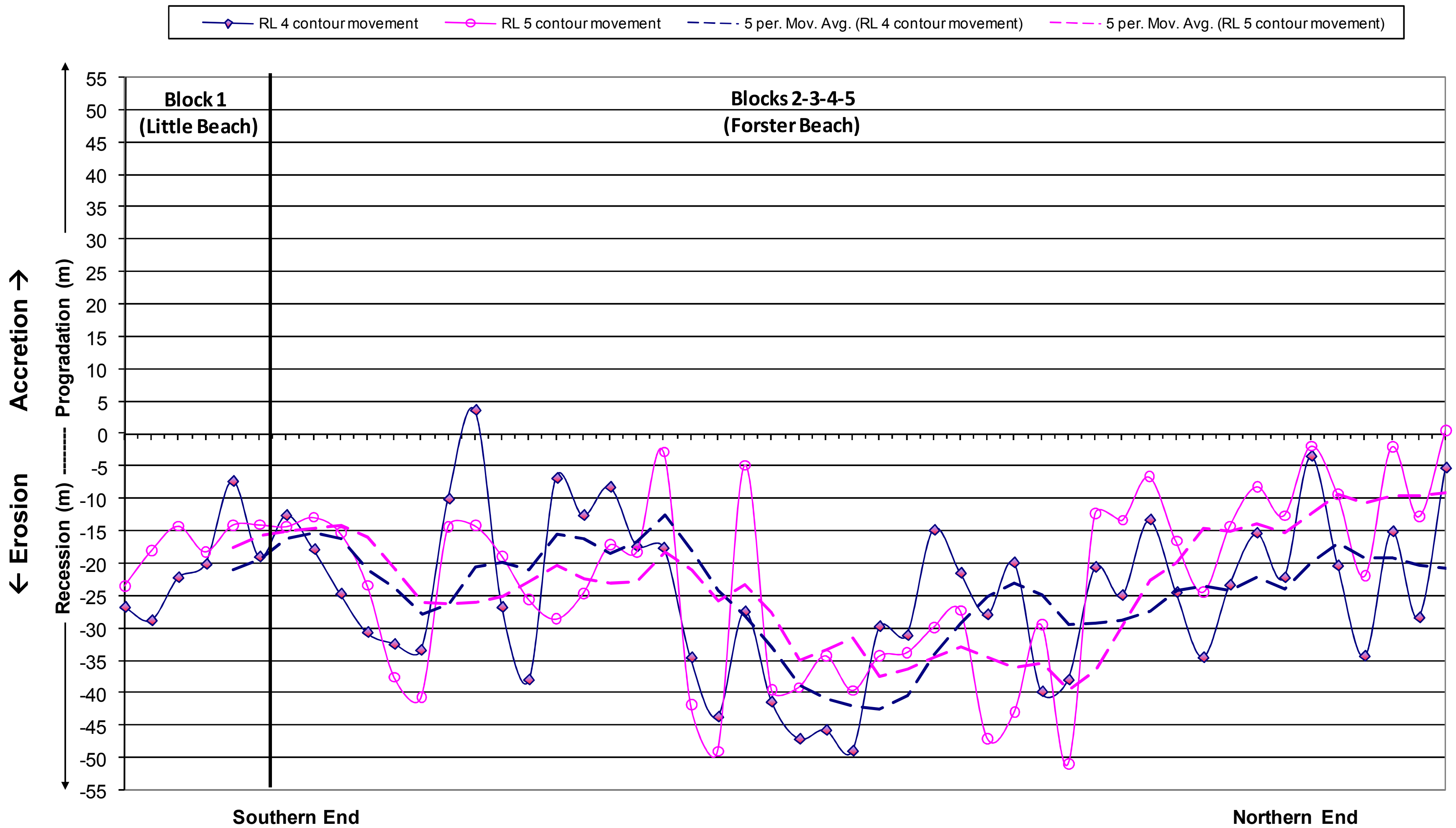


Figure A.20 – Movement of RL 4 and RL 5 contours, Scotts Head 1942 – 2004

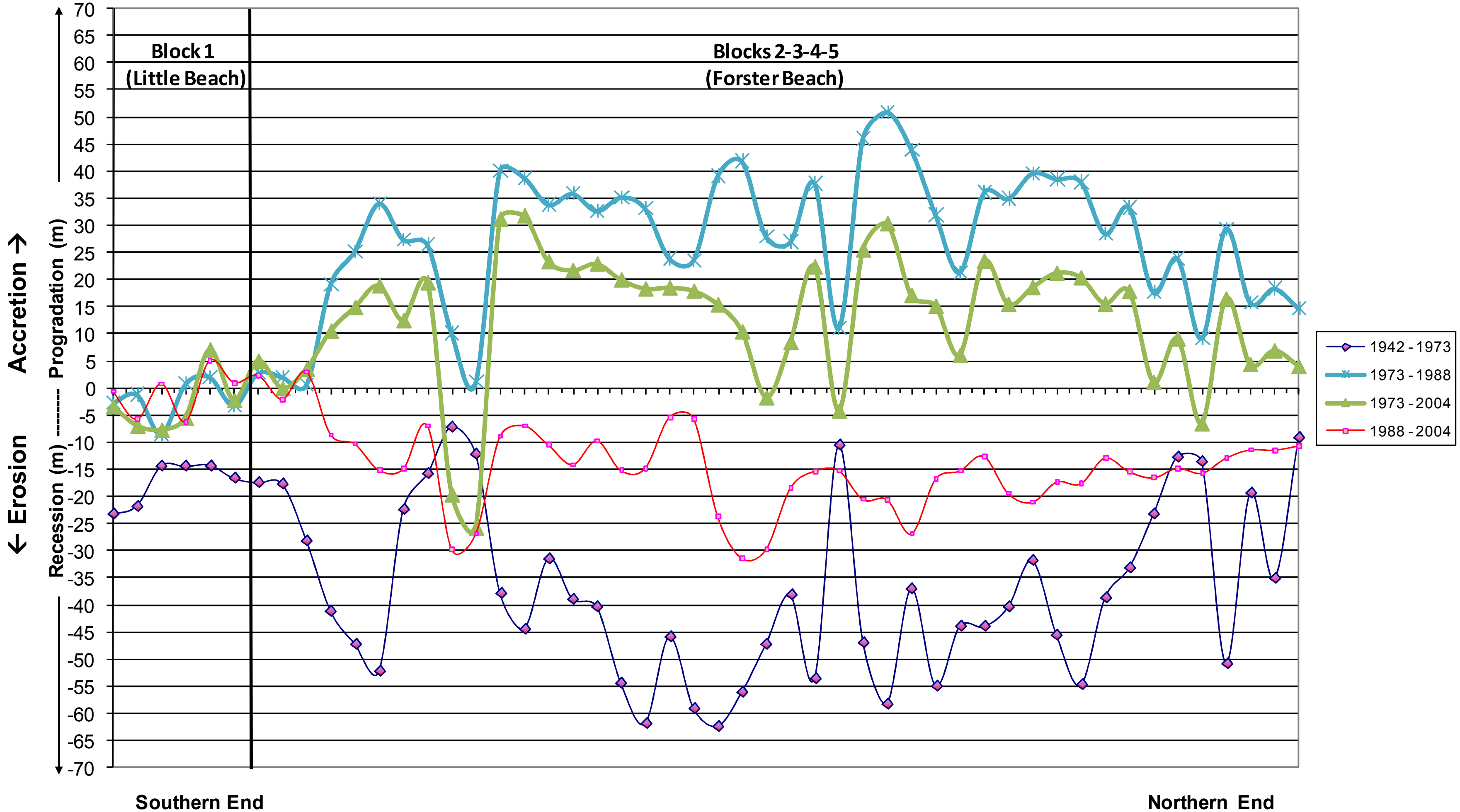


Figure A.21 – Movement of RL 4 contour, Scotts Head 1942 – 1973 – 1988 – 2004

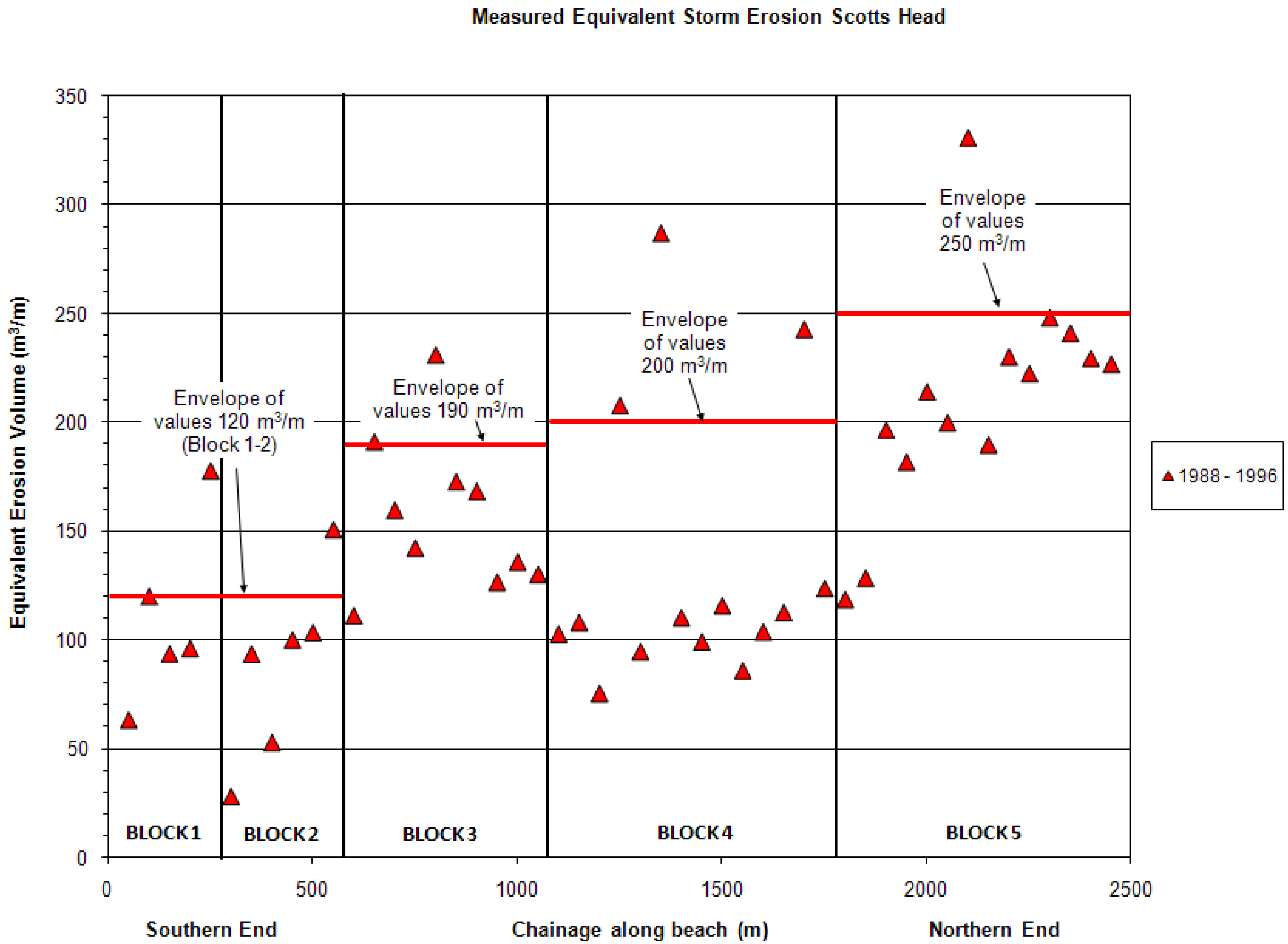


Figure A.22 – Measured Equivalent Storm Erosion, Scotts Head (1988 – 1996)

2.3 Nambucca Heads - Quantifying Storm Erosion Demand from historical storms

Photogrammetric data for Nambucca Heads were not entirely suitable for analysing dune volume changes induced by storm erosion, because the photographs were not taken immediately before and after a storm event. Several large storms occurred during the period between 1956 and 1967, as shown in Figure A.2. These storms included the June 1967 storms which impacted greatly on the NSW north coast and on the study area.

In the current investigation, photogrammetric data immediately following the significant storms of 1967 and 1974 were not available.

For empirical measurement of short-term dune recession, it was found that the most appropriate photogrammetric profiles to compare were the 1973 and 1980 photogrammetric profiles. An *equivalent* storm erosion has been estimated empirically using data from 1973 and 1980 and by applying the protocol described in Figure A.16 by Nielsen *et al.* (1992).

2.3.1 Nambucca Heads - Estimation of Storm Erosion Volumes

From the 1980 photogrammetry data, the location of the top of the scarp feature seems to have been affected by a storm event which occurred between 1973 and 1980, despite the post-storm photogrammetry data being taken several years after the storm events. This is because at most locations, the dune face had not yet recovered from the storms. Although the dune scarp was still visible, considerable beach berm recovery had occurred and the storm erosion demand that may be measured by comparing these two profiles would be considerably less than the “actual” storm bite as a result of this storm. Several cyclones affected the north coast of NSW during the 1970’s, with cyclone Zoe coming within 200km from the study area in March 1974 with a central pressure of approximately 986hPa.

Figure A.19 illustrates the procedure used to estimate the *equivalent* storm erosion volume. This storm erosion demand consists of the sum of the measured volume difference between pre and post-storm photogrammetric profiles (Volume 1) and the assumed post-storm recovered volume (Volume 2) obtained by applying the protocol from Nielsen *et al.* (1992). This equivalent storm erosion demand corresponds to the *Zones of Wave Impact and Slope Adjustment* illustrated in Figure A.18.

Dune face locations were analysed over the length of the study area, by examining the relative location of the RL 4.0 m and RL 5.0 m contours over the various years of photogrammetric data. Dune face locations over the entire photogrammetric record are plotted in Figure A.23, for the 2004 photogrammetry relative to the 1942 photogrammetry. It can be seen from this Figure that the RL 4.0 m and RL 5.0 m contours underwent large fluctuations near the entrance to Nambucca River, and that they are generally landward of their 1942 locations at the northern end of Forster Beach, Shelly Beach and Beilbys Beach (indicating some net recession between 1942 and 2004). At Main Beach and Swimming Creek, the location of these contours has moved seaward between 1942 and 2004, indicating some net progradation (accretion).

Figure A.24 analyses the movement of the RL 4.0 m contour between the dates of 1942, 1980 and 2004 photography. It can be seen that, for all Blocks, there has been a general landward movement between 1942 and 1980 (indicating recession), and a general seaward movement between the 1980 and 2004 photography (indicating beach recovery).

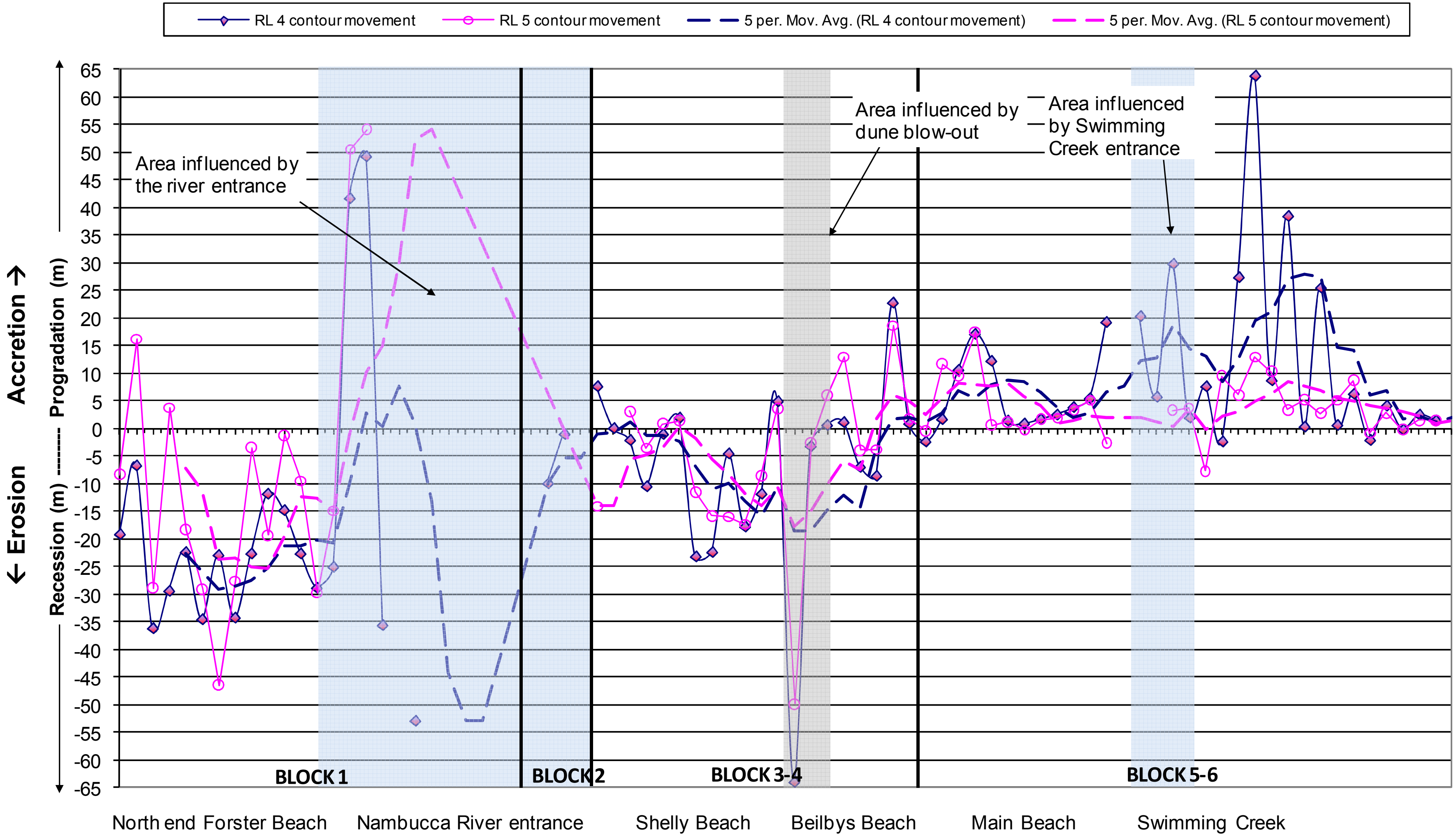


Figure A.23 – Movement of RL 4 and RL 5 contours, Nambucca Heads, 1942 – 2004.

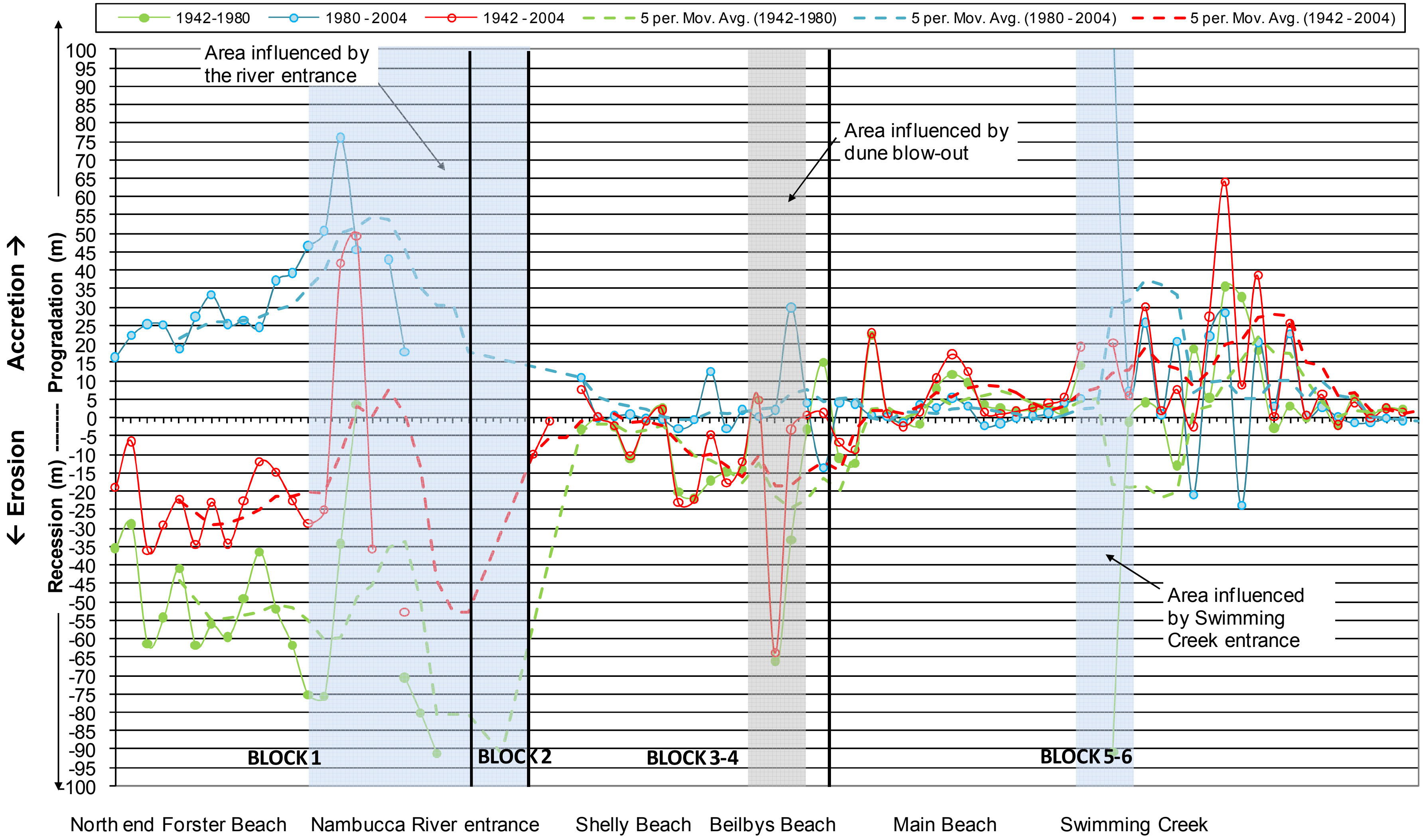


Figure A.24 - Movement of RL 4 contour, Nambucca Heads 1942 – 1980 – 2004

For the analysis of equivalent storm erosion volumes, the values at the local maxima of the landward movement of the RL 4.0m and RL 5.0m contours have been calculated and applied to the whole beach, in order to take account of the formation of rip-heads and to arrive at a conservative estimate of storm erosion demand for the beach.

