Great Lakes Coastal Hazard Study

Appendix B – Photogrammetric Analysis

For: Great Lakes Council

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1 INTRODUCTION

1.1 Background

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 Great Lakes Council Coastline from Nine Mile Beach to Bennetts Beach was undertaken by the Office of Environment and Heritage (OEH) using various aerial photographs dating from 1937 to 2008. The beaches for which relevant photogrammetric survey data were obtained for this study include:

- Nine Mile Beach / Tuncurry Beach
- Forster Main Beach
- One Mile Beach
- Burgess Beach
- Seven Mile Beach
- Elizabeth Beach
- Sandbar Beach
- Number One Beach
- Boat Beach
- Bennetts Beach
- Jimmys Beach (covered in Appendix E)

This Appendix documents the observations made on the photography and two techniques used to quantify subaerial beach changes using the digital data files:

- Carrying out a volumetric analysis of the profiles to determine beach response over time
- Plotting the location of the main dune face along the beach with time

The results and comments are detailed separately for every beach as the photogrammetry dates are not the same for all beaches.

Figure B.1 illustrates the dates of photogrammetry when compared with the occurrence of major storm events offshore of the Great Lakes coastline.

1.2 Nine Mile Beach (Tuncurry Beach) / Main Beach

Photogrammetry data for Nine Mile Beach / Tuncurry Beach and Main Beach were obtained for the following years of aerial photography:

- 1952
- 1963
- 1972
- 1974
- 1980
- 1986
- 1994
- 2001
- 2008

For the photogrammetric surveys, Nine Mile Beach and Main Beach were divided into seven blocks, delineating the beach from south to north. Figure B.2 illustrates the block divisions along the beach. The northernmost blocks, Block 6 and Block 7 cover the fronting area of Darawank Nature Reserve. The area fronting the Golf Club is within the Block 5 and Block 4 divisions. Block 2 and Block 3 cover the area fronting the urban development of Tuncurry and northern entrance wall for the harbour. Block 1 starts from the south entrance wall for the harbour to the southern end of the seawall backing the beach.

Profiles from Blocks 1 to 7 cover approximately five kilometres of coastline along Nine Mile Beach and Main Beach, with profiles at 20 m intervals for Blocks 1 to 3 and 40 m intervals for Blocks 4 to 7. Digital files containing the geographic locations and elevations of transects in each of these blocks for each year of photogrammetry have been obtained and analysed for this study.

1.3 One Mile Beach / Burgess Beach

Photogrammetry for One Mile Beach and Burgess Beach were obtained for the following years of aerial photography:

- 1963
- 1972
- 1974
- 1986
- 1994
- 2001
- 2008

For the photogrammetric surveys, One Mile Beach was divided into two blocks and Burgess Beach was described by 10 profiles within a single block. Figure B.3 illustrates the block divisions along One Mile Beach and Burgess Beach. Ten profiles within Block 1 cover the whole length of Burgess Beach and the area fronting Burgess Road. Block 2 covers the Cape Hawke Surf Club and the residential development immediately behind the main dune at One Mile Beach. Block 3 covers a golf course in the centre and high wind-blown dune at the north end. Digital files containing the geographic locations and elevations of transects at 50 m intervals for One Mile Beach and Burgess Beach have been obtained and analysed for this study.

1.4 Seven Mile Beach

Photogrammetry for Seven Mile Beach was obtained for the following years of aerial photography:

- 1963
- 1973
- 1986
- 1997
- 2008

For the photogrammetric surveys, Seven Mile Beach was delineated from south to north in one block, as shown in Figure B.4. Block 1 covers the beach area from Booti Booti to the northern end of Tiona. Digital files containing the geographic locations and elevations of transects at 50 m for Seven Mile Beach have been obtained and analysed for this study.

1.5 Elizabeth Beach

Photogrammetry for Elizabeth Beach was obtained for the following years of aerial photography:

- 1956
- 1964
- 1972
- 1975
- 1983
- 1996
- 2008

For the photogrammetric surveys, Elizabeth Beach was divided into two blocks. Figure B.5 illustrates the block divisions along the beach. Block 1 covers the area fronting Lakeside Crescent and the creek at the southern end. The southernmost profiles of Block 1 are substantially influenced by the presence of the creek flowing out below Lakeside Crescent. Block 2 covers the redevelopment area of Pacific Palms Surf Life Saving Club near the centre of the beach, with public car parking spaces and public toilets at the northern end of the beach. Digital files containing the geographic locations and elevations of transects at 50m intervals have been obtained and analysed for this study.

1.6 Sandbar Beach

Photogrammetry for Sandbar Beach was obtained for the following years of aerial photography:

- 1963
- 1975
- 1986
- 1994

- 2001
- 2008

For the photogrammetric surveys, Sandbar Beach was divided into two blocks delineating the beach from south to north. Figure B.6 illustrates the block divisions along the beach. Block 1 covers the beach area from the mouth of Smiths Lake entrance to the southern 50 m high dune covered rock boundary. Block 2 covers the northern 40 m high Bald Head.

Digital files containing the geographic locations and elevations of transects at 50 m for Sandbar Beach have been obtained and analysised for this study.

1.7 Number One Beach / Boat Beach

Photogrammetry for Number One Beach and Boat Beach was obtained for the following years of aerial photography:

- 1963
- 1972
- 1975
- 1986
- 1994
- 2001
- 2008

For the photogrammetric surveys, Number One Beach was divided into two blocks delineating the beach from south to north. Boat Beach was divided into two blocks, delineating the beach from east to west. Figure B.7 and B.8 illustrate the block divisions along Boat Beach and Number One Beach. Blocks 1 and 2 at Boat Beach cover the whole stretch of the beach, the residential development along Kinka Rd and the cliff zone to the west which has undergone a geological stability assessment (Appendix F). Block 1 at Number One Beach covers the low lying parts of Seal Rocks Road along Number One Beach and the fill embankment below Seal Rocks Road which has undergone geological stability assessment (Appendix F). Block 2 covers steep rocky terrain fronted by sandy beach, and is part of Myall Lakes National Park.

Digital files containing the geographic locations and elevations of transects at 50 m for Number One Beach and Boat Beach have been obtained and analysed for this study.

1.8 Bennetts Beach

Photogrammetry for Bennetts Beach was obtained for the following years of aerial photography:

- 1951
- 1963
- 1974
- 1983
- 1994
- 2001
- 2008

For the photogrammetric surveys, Bennetts Beach was divided into two blocks, delineating the beach from south to north. Figure B.9 illustrates the block divisions along the beach. The northern Block 2 covers the fronting area of Hawks Nest Golf Club and Sewage Treatment Works. Block 1 covers the area fronting the urban development of Hawks Nest, including Tea Gardens Hawks Nest SLSC. Block 1 ends at the start of Hawks Nest Beach.

Profiles from Block 1 and Block 2 cover approximately three kilometres of coastline along Bennetts Beach, with profiles at 50 m intervals. Digital files containing the geographic locations and elevations of transects in each of these blocks for each year of photogrammetry have been obtained and analysed for this study.

2 SHORT TERM FLUCTUATIONS

2.1 Beach erosion

Storm bite 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 is defined as the volume of eroded sand as measured above mean sea level (~ 0 m AHD datum). For each beach, the storm bite (or beach erosion demand) has been quantified empirically with data obtained from photogrammetric surveys. For a particular beach, the storm bite (or beach erosion demand) may be quantified empirically with data obtained from photogrammetric surveys, or it may be quantified analytically using a verified numerical model.

For Great Lakes, details of the empirical analysis are given below.

2.2 Quantifying Beach erosion Demand From Historical Storms

Photogrammetric data for Great Lakes were not entirely suitable for analysing dune volume changes induced by beach erosion, because the photographs were not always taken immediately before and after a storm event. The lack of suitable pre-storm and post storm photographs mean that the eroded dune would already have undergone recovery and the estimation of dune volume changes would be non-conservative.

Photogrammetric data were available for 1972 and 1975 for the different beaches along Great Lakes coastline, which allows an estimation of the storm bite of the May-June 1974 storm. Photogrammetric data were also available for 1994 and 2001, which allows storm bite resulting from the 1995 Cyclone Violet and 1997 storm to be determined, as shown in Figure B.1.

The dates of the most appropriate photogrammetric data to compare to quantify the *equivalent* beach erosion demand for each beach, are provided in Table B.1. The protocol applied to calculate *equivalent* beach erosion demand is described in Nielsen *et al.* (1992) and outlined in following section. The dates were chosen based on which storm event was most visible in the available photogrammetric data at each beach – various beaches may have been more impacted by particular storm events than others due to their orientation with respect to the direction of approach of each storm.

Table B.1: Storm events used for the storm bite calculation at the beaches of Great Lakes

Beach Name	Year of photogrammetric data used for storm bite calculation	Storm event associated with the photogrammetric data date*
Nine Mile Beach / Tuncurry Beach / Main Beach	1994 and 2001	Cyclone Violet (March 1995) May 1997 storm
One Mile Beach / Burgess Beach	1972 and 1974	May - June 1974 storms
Seven Mile Beach	1986 and 1997	Cyclone Violet (March 1995) May 1997 storm
Elizabeth Beach	1964 and 1972	June 1967 East Coast Low
Sandbar Beach	1994 and 2001	Cyclone Violet (March 1995) May 1997 storm

Beach Name	Year of photogrammetric data used for storm bite calculation	Storm event associated with the photogrammetric data date*
Boat Beach/ Number One Beach	1994 and 2001	Cyclone Violet (March 1995) May 1997 storm
Bennetts Beach	2001 and 2008	June 2007 storm

* *The storm event presented in this table is not the only storm event that has impacted the beach but is the one that is the most clearly visible within the photogrammetric data.*

Historical photogrammetry data provides valuable information about the medium to long term beach and shoreline change.However,this information is provided as descrete 'snapshots in time'. Beach morphological change is continually evolving and can be eposidically dynamic (i.e. beach erosion and recovery during and following storm events). Furthermore at best the available history of photogrametry spans only the last 60 years. As such defining coastal hazard parameters for planning purposes based on past measured data is an imprecise exercise. By virtue it is necessary to adopt a conservative, precautionary approach to the adoption of coastal hazard parameters for planning purposes.

2.3 Beach erosion / Dune Stability Schema

A generalised dune stability schema relating to bbeach erosion is presented schematically in Figure B.10. 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 described in Scetion 5.2.1 of the main report (after Nielsen *et al*., 1992):

- The *Zone of Wave Impact*
- A *Zone of Slope Adjustment*
- A *Zone of Reduced Foundation Capacity*
- The *Stable Foundation Zone*

To determine the impact of beach erosion on a homogeneous sand dune, the *design beach erosion demand* is subtracted from the available sand storage on the beach. The slumped beach 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.10). 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.

2.4 Estimation Of beach erosion Volumes

The impact of the May-June 1974 storms and 1995/1997 storms was able to be assessed using the photogrammetric data. Figure B.11 illustrates the procedure used to estimate the *equivalent* beach erosion volume. This beach 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 beach erosion demand corresponds to the *Zones of Wave Impact and Slope Adjustment* illustrated in Figure B.10.

The equivalent beach erosion volumes were assessed for every beach, with site specific conditions being taken into account when considering the impact along different sections of each beach. The assessment of the storm bite was undertaken using two different methods:

- Dune face movement assessment: this method consists of observing the movement of a characteristic level of the dune (e.g. RL 4 m) landward or seaward over time;
- Volume change assessment: this method consists of observing the volume changes over time and calculating the beach recession or accretion using the calculated volume change rate over the height of the dune.

In addition, it was found that the vertical accuracy of the photogrammetry was important in assessing the impact of the storms, especially for relatively protected beaches such as Burgess Beach, Elizabeth Beach and Number One Beach where the impact of the storm is less severe than for an open coast beach such as Nine Mile Beach, One Mile Beach and Seven Mile Beach.

The photogrammetric data profiles were examined to determine whether errors were apparent in the datum of these profiles. It was found that the data profiles generally did not need to be corrected for datum shifts. However, some vertical and horizontal error is inherent in the photogrammetric technique due to the orientation of the photography and scale effects.

2.4.1 Photogrammetry Error Range

Table B.2 lists the aerial photographs analysed with photogrammetry which also indicates a measure of the survey accuracy as derived from the orientation of the photography in the stereo restitution instrument. From the Table B.2, it can be seen that earlier photography was at a smaller scale, leading to vertical accuracies of up to ±0.4 - 0.5 m. Later photography, being clearer and at a larger scale, allowed the technique to bear more accurate results, with vertical and horizontal accuracies of ±0.2 - 0.3 m on most photographs.

Checking of each profile data set was carried out, to ensure that the measured erosion for the major storms was reasonable and suitable for use in the analysis.

Table B.2: List of aerial photographs and accuracies used for photogrammetric analysis

Date	Scale (1:X)	Horizontal Accuracy (m)	Vertical Accuracy (m)
27/05/2008	10000	0.3	0.3
24/09/2001	10000	0.3	0.3
22/06/1994	10000	0.3	0.3
22/08/1986	10000	0.3	0.3
25/01/1984	16000	0.3	0.3
13/06/1981	25000	0.3	0.4
13/01/1980	8000	0.2	0.2
08/08/1974	41000	0.3	0.4

Date	Scale (1:X)	Horizontal Accuracy (m)	Vertical Accuracy (m)
09/09/1972	40000	0.3	0.4
11/1963	42000	0.3	0.3
10/1952	31000	0.5	0.4
19/10/1937	21000	0.5	0.5

2.4.2 Beach erosion at Nine Mile Beach (Tuncurry Beach) / Main Beach

From the photogrammetric data at Nine Mile Beach and Main Beach, the location of the top of the scarp feature seems to have been affected by a storm event which occurred between 1994 and 2001, despite the post-storm photogrammetry data being taken several years after the 1997 storm event. This is because at most locations, the dune face had not fully recovered from the storm. Although the dune scarp was still visible, considerable beach berm recovery had occurred and the beach 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. A tropical cyclone occurred in March 1995 and a large East Coast Low occurred in May 1997. These storm events are described in further detail in Appendix A.

Equivalent beach erosion volumes were obtained from the analysis of the beachfront areas along the seven blocks at Nine Mile Beach (Tuncurry Beach) and Main Beach for the 1995/1997 storms. As shown in Figure B.12, for photogrammetric data Block 1 (Main Beach) an upper envelope value of 200 m^3/m was established for the loss of sand volume for the 1995/1997 storms. For photogrammetric data Block 2 to 3 (Tuncurry Beach) the beach erosion demand value adopted was 230 m^3/m, and for photogrammetric data Block 4 to 7 (encompassing the Golf Club) the beach erosion demand value adopted was 240 m^3/m. Several values along the beach do exceed the upper envelope value due to the presence of beach access ways or coastal protection works, such as the large exposed beach berm in front of the seawall at Main Beach which is subject to wind erosion, and edge effects from the breakwater at the entrance to Wallis Lake.

The beach erosion demand value of 200 ~ 250 m^3/m is commensurate with typical storm bite values measured along open coast beaches throughout NSW and has been used in the hazard lines calculations for all blocks along Main Beach and Tuncurry Beach.

2.4.3 Beach erosion at One Mile Beach / Burgess Beach

From the photogrammetric data at One Mile Beach, the top of the scarp feature seems to have been affected by a storm event which occurred between 1972 and 1974. The storm events that may have generated this erosion are the May-June 1974 storm events that are further described in Appendix A.