The estimated storm erosion demand for the storms between 1973 and 1980 for these locations is plotted in Figure A.25. It can be seen that most of these values are between 210 m^3/m and 310 m^3/m for Block 1, between 50 and 230 m^3/m for Blocks 2 - 4 and between 40 and 180 m^3/m for Blocks 5 – 6. These storm erosion volumes represent dune losses of between 23 – 38 m. In some areas that are underlain by rock and backed by steep bluffs, these erosion volumes represent a temporary loss of almost all the available sand on the beach. It should be noted that the values of storm erosion shown here for Block 1 are higher than typical values of 200 – 250 m^3/m that have been measured on other open-coast beaches along the NSW coast. This is possibly as a result of the influence of the river entrance which has much more dynamic morphology and is subject to a range of influences including the effect of flood discharges from the Nambucca River. At the other blocks, the storm erosion shown is on average lower than the typical open coast values of 250m^3/m, except for a few locations which were possibly subject to the effects of rips or wind-blown erosion.

From this analysis, a design loss of sand volume of 290 m^3/m was assessed for the entrance berm at Nambucca River and the northern end of Forster Beach (Block 1). A storm erosion volume of 100 m^3/m was assessed for the small pocket beach adjacent to the breakwater at the northern side of the river entrance (Block 2). Design storm erosion volumes of 190 m^3/m for Shelly and Beilby's beaches (Blocks 3 and 4), and 160 m^3/m for Main Beach and Swimming Creek (Blocks 5 and 6) between 1973 and 1980 have been assessed for the 1974 storms at Nambucca Heads.

For Shelly and Main beaches, long term recession is not significant. This illustrates that the beaches along Nambucca Heads coast are relatively stable in the long term, and that storm erosion is the major concern.

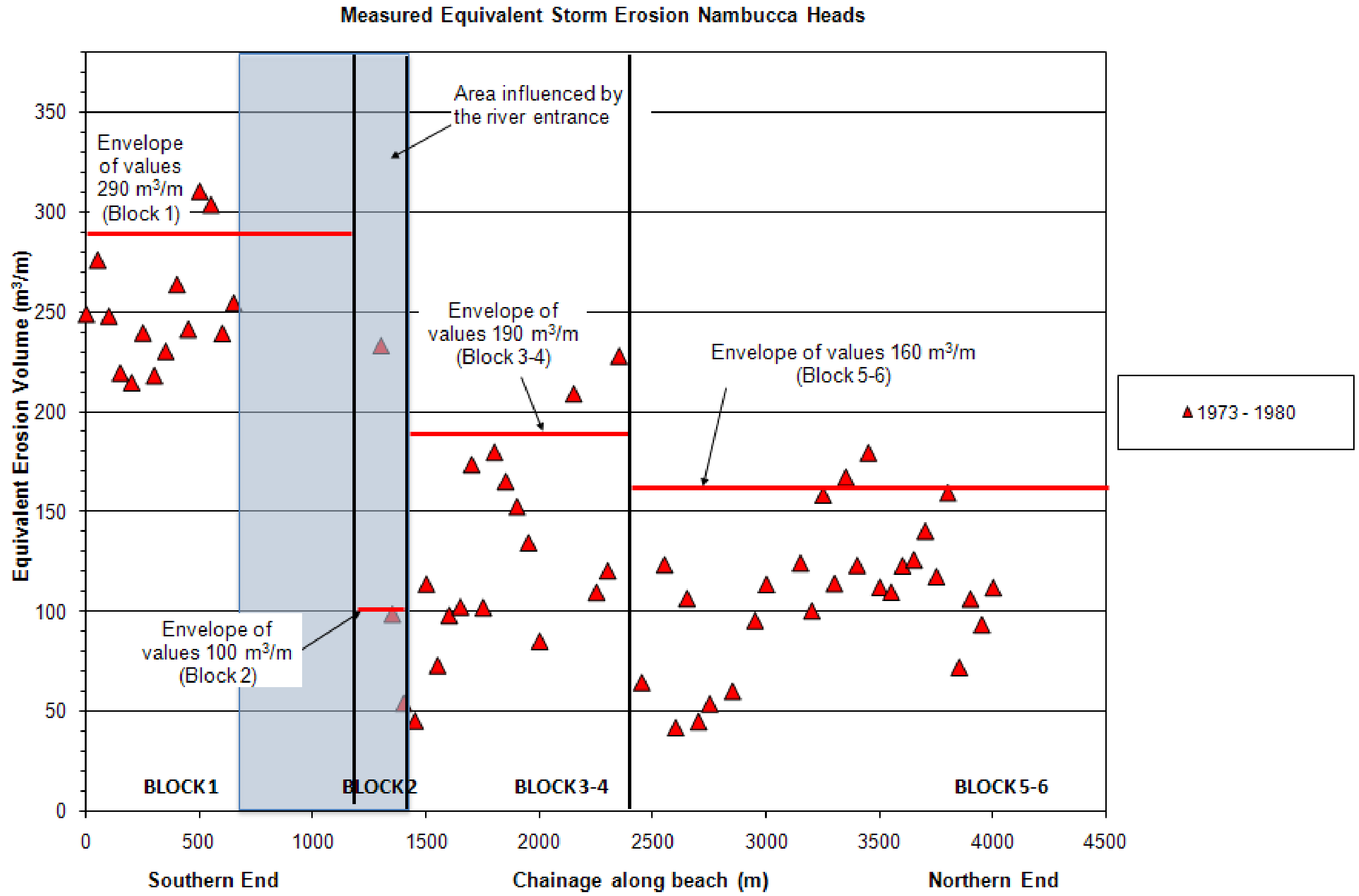


Figure A.25 – Measured Equivalent Storm Erosion, Nambucca Heads

2.4 Valla Beach - Quantifying Storm Erosion Demand from historical storms

Photogrammetric data for Valla Beach were not entirely suitable for analysing dune volume changes induced by storm erosion, because the photographs were not taken immediately before and after a storm event. Several large storms occurred during the period between 1963 and 1981, as shown in Figure A.3, these storms included the June 1967 storms which impacted greatly on the NSW north coast, and the storms of May-June 1974 whose impacts were greatest felt on the NSW central coast. Despite these storms, no significant storm bites during this period have been noticeable in the photogrammetric data. The beaches located along Valla Beach coastline seem to have been more impacted by the several storms and Cyclone Nancy which occurred in February 1990. Cyclone Nancy came as close as 75km from Valla Beach around the 3rd of February 1990 with a central pressure of 986 hPa and three different storms, which last between 1 and 3 days with some wave height ranging from 6.3 to 6.7 meters, occurred in March, May and October 1990. For this reason, volume changes between the photogrammetric data of 1988 and 1991 were analysed to estimate a storm bite recession.

At other locations in NSW, a relationship between beach erosion and whether an adjacent river entrance is open or closed has been found – such a relationship was found at Shoalhaven Heads on the NSW south coast (SMEC Australia, 2007). It was found that more beach erosion occurred when a coastal storm event coincides with an open entrance. The entrance to Deep Creek has tended toward being naturally open. Council records suggest that the entrance was mechanically opened for the first time in 20 years in 1991 was opened 3 times between 1991 and January 1998. Aerial photography of the entrance which includes 11 photographs dating back to 1942 also suggest the entrance is mostly open with only one date of photography showing the entrance closed (17-6-93). The relatively high number of entrance closure events during the 1990's are likely to have been the product of lower rainfall over this period (NSW Department of Land and Water Conservation, 2000).

Examination of the beach profiles revealed that dune accretion continued throughout the period of the photogrammetric data. For empirical measurement of short-term dune recession, it was found that the most appropriate photogrammetric profiles to compare were the 1988 and 1991 photogrammetric profiles. An *equivalent* storm erosion has been estimated empirically using data from 1988 and 1991 and by applying the protocol described in Nielsen *et al.* (1992) (Figure A.18).

2.4.1 Valla Beach - Estimation of Storm Erosion Volumes

From the 1991 photogrammetric data, the location of the top of the scarp feature resulting from the 1990 storms is still visible, despite the post-storm photogrammetric data being taken one year after the storm events. Although the dune scarp was still visible, considerable beach berm recovery had occurred and the storm erosion demand that may be measured by comparing these two profiles would be considerably less than the "actual" storm bite as a result of these storms.

Figure A.19 illustrates the procedure used to estimate the *equivalent* storm erosion volume. This storm erosion demand consists of the sum of the measured volume difference between pre and post-storm photogrammetric profiles (Volume 1) and the assumed post-storm recovered volume (Volume 2) obtained by applying the protocol from Nielsen *et al.* (1992). This equivalent storm erosion demand corresponds to the *Zones of Wave Impact and Slope Adjustment* illustrated in Figure A.18.

From the analysis of dune face locations undertaken in this appendix, it can be seen that there was a general movement of the RL 4.0m and RL 5.0m contours seaward between the dates of the 1942 and 2004 photography, and that this seaward translation varies along the beach (Figure A.26). Nevertheless, a landward movement is visible for the different beaches between 1988 and 1991 profiles (except for block O where there was no data for 1991 and the storm bite was masked by the accretion occurring along the Valla Beach coast.

For the analysis of equivalent storm erosion volumes, the values at the local maxima of the landward movement of the RL 4.0m and RL 5.0m contours have been calculated and applied to the whole beach, in order to take account of the formation of rip-heads and to arrive at a conservative estimate of storm erosion demand for the beach.

The estimated storm erosion demand for the storms between 1988 and 1991 for these locations is plotted in Figure A.27. *Equivalent* storm erosion volumes were obtained from the analysis of the beachfront areas along the entire Valla Beach coastline. Analysis of the photogrammetric data between 1988 and 1991 showed that most of the erosion values range from 150 to 290 m^3/m for Block L and from 50 to 230 m^3/m for Blocks M and N. Some higher values were noted but were checked and found to be outliers, due to inconsistencies in the photogrammetric data. Maximum storm erosion demand values of **280 m^3/m for Block L, 230 m^3/m for Blocks M and N and 250 m^3/m for Block O** were therefore adopted for the 1990 storms at Valla Beach. These values are equivalent to a dune loss of approximately 33 – 42 m.

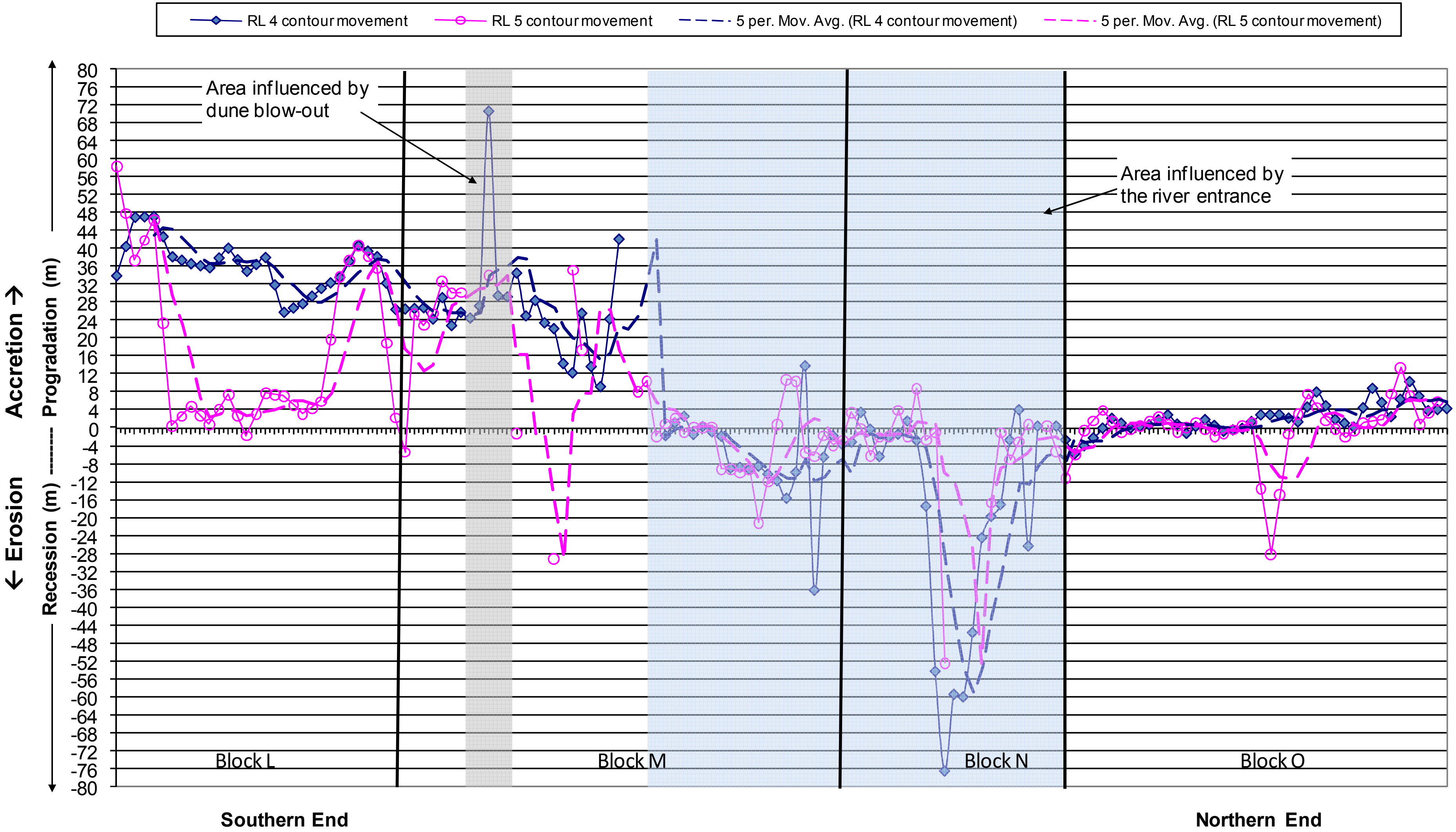


Figure A.26 – Movement of RL 4 and RL 5 contours, 1942 – 2004.

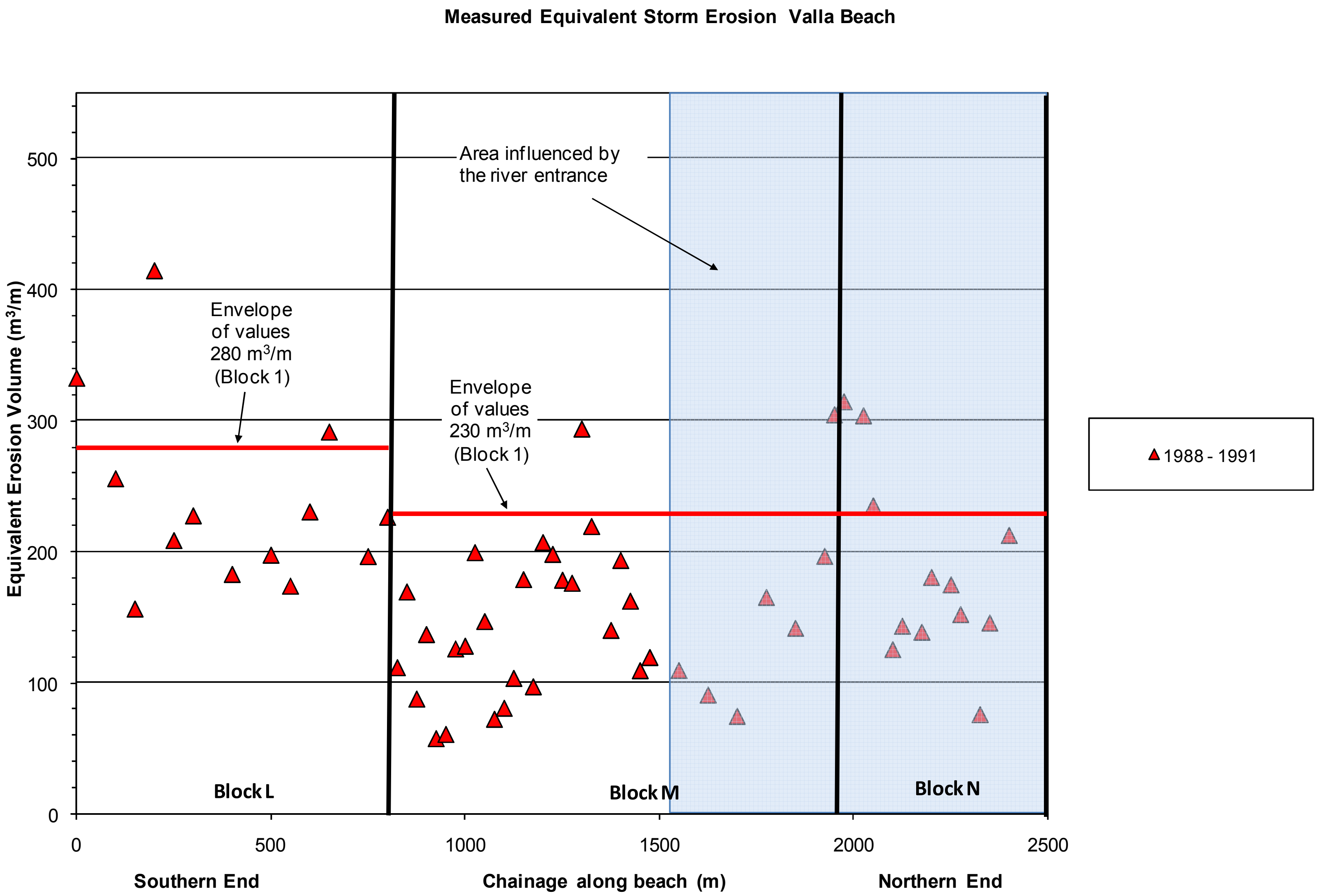


Figure A.27 – Measured Equivalent Storm Erosion, Valla Beach

2.5 River Entrance Instability Hazard

Short term beach fluctuations can be enhanced at natural estuary entrances. Natural entrances tend to migrate along the beach in response to freshwater flooding and coastal storm effects (NSW Government, 1990).

At Valla Beach, the location of Deep Creek entrance fluctuates over more than 500 metres (from approximately profile 27 of Block M to profile 15 of Block N). The entrance tends to continuously migrate along this zone from north to south, and back toward the north again. Based on these observations and examination of the photogrammetric data, it would appear that the river entrance instability hazard is confined to the area comprising the existing entrance berm, and the probability that a major flood or future storm event could cause breakthrough at unexpected locations is low. However, this instability has caused past erosion damage to the picnic area at South Valla Beach (Figure A.16). Outside of the berm area, the river entrance dynamics may influence the dune erosion. Any influences of river entrance dynamics on storm erosion are therefore incorporated in the design storm erosion demand.

2.6 Beach Rotation

Studies of embayed beaches on the NSW coast have identified a sensitivity of shoreline alignment to wave direction (Short *et al*., 2000). The background to this phenomenon is given in the main report.

Goodwin (2005) showed that from 1884 to 2004 the annual Mean Wave Direction (MWD) for the NSW coast has varied from around 127°TN to 140°TN and that the MWD varied with a strong annual cycle, coupled to mean, spectral-peak wave period.