Close examination of the photogrammetric profiles from 1972 and 1974 was carried out, to determine the impact of the May-June 1974 storm on the area of beach which has undergone urban development. Equivalent beach erosion volumes were obtained from the analysis of the beachfront areas with Block 2 and 3 along One Mile Beach for the 1974 storms. As shown in Figure B.13, an upper envelope value of 220 m^3/m was established for the loss of sand volume for the 1974 storm. A single value exceeding 250 m^3/m at the northern end of the beach is due to the presence of a small creek entrance at the golf course. beach erosion demand was also examined for the May 1997 storm event by comparing photogrammetry profiles between 1994 and 2001. The beach erosion demand was found to be similar but slightly less than that found from the May-June 1974 storm.

It is noted that this beach erosion demand value is similar to those obtained in the photogrammetric analysis carried out for Nine Mile Beach, with both beaches having a similar wave climate and exposure to swell and sea waves.

Burgess Beach measured beach erosion demand was low because the beach is backed and underlain by bedrock. However, beach erosion demand of up to 140 m^3/m was measured here due to the impact of the 1997 storm event. A large storm at Burgess Beach would lead to the beach losing its sandy part and exposure of the underlying bedrock. beach erosion demand at Burgess Beach for the 1997 storm event is shown in Figure B.14.

2.4.4 Beach erosion at Seven Mile Beach

From the photogrammetric data at Seven Mile Beach, there are clear scarp features evident from the 1995-1997 storms, as the post storm photogrammetry data has been taken several months after the May 1997 storms. At most locations, the dune face had not had enough time to recover from the storm. The southern end of the beach seemed to have been more impacted by the several storms and Cyclone Violet from the north-easterly direction, as the southern corner of the beach is more exposed to the north.

Close examination of the photogrammetric profiles from 1986 and 1997 was carried out, to determine the impact of the 1995/1997 storms on the beach. The estimated beach erosion demand from the 1995/1997 storm for Seven Mile Beach is plotted in Figure B.15. It can be seen that maximum beach erosion demand values of 320 m^3/m for the southern corner of the beach and 200 m^3/m for the main part of Seven Mile Beach were adopted for the 1995/1997 storms.

2.4.5 Beach erosion at Elizabeth Beach

From the photogrammetric data at north-facing Elizabeth Beach, the location of the top of the scarp feature resulting from the 1967 storms is the most clearly evident and the scarp was undergoing recovery between 1972 and 1974. However, as the 1972 post-storm photogrammetry data was taken about five years after the storm event, considerable beach berm recovery had occurred and the beach erosion demand that may be measured by comparing 1964 and 1972 profiles was considerably less than the “actual” storm bite as a result of this storm. The storm event that may have generated this erosion is the 1967 storm that is further described in Appendix A. The impact of other storms such as the 1997 storm could not be ascertained from the photogrammetry as there was no suitable post storm photogrammetry available for Elizabeth Beach until 2008.

Close examination of the photogrammetric profiles from 1964 and 1972 was carried out, to determine the impact of the 1967 storm on the beach. The estimated beach erosion demand from the 1967 storm for the Elizabeth Beach is plotted in Figure B.16. It can be seen that most of these values are between 80 m^3/m and 180 m^3/m and an upper envelope value of 180 m^3/m was established for the loss of sand volume for the 1967 storm at Elizabeth Beach. Profiles within the southernmost part of Block 1 did not measure any erosion, as these were affected by the entrance dynamics of the creek entrance flowing out below Lakeside Crescent.

2.4.6 Beach erosion at Sandbar Beach

From the photogrammetric data at Sandbar Beach, there are clear scarp features at the two ends of the beach apart from the entrance berm area between 1963 and 1975, also between 1994 and 2001. The photogrammetric data between 1963 and 1975 were not suitable for analysing beach erosion, because both 1967 and 1974 storms occurred within this period which could cause overestimation of beach erosion and because the time interval between photogrammetric data was too long to give a reliable result. The amount of beach erosion were determined by analysing photogrammetric data between 1994 and 2001.

From photogrammetric data at the entrance berm, the top of the dune is normally above 2.5 m which keeps the lake entrance closed. Since the entrance has been opened by Council on average about every 1.5 years over 50 years to prevent flooding, the dune location at the entrance berm has migrated over a distance of 100 m. It should be noted that more beach erosion occurred when a coastal storm event coincided with an open entrance.

Close examination of the photogrammetric profiles from 1994 and 2001 was carried out, to determine the impact of the 1995/1997 storms at the Sandbar beach. As shown in Figure B.17, an upper envelope of 230 m^3/m was established for the loss of sand volume for Sandbar Beach on either side of the lake entrance.

2.4.7 Beach erosion at Number One Beach / Boat Beach

From the photogrammetric data for 1975, there is no clear scarp feature evident from the 1974 storms. As these storms were predominantly from the southerly direction, and Boat Beach and Number One Beach are sheltered from the south, it is possible that these storms did not cause much erosion of the dune.

Close examination of the photogrammetric profiles from 1994 and 2001 was carried out, to determine the impact of the 1995/1997 storms on the beach. As the 1995 storm was due to Cyclone Violet, this storm will have generated swell from the north-easterly direction, which would be more likely to cause erosion at Number One and Boat Beaches. The estimated beach erosion demand from the 1995/1997 storm for Boat Beach and Number One Beach is plotted in Figure B.18 and Figure B.19. It can be seen that most of these values are between 30 m^3/m and 120 m^3/m for Boat Beach and the same for Number One Beach. An upper envelope of 120 m^3/m was established for the loss of sand volume for Number One Beach and Boat Beach.

This beach erosion demand is lower than for other open coast beaches in NSW, as the beach is sheltered from southerly waves and most large storms that attack the NSW coast. A storm with waves approaching from the east or north-east sector would cause a greater beach erosion demand at Number One and Boat Beaches than for waves from the south or south-east, due to more exposure to wave energy from this direction. However, it is rare for waves to approach the central NSW coast from this direction. Waves approaching from a direction north of east with a significant wave height larger than 5.0 m have not been recorded at the Sydney directional Waverider buoy since its deployment (Lord and Kulmar, 2000; Department of Commerce Manly Hydraulics Laboratory 2006).

2.4.8 Beach erosion at Bennetts Beach

From the photogrammetric data at Bennetts Beach, there are clear scarp features evident between 2001 and 2008 data resulting from 2007 storms and between 1963 and 1974 resulting from 1974 storms. Evidence from 1983 photogrammetric data indicates that Bennetts Beach has the ability to recovery relatively quickly from the major erosion events. Although not completely recovered it is evident that much of the volume eroded by 1974 storms has returned to the beach berm.

Close examination of the photogrammetric profiles from 2001 and 2008 was carried out to determine equivalent beach erosion volumes from the 2007 storms. As shown in Figure B.20, the storm bite for the 2007 events was greatest in the southern part up to 250 m^3/m where the erosion escarpment appears highest, reducing into the range of 150 m^3/m and 200 m^3/m toward the northern end of Bennetts Beach. This pattern of erosion is likely to reflect the diffraction of south to south east waves by Yacaaba Head. Given the uncertainties involved in estimating storm demand, a storm demand of 250 m^3/m adopted for the entire length of Bennetts Beach is deemed precautionary.

2.4.9 Beach erosion Summary

The storm bite (or beach erosion demand) has been quantified empirically with data obtained photogrammetrically. An equivalent beach erosion volume has been derived empirically based on the schema presented in Nielsen *et al.* (1992). From this analysis, an envelope of values for the loss of sand volume was calculated for each of the different beaches along the Great Lakes coastline and the result is summarised in Table B.3.