Beach rotations have been shown to be reflected in the translation of the mean waterline or swash zone of the beach berm and do not affect the dune alignment. Analysis of 23 years of monthly profiles at Narrabeen Beach showed that rotations accounted for up to 15 m and some 30 m^3/m (above MSL) of the shore-normal beach sand exchange (Short *et al*., 2000). It is noted that for a given degree of beach rotation, greater recession or progradation of the swash zone and, hence, greater beach sand exchange would be expected on longer beaches.

2.6.1 Beach Rotation at Scotts Head

At Scotts Head, analysis of the photogrammetric data does not show real evidence of beach rotation. Little Beach also seems relatively stable since 1973 and beach changes on one side of the beach were positively correlated with changes on the other side of the beach.

There are large fluctuations in sand volumes along Forster Beach, with some areas showing net accretion alternating with areas of net beach recession. This could be the result of rip current cells forming along the beach during storms, which would lead to large variations in storm erosion volumes along the same stretch of beach. They could also be evidence of past wind-borne dune erosion.

Beach rotation was estimated by way of analysis of mean approach wave directions, and was estimated to result in a sand volume fluctuation in the beach berm of approximately ±4 m^3/m along Little Beach and ±140 m^3/m along Forster Beach. However, beach rotation was not evident in the photogrammetric data, as the beach is undergoing net northerly longshore drift. The storm erosion hazard protocol herein (Nielsen *et al*., 1992) has applied the design storm erosion demand to an average profile over the years, as the beach has been recovering since the storms of the 1970's. The calculation of estimated beach rotation is given in Appendix B.

2.6.2 Beach Rotation at Nambucca Heads

At Nambucca Heads, analysis of the photogrammetric data showed evidence of a littoral drift from south to north. The photogrammetric data showed that while the beach south of the river entrance was eroding significantly, the north end of Main Beach (Block 6) was accreting. Therefore, it can be postulated that the sediments from the river entrance and from the northern extremity of Forster Beach can bypass the headland on the northern side of the Nambucca River, are carried by the prevailing northward currents and deposited on the beaches on the north side of the river entrance. Evidence of this sand bypassing mechanism can be seen in aerial photography.

Beach rotation was estimated by way of analysis of mean approach wave directions, and was estimated to result in a sand volume fluctuation in the beach berm of approximately ±8 m^3/m along Beilbys-Shelly Beach and ±12 m^3/m along Main Beach. Beach rotation in this area is insignificant, given the presence of underlying rock strata along these beaches, which limit the beach plan-form fluctuations along this coastline. The storm erosion hazard protocol herein (Nielsen *et al*., 1992) has applied the design storm erosion demand to an average profile over the years, as the beach is recovering regularly. The calculation of estimated beach rotation is given in Appendix B.

2.6.3 Beach Rotation at Valla Beach

At Valla Beach, analysis of the photogrammetric data showed little evidence of beach rotation. There is some beach rotation occurring on North Valla Beach (Block O), with beach fluctuations on one end of the beach correlated negatively with changes on the other end, with the southern end eroding while the northern end is accreting. Blocks L-M-N are directly influenced by the entrance to Deep Creek (Block M-N) or by Deep Creek itself (Block L). In this area, beach rotations are not discernible from the data.

Beach rotation was estimated by way of analysis of mean approach wave directions, and was estimated to result in a sand volume fluctuation in the beach berm of approximately ±32 m^3/m along South Valla Beach, ±6 m^3/m at the south end of North Valla Beach and ±64 m^3/m along the rest of North Valla Beach. This estimated sand volume fluctuation may be conservative, given the presence of rocks along the beaches. The storm erosion hazard protocol herein (Nielsen *et al*., 1992) has applied the design storm erosion demand to an average profile over the years. This is a conservative approach, as the beach has been recovering regularly. The calculation of estimated beach rotation is given in Appendix B.

2.7 Analysis of Aerial Photography

Aerial pictures of the Nambucca Shire coastline from 1942 to 2007 have been examined and analysed. The observations and the dates for Scotts Head, Nambucca Heads and Valla Beach are given below.

2.7.1 Scotts Head

The observations and the dates of aerial photography for Scotts Head are given below.

09/11/1942 The dune along Forster Beach is not stabilised as there is much less vegetation than today. Some significant dune blow outs are noticeable all along the beach. The beach at Scotts Head is backed by rural land. The SLSC is not built.

05/1956 Dunes along Forster Beach are still more sparsely vegetated than today. The dunes are more mobile in the middle of the beach than at the town of Scotts Head. The town of Scotts Head is already established.

14/04/1973 The significant dune blow outs are still occurring along Forster Beach. The surf club has been built since 1956.

02/12/1976 Dunes are still mobile and denuded of vegetation along Forster Beach. Several rip currents are noticeable along the beach. Scotts Head township is similar to today.

30/10/1980 Dunes are stabilising on northern and southern ends of Forster Beach while the middle is still completely unstable and denuded of vegetation.

23/04/1986 The surf club and the car park have been built with the seawall. The beach dune is narrow at the southern end. Beach is in a similar state to today except for the presence of a dune blow-out midway along Forster Beach.

28/06/1996 The beach is very narrow along the coast with the vegetation being very close to the beach. An erosion scarp is evident. The dunes are now well vegetated.

11/01/2007 The beach had accreted since 1996.

The analysis of the photographs does not show any evidence of sand mining in the area, except for a small area of the hind dune at the northern end of the beach (toward the river entrance). Nonetheless, significant erosion could have occurred because of the dune blow-outs created by the wind while the dunes were denuded of vegetation. Moreover, many rip currents are noticeable along Forster Beach, which indicate that the beach is subject to a strong wave climate, making the beach more dynamic. The significant impact of the 1995 storms is highlighted by the severely eroded shape of the beach on the 1996 photographs. The beach had been accreting in the 10 last years (until the May 2009 storm event).

2.7.2 Nambucca Heads

The observations and the dates of aerial photography for Nambucca Heads are given below.

09/11/1942 The northern end of Forster Beach is very mobile and there is no vegetation to stabilise it. Main Beach SLSC is not built. The caravan park does not exist yet.

06/1959 The V-wall is linked to the main breakwall on the northern side of the river entrance. The only opening in the seawall between Bellwood Park and the V-wall is located in front of the picnic area. Some mangroves are starting to grow on the sandy tidal delta between the seawall and the coast. There is generally much less vegetation on the beach dunes than today, which makes the sandy part of the beaches wider. The small beach east of the caravan park extends more westward than at present. Main Beach SLSC has been built.

20/04/1965 The picture has been taken after the March 1964 flood event. Therefore the river entrance is wider. The mangroves on the sandy tidal delta are spreading as is the dune vegetation at the north end of Forster Beach.

02/12/1976 The breakwall on the northern side of the river entrance has broken between 1965 and 1976 creating a second opening in the wall on the west side of the V-wall. The caravan park has not encroached to the east of the closed off lagoon area.

12/10/1977 The beach is stabilised by dune vegetation along Shelly, Beilbys, Main Beaches and the northern end of Forster Beach. Many rip currents are noticeable along Forster Beach.

21/05/1978 A dune blow out is visible immediately south of the Beilbys Beach carpark. The caravan park is extending to the east.

30/10/1980 The caravan park on the eastern side of the “lagoon” has been reclaimed. The beach appears to be similar to today from Shelly to Main Beach.

31/08/1983 The vegetation of Forster Beach has reached the same northward extent as today, although it is less dense. The river entrance is very wide and extends across the full width of today’s entrance berm to the northern river bank.

23/04/1986 The northern end of Forster Beach is accreting. The rocks in front of Swimming Creek are much less visible than in 2007 and a loss of sand appears to have occurred between 1986 and 2007 along Main and South Valla Beaches.

09/05/1988 Significant erosion has occurred all along the coast. A storm seems to have occurred. A new SLSC has been built on Main Beach. A dune blow out is noticeable at Swimming Creek entrance.

11/01/2007 In contrast to what was observed in the 1983 photograph, the reefs in front of Swimming Creek entrance appear to have an impact on the beach shape as some accretion is visible between the reefs and the entrance.

The analysis of the photographs does not show any evidence of sand mining in the area. The shape of Main Beach seems to vary regularly, and the reefs in front of Swimming Creek have some influence on the beach plan-form. This phenomenon creates a beach rotation between Swimming Creek and the northern end of Main Beach. The Nambucca Heads coastline fluctuates often between a healthy state and an eroded one, sometimes within the space of less than two years. A full beach recovery following these fluctuations is noticeable from the aerial photography on the various beaches.

2.7.3 Valla Beach

The observations and the dates of aerial photography for Valla Beach are given below.

09/11/1942 Some dune blow outs are visible at South Valla Beach. North Valla Beach is similar to today due to the presence of coastal bluffs which limit the level of erosion.

14/04/1973 The footbridge is still not built. There is no vegetation on the dune separating Deep Creek from the ocean between the location of the existing footbridge in the south to the Creek entrance in the north. Valla Beach township consists of only five streets around Valla Beach road.

1991 Large quantities of sand are fronting Deep Creek entrance. The entrance is moving toward the south. The beach plan-form looks the same as today.

11/01/2007 There is less sand in front of the South Valla Beach picnic area.

The analysis of the photographs does not show any evidence of sand mining in the area. However, historical sand mining is known to have occurred at the rear of the dune at the northern end of the study area.

Most of the Valla Beach coastline is underlain by rock and there is no visible significant change along North Valla Beach. Deep Creek entrance is oscillating over the years, which makes the sandy zone in front of the South Valla Beach picnic area very dynamic. The vegetation of the main dune at South Valla has expanded over the years.

3 Long Term Changes

3.1 Introduction

This analysis has used two techniques to measure long term changes at the beaches of Nambucca Shire over time, namely

- Volumetric analysis of profiles, whereby the volume of sand on the beach at discrete snapshots in time has been measured, and
- Translation of the dune over time, whereby the location of the dune face at discrete snapshots in time has been measured and plotted over time.

The results of the analysis using both of these methods are presented below.

3.2 Volumetric Analysis of Profiles

The photogrammetric data listed in Tables A.1, A.2 and A.3 were analysed for volume change to determine trends in beach erosion or accretion over time along the beachfront.

The digital photogrammetry files were processed and analysed using the software program, Beach Morphology Analysis Package (BMAP). BMAP consists of automated and interactive procedures to analyse morphologic and dynamic properties of beach profiles (Sommerfeld *et al.,* 1994).

All the profiles from each Block along the several beaches were read into the program BMAP, which is able to calculate volumes under specific beach profiles or the average over multiple profiles. In order to represent more clearly the processes occurring along the beach, the beaches were compartmentalised into the respective blocks and an average profile for each year of photogrammetry was produced consisting of the average of all profiles in that block for each particular year. It should be noted that the volume considered was that above 0.0 m AHD landward of the 2.0m AHD contour. The profile volumes were taken to a point just on the landward side of the dune, to minimise errors in the volume calculations due to discrepancies in the vertical datum for different years of photography.

Details of the analysis for Scotts Head, Nambucca Heads and Valla Beach are provided below.

3.2.1 Scotts Head

At Scotts Head, three zones have been delineated: Little Beach (Block 1), the southern end of Forster Beach (Block 2-3) and the mid – north end of Forster Beach (Block 4-5). The volume under the average profile for each block and zone for each year was plotted in Figure A.28. It should be noted that the volume considered was that above 0.0 m AHD landward of the 2.0m AHD contour. The profile volumes were taken to a point just on the landward side of the dune, to minimise errors in the volume calculations due to discrepancies in the vertical datum for different years of photography.

From this plot it can be seen that, on average, significant erosion occurred between 1942 and 1973. Since 1973, Little Beach (Block 1) has been relatively stable and had almost reached its initial volume of 1942. In the meantime, Forster Beach (Blocks 2-3-4-5) was recovering and accreting until 1988, when its volume almost recovered to the 1942 beach profile volumes. However, between 1988 and 1996, there was a sharp decrease in beach profile volume, possibly the result of the March 1995 storm (Cyclone Violet). This storm appears to have greatly impacted Forster Beach and since this storm the beach was resuming its accretion and recovery (until the storms of May 2009).

The average volume change rates for the different zones are shown in Table A.5 between 1942 and 2004.

Block Number	Cumulative volume change between 1942 and 2004 (m^3/m)	Average volume change per year from cumulative volume (m^3/m/year)	Average volume change per year from lines of best fit (m^3/m/year)
1	-10.5	-0.17	-0.51
2-3	-128.9	-2.06	-2.26
4-5	-239.1	-3.83	-4.16

TABLE A.5 – List of the average volume change for the different blocks from 1942 - 2004

Table A.6 and Figure A.29 show the average volume change from 1973 (excluding the 1942 volume).

Block Number	Cumulative volume change between 1973 and 2004 (m^3/m)	Average volume change per year from cumulative volume (m^3/m/year)	Average volume change per year from lines of best fit (m^3/m/year)
1	+55.2	+1.78	+1.26
2-3	+45.2	+1.46	+0.57
4-5	+19.3	+0.62	-0.92

TABLE A.6 – List of the average volume change for the different blocks, 1973 - 2004

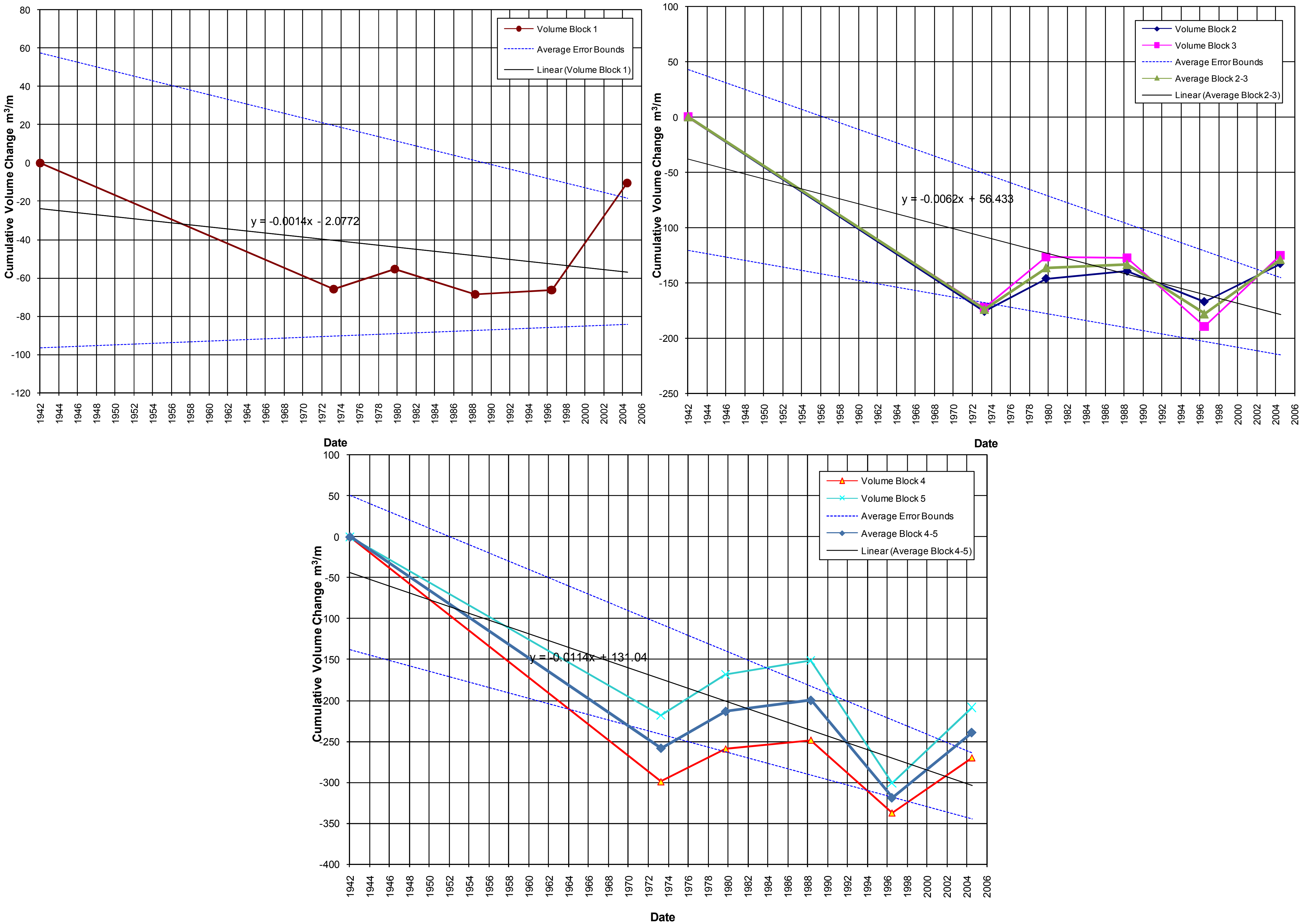


Figure A.28 – Long term recession volume analysis at Scotts Head for the different Block 1, 2-3 and 4-5 (1942 – 2004).

It should be noted that the erosion is occurring in episodic bursts most likely brought about by storm activity. In periods characterised by little storm activity, beach recovery or little change occurs. Some of the observed changes in beach volume could be due to anthropogenic influence, such as reshaping of the dune in areas where major development is located, due to construction works.

As well as the considerable variation in the calculated rate of volume change caused by natural fluctuations, there is a considerable error band as a result of the accuracy of the photogrammetry. As noted in Table A.1, the vertical accuracy of the photogrammetry varies between ±0.3m to ±0.7m. Given the average profile length and these accuracy rates, an error in the erosion rate could be assessed as shown in Table A.7.

Block Number	Average Profile Length (m)	Volume change minimum (m^3/m)	Volume change maximum (m^3/m)
1	110	+77	-141
2-3	116	-24	-256
4-5	134	-125	-391

TABLE A.7 – List of the average erosion change for the different blocks, 1942 - 2004

Given the dune height and the long term erosion rate for each block, the average long term recession rate between 1942 and 2004 has been calculated and the results are summarised in Table A.8.

Block Number	Volume change minimum (m^3/m/yr)	Volume change maximum (m^3/m/yr)	Dune height (m)	Long term beach recession minimum (m/yr)	Long term beach recession maximum (m/yr)	Average beach recession/accretion (m/yr)
1	+1.25	-2.27	6.7	+0.19	-0.34	-0.08
2-3	-0.39	-4.13	8.6	-0.05	-0.48	-0.26
4-5	-2.02	-6.30	12.5	-0.16	-0.50	-0.33

TABLE A.8 – List of the average long term beach change for the different blocks 1942 - 2004

As previously discussed, the 1942 photogrammetry data shows the beach state to be significantly different from the data from 1973 onwards, and is generally subject to greater error. It may be more appropriate in this instance to consider the long term trends from 1973 onwards. If the 1942 photogrammetry data are excluded from the analysis, the average long term volume changes since 1973 are shown in Table A.9.

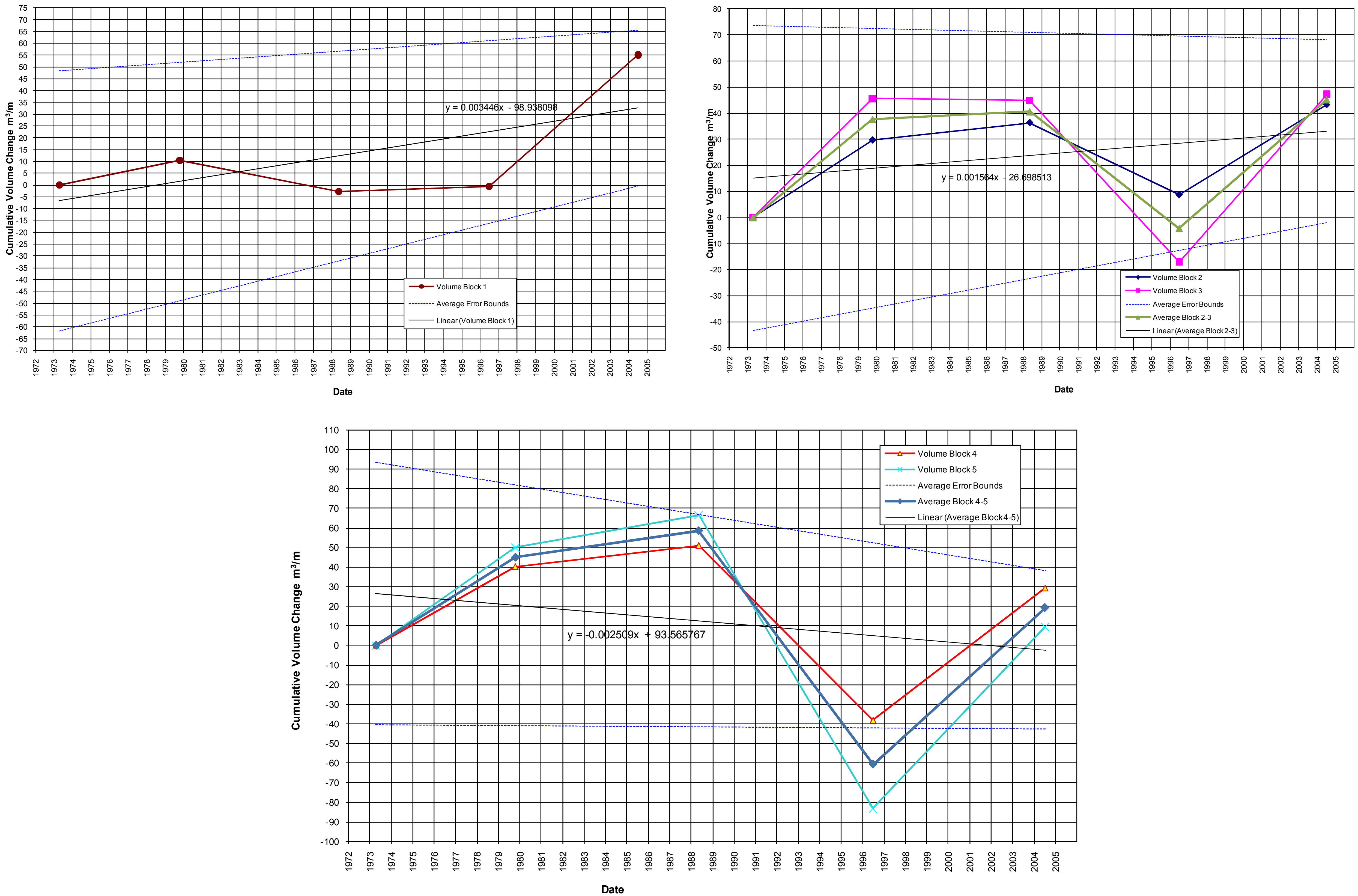


Figure A.29 – Scotts Head long term recession volume analysis for Blocks 1, 2-3 and 4-5 (1973 – 2004).

Block Number	Volume change minimum (m^3/m/yr)	Volume change maximum (m^3/m/yr)	Dune height (m)	Long term beach recession minimum (m/yr)	Long term beach recession maximum (m/yr)	Average beach recession/accretion (m/yr)
1	+4.07	-1.56	6.9	+0.59	-0.23	+0.18
2-3	+3.57	-2.42	8.8	+0.40	-0.28	+0.06
4-5	+2.51	-4.35	12.5	+0.20	-0.35	-0.07

TABLE A.9 – List of the average long term beach change for the different blocks 1973 - 2004

All five blocks have receded on average at a rate ranging from -0.08 to -0.33 m/yr since 1942. However, since 1973, both Forster Beach and Little Beach have been relatively stable or undergoing net accretion.

3.2.2 Nambucca Heads

Figure A.30 illustrates the cumulative change in beach volume in cubic metres per metre length of beach, for each block over time. It plots also the occurrences of extreme storms with their estimated significant wave heights, so that major storm occurrences could be related to major erosional events. It should be noted that wave height is not the only determinant of whether beach erosion will occur – it is more likely to occur if large waves coincide with high water levels, long storm durations and, to some extent, strong winds. Nevertheless, the graph gives a good indication of when the major storms occurred in relation to volumetric changes along the beach.

From this plot it can be seen that all along the coast, a decrease in the positive volume change or an increase in the negative volume change occur between 1973 and 1980, as well as a general beach volume recovery between 1991 and 2004.

The beach located south of Nambucca Heads (Block 1) is highly influenced by the river entrance and undergoes significant fluctuations in volume (more than 250m^3/m). The small beach located at the northern breakwater (Block 2) as well as Shelly Beach (Block 3) and Beilbys Beach (Block 4) are relatively stable with an overall decrease in volume of less than 30m^3/m. Main Beach (Blocks 5-6) seems to be accreting with an average volume change of approximately 20m^3/m at the southern end and more than 150m^3/m at the northern end.

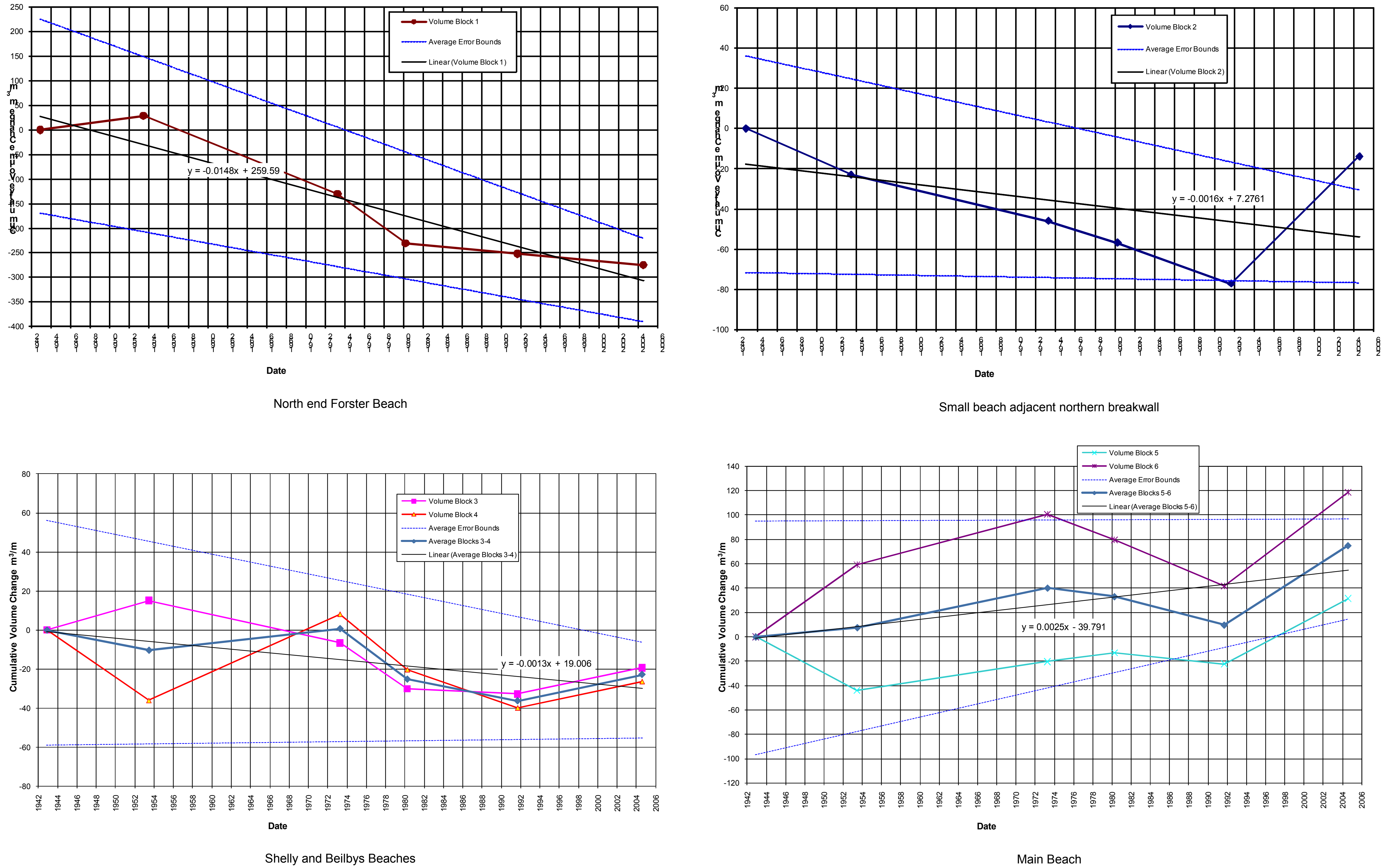


Figure A.30 – Nambucca Heads - long term recession volume analysis for the different blocks

Noting that the northern end of Forster Beach (Block 1) is highly influenced by fluctuations in the river entrance, a line of best fit drawn through the data from this Block indicates that there has been a significant volume decrease of approximately 5.4 m^3/m/year since 1942. The data from Blocks 5-6 indicate an increase of between 0.5 and 1.3 m^3/m/year. The average of the three other Blocks 2, 3 and 4 show that these beaches are relatively stable or undergoing low rates of long term erosion, as the line of best fit drawn through all the data show an average decrease in the volume change of 0.3 to 0.6 m^3/m/year.

Block Number	Location	Cumulative volume change between 1942 and 2004 (m^3/m)	Average volume change per year from cumulative volume (m^3/m/year)	Average volume change per year from lines of best fit (m^3/m/year)
1	Entrance berm area	-275.5	-4.46	-5.42
2	Northern breakwater small beach	-13.9	-0.23	-0.58
3	Shelly Beach	-19.3	-0.31	-0.61
4	Beilbys Beach	-26.3	-0.43	-0.32
5	Main Beach Surf Club	+31.4	+0.51	+0.53
6	Main Beach and Swimming Creek	+118.4	+1.92	+1.28

TABLE A.10 – List of the average volume change for the different blocks

It should be noted that erosion may be occurring in episodic bursts most likely brought about by storm activity. In periods characterised by little storm activity, beach recovery or little change occurs. Some of the observed changes in beach volume could be due to anthropogenic influence, such as reshaping of the dune in areas where major development is located, due to construction works.

As well as the considerable variation in the calculated rate of volume change caused by natural fluctuations, there is a considerable error band as a result of the accuracy of the photogrammetry. As noted in Table A.2, the vertical accuracy of the photogrammetry varies between ±0.3m to ±0.7m. Given the average profile length and these accuracy rates, an error in the erosion rate could be assessed as shown in Table A.11.

Given the dune height and the long term erosion rate for each block, the average long term recession rate has been calculated and the results are summarised in Table A.12.

Block number	Location	Average Profile Length (m)	Volume change minimum (m^3/m)	Volume change maximum (m^3/m)
1	Entrance berm area	283	-50.6	-616.7
2	Northern breakwater small beach	77	+40.9	-113.1
3-4	Shelly, Beilbys Beach	82	+52.7	-111.3
5-6	Main Beach and Swimming Creek	137	+193.4	-80.6

TABLE A.11 – List of the average erosion change for the different blocks

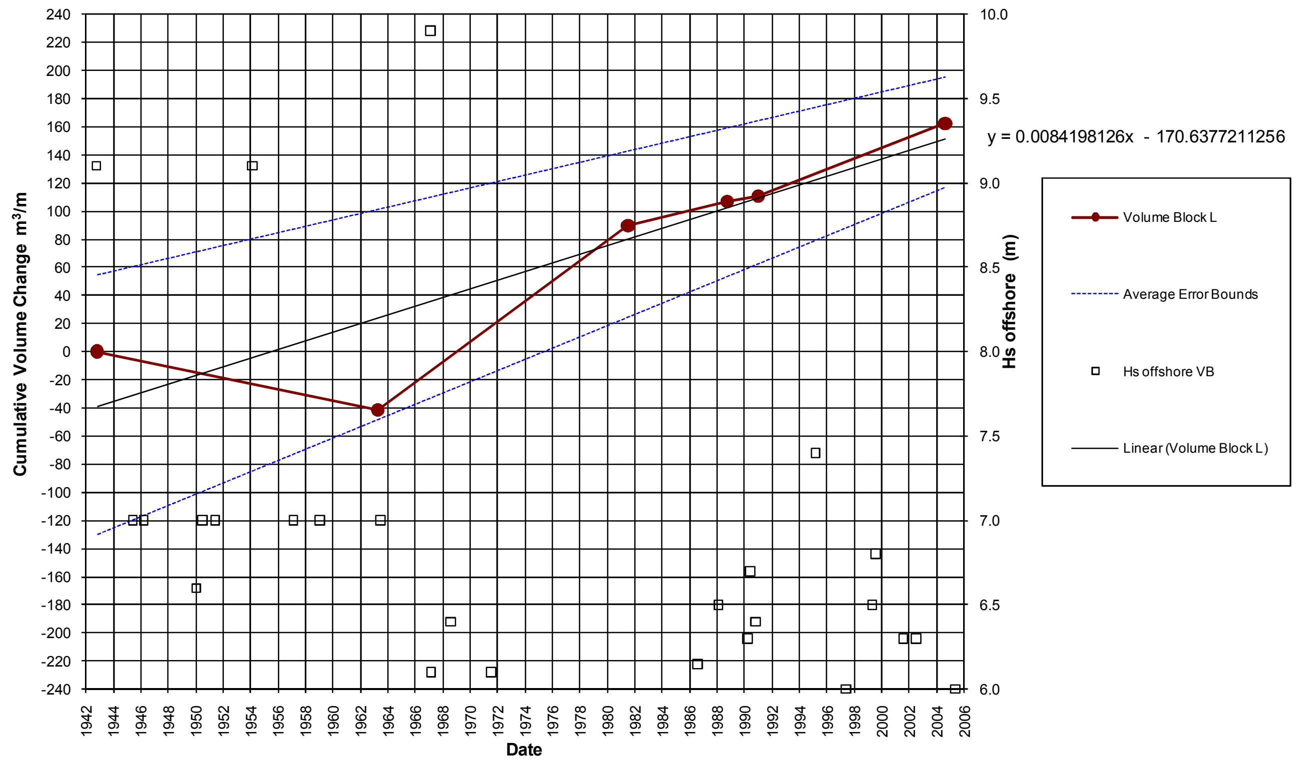
Block Number	Volume change minimum (m^3/m/yr)	Volume change maximum (m^3/m/yr)	Dune height (m)	Long term beach recession minimum (m/yr)	Long term beach recession maximum (m/yr)	Average beach recession/accretion (m/yr)
1	-0.8	-10.0	9	-0.09	-1.11	-0.60
2	+0.66	-1.83	4	+0.16	-0.45	-0.14
3-4	+0.85	-1.80	5	+0.17	-0.36	-0.09
5-6	+3.13	-1.31	7	+0.45	-0.19	+0.13

TABLE A.12 – List of the average long term beach recession for the different blocks

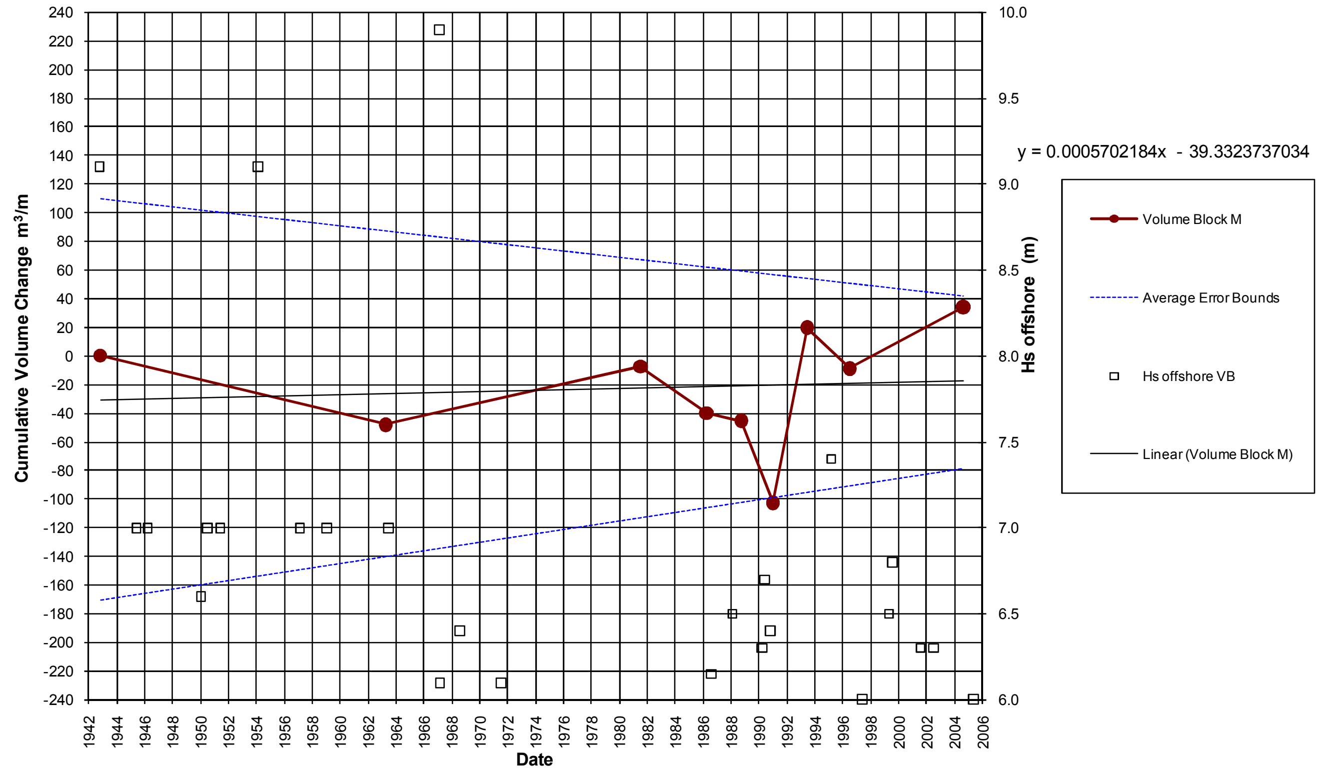
From these results, Block 1 (which is highly influenced by the river entrance) appears to be suffering a net loss of sand, possibly due to ingress of sediment into the river entrance and longshore drift to the north. The small beach at the northern end of the breakwater, Shelly Beach and Beilbys Beach may be undergoing long term beach recession at a low rate. Main Beach and Swimming Creek are quite stable over the long term, and appear to be accreting.

3.2.3 Valla Beach

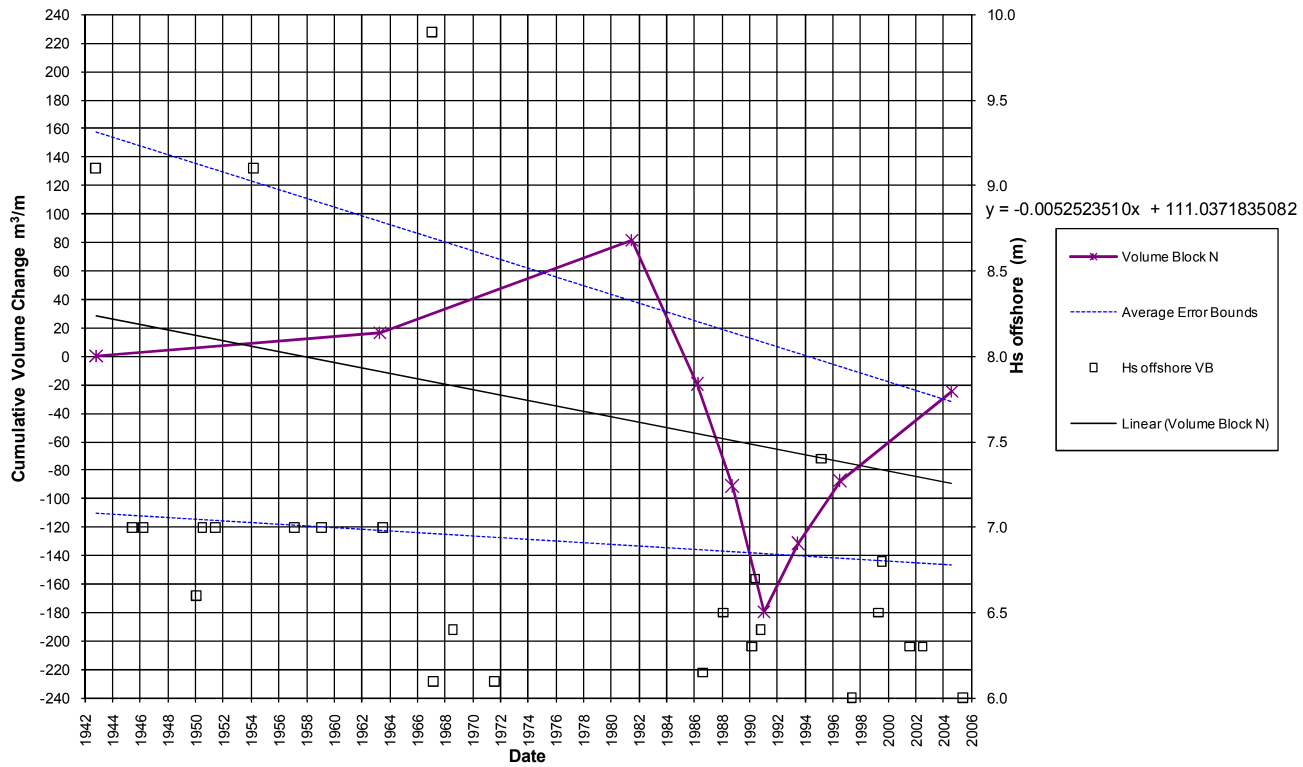
Figure A.31 illustrates the cumulative change in beach volume in cubic metres per metre length of beach, for each block over time. It plots also the occurrences of extreme storms with their estimated significant wave heights, so that major storm occurrences could be related to major erosional events. It should be noted that wave height is not the only determinant of whether beach erosion will occur – it is more likely to occur if large waves coincide with high water levels, long storm durations and, to some extent, strong winds. Nevertheless, the graph gives a good indication of when the major storms occurred in relation to volumetric changes along the beach.