Table B.3: Design storm bite assessment at the beaches of Great Lakes Council

Beach Name	Design Storm Bite (m^3/m)
Nine Mile Beach / Tuncurry Beach Northern End	240
Nine Mile Beach / Tuncurry Beach Southern End	230
Main Beach	200
One Mile Beach	220
Burgess Beach	35
Seven Mile Beach	320 for southern end; 200 for the main section of the beach
Elizabeth Beach	150 for southern end; 180 for central and northern end
Sandbar Beach	230
Number One Beach	120 for southern end and 90 for northern end
Boat Beach	30-50 for eastern end; 120 for middle section and 80 for western end
Bennetts Beach	250

2.5 Estuary Entrance Instability Hazard

Wallis Lake has an entrance trained by two breakwaters located on both sides of the entrance (at the southern end of Nine Mile Beach and the northern end of Main Beach). Therefore, the entrance would not suffer from instability hazard as the entrance cannot migrate along the beach in response to freshwater inflow or coastal storm effects. However, future sea level rise would increase the tidal prism within the lake, which could generate some scour within the entrance channel that would deepen the entrance. In addition, the tidal prism has been increasing over time as a response to construction of the entrance breakwalls during the 1960s. Entrance stability is discussed in more detail in Appendix G.

Smiths Lake is a natural entrance opening onto Sandbar Beach. This lake is an ICOLL (Intermittently Closed and Open Lake or Lagoon) which means that the lake can open naturally depending on the water level in the lake or on storm events along the coast. From historical aerial photography, this lake appears to be usually closed. The sandbar closing the lake entrance is currently around 100 m wide and appears to tend to open at the southern end of the entrance given the lack of vegetation at this location. There also is a visible narrow channel on the northern side of the entrance. Based on the observations of beach berm fluctuations at RL 2.0 m AHD from the photogrammetric data, the area of the beach affected by lake entrance instability hazard was able to be delineated. Outside of the berm area, the lake entrance dynamics may influence the dune erosion, though the escarpment crests are above 8 m AHD and storm overwash of these areas is extremely unlikely. Storm overwash and coastal inundation are quantified in Appendix C.

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 Appendix C (Climate Change) of this report.

At Nine Mile Beach, One Mile Beach and Seven Mile Beach, analysis of the photogrammetric data showed no evidence of any beach rotation, with beach fluctuations on one end of the beach correlated positively with changes on the other end, generally indicating that if the southern end was eroding, the northern end was also eroding; and *vice versa*. As photogrammetry data were not available for the northern half of Nine Mile Beach compartment, it was not possible to determine whether beach rotation was occurring at Nine Mile Beach. However, changes measured near the centre of Nine Mile Beach were generally positively correlated with changes measured at the southern end. From historical aerial photos at Seven Mile Beach, there were sand mining activities in the early 1970s around the northern part of Seven Mile Beach. The photogrammetry data showed no evidence of beach rotation at Seven Mile Beach since 1973.

Potential beach rotation was also estimated by way of analysis of mean approach wave directions, and this is described in Appendix C.

3 LONG TERM CHANGES

3.1 Volumetric Analysis of Profiles

The photogrammetric data were analysed for volume change to determine trends in beach erosion or accretion over time along the beachfront. Trends in historical beach change can be estimated in two ways:

- by assessment of the volume of sand contained within the beach and dune system above 0 m AHD; and
- by measurements of the position of various beach features, such as the position of the back beach erosion escarpment or the position in plan of a certain "cut" level through the foredune.

Both of these approaches have been used for this study with the prupose of providing a sensitivity check to guide the selection of an approapriate hazard parameter for planning purposes. 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. It should be noted that the volume considered was that above 0.0 m AHD landward of the 2.0 m 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.

Table B.4 illustrates the beach recession rates measured for the various beaches in the study area. The average volume change per year for the different beaches is also provided in Table B.4. Several beaches within Great Lakes were found to be accreting in the long term. At such locations the long term recession rate was conservatively considered to be nil.

Table B.4: List of the average volume change for the different beaches[1]

Beach Name	Measured long term recession rate (m/yr)	Average volume change per year from lines of best fit* (m^3/m/yr)
Nine Mile / Tuncurry Beach	Nil	Nil
Main Beach	-0.2	-0.9
One Mile Beach	Nil	Nil
Burgess Beach	Nil	Nil
Seven Mile Beach	Nil	Nil
Elizabeth Beach	-0.1	-0.5
Sandbar Beach	Nil	Nil
Number One Beach	-0.1	-0.8

[1] Negative values relate to recession and positive values to accretion.

Beach Name	Measured long term recession rate (m/yr)	Average volume change per year from lines of best fit* (m^3/m/yr)
Boat Beach	Nil	Nil
Bennetts Beach North	Nil	Nil
Bennetts Beach South	-0.1	-0.4

* Note – Negative values indicate long term beach erosion and nil values indicate beach accretion

It should be noted that erosion may be occurring in episodic bursts most likely brought about by storm activity. 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. 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, dune stabilisation or sand extraction.

3.2 Long Term Recession at Nine Mile Beach / Main Beach

For Nine Mile Beach and Main Beach, profiles in Blocks 1 to 7 were examined to determine whether any long term trend in beach profile volumes were evident for the length of beach encompassing the Golf Club, Tuncurry Beach and Forster Main Beach. Figures B.21 to B.23 illustrate the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

The photogrammetry data for Nine Mile Beach (Tuncurry Beach) does not exhibit a recessionary trend, but rather, the data suggests Nine Mile Beach (Tuncurry Beach) is accreting at 5.2 m^3/m/yr from 1972 to 2008. From photogrammetric data, it could be found that Tuncurry Beach had experienced strong accretion from 1963 to 1972, which is attributable to the construction of the Tuncurry entrance breakwall. The response of Tuncurry Beach to the training wall construction has increased the rate of beach progradation, due to fast accumulation of sediment updrift of the breakwater, which was excluded from the sub-aerial beach volume change calculation.

Ongoing recession is evident at Main Beach, with typically 60-100 m^3/m change in volumetric reserves between the most accreted (~1980) and most eroded (~2001) states. The photogrammetric data indicates a trend of long term erosion, with sand possibly being transported offshore and trapped in the reefs and not being returned onshore. The long term recession of Main Beach may also be the result of changes in the long term average wave climate, bought about by changes to offshore bathymetry caused by construction of the breakwalls (ie. entrance bar at Wallis Lake moving offshore into deep water). The 1963 profile cross sections suggest the incipient dunes were human-modified by the construction of the seawall. This was confirmed by observations of ground photography from that time. Excluding the photogrammetric data from 1963, the remaining data from 1972 to 2008 suggests Main Beach is receding at 0.9 m^3/m/yr.

The long term erosion and recession rate for Main Beach and Nine Mile Beach (Tuncurry Beach) is summarised in Table B.5.

Table B.5: Long-term volume change rates for Main Beach and Nine Mile Beach (Tuncurry Beach) [2]

Long term recession or accretion rate from erosion volume (m^3/m/yr)							
Main Beach	**Nine Mile Beach**						
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**	**Block 7**	**Averaged**
-0.92	3.68	3.88	4.89	5.66	5.25	5.09	5.20
Dune Height H (m)							
Main Beach	**Nine Mile Beach**						
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**	**Block 7**	**Averaged**
6.10	5.40	5.40	5.00	5.20	4.90	5.10	5.00
Adopted long term recession or accretion rate (m/yr)							
Main Beach	**Nine Mile Beach**						
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**	**Block 7**	**Averaged**
-0.15	0.68	0.72	0.98	1.08	1.06	1.01	1.0

As well as the 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 B.2, the vertical accuracy of the photogrammetry at Main Beach and Nine Mile Beach (Tuncurry Beach) varies between ±0.3m to ±0.4m and this means that the accuracy of the determined rate of volume change is estimated to be in a range of +1.0 ~ -3.1 m^3/m/yr for Main Beach, 2.1 ~ 5.5 m^3/m/yr for Tuncurry Beach and 4.1 ~ 6.2 m^3/m/yr for Nine Mile Beach. It indicates that the net rate of volume change averaged over the whole length of Main Beach could, at best, represent an accretion of sand volume of 1.0 m^3/m/yr, or at worst, erosion of 3.1 m^3/m/yr. Tuncurry Beach and Nine Mile Beach are undergoing long term accretion and this is not impacted by the accuracy of the photogrammetry.