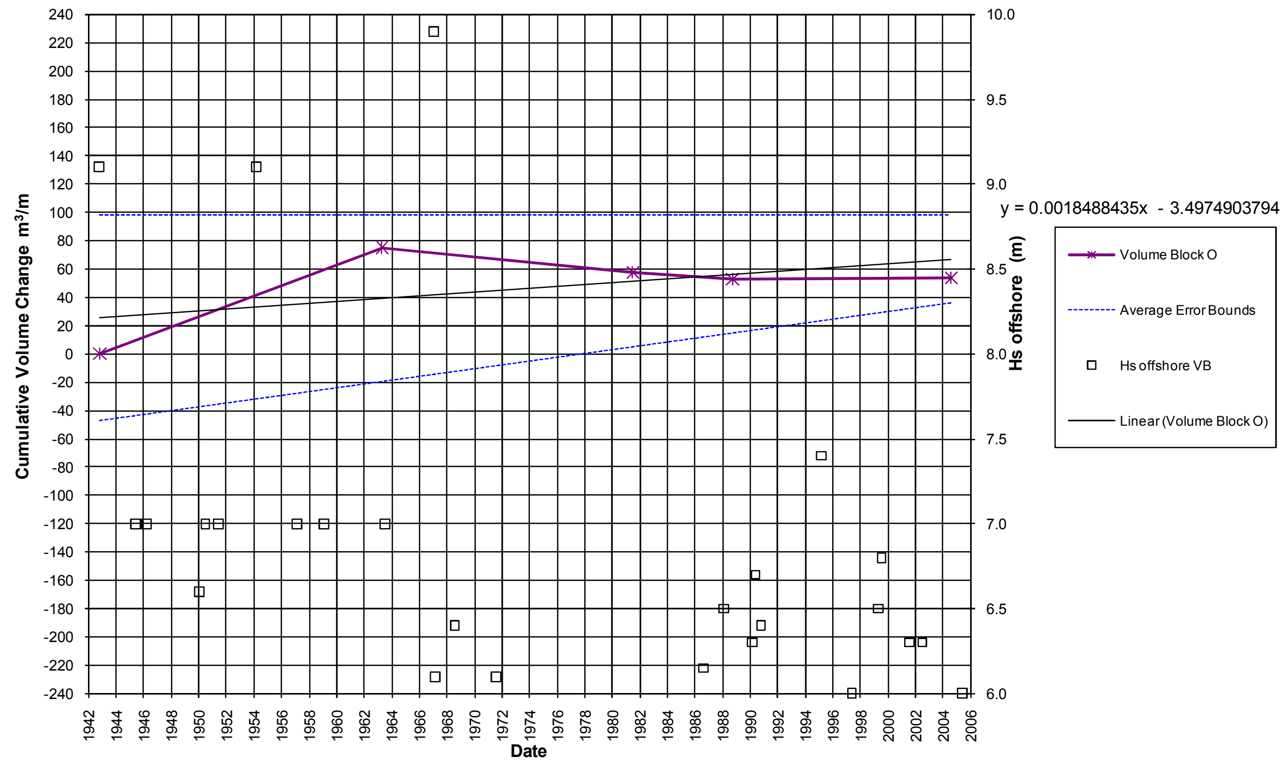
Long term recession volume analysis for Block L



Long term recession volume analysis for Block M



Long term recession volume analysis for Block N



Long term recession volume analysis for Block O

Figure A.31 – Long term recession volume analysis, Valla Beach

From this plot it can be seen that, on average, there has been a slight increase in subaerial beach volumes between 1940 and 2004. The volume change in Block L is increasing steadily up to volume difference of 160 m^3/m between 1942 and 2004. The volume in Block M is increasing slightly and was relatively constant until 1981 when the influence of the river entrance seems to have strengthened. South Valla Beach (Block N) is significantly affected by the river entrance and the volume change is continuously fluctuating which makes the observation of a trend of increase or decrease in beach volume difficult. North Valla Beach (Block O) is relatively stable and slightly accreting.

For the portion of the beach south of the footbridge (Block L), a line of best fit drawn through the data of this block would indicate that there has been a volume increase of approximately 3.07 m^3/m/year since 1942 (Table A.13). The data of Block M, influenced both by the ocean and the presence of Deep Creek on the inland side of the dune, would indicate a very slight increase of 0.21 m^3/m/year. The data of the block fronting South Valla Beach (Block N), which has been significantly influenced by Deep Creek entrance, showed a decrease in the volume change of -1.92 m^3/m/year. At last, the data of the block fronting North Valla Beach (Block O), which is relatively stable, indicated an increase in the volume change of 0.67 m^3/m/year.

Block Number	Cumulative volume change between 1942 and 2004 (m^3/m)	Average volume change per year from cumulative volume (m^3/m/year)	Average volume change per year from lines of best fit (m^3/m/year)
L	+162.40	+2.62	+3.07
M	+34.10	+0.55	+0.21
N	-24.80	-0.40	-1.92
O	+54.00	+0.87	+0.67

TABLE A.13 – List of the average volume change for the different blocks

It should be noted that erosion may be occurring in episodic bursts most likely brought about by storm activity. In periods characterised by little storm activity, beach recovery or little change occurs. Some of the observed changes in beach volume could be due to anthropogenic influence, such as reshaping of the dune in areas where major development is located, due to construction works.

As well as the considerable variation in the calculated rate of volume change caused by natural fluctuations, there is a considerable error band as a result of the accuracy of the photogrammetry. As noted in Table A.3, the vertical accuracy of the photogrammetry varies between ±0.3m to ±0.7m. Given the average profile length and these accuracy rates, an error in the erosion rate could be assessed as shown in Table A.14.

Block number	Average Profile Length (m)	Volume change minimum (m^3/m)	Volume change maximum (m^3/m)
L	126	+323	+58
M	200	+213	-188
N	191	+73	-310
O	104	+146	-62

TABLE A.14 – List of the average erosion change for the different blocks

Given the dune height and the long term erosion rate for each block, the average long term recession rate has been calculated and the results are summarised in Table A.15.

Block Number	Rate in worst case (m^3/m/yr)	Rate in best case (m^3/m/yr)	Dune height (m)	Long term beach recession in worst case (m/yr)	Long term beach recession in best case (m/yr)	Average beach recession/accretion (m/yr)
L	+0.94	+5.21	11	+0.09	+0.74	+0.42
M	-3.03	+3.44	7	-0.43	+0.49	+0.03
N	-5.01	+1.17	3	-1.67	+0.39	-0.64
O	-1.01	+2.36	6	-0.16	+0.39	+0.23

TABLE A.15 – List of the average long term beach recession for the different blocks

From these results, the beach appears to be accreting on average. Block N, which is highly influenced by the entrance to Deep Creek, appears to be losing sand in the long term.

3.3 Translation of Dune Escarpment

As the natural fluctuations of a beach and dune are large compared with any underlying long term trend in beach change, sometimes it can be difficult to quantify an accurate rate of erosion or accretion. Often it can be more accurate to measure beach recession by mapping the response of the dune erosion escarpment over time. This can be done by measuring the location of the dune face along each profile, for example, by measuring the chainage along each profile of the toe or the crest of the dune.

By inspection of the profiles, it was determined that from these data the location of the 4.0m and 5.0 m AHD contours best represented the location of the front face of the dune along the beach. The locations of these contours were based on the AMG coordinates of the surrounding points in the photogrammetric profile data. This allowed the location of the front face of the dune to be plotted in the GIS and enabled an examination of the dune location over time. It was noted that this method is dependent also on the accuracy of the photogrammetry, as the spatial location of the 4.0m AHD contour will be dependent on the vertical resolution of the photogrammetric technique.

The results of the dune escarpment analysis for Scotts Head, Nambucca Heads and Valla Beach are presented below.

3.3.1 Scotts Head

At Scotts Head, in general, it was found that the 1973 locations of the 4.0m and 5.0m AHD contours were furthest landward, while the 1942 location of these contours were the furthest seaward.

Figure A.32 shows the cumulative movement of the 4.0 m AHD contour over time for Scotts Head as well as the average dune movement for each of the blocks, between 1942 and 2004. Negative values represent dune recession. It can be seen that there was a general pattern of dune face recession between 1942 and 1980 along Little Beach with the dune face being relatively stable between 1980 and 2004. It can also be seen that the dune movement of Forster Beach is fluctuating periodically, alternating between recession and progradation.

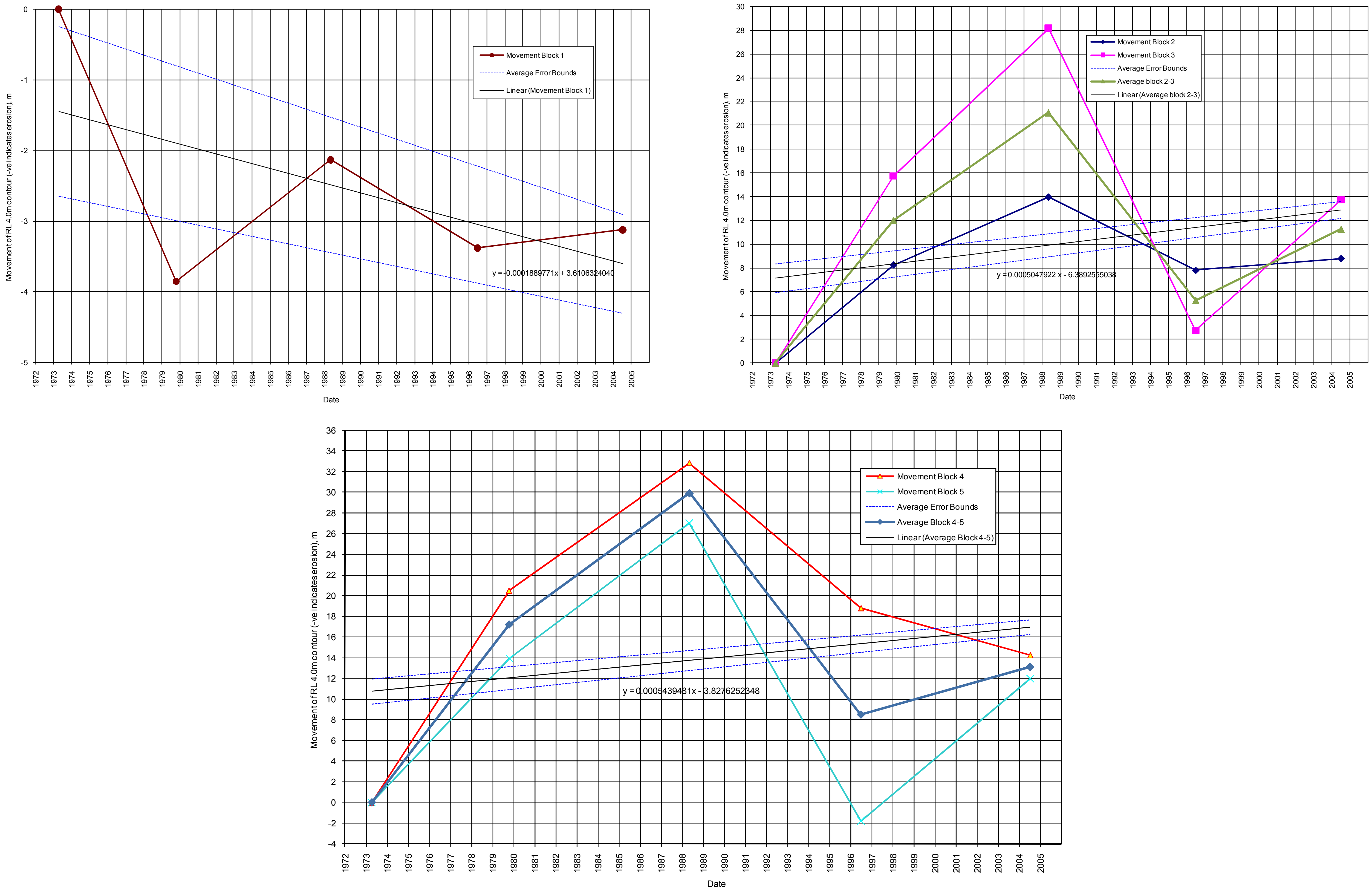


Figure A.32 – Scotts Head - long term recession dune face analysis for the Block 1, 2-3 and 4-5, 1973 – 2004.

Figure A.33 represents the dune face analysis from 1973 to 2004. While the dune face at Little Beach appears to have receded by around 3 metres between 1973 and 2004, the dune face at Forster Beach has prograded on average by between 8 and 14 metres over the same period.

There is an error band in using this technique due to limitations in the horizontal and vertical accuracy of the photogrammetry. For the 1942 photography, the spatial accuracy (encompassing both the horizontal and vertical accuracies) of the location of the 4.0 m contour is ±1.7 m, whereas the spatial accuracy for the 2004 photography is ±0.7 m.

Figure A.33 presents a time history of the location of the dune face based on the photogrammetric analysis, which illustrates that the dune contour is fluctuating regularly and recovering after each significant storm bite. However, it can be seen that most of the recession occurred between 1942 and 1973 and that dune recession appears to have slowed since then. This is confirmed by Tables A.16 and A.17.

Block Number	Average dune migration between 1942 and 2004 (m)	Average dune migration per year (m/year)
1	-20.5	-0.33
2-3	-20.9	-0.34
4-5	-27.1	-0.44

TABLE A.16 – List of the average dune migration for the different blocks from 1942. Landward migration is characterised by (-) and seaward migration by (+)

Block Number	Average dune migration between 1973 and 2004 (m)	Average dune migration per year (m/year)
1	-3.1	-0.10
2-3	+11.3	+0.36
4-5	+13.1	+0.41

TABLE A.17 – List of the average dune migration for the different blocks from 1973. Landward migration is characterised by (-) and seaward migration by (+)

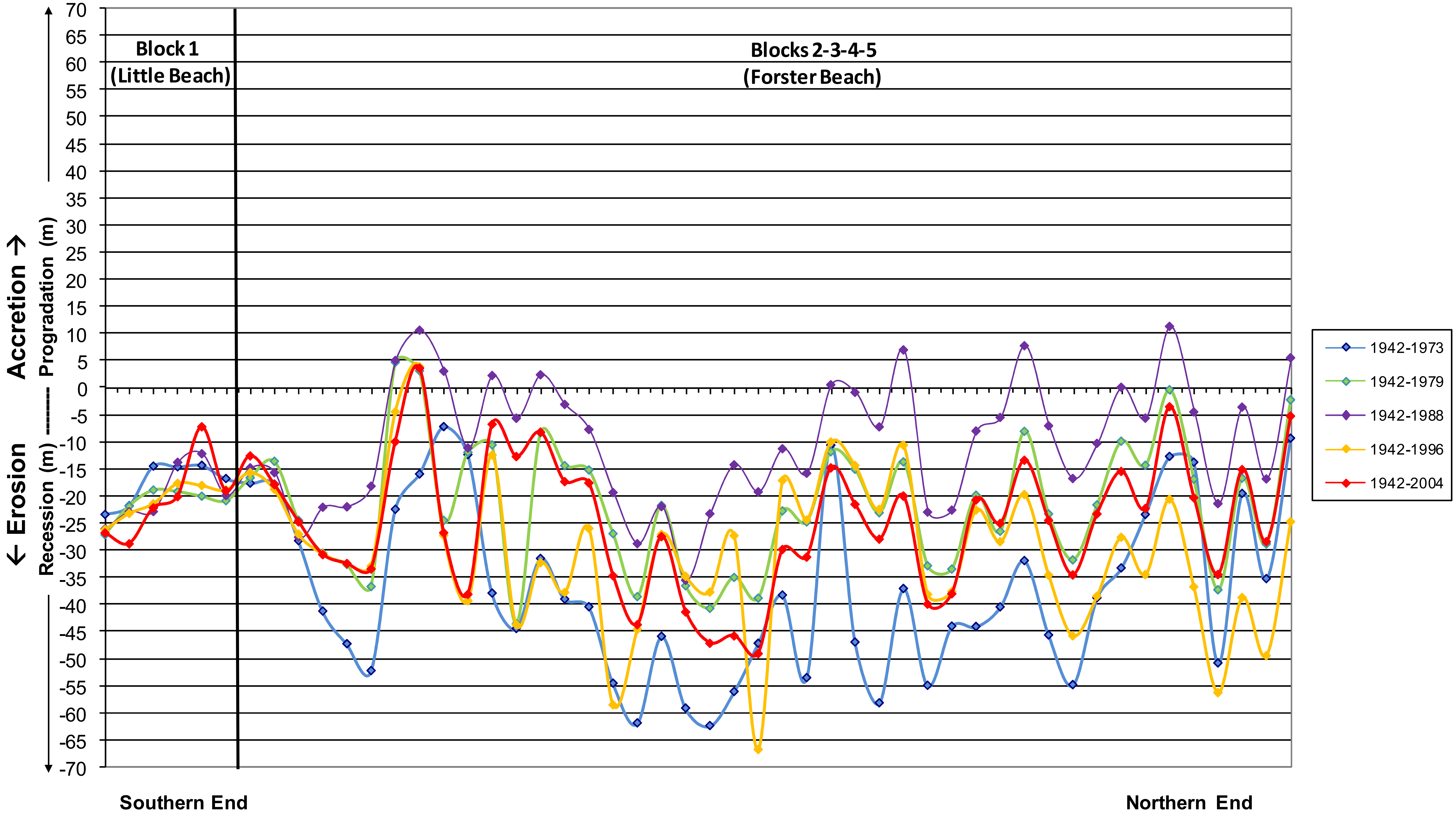


Figure A.33 – Movement of RL 4 contour along beach

3.3.2 Nambucca Heads

At Nambucca Heads, in general, it was found that the 2004 locations of the 4.0m and 5.0m AHD contours were further landward than the 1942 location, except for Main Beach (Block 6). The profiles that were furthest landward were generally the 1980 locations (for Blocks 1, 2 and 4) and 1991 locations (for Blocks 3, 5 and 6).

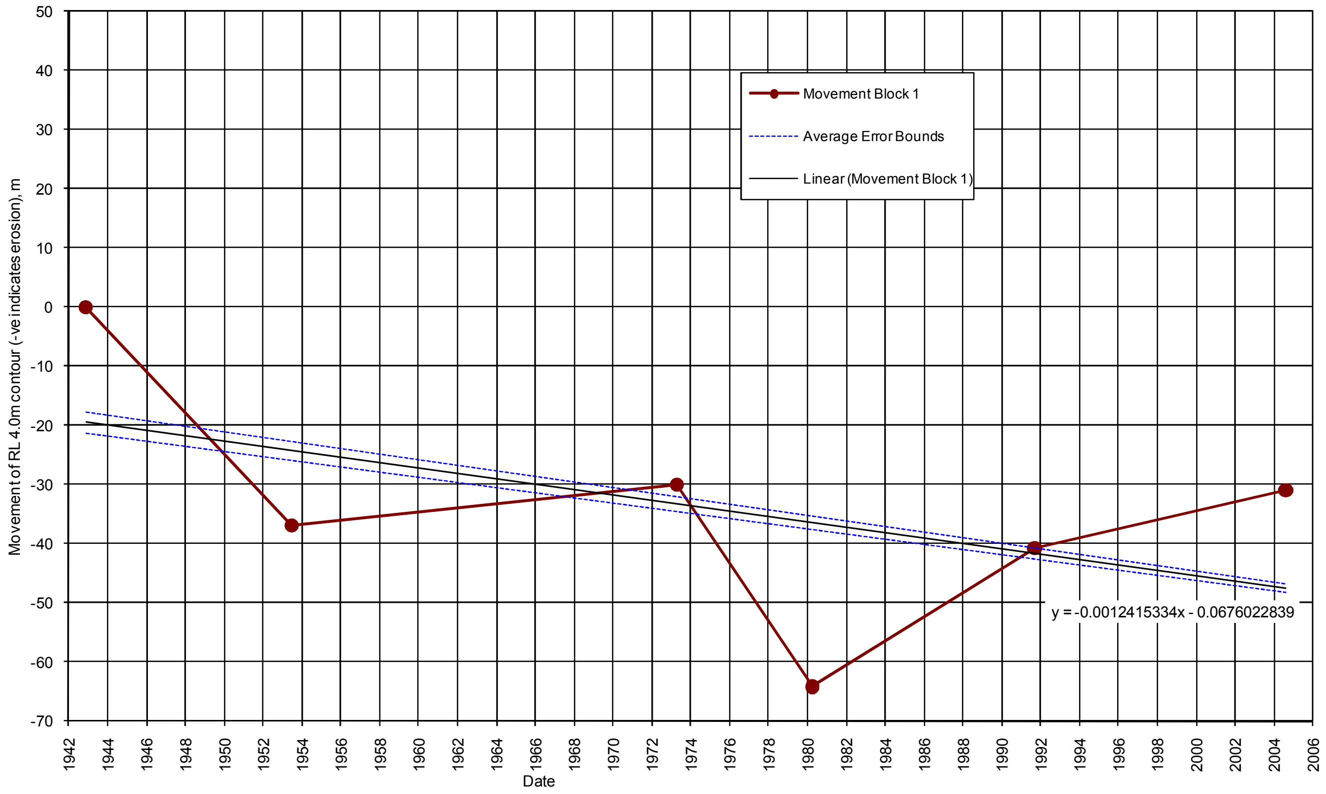
Figure A.34 shows the cumulative movement of the 4.0 m AHD contour over time for the different beaches around Nambucca Heads as well as the average dune movement for each of the Blocks. Negative values represent dune recession and positive values represent dune accretion. It can be seen that there was a general pattern of dune face recession along the beaches at Blocks 1 to 4 and one of a dune accretion for Blocks 5 and 6 (see Table A.18).

There is an error band in using this technique due to limitations in the horizontal and vertical accuracy of the photogrammetry. For the 1942 photography, the spatial accuracy (encompassing both vertical and horizontal accuracies) of the location of the 4.0 m contour is ±1.7 m, whereas the spatial accuracy for the 2004 photography is ±0.7 m.

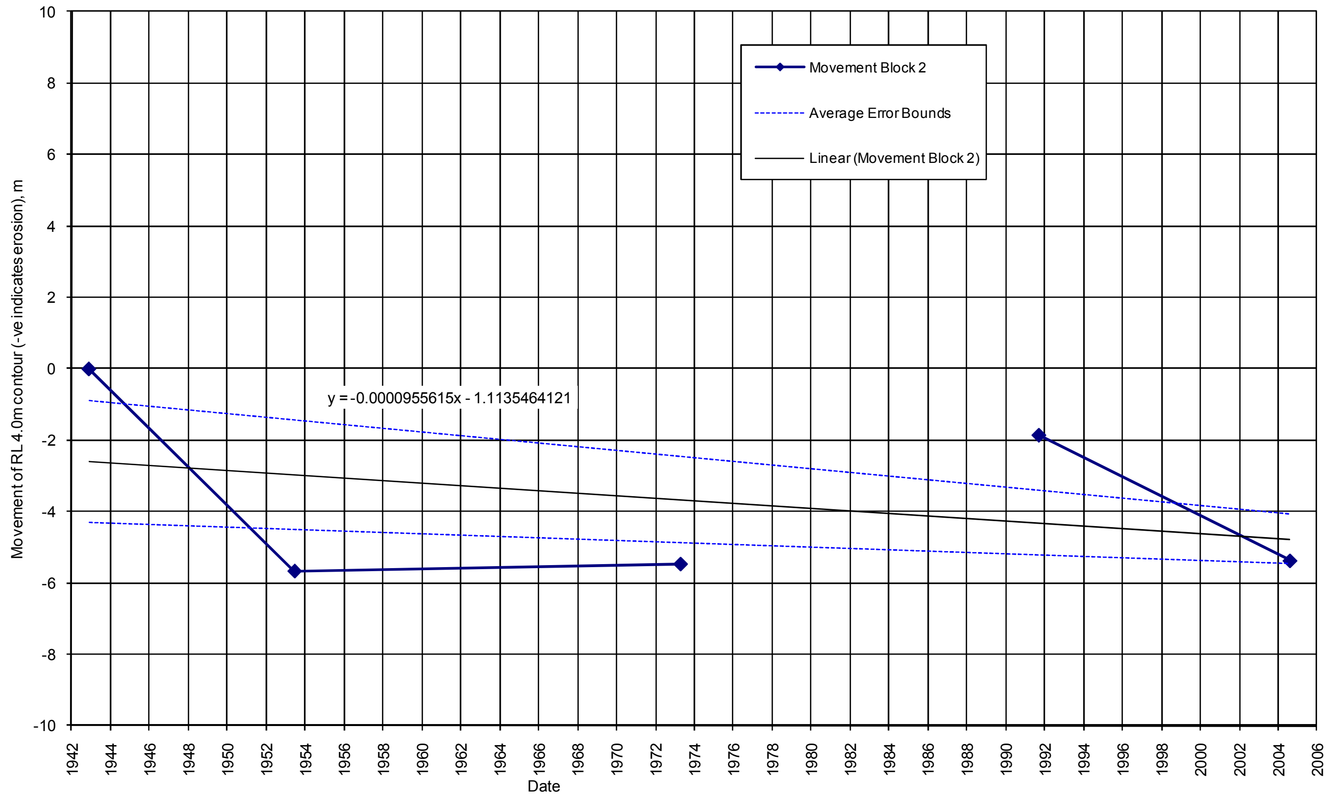
Figure A.35 presents a time history of the location of the dune face based on the photogrammetric analysis, which illustrates that the dune is relatively stable and changes in the dune are mainly due to storm bite. In fact, a regular recovery is noticeable on Figure A.35, where a beach recession is visible until 1980 and followed by a recovery between 1980 and 2004.

Block Number	Location	Average dune migration between 1942 and 2004 (m)	Average dune migration per year (m/yr)
1	Nambucca River entrance	-30.9	-0.50
2	Northern breakwater	-5.4	-0.09
3	Shelly Beach	-1.2	-0.02
4	Beilbys Beach	-8.2	-0.13
5	Main Beach Surf Club	-0.3	0.00
6	Main Beach and Swimming Creek	+10.6	+0.17

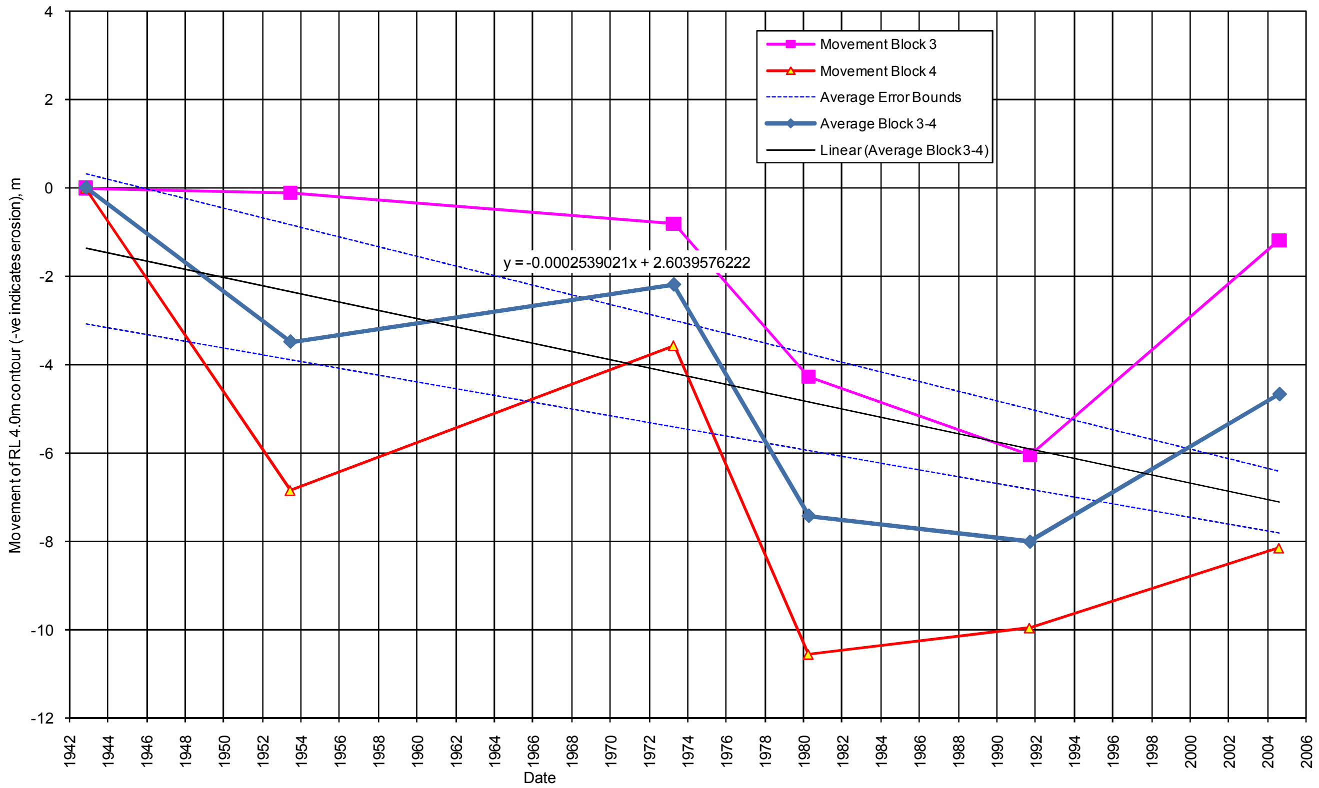
TABLE A.18 – List of the average dune migration for the different blocks (landward migration is characterised by (-) and seaward migration by (+)



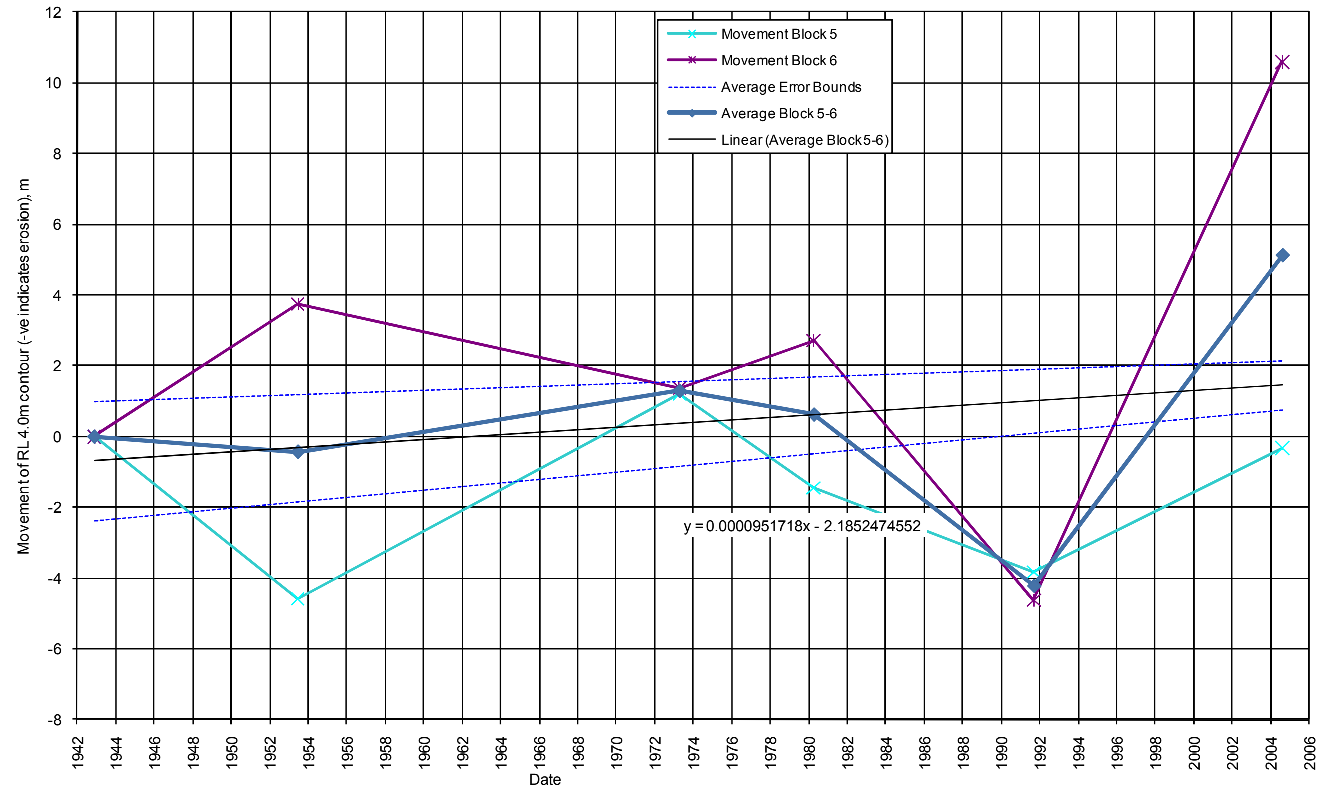
Northern end Forster Beach



small beach adjacent northern breakwater



Shelly and Beilbys beaches



Main Beach

Figure A.34 – Long term recession dune face analysis for the different blocks

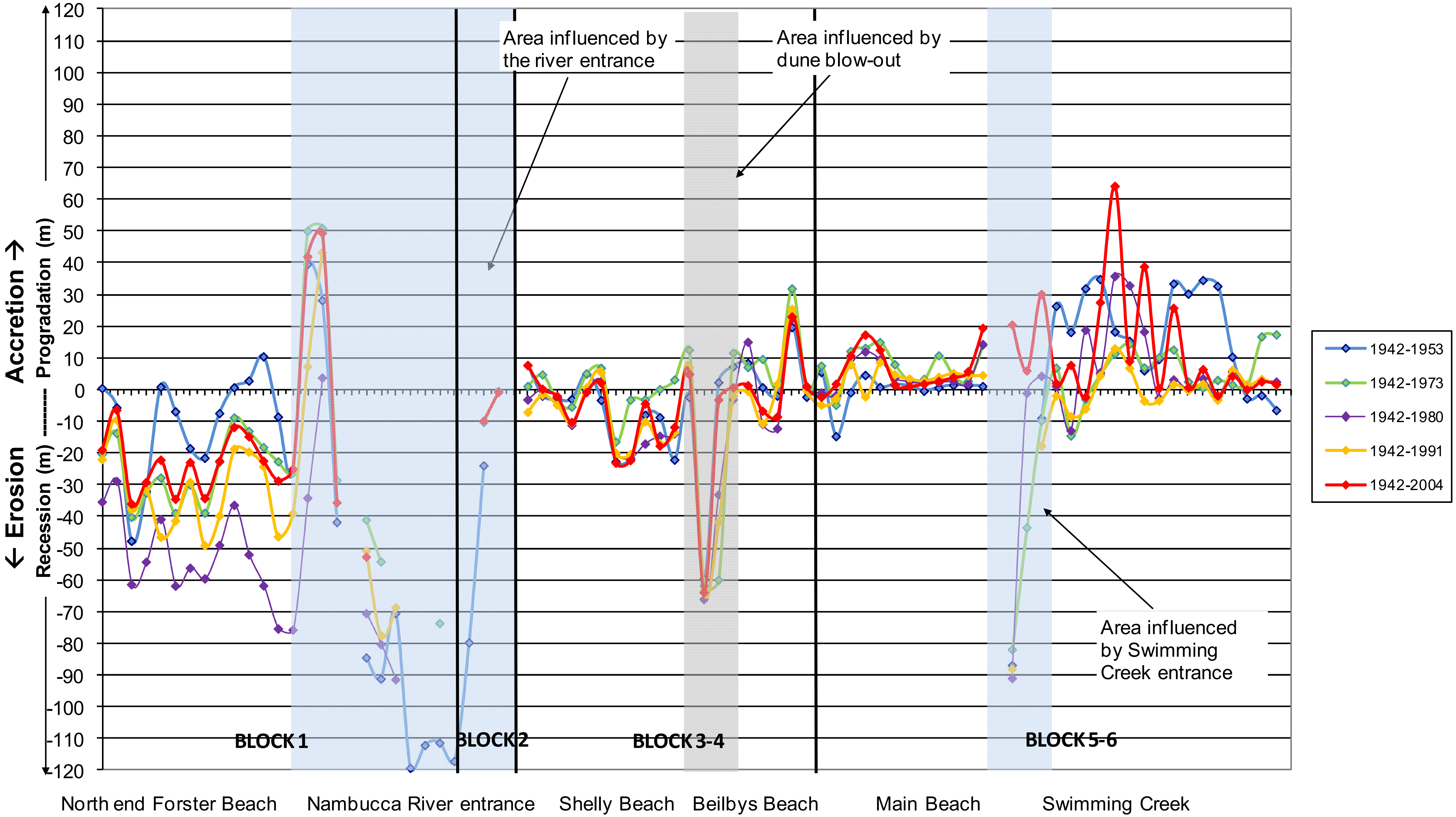


Figure A.35 – Movement of RL 4 contour along beach

3.3.3 Valla Beach

At Valla Beach, in general, it was found that the 2004 locations of the 4.0m contours were further seaward than the 1942 locations. A clear progression of the dune face seaward was seen for the beach south to Deep Creek entrance (Block L and north half of Block M) with the dune face moving forward of between 25 and 50 metres. The beaches directly influenced by Deep Creek entrance (South half of Block M and Block N) are very dynamic places where the main trend is not easily measurable. North Valla Beach (Block O) seems to have slightly moved up to 10m seaward.

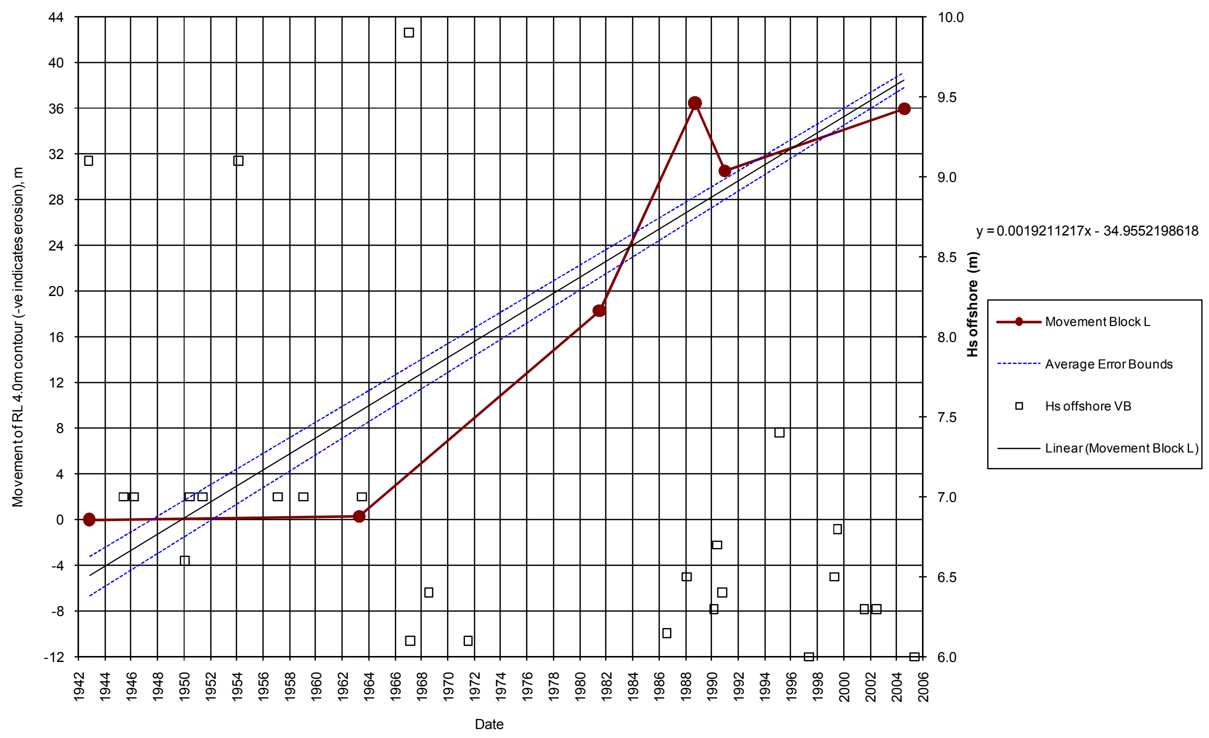
Figure A.36 shows the cumulative movement of the 4.0 m AHD contour over time for the different beaches along Valla Beach coastline as well as the average dune movement for each of the blocks. Negative values represent dune recession and positive values represent dune accretion. It can be seen that there was a general pattern of dune face progradation between 1942 and 2004 along the beach, with an average seaward movement of the dune of 30 to 36 m between 1942 and 2004 for Block L and M, of around 63 m for block N and of around 13 m for Block O (see Table A.19).