3.3 Long Term Recession at One Mile Beach / Burgess Beach

For One Mile Beach and Burgess Beach, profiles in each of the photogrammetric blocks were examined to determine whether any long term trends in beach profile volumes were evident for the length of beach encompassing Forster-Tuncurry Golf Course, residential development along One Mile Beach, Cape Hawke Surf Club and Burgess Beach. Figure B.24 and Figure B.25 illustrate the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

The photogrammetric data did not suggest long term recession to be occurring at One Mile Beach. Rather there has been a gradual increase in subaerial beach volumes since 1963, with a net increase of 20 – 90 m^3/m over the 45 years of data. A decrease of up to 100 m^3/m occurred between 1972 and 1974 which may be attributable to storms in 1974. Burgess Beach is a small pocket beach well protected by foreshore rocks and headland which is not undergoing any significant long-term shoreline recession.

If the beach volume change since 1963 were averaged for the all blocks of One Mile Beach, a line of best fit drawn through all the data would indicate that there has been a net volume increase since 1963 of 1.48 m^3/m/yr. At Burgess Beach, the average rate of net volume increase between 1963 and 2008 was 1.18 m^3/m/yr. As there has been no decrease in sand volume, a beach recession rate of zero was adopted for both One Mile Beach and Burgess Beach. The long term volume change for One Mile Beach and Burgess Beach is summarised in Table B.6.

[2] Negative values relate to recession and positive values to accretion.

Table B.6: Long-term volume change rates for One Mile Beach and Burgess Beach[3]

Long term recession or accretion rate from erosion volume (m^3/m/yr)			
Burgess Beach	**One Mile Beach**		
Block 1	**Block 2**	**Block 3**	**Averaged**
1.18	1.81	0.95	1.48
Dune Height H (m)			
Burgess Beach	**One Mile Beach**		
Block 1	**Block 2**	**Block 3**	**Averaged**
7.00	6.50	6.90	6.70
Adopted long term recession or accretion rate (m/yr)			
Burgess Beach	**One Mile Beach**		
Block 1	**Block 2**	**Block 3**	**Averaged**
0.17	0.28	0.14	0.22

From Table B.6, it has been found that the location of Cape Hawke Surf Club at the southern end of One Mile Beach is accreting by up to 1.81 m^3/m/yr.

As noted in Table B.2, the vertical accuracy of the photogrammetry at One Mile Beach and Burgess Beach is around ±0.3 m and this means that the accuracy of the determined rate of volume change is estimated to be in a range of 0.6 ~ 2.3 m^3/m/yr for One Mile Beach and 0.6 ~ 1.7 m^3/m/yr for Burgess Beach. This indicates that both One Mile Beach and Burgess Beach are undergoing long term accretion of sand volume and this is not impacted by the accuracy of the photogrammetry.

3.4 Long Term Recession at Seven Mile Beach

For Seven Mile Beach, profiles in Block 1 were examined to determine whether any long term trend in beach profile volumes were evident for the length of beach encompassing several residential lots and the Lakes Way behind the beach area. Figure B.26 illustrates the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

From this plot it can be seen that, on average, significant erosion occurred between 1986 and 1997, with a net volume decrease of 100 m^3/m. Since 1997, the beach has been accreting and had increased above the initial beach volume of 1963. Over 45 years, the photogrammetric data for Seven Mile Beach does not exhibit a recessionary or accretionary trend on average.

3.5 Long Term Recession at Elizabeth Beach

For Elizabeth Beach, profiles in Block 1 and 2 were examined to determine whether any long term trend in beach profile volumes were evident for the length of beach encompassing the Pacific Palms Surf Life Saving Club. Figure B.27 illustrates the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

Beach volume data has been analysed to determine that since 1956, Elizabeth Beach has been receding at a rate of 0.07 m/yr. Photogrammetric cross sections for 1972 and 1996 exhibit the lowest beach volume. Between 1972 and 1983, 1996 and 2008 the cross sections indicate accretion upon the sub-aerial beach volume.

If the beach volume change since 1956 were averaged for both blocks of Elizabeth Beach, a line of best fit drawn through all the data would indicate that there has been a

[3] Negative values relate to recession and positive values to accretion.

net volume decrease since 1956 of 0.47 m^3/m/yr. From the photogrammetry data a beach recession rate of 0.1 m/yr was adopted for Elizabeth Beach. The long term erosion and recession rate for Elizabeth Beach is summarized in Table B.7.

Table B.7: Long-term recession rates for Elizabeth Beach[4]

Long term recession or accretion rate from erosion volume (m^3/m/yr)		
Block 1	**Block 2**	**Averaged**
-0.33	-0.55	-0.47
Dune Height H (m)		
Block 1	**Block 2**	**Averaged**
7.10	7.10	7.10
Adopted long term recession or accretion rate (m/yr)		
Block 1	**Block 2**	**Averaged**
-0.05	-0.08	-0.07

As noted in Table B.2, the vertical accuracy of the photogrammetry at Elizabeth Beach is around ±0.3 m and this means that the accuracy of the determined rate of volume change is estimated to be in a range of -1.3 ~ +0.3 m^3/m/yr for Elizabeth Beach. It indicates that the net rate of volume change averaged over the whole length of the Elizabeth Beach could, at best, represent an accretion of sand volume of 0.3m^3/m/yr, or at worst, erosion of 1.3m^3/m/yr.

3.6 Long Term Recession at Sandbar Beach

For Sandbar Beach, profiles in Block 1 and 2 were examined to determine whether any long term trend in beach profile volumes were evident for the length of beach encompassing the entrance berm to Smiths Lake. Figure B.28 illustrates the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

Beach volume data has been analysed to determine that since 1963, Sandbar Beach including the lake entrance berm has been accreting at a rate of 3.49 m^3/m/yr, with a net increase in volume of 100 m^3/m/yr over the 40 years of data. A sand loss up to 80m^3/m occurred after the 1974 storms and 1995/1997 storms and the natural beach recovery process restored the sand volume by about 200 m^3/m from 1975 to 1994.

If the beach volume change since 1963 was averaged for both blocks at Sandbar Beach, a line of best fit drawn through all the data would indicate that there has been a net volume increase since 1963 of 0.60 m^3/m/yr at Sandbar Beach. The long term erosion and recession rate for Sandbar Beach is summarised in Table B.8.

Table B.8: Long-term volume change rates for Sandbar Beach[5]

Long term recession or accretion rate from erosion volume (m3/m/yr)		
Block 1	**Block 2**	**Averaged**
1.51	5.63	3.49
Dune Height H (m)		
Block 1	**Block 2**	**Averaged**
5.90	5.80	5.90
Calculated long term recession or accretion rate (m/yr)		
Block 1	**Block 2**	**Averaged**
0.25	0.97	0.60

[4] Negative values relate to recession and positive values to accretion.
[5] Negative values relate to recession and positive values to accretion.

As noted in Table B.2, the vertical accuracy of the photogrammetry at Sandbar Beach is around ±0.3 m and this means that the accuracy of the determined rate of volume change is estimated to be in a range of +2 ~ +4 m^3/m/yr for Sandbar Beach. This indicates that Sandbar Beach would undergo long term accretion of sand volume and this is not impacted by the accuracy of the photogrammetry.

3.7 Long Term Recession at Number One Beach / Boat Beach

For Boat Beach and Number One Beach, all profiles in each of the photogrammetric blocks were examined to determine whether any long term trends in beach profile volumes were evident for the length of beach encompassing residential development along Kinka Rd, Boat Ramp at Boat Beach and urban development along Number One Beach. Figures B.29 and Figure B.30 illustrate the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

In the active beach zone, analysis of beach volumes suggests Boat Beach has been accreting at an average rate of 0.1m/yr between 1963 and 2008. Boat Beach experiences relatively low wave energy, protected by Sugarloaf Point to the east and rock reefs.