Block Number	Average dune migration between 1942 and 2004 (m)	Average dune migration per year (m/year)
L	+35.9	+0.58
M	+30.5	+0.49
N	+62.9	+1.01
O	+8.3	+0.13

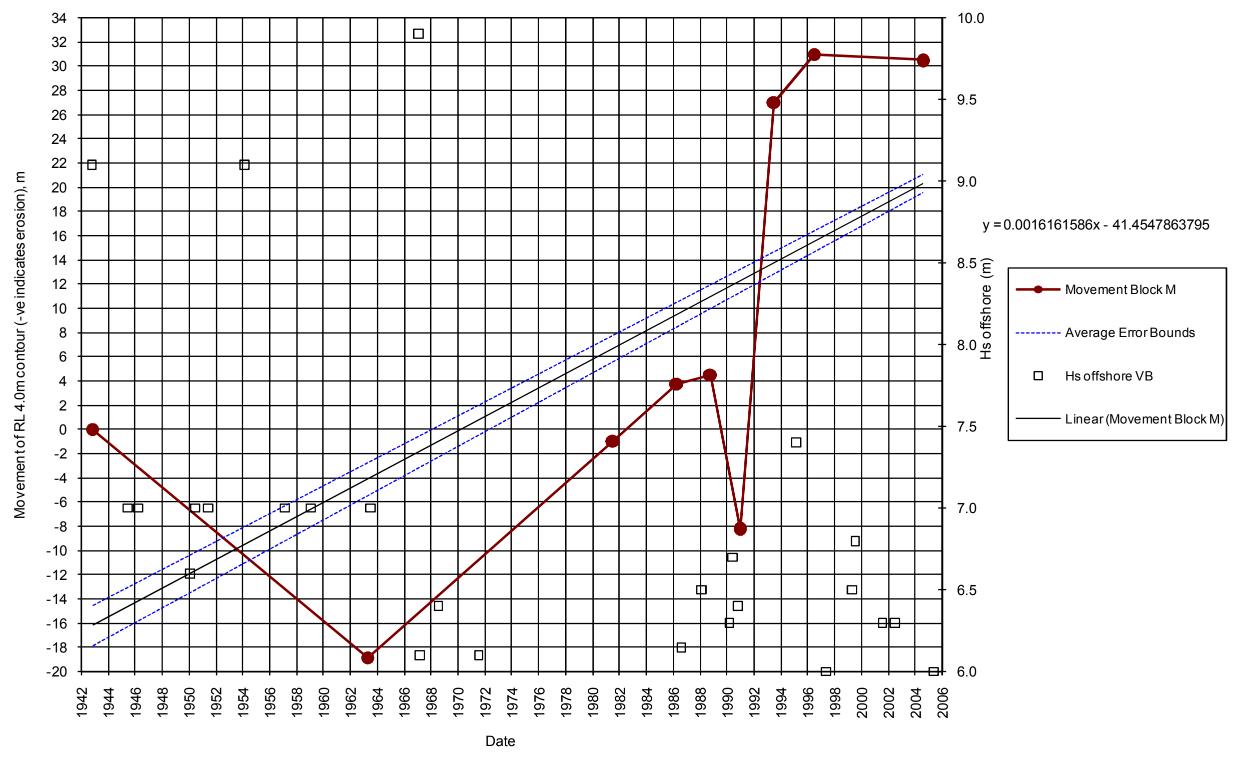
TABLE A.19 – List of the average dune migration for the different blocks landward migration is characterised by (-) and seaward migration by (+)

There is an error band in using this technique due to limitations in the horizontal and vertical accuracy of the photogrammetry. For the 1942 photography, the spatial accuracy (encompassing both the horizontal and vertical accuracies) of the location of the 4.0 m contour is ±1.7 m, whereas the spatial accuracy for the 2004 photography is ±0.7 m.

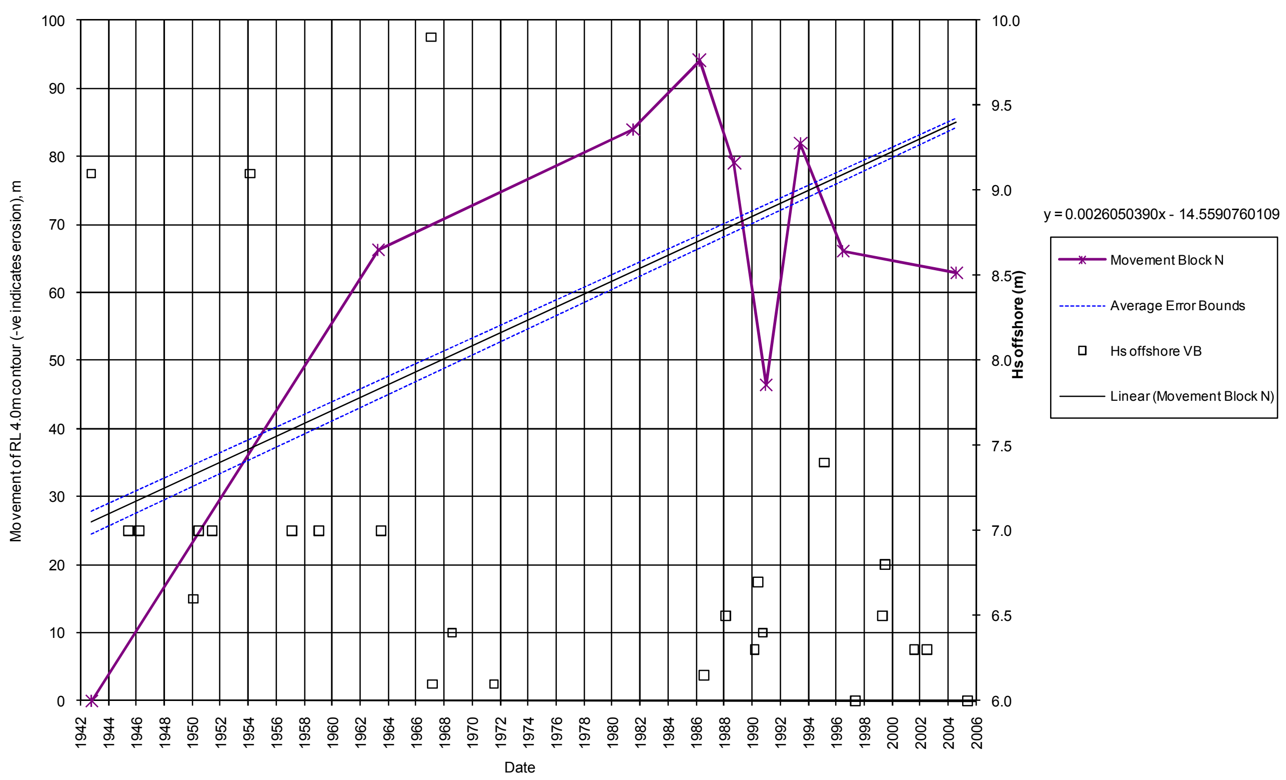
Figure A.37 presents a time history of the location of the dune face based on the photogrammetric analysis, which illustrates that the dune has continued to undergo accretion between 1942 and 2004 (except in the area immediately surrounding the entrance to Deep Creek). Some accretion occurred on Block O which is relatively stable and significant accretion is noticeable for Blocks L and M, while Block N is continuously fluctuating due to the estuary entrance dynamics.



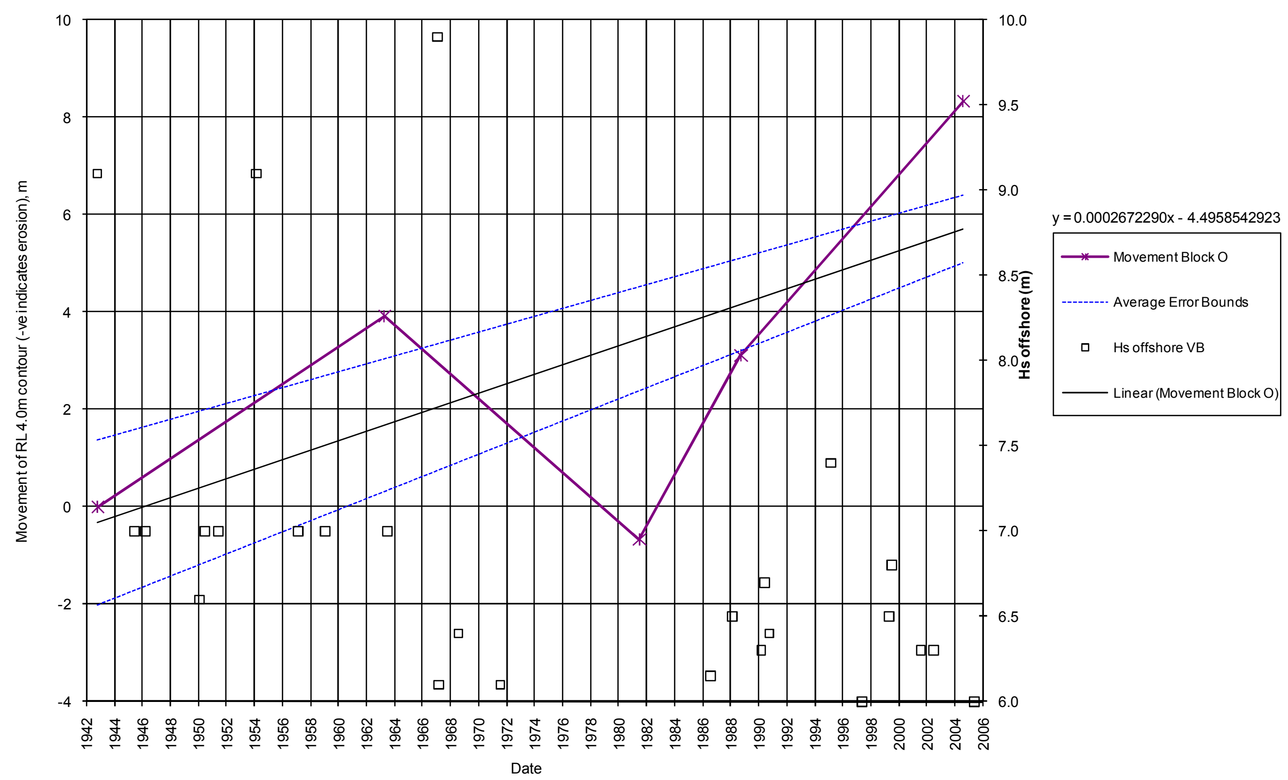
Long term recession dune face analysis for Block L



Long term recession dune face analysis for Block M



Long term recession dune face analysis for Block N



Long term recession dune face analysis for Block O

Figure A.36 – Valla Beach Long term recession dune face analysis

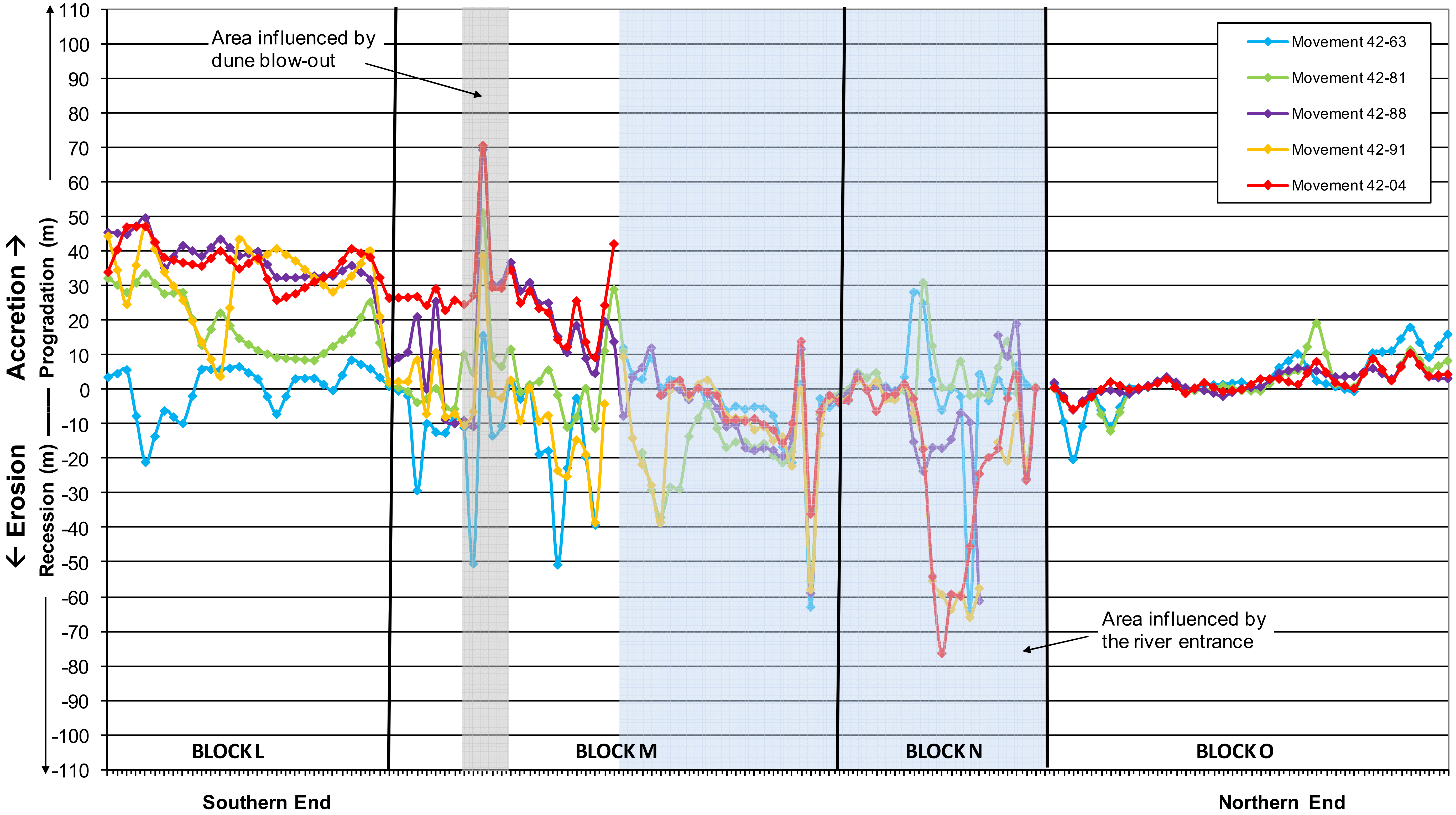


Figure A.37 – Movement of RL 4 contour along beach

3.4 Measured Recession Rate

3.4.1 Scotts Head

At Scotts Head, both the volumetric and dune translation techniques show that the dune appears to have undergone a net loss of sand between 1942 and 1973. However, since 1973, the beaches have been relatively stable or have been undergoing net accretion. The best indicator of a long term trend may be provided by the data since 1973, as the 1942 data may have been affected by factors such as wind erosion of the dune (which has since been stabilised), as well as the small scale of the photography and low spatial accuracy.

In addition, the morphology of the beach supports the long term accretionary trend, with a healthy, well established dune system at Forster Beach. Research being carried out by Goodwin (2009) along the north coast of NSW (and specifically at Scotts Head) shows that the beach barrier at Scotts Head has been almost continuously accreting for around 2000 years. This research used detailed reconstructions of late Holocene strandplains, constrained by sand deposition ages using optically stimulated luminescence (OSL) methods, to determine the geological age of the sand barrier at Scotts Head.

The measured dune recession/accretion rates using both the volumetric and dune translation techniques and using data between 1973 and 2004 are given in Table A.20.

Block Number	Average dune accretion/recession 1973 to 2004 (volumetric technique) m/yr	Average dune accretion/recession 1973 to 2004 (dune translation technique) m/yr
1	+0.18	-0.10
2-3	+0.06	+0.36
4-5	-0.07	+0.41

TABLE A.20 – List of the average dune migration for the different blocks from 1973 – Volumetric and dune translation techniques

The measured long term recession rate may have been in part influenced by sea level rise due to climate change that has already occurred. Table 5.3 from IPCC (2007) summarises the observed sea level rise due to climate change that occurred between 1961 and 2003. It was found that the globally-averaged rate of sea level rise that could be attributed to climate change was 1.8 ± 0.5 mm/year between 1961 and 2003. This rate of rise increased to 3.1 ± 0.7 mm/year between 1993 and 2003. This implies a total sea level rise due to climate change of 76 mm between 1961 and 2003, with 31 mm of this rise occurring between 1993 and 2003 and 45 mm of the rise occurring between 1961 and 1993. Projecting the long-term average rate of sea level rise of 1.8 mm/year over the period of photogrammetry between 1942 and 2004, approximately 112 mm (±31 mm) of sea level rise due to climate change would have occurred between 1942 – 2004, and approximately 56 mm (±16 mm) between 1973 and 2004.

Table 5.3. *Estimates of the various contributions to the budget of global mean sea level change for 1961 to 2003 and 1993 to 2003 compared with the observed rate of rise. Ice sheet mass loss of 100 Gt yr⁻¹ is equivalent to 0.28 mm yr⁻¹ of sea level rise. A GIA correction has been applied to observations from tide gauges and altimetry. For the sum, the error has been calculated as the square root of the sum of squared errors of the contributions. The thermosteric sea level changes are for the 0 to 3,000 m layer of the ocean.*

Source	Sea Level Rise (mm yr^{-1}) 1961–2003	1993–2003	Reference
Thermal Expansion	0.42 ± 0.12	1.6 ± 0.5	Section 5.5.3
Glaciers and Ice Caps	0.50 ± 0.18	0.77 ± 0.22	Section 4.5
Greenland Ice Sheet	0.05 ± 0.12	0.21 ± 0.07	Section 4.6.2
Antarctic Ice Sheet	0.14 ± 0.41	0.21 ± 0.35	Section 4.6.2
Sum	1.1 ± 0.5	2.8 ± 0.7	
Observed	1.8 ± 0.5		Section 5.5.2.1
		3.1 ± 0.7	Section 5.5.2.2
Difference (Observed –Sum)	0.7 ± 0.7	0.3 ± 1.0	

TABLE A.21 – Estimated globally-averaged sea level rise due to climate change (IPCC, 2007)

The measured long term recession rate will include a component due to the 56 mm of climate change-induced sea level rise that occurred between 1973 and 2004. Using a *Bruun Rule* analysis with a nearshore slope of 1:60 to 1:70 (see Appendix B for details of the *Bruun Rule*), 3.4 m (± 1.0 m) to 3.9 m (± 1.3 m) of the measured long-term recession may be attributed to climate change-induced sea level rise that has already occurred. This equates to around 0.11 to 0.13 m/year. As future climate change-induced beach recession has been determined separately, (refer Appendix B), it is appropriate to remove the component of long term recession that can be attributed to climate change from the underlying long term recession rate.

The estimate of the long term recession rate using the volumetric analysis can therefore be reduced as shown in Table A.22.

Block Number	Total long term beach recession/accretion (m/yr)	Long term recession due to sea level rise 1973 – 2004	Long term recession/accretion without climate change effect (m/yr)
1	-0.10 to +0.18	-0.11	+0.01 to +0.18
2-3	+0.06 to +0.36	-0.11	+0.17 to +0.47
4-5	-0.07 to +0.41	-0.11	+0.03 to +0.52

TABLE A.22 – List of the average long term beach recession for the different blocks with and without climate change impact (1973 to 2004)

3.4.2 Nambucca Heads

From both the volumetric and dune translation techniques, similar results were obtained. These results show that the dune at the entrance berm is undergoing a net loss of sand, probably due to ingress of sand into the estuary and northward longshore sediment transport. Beaches immediately to the north of the entrance area (at the northern breakwater, Shelly Beach and Beilbys Beach) appear to be undergoing beach recession at a low rate. Main Beach and Swimming Creek are relatively stable, with net accretion occurring over the period of the photogrammetry data.

The measured recession rates using both the volumetric and dune translation analysis techniques are given in Table A.23.

Block Number	Location	Average dune recession (volumetric technique) m/yr	Average dune recession (dune translation technique) m/yr
1	Nambucca River entrance	-0.60	-0.50
2	Northern breakwater	-0.14	-0.09
3	Shelly Beach	-0.09	-0.02
4	Beilbys Beach	-0.09	-0.13
5	Main Beach Surf Club	+0.13	0.00
6	Main Beach and Swimming Creek	+0.13	+0.17

TABLE A.23 – List of the average dune migration for the different blocks – Volumetric and dune translation techniques

The measured long term recession rates at Shelly and Beilbys beaches may have been in part influenced by observed sea level rise due to climate change that has already occurred.

Table 5.3 from IPCC (2007) summarises the observed sea level rise due to climate change that occurred between 1961 and 2003. It was found that the globally-averaged rate of sea level rise that could be attributed to climate change was 1.8 ± 0.5 mm/year between 1961 and 2003 (Table A.21). This rate of rise increased to 3.1 ± 0.7 mm/year between 1993 and 2003. This implies a total sea level rise due to climate change of 76 mm between 1961 and 2003, with 31 mm of this rise occurring between 1993 and 2003 and 45 mm of the rise occurring between 1961 and 1993. Projecting the long-term average rate of sea level rise of 1.8 ± 0.5 mm/year over the period of photogrammetry between 1942 and 2004, approximately 111 mm (± 31 mm) of sea level rise due to climate change would have occurred between 1942 and 2004.

The measured long term recession rate will include a component due to the 111 mm (± 31 mm) of climate change-induced sea level rise that has already occurred. Using a *Bruun Rule* analysis with a nearshore slope of 1:90 - 1:100, 10 m (± 2.7 m) to 11 m (± 3.0 m) of the measured long-term recession can be attributed to climate change-induced sea level rise that has already occurred. This equates to around 0.16 m/year. As future climate change-induced beach recession has been determined separately, (refer Appendix B), it is appropriate to remove the component of long term recession that can be attributed to climate change from the underlying long term recession rate.