From the photogrammetry data analysis, Number One Beach was found to be receding landward by up to 1.09 m^3/m/yr. On average, there has been a net decrease in subaerial beach volumes of about 10 – 40 m^3/m for Number One Beach between 1963 and 2008 (Figure B.29). Most of this loss has been from the beach berm, as the beach is backed by bedrock slopes which are resistant to erosion.

If the beach volume change since 1963 was averaged for both blocks at Boat Beach and Number One Beach respectively, a line of best fit drawn through all the data would indicate that there has been a net volume increase since 1963 of 0.54 m^3/m/yr at Boat Beach and a net volume decrease since 1963 of 0.80 m^3/m/yr at Number One Beach. The long term erosion and recession rate for Boat Beach and Number One Beach is summarised in Table B.9.

Table B.9 – Long-term recession rates for Number One Beach and Boat Beach[6]

Long term recession or accretion rate from erosion volume (m3/m/yr)					
Boat Beach			Number One Beach		
Block 1	**Block 2**	**Averaged**	**Block 1**	**Block 2**	**Averaged**
0.48	0.59	0.54	-0.21	-1.09	-0.80
Dune Height H (m)					
Boat Beach			**Number One Beach**		
Block 1	**Block 2**	**Averaged**	**Block 1**	**Block 2**	**Averaged**
4.80	6.60	5.70	6.40	7.80	7.30
Calculated long term recession or accretion rate (m/yr)					
Boat Beach			**Number One Beach**		
Block 1	**Block 2**	**Averaged**	**Block 1**	**Block 2**	**Averaged**
0.10	0.09	0.10	-0.03	-0.14	-0.10

As noted in Table B.2, the vertical accuracy of the photogrammetry at Number One Beach and Boat Beach is around ±0.3 m and this means that the accuracy of the determined rate of volume change is estimated to be in the range of -0.4 ~ -1.2 m^3/m/yr for Number One Beach and 0 ~ 1.1 m^3/m/yr for Boat Beach. It indicates that the net rate of volume change averaged over the whole length of Number One Beach could, at best, represent long term erosion of sand volume of 0.4 m^3/m/yr, or at worst, erosion of 1.2 m^3/m/yr. The net rate of

[6] Negative values relate to recession and positive values to accretion.

volume change averaged over the whole length of Boat Beach represents an accretion of up to a maximum of 1.1 m^3/m/yr.

3.8 Long Term Recession at Bennetts Beach

For Bennetts Beach, profiles in Blocks 1 to 2 were examined to determine whether any long term trend in beach profile volumes were evident for the length of beach encompassing the Hawks Nest Golf Club, Sewage Treatment Works and Tea Gardens/ Hawks Nest SLSC. Figure B.31 illustrates the cumulative change in beach volume in cubic metres per metre length of beach for each block over time.

The photogrammetric data for northern Bennetts Beach does not exhibit a recessionary trend, but rather, the data suggests northern Bennetts Beach is accreting at 1.12 m^3/m/yr from 1963 to 2008. Ongoing recession is evident at southern Bennetts Beach, at a recession rate of 0.40m^3/m/yr with approximately 100m^3/m erosion between the most accreted (~1994) and most eroded (~2008) states.

If the beach volume change since 1963 were averaged for the all blocks of Bennetts Beach, a line of best fit drawn through all the data would indicate that there has been no net increase or decrease of volume change since 1963. The long term volume change for Bennetts Beach is summarised in Table B.10.

Table B.10: Long-term volume change rates for Main Bennetts Beach[7]

Long term recession or accretion rate from erosion volume (m3/m/yr)		
Block 1	**Block 2**	**Averaged**
-0.40	1.12	0.41
Dune Height H (m)		
Block 1	**Block 2**	**Averaged**
5.30	5.80	5.60
Calculated long term recession or accretion rate (m/yr)		
Block 1	**Block 2**	**Averaged**
-0.075	0.19	0.07

As well as the 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 B.2, the vertical accuracy of the photogrammetry at Bennetts Beach varies by ±0.3 m and this means that the accuracy of the determined rate of volume change is estimated to be in a range of -0.51 ~ 1.34 m^3/m/yr for Bennetts Beach. It indicates that the net rate of volume change averaged over the whole length of Bennetts Beach could, at best, represent an accretion of sand volume of 1.75 m^3/m/yr, or at worst, erosion of 0.1 m^3/m/yr.

3.9 Translation of Dune Escarpment

As the natural short-term 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 a consistent or readily identifiable feature such as the dune erosion escarpment over time. This can be done by measuring the location of the dune face along each profile, by selecting a representative contour level and measuring the chainage along each profile of the toe or the crest of the dune.

[7] Negative values relate to recession and positive values to accretion.

A representative contour location along the dune was selected to observe if there is a potential movement or translation of the dune escarpment. The selected contour studied for each beach as well as the resulting average movement of the dune escarpment over time is given in Table B.11. Positive values of beach dune translation movement represent accretion along the beach. For these beaches, the average dune movement (or long term recession rate) was conservatively selected as nil.

Table B11 - Translated Dune Escarpment Contour [8]

Beach Name	Selected reduced level contour for the dune translation movement analysis (m AHD)	Average dune movement (m/yr)
Nine Mile	4	1.2
Tuncurry Beach	3	1.0
Main Beach	4	-0.4
One Mile Beach	5	0.1
Burgess Beach	3	0.0
Seven Mile Beach	5	0.1
Elizabeth Beach	5	0.0
Sandbar Beach	4	0.6
Number One Beach	4	-0.0
Boat Beach	4	0.0
Bennetts Beach	4	0.2

The locations of these contours were based on the MGA 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 selected contour will be dependent on the vertical resolution of the photogrammetric technique.

3.9.1 Dune Movement at Nine Mile Beach and Main Beach

By inspection of the profiles at Nine Mile Beach and Main Beach, it was determined that from these data the location of the RL3.0 m AHD contour best represented the location of the front face of the dune along the Tuncurry Beach and the RL4.0 m AHD contour best represented the location of the front face of the dune along Nine Mile Beach and Main Beach.

For Main Beach, Figure B.32 shows the accumulative movement of the 4.0 m AHD contour over time, for the profiles along Main Beach with seawall and the profiles without seawall. Negative values represent dune recession. Large storms that occurred in 1974 and the storms in 1995/1997, most likely were the cause of the dune recession measured between 1972 – 1975, and 1994 – 2001. Averaged over the 36 years of photogrammetric

[8] Negative values relate to recession and positive values to accretion.

data between 1972 and 2008, the rate of dune face migration equates to a recession rate of 0.23 m/yr at the southern end of the beach which is backed by a seawall and 0.43 m/yr at the northern end where there is no seawall. Figure B.43 presents a time history of the location of the dune face based on the phtotgrammetric analysis, which illustrates the dune has receded most at the northern end since 1986. It was found that the 1972 location of the 4.0 m AHD contour was furthest seaward, while the 2001 location of this contour was the furthest landward. The dune face recession has ranged between 14 and 16 m along the entire beach length between 1972 and 2008.

For Nine Mile Beach, Figure B.33 shows the 3.0 m AHD contour for Block 2 and 3 along Tuncurry Beach and Figure B.34 shows the accumulative movement of the 4.0 m AHD contour for Block 4 to 7 along Nine Mile Beach, as well as the average dune movement for each of the blocks. Negative values represent dune recession. It can be seen that while there is variation between blocks along Nine Mile Beach (Tuncurry Beach), the movement of the dune face followed a similar pattern. On average, the rate of dune face migration equates to a progradation rate of 1.20 m/yr. Figure B.44 presents a time history of the location of the dune face based on the photogrammetric analysis, which illustrates that the dune has prograded in most locations along Nine Mile Beach between 1972 and 1994. Following the storms in 1995 and 1997, there was a generally a dune face recession of between 10 and 30 m. It was found that the 1972 or 1974 location of the 3.0 m AHD contour was furthest landward, while the 1994 location of this contour was the furthest seaward. This was especially true for the northern blocks of Nine Mile Beach which indicates a trend toward beach progradation.

Table B.12 shows the long term dune escarpment movement rate at Nine Mile Beach and Main Beach.

Table B12: Long Term Dune Escarpment movement Rate at Nine Mile Beach and Main Beach[9]

Dune Escarpment Accretion or Recession rate (m/yr)							
Main Beach	Nine Mile Beach						
Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Averaged
-0.43	1.38	0.78	1.49	1.27	1.11	0.95	1.2

There is an error band in using this technique due to limitations in the horizontal and vertical accuracy of the photogrammetry. For the 1972 photography, the spatial accuracy of the location of the 4.0 m/3.0 m contour is ±0.7 m, whereas the spatial accuracy for the 2008 photography is ±0.6 m. This accuracy limitation means that the recession rate may be as large as 0.27 m/yr, or as small as 0.20 m/yr for Main Beach for the portion of the beach backed by the seawall. The progradation rate at Tuncurry Beach may be in the range of 0.98 ~ 1.05 m/yr and 1.19 ~ 1.24 m/yr at Nine Mile Beach.

3.9.2 Dune Movement at One Mile Beach and Burgess Beach

By inspection of the profiles at One Mile Beach and Burgess Beach, it was determined that from these data the location of the RL5.0 m AHD contour best represented the location of the front face of the dune along One Mile Beach and the RL3.0 m AHD contour best represented the location of the front face of the dune along Burgess Beach.

For One Mile Beach, Figure B.35 shows the accumulative movement of the 5.0 m AHD contour over time, for both blocks along One Mile Beach, as well as the average dune movement for each of the blocks. Negative values represent dune recession. It can be seen that the movement of the dune face at Block 2 and 3 followed an opposite pattern between 1963 and 1972, possibly indicating beach rotation between those years. Averaged over all the blocks along the entire length of One Mile Beach, it was found that

[9] Negative values relate to recession and positive values to accretion.

the rate of dune face migration equates to a progradation rate of 0.11 m/yr. Figure B.45 presents a time history of the location of the dune face based on the photogrammetric analysis. It was found that the 1974 location of the 5.0 m AHD contour was furthest landward, while the 1994 location of this contour was the furthest seaward, which indicates a trend toward beach recovery between 1974 and 1994. Figure B.36 shows the accumulative movement of 4.0 m AHD contour over time, for both blocks along One Mile Beach, as well as the average dune movement for each of the blocks. Following the storms of May-June 1974, there was a dune face recession of between 5 and 20 m and then full recovery by 1986. Following the storms of 1995 and 1997, there was a dune face recession of between 5 and 15 m and then recovery back to the 1986 locations.

Burgess Beach is underlain by bedrock and no long term recession rate of the dune escarpment was observed. Table B.13 shows the long term dune escarpment movement rate at One Mile Beach.

Table B13: Long Term Dune Escarpment Movement Rate at One Mile Beach[10]

Dune Escarpment Accretion or Recession rate (m/yr)			
Burgess Beach	**One Mile Beach**		
Block 1	**Block 2**	**Block 3**	**Averaged**
0.01	0.11	0.11	0.11

For the 1963 and 2008 photography at One Mile Beach and Burgess Beach, the spatial accuracy of the location of the 5.0 m contour is ±0.6 m. This accuracy limitation means that the progradation rate at One Mile Beach may be in the range of 0.08 ~ 0.13 m/yr and 0 ~0.04 m/yr at Burgess Beach.

3.9.3 Dune Movement at Seven Mile Beach

By inspection of the profiles at Seven Mile Beach, it was determined that from these data the location of the RL5.0 m AHD contour best represented the location of the front face of the dune along Seven Mile Beach.

Figure B.37 shows the accumulative movement of the 5.0 m AHD contour over time along Seven Mile Beach. It can be seen that there was a general pattern of dune face progradation between 1973 and 2008 with the dune face being relatively stable between 1973 and 1997. The average of all the profiles of Seven Mile Beach showed that the location of the dune face prograded seaward from 1973 to 2008 at an average rate of 0.1 m/yr. Figure B.46 presents a time history of the location of the dune face based on the photogrammetric analysis. It was found that the 1963 location of the 5.0 mAHD contour was furthest landward, while the 2008 location of this contour was furthest seaward, which indicates a trend toward beach recovery between 1963 and 2008.

From historical aerial photos at Seven Mile Beach, there were sand mining activities in the early 1970s around the northern end of Seven Mile Beach. Due to the influence of sand mining on beach profiles, the photogrammetry data between 1963 and 1973 cannot be used for long term recession analysis.

3.9.4 Dune Movement at Elizabeth Beach

By inspection of the profiles at Elizabeth Beach, it was determined that from these data the location of the RL5.0 m AHD contour best represented the location of the front face of the dune along Elizabeth Beach.

[10] Negative values relate to recession and positive values to accretion.

Figure B.38 shows the accumulative movement of the 5.0 m AHD contour over time, for both blocks along Elizabeth Beach, as well as the average dune movement for each of the blocks. Negative values represent dune recession. The movement of the dune face followed a similar pattern along the entire beach length however the progradation of the dune face at Block 2 was generally greater than that at Block 1. Averaged over all the blocks along the entire length of Elizabeth Beach, it was found that the rate of dune face migration equates to a progradation rate of 0.03 m/yr. Figure B.47 presents a time history of the location of the dune face based on the photogrammetric analysis. It was found that the 1975 location of the 5.0 m AHD contour was furthest landward, while the 2008 location of this contour was furthest seaward, which indicates a trend toward beach recovery between 1974 and 2008.

Table B14 shows the long term dune escarpment movement rate at Elizabeth Beach.

Table B14: Long Term Dune Escarpment Movement Rate at Elizabeth Beach[11]

Dune Escarpment Accretion or Recession rate (m/yr)		
Block 1	**Block 2**	**Averaged**
0.01	0.04	0.03

For the 1963 and 2008 photography at Elizabeth Beach, the spatial accuracy of the location of the 5.0 m contour is ±0.6 m. This accuracy limitation means that the progradation rate may be as large as 0.06 m/yr, or as small as 0m/yr for Elizabeth Beach.

3.9.5 Dune Movement at Sandbar Beach

By inspection of the profiles at Sandbar Beach, it was determined that from these data the location of the RL4.0 m AHD contour best represented the location of the front face of the dune along Sandbar Beach apart from the entrance berm area.

Figure B.39 shows the accumulative movement of the 4.0m AHD contour over time along Sandbar Beach, as well as the average dune movement for each of the blocks. From 1975 to 1994, the front dune face averaged along the beach had prograded seaward by approximately 25m. An average progradation rate of 0.60m/yr along the beach over 40 years of data was found as shown in Table B.15, a higher rate of dune progradation was observed at the northern end of the beach at 0.80m/yr and a progradation rate of 0.40m/yr was observed at the southern end of the beach including the berm of the entrance. Figure B.48 presents a time history of the location of the beach berm at 4m AHD level based on the photogrammetric analysis. The 1963 location of the 4.0m AHD contour was furthest landward, while the 2008 location of this contour was furthest seaward, which indicates a trend toward beach recovery between 1963 and 2008.

Table B.15 shows the long term dune escarpment recession rate at Sandbar Beach.

Table B15: Long Term Dune Escarpment Movement Rate at Sandbar Beach[12]

Dune Escarpment Accretion or Recession rate (m/yr)		
Block 1	**Block 2**	**Averaged**
0.40	0.80	0.60

For the 1963 and 2008 photography at Sandbar Beach, the spatial accuracy of the location of the 2.0 m contour is ±0.6 m. This accuracy limitation means that the progradation rate may be in the range of 0.12 m/s to 1.32 m/s.

[11] Negative values relate to recession and positive values to accretion.
[12] Negative values relate to recession and positive values to accretion.

3.9.6 Dune Movement at Boat Beach and Number One Beach

By inspection of the profiles at Boat Beach and Number One Beach, it was determined that from these data the location of the RL4.0 m AHD contour best represented the location of the front face of the dune along Boat Beach and Number One Beach.