The estimate of the long term recession rate from 1942 to 2004 using the volumetric analysis can therefore be reduced as shown in Table A.24.

Block Number	Total long term beach recession/accretion (m/yr)	Long term recession due to climate change (m/yr)	Long term recession/accretion without climate change effect (m/yr)
1	-0.5 to -0.6	-0.16	-0.34 to -0.44
2	-0.09 to -0.14	-0.16	+0.02 to +0.07
3-4	-0.02 to -0.13	-0.16	+0.03 to +0.14
5-6	+0.00 to +0.17	-0.16	+0.16 to +0.33

TABLE A.24 – List of the average long term beach recession for the different blocks with and without climate change impact

3.4.3 Valla Beach

At Valla Beach, the average long term position of the 4.0m AHD contour levels have continued to move seaward for both the volumetric and dune face analysis, indicating that the zone around Valla Beach is undergoing net accretion. The only area which may be undergoing loss of sand volume is the zone around the entrance to Deep Creek. Based on this, the beaches along the Valla Beach coastline were assessed to be accreting and there is no long term recession. Therefore, a long term recession rate of zero has been assumed in the calculation of the future coastal hazard zones.

The measured long term recession rate may have been in part influenced by sea level rise due to climate change that has already occurred. However, as the measured rate indicated net beach accretion, no adjustments were considered necessary.

3.5 Adopted Long Term Recession Rates

The adopted long term recession rates for Scotts Head, Nambucca Heads and Valla Beach are presented below. It should be noted that further photogrammetry data collected in the future may change this prognosis and that this analysis would need to be repeated in the future and every few years thereafter. It should also be noted that the impact of the storms of May 2009 is not seen in the photogrammetry data and has not been included in this analysis.

3.5.1 Scotts Head

At Scotts Head, from the above analysis, the average long term position of the 4.0m AHD contour levels have moved landward on average since 1942 (though the beaches have accreted or remained stable since 1973). This conclusion was confirmed by the volumetric photogrammetry analysis. Geomorphological studies have shown that the beaches of Scotts Head have been undergoing net accretion for around 2000 years.

Based on this, the beaches at Scotts Head appear to be relatively stable and a long term recession of zero has been used to determine the location of the hazard lines at Scotts Head.

3.5.2 Nambucca Heads

At Nambucca Heads, from the above analysis, the average long term position of the 4.0m AHD contour level moved landward on average since 1942 for Blocks 1 to 4, indicating long term recession, and seaward for Blocks 5 and 6, indicating long term accretion. This conclusion was confirmed by the volumetric photogrammetry analysis. Based on this, a long term recession rate of -0.4 m/y was adopted for Block 1 (which covers the Nambucca River entrance area). Long term recession at Blocks 2, 3 and 4 (Shelly and Beilbys beaches) is small and can be explained by sea level rise due to climate change that has already occurred. For Blocks 5 and 6 (Main Beach and Swimming Creek), long term accretion appears to be occurring.

From this analysis, the beaches appear to be relatively stable with no underlying long term recession (above what could be explained by sea level rise that has already occurred). The beaches at Shelly and Main Beach are partly protected from landward erosion due to the existing seawalls, which limits the erosion to the area within the beach berm.

The exception to this general stability is the Nambucca River entrance area, which appears to be suffering a long term loss of sand. This may be due to ingress of sand into the river entrance, or longshore transport toward the north.

3.5.3 Valla Beach

At Valla Beach, from the above analysis, the average long term position of the 4.0m AHD contour levels have continued to move seaward, indicating that the zone around Valla Beach is undergoing net accretion. The only area which may be undergoing loss of sand volume is the zone around the entrance to Deep Creek. Based on this, the beaches along the Valla Beach coastline were assessed to be accreting and there is no long term recession. Therefore, a long term recession rate of zero has been assumed in the calculation of the future coastal hazard zones

4 Oceanic Inundation

Design incident wave conditions for the assessment of wave runup were determined for a maximum deepwater offshore wave height corresponding to the 0.1% AEP (Annual Exceedence Probability). From long term wave statistics as measured at the Sydney directional Waverider buoy (which is representative of the study region), this corresponds to an offshore deepwater significant wave height of around 11 m. At the Byron Bay Waveruder buoy, the offshore deepwater significant wave height corresponding to a 0.1% AEP event is around 9 m, though there were several severe events at this buoy that were not recorded due to equipment failure and buoy loss (Kulmar *et al.*, 2005). As the Nambucca Heads coastline is fairly exposed to swell waves, it can be assumed that the peak wave height reached offshore at the different beaches along this coast would be similar to what could be expected at Sydney.

Wave runup levels at Scotts Head, Nambucca Heads and Valla Beach were estimated using the Automated Coastal Engineering Software (ACES) and using the value of the nearshore significant wave height calculated using SBEACH software. The wave runup module of ACES was used to determine the levels, which assumes a smooth slope, linear beach.

4.1 Scotts Head

The nearshore boundary conditions for ACES that have been adopted for various locations along the beach are shown in Table A.25. The assumed nearshore beach profile is measured from approximately 2 m below AHD to the top of the dune, to obtain a beach slope for use in the wave runup calculation. The runup was added to the nearshore water level, which included an allowance for wave setup and wind setup. The maximum expected wave runup and 2% wave runup (runup level exceeded by 2% of waves) is given in Table A.26. The runup level has been calculated by adding up the runup calculated by ACES to the nearshore water level and the maximum recorded ocean water level at Sydney of 1.48 m on AHD (Kulmar and Nalty, 1997).

Profile	Location	Deepwater significant Wave Height (m)	Nearshore Water Level (m)	Nearshore Beach Slope (1:X)	Maximum Wave Runup Level (m)	2% Wave Runup Level (m)	*Significant* Wave Runup Level (m)	Maximum Runup+Set up+High Tide (m AHD)
1-1	Little Beach	11	1.10	17	3.12	2.57	1.92	**5.71**
1-5		11	1.13	22	2.46	2.05	1.53	**5.07**
2-1	Surf Club	11	1.15	30	1.60	1.35	1.01	**4.23**
2-5	Southern end Forster Beach	11	1.14	18	2.30	1.88	1.40	**4.92**
3-1	Mid Forster Beach	11	1.10	18	2.91	2.40	1.79	**5.49**
3-9		11	1.14	22	2.13	1.76	1.31	**4.77**
4-1	Main Beach	11	1.13	14	3.18	2.57	1.91	**5.79**
4-7		11	1.14	17	2.54	2.07	1.54	**5.16**
4-14		11	1.15	17	2.43	1.97	1.46	**5.06**
5-1		11	1.17	18	2.32	1.89	1.41	**4.97**
5-7		11	1.14	17	2.35	1.91	1.42	**4.97**
5-14		11	1.15	24	1.79	1.48	1.10	**4.42**

Table A.25 – Wave runup levels for Scotts Head, 0.1% AEP storm event

From these results, it can be seen that the maximum expected wave runup level along the beach is around 5.8 m AHD. From the photogrammetric data, this indicates that, at a maximum, wave runup would not overtop the existing dune embankment and there would be no impact on dwellings or other infrastructure. The only area that would most likely experience inundation due to wave runup would be the SLSC located between Little and Forster Beach as the building is not protected by any dune and the retaining wall on the side of the SLSC fronting Little Beach would certainly be overtopped if a 5m high run up occurs. Wave inundation may also impact the carpark adjacent to the surf club, which may also affect the adjacent caravan park. Mapping of wave runup levels is provided in the Main Report.

4.2 Nambucca Heads

Wave runup at the beaches of Nambucca Heads has been calculated, as well as a separate assessment of wave inundation for the Wellington Drive area.

4.2.1 Wave Runup levels – Ocean Beaches

The nearshore boundary conditions for ACES that have been adopted for various locations along the beach are shown in Table A.26. The assumed nearshore beach profile is measured from approximately 2 m below AHD to the top of the dune, to obtain a beach slope for use in the wave runup calculation. The runup was added to the nearshore water level, which included an allowance for wave setup and wind setup. The maximum expected wave runup and 2% wave runup (runup level exceeded by 2% of waves) is given in Table A.27. The runup level has been calculated by adding up the runup calculated by ACES to the nearshore water level and the maximum recorded ocean water level at Sydney of 1.48 m on AHD (Kulmar and Nalty, 1997).

Table A.26 – Wave Runup levels for Nambucca Heads, 0.1% AEP storm event

Profile	Location	Deepwater significant Wave Height (m)	Nearshore Water Level (m)	Nearshore Beach Slope (1:X)	Maximum Wave Runup Level (m)	2% Wave Runup Level (m)	*Significant* Wave Runup Level (m)	Maximum Runup+Set up+High Tide (m AHD)
1-1	Entrance berm area	11	1.144	19.5	2.11	1.73	1.29	**4.73**
1-6		11	1.119	20	2.08	1.71	1.27	**4.68**
1-13		11	1.137	20	2.04	1.68	1.25	**4.66**
1-20		11	1.159	35.5	1.32	1.12	0.84	**3.96**
1-26		11	1.269	52.5	1.1	0.96	0.73	**3.85**
2-2	Northern breakwater	11	1.169	31	1.54	1.3	0.97	**4.19**
3-2	Shelly Beach	11	1.073	21.5	2.15	1.78	1.32	**4.70**
4-1	Beilbys Beach	11	1.081	15	2.86	2.32	1.72	**5.42**
4-8		11	1.058	14.5	2.9	2.35	1.74	**5.44**
4-16		11	1.034	12	3.5	2.8	2.08	**6.01**
5-1	Main Beach Surf Club	11	1.04	14	3.14	2.54	1.88	**5.66**
6-1	Main Beach	11	1.014	19	2.46	2.02	1.51	**4.95**
6-7		11	1.022	10.5	3.79	3	2.22	**6.29**
6-15		11	0.978	19	2.6	2.15	1.6	**5.06**
6-22		11	1.004	21	2.23	1.84	1.37	**4.71**
6-30		11	1.016	19.5	2.3	1.89	1.41	**4.80**

From these results, it can be seen that the maximum expected wave runup level along the beach is around 6.3 m AHD. From the photogrammetric data, this indicates that some areas would experience inundation due to wave runup. These areas include:

- the sand berm area at the entrance of the river (Block 1) but no infrastructure are at risk there;
- the toilet infrastructure at Shelly Beach (but the effect should be minimal as a seawall has been built at this location); and
- the Main Beach SLSC as it is directly exposed to the sea. The light protection provided by the 0.3m high concrete slab placed in front of the surf club would not be sufficient to prevent flooding of the lower level of the building due to the 5.7 m high wave runup that is possible in a 0.1% AEP storm.

Mapping of the wave runup levels is provided in the main report.

4.2.2 Wellington Drive and Bellwood Park Wave Inundation

Wave penetration into the lower estuary was investigated using bathymetry for scoured entrance conditions and A wave refraction analysis. 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 wave penetration analysis found that wave heights of up to 1 m can penetrate the entrance and reach the Wellington Drive area, and that wave heights of up to 0.5 m can penetrate the Bellwood Park area. Wave penetration into the entrance is possible when the entrance is open, following a major flood event. Wave penetration is most dependent on the bathymetry of the lower entrance area, as well as the oceanic water level due to storm surge and barometric setup. Inundation due to freshwater flows from upstream is to be examined in detailed in the Lower Nambucca Flood Study (BMT WBM, in preparation).

Bathymetry of scoured entrance conditions was obtained for the lower Nambucca area following the flood event of May 2009. A 100 year Annual Recurrence Interval (ARI) ocean water level of 2.4 m was modelled, together with an offshore significant wave height of 7 m (based on Waverider buoy data). It was found that waves would be depth-limited in the lower estuary, and wave breaking would occur on the many shoals. However, under the right conditions, ocean waves up to 0.9 m in height could penetrate into the harbour (through the "hole" in the breakwall) at Wellington Drive, and waves up to 0.5 m in height could reach Bellwood Park, if the entrance is open and the ocean water level is high enough. Wave heights at Bellwood Park and Wellington Drive are independent of the offshore wave height – the above wave heights could occur even under average ocean wave conditions if the ocean water level is high enough and the entrance scoured deeply enough.

Wave runup levels at Wellington Drive and Bellwood Park were obtained by applying standard wave runup algorithms to nearshore slopes estimated from a combination of bathymetry data and land contours.

Wave runup levels could reach an additional 1 – 1.2 m above the nearshore water level, based on the nearshore slope and wave height at Wellington Drive and Bellwood Park. In addition to the wave runup, local wave setup would add approximately 0.2 m to the nearshore water level (estimated based on SBEACH modelling of the wave transformation within the lower estuary). The estimated wave runup level at Bellwood Park and Wellington Drive is approximately 3.6 – 3.8 m AHD. This would inundate the roadway of Wellington Drive, and low-lying parts of Riverside Drive. Wave runup levels would likely increase by 2100 as a result of sea level rise due to climate change. The extent of any future increase cannot be quantified at this time, due to future morphological changes in the lower estuary affecting future runup levels.

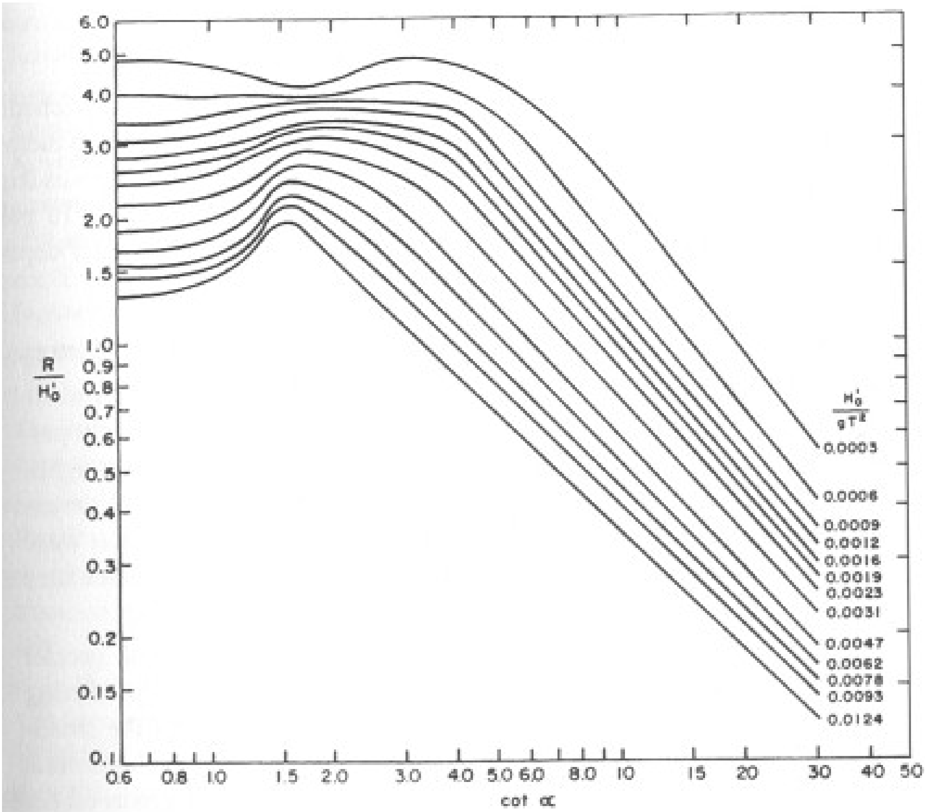


Figure A.38 – Wave runup nomogram, CERC (reproduced from Sorensen 1997)

Wave overtopping of the main breakwater east of the V-wall (between the V-wall and Wellington Rocks) is also likely in a large storm event. While the main breakwall is generally well constructed and has withstood the forces of many large storms, the crest level is only around 4 m AHD and wave overtopping in a large storm would result in a hazard to pedestrians using the walkway behind the breakwall. Wave overflow water could pond on the northern side of the breakwall, as the ability for water to drain back through the breakwall would be limited if the water levels are high in the river. This may result in nuisance flooding of the White Albatross caravan park and carpark, especially as parts of these areas are below 2 m AHD. However, the Caravan Park would not be subject to erosion or reduced foundation capacity as a result of storms.

4.3 Valla Beach

The nearshore boundary conditions for ACES that have been adopted for various locations along the beach are shown in Table A.27. The assumed nearshore beach profile is measured from approximately 2 m below AHD to the top of the dune, to obtain a beach slope for use in the wave runup calculation. The runup was added to the nearshore water level, which included an allowance for wave setup and wind setup. The maximum expected wave runup and 2% wave runup (runup level exceeded by 2% of waves) is given in Table A.27. The runup level has been calculated by adding up the runup calculated by ACES to the nearshore water level and the maximum recorded ocean water level at Sydney of 1.48 m on AHD (Kulmar and Nalty, 1997).

Table A.27 – Wave Runup levels for Valla Beach, 0.1% AEP storm event

Profile Number	Deepwater significant Wave Height (m)	Nearshore Water Level (m)	Nearshore Beach Slope (1:X)	Maximum Wave Runup Level (m AHD)	2% Wave Runup Level (m AHD)	*Significant* Wave Runup Level (m AHD)	Maximum runup+Set Up+High Tide (m AHD)
L-1	11	1.039	32.5	1.35	1.14	0.85	**3.869**
L-8	11	1.046	31.5	1.31	1.1	0.82	**3.836**
L-16	11	1.052	54	0.87	0.76	0.57	**3.402**
M-1	11	1.041	58.5	0.884	0.73	0.55	**3.361**
M-11	11	1.057	54	0.88	0.76	0.57	**3.417**
M-23	11	1.047	37.5	1.25	1.06	0.79	**3.777**
M-34	11	1.058	41.5	1.15	0.98	0.74	**3.688**
M-46	11	1.049	45.5	1.13	0.97	0.73	**3.659**
N-1	11	1.03	37.5	1.23	1.04	0.78	**3.74**
N-12	11	1.033	39.5	1.17	1	0.75	**3.683**
N-24	OVERTOPPED						
O-1	11	1.144	23.5	1.85	1.53	1.14	**4.474**
O-8	11	1.178	13.5	2.81	2.25	1.67	**4.508**
O-15	11	1.116	13.5	3.43	2.77	2.06	**6.026**
O-22	11	1.184	22	1.97	1.63	1.21	**4.634**

From these results, it can be seen that the maximum expected wave runup level along the beach is around 6 m AHD. From the photogrammetric data, this indicates that, at a maximum, wave runup would not overtop the existing dune embankment except at Block N and there would be no impact on dwellings or other infrastructure. The only area that would experience overtopping due to wave runup would be the sand berm area at the entrance of Deep Creek as the berm heights are very low there. This wave runup could affect the existing carpark, picnic area and toilet block in the area immediately landward of the entrance berm to Deep Creek. Maximum wave runup extent is mapped within the Main Report.

There are no dwellings that may be subject to coastal inundation from Valla Beach during storm events.

5 Conclusions

The photogrammetric data analysed here could not be used to quantify storm erosion volume demand accurately, as this would require photography to be taken at least immediately after a major storm. However, it has allowed an estimate of storm bite recession as well as long term beach recession rates.

The long term beach change for Scotts Head between 1942 and 1973 was for recession. However, since 1973, the beach has been accreting on average. The long-term trend from 1973 was considered to be more appropriate for use than that from 1942, as the 1942 aerial photography was of small scale and the dune has since been stabilised by native vegetation.

The trend for long term beach change for Nambucca Heads was one of long term recession on the south side of the river entrance (Block 1), with an average recession rate of -0.4 m/year, representing a loss of sand of around 4 - 5 m^3/m/year given the respective berm height.

For the beaches north of the river entrance (Shelly and Beilbys beaches, Blocks 2, 3 and 4), there is a low rate of recession (around 0.1 m/year) which can be wholly accounted for by sea level rise that has occurred over the last 60 years. In addition, these beaches are partly protected from landward recession by the presence of seawalls. For Main Beach and Swimming Creek, accretion is has been measured (Blocks 5 and 6) with an accretion rate of around +0.2 m/y, representing a gain of sand of around 1.5 m^3/m/year. This shows that the beaches of Nambucca Heads are relatively stable, with the exception of the area immediately south of the river entrance.

The trend for long term beach change for Valla Beach is for global accretion, with an average accretion rate ranging from around 0.1 to 1.0 m/yr.

The accuracy of these estimates depends on the horizontal and vertical accuracy of the photogrammetry, as well as the period of time over which the photogrammetry is carried out. This estimate is based on the existing photogrammetric data and may be subject to change in the future as more data is collected.

Wave runup for the open coast beaches and wave inundation assessments for the lower Nambucca estuary were carried out. It was found that wave inundation could impact on low-lying areas of Wellington Drive and Bellwood Park, and that wave overtopping can impact on the carpark and walkway behind the V-wall, as well as lead to flooding of low lying parts of the White Albatross Caravan Park.

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