For Boat Beach, Figure B.40 shows the accumulative movement of the 4.0 mAHD contour over time, for both blocks along Boat Beach, as well as the average dune movement for each of the blocks. Over the 45 years of photogrammetric data since 1963, the rate of dune face migration equates to a progradation rate of 0.04 m/yr. Figure B.49 presents a time history of the location of the dune face based on the photogrammetric analysis. It can be seen that there has been not much change in the location of the dune face.

For Number One Beach, Figure B.41 shows the accumulative movement of the 4.0 m AHD contour over time, for both blocks along Number One Beach, as well as the average dune movement for each of the blocks. The rate of migration of the 4.0 m contour varies at different compartments along the beach. The sandy portion of the beach backed by rocky cliffs is undergoing long term recession with a recession rate of 0.05 m/yr. However, the other locations are relatively stable with a progradation rate of 0.08 m/yr. Figure B.50 presents a time history of the location of the dune face based on the photogrammetric analysis. It was found that there has been not much change in the location of the dune face in the area backed by cliffs. Except for the area backed by cliffs, the 1963 location of the 4.0 mAHD contour was furthest landward, while the 2008 location of this contour was furthest seaward, which indicates a trend toward beach recovery between 1963 and 2008.

Table B.16 shows the long term dune escarpment recession rate at Boat Beach and Number One Beach.

Table B16: Long Term Dune Escarpment Movement Rate at Boat Beach and Number One Beach [13]

Dune Escarpment Accretion or Recession rate (m/yr)					
Boat Beach			Number One Beach		
Block 1	Block 2	Averaged	Block 1	Block 2	Averaged
0.06	0.02	0.04	0.08	-0.05	-0.01

For the 1963 and 2008 photography at Number One Beach and Boat Beach, the spatial accuracy of the location of the 4.0 m contour is ±0.6 m. This accuracy limitation means that for Number One Beach, the dune face may be receding at a rate of 0.03 m/yr, or prograding at a rate of 0.02 m/yr. For Boat Beach, the average progradation rate may be as large as 0.07 m/yr, or as small as 0.01 m/yr.

3.9.7 Dune Movement at Bennetts Beach

By inspection of the profiles at Bennetts Beach, it was determined that from these data the location of the RL4.0 m AHD contour best represented the location of the front face of the dune along Bennetts Beach.

Figure B.42 shows the accumulative movement of the 4.0 m AHD contour over time, for both blocks along Bennetts Beach, as well as the average dune movement for each of the blocks. The average of all the profiles of Bennetts Beach showed that the location of the dune face prograded seaward from 1963 to 2008 at an average rate of 0.22 m/yr. A higher rate of dune progradation was observed at the northern end of the beach, at 0.31 m/yr on average. Dune face location was subject to fluctuations between various

[13] Negative values relate to recession and positive values to accretion.

years of photography of up to ±15 m. Figure B.51 presents a time history of the location of the dune face based on the photogrammetric analysis. It was found that the 1974 location of the 4. mAHD contour was furthest landward, while the 1994 location of this contour was furthest seaward, which indicates a trend toward beach recovery between 1974 and 1994.

Table B.17 shows the long term dune escarpment recession rate at Bennetts Beach.

Table B17: Long Term Dune Escarpment Movement Rate at Bennetts Beach[14]

Dune Escarpment Accretion or Recession rate (m/yr)		
Block 1	**Block 2**	**Averaged**
0.10	0.31	0.22

For the 1963 and 2008 photography at Bennetts Beach, the spatial accuracy of the location of the 4.0 m contour is ±0.6 m. This accuracy limitation means that the progradation rate may be as large as 0.24 m/yr, or as small as 0.18 m/yr for Bennetts Beach.

3.10 Adopted Long Term Recession Rates

The conclusion of the dune face analysis was confirmed also by the volumetric photogrammetry analysis at most of the beaches. Based on this, the long term recession rate has been estimated as per Table B.18.

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.

*Table B18: Adopted Beach Recession Rates from Photogrammetric Analysis*15

Beach Name	Measured Long Term rate of change (m/yr)	Adopted Long Term recession rate (m/yr)	Beach Recession (2060, m)*	Beach Recession (2100, m)*
Nine Mile Beach	1.0	Nil	Nil	Nil
Tuncurry Beach	0.68	Nil	Nil	Nil
Main Beach	-0.15	0.15	8.25	14.25
One Mile Beach	1.48	Nil	Nil	Nil
Burgess Beach	0.17	Nil	Nil	Nil
Seven Mile Beach	0	Nil	Nil	Nil
Elizabeth Beach	-0.07	0.07	3.85	9.50
Sandbar Beach	0.60	Nil	Nil	Nil
Number One Beach	-0.10	0.10	5.50	9.50
Boat Beach	0.10	Nil	Nil	Nil

[14] Negative values relate to recession and positive values to accretion.
[15] Negative values relate to recession and positive values to accretion.

Beach Name	Measured Long Term rate of change (m/yr)	Adopted Long Term recession rate (m/yr)	Beach Recession (2060, m)*	Beach Recession (2100, m)*
Bennetts Beach North	0.19	Nil	Nil	Nil
Bennetts Beach South	-0.075	0.075	4.125	7.125

* Note – the beach recession values have been calculated based on 2005 as a base year, which corresponds to the year when the ALS data were captured. The ALS data has been used as the basis of the hazard maps.

4 CONCLUSIONS

The photogrammetric data analysed here was used to quantify beach erosion volume demand for the different beaches along Great Lakes coastline. It has allowed a good estimate of the storm bite as well as long term beach recession rates.

The trend for long term beach change for Great Lakes was a clear long term accretion along Nine Mile Beach, One Mile Beach, Burgess Beach, Boat Beach and Seven Mile Beach with Main Beach, Elizabeth Beach, Number One Beach and Bennetts Beach undergoing long term recession at relatively low rates of less than 1 m^3/m/yr. The accuracy of this estimate depended on the horizontal and vertical accuracy of the photogrammetry, as well as the period of time the photogrammetry covers. This estimate is based on the existing photogrammetric data and may be subject to change in the future as more data is collected.

Hazard mapping for the 2050, 2060 and 2100 planning periods has been carried out, using the estimated storm bite and recession rate due to sea level rise. Details of the hazard calculations are given in Appendix D.

REFERENCES

Bureau of Meteorology, Significant Weather - May 1997, http://www.bom.gov.au/inside/services_policy/public/sigwxsum/sigw0597.shtml

Department of Commerce Manly Hydraulics Laboratory (2007), Crowdy Head Waverider Storm History data 1985 – 2007, owned by Department of Environment and Climate Change.

Goodwin, I.D. (2005). A mid-shelf, mean wave direction climatology for south-eastern Australia, and its relationship to the El Nino – Southern Oscillation since 1878 A.D. Int. J. Climatol. 25, (2005).

IPCC (2007). "*Climate Change 2007 – The Physical Science Basis, Fourth Assessment Report of Working Group 1 of the Intergovernmental Panel on Climate Change*", Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2007.

Nielsen, A.F., D.B.Lord & H.G. Poulos (1992). "Dune Stability Considerations for Building Foundations", ", IEAust., Aust. Civ. Eng. Trans., Vol. CE 34, No. 2 pp 167-173.

NSW Government (1990). "Coastline Management Manual", ISBN 0730575063, September 1990.

Short, A.D., A.C. Trembanis & I.L. Turner (2000). "Beach oscillation, rotation and the Southern Oscillation, Narrabeen Beach, Australia", Proc. 27th ICCE, ASCE, Sydney, July, 2000, 2439−2452.

Sommerfeld, B. G., Mason, J. M., Kraus, N. C., Larson, M. (1994) "BFM: Beach Fill Module – Report 1 Beach Morphology Analysis package (BMAP) – User's Guide, U.S. Army Corps of Engineers.

FIGURES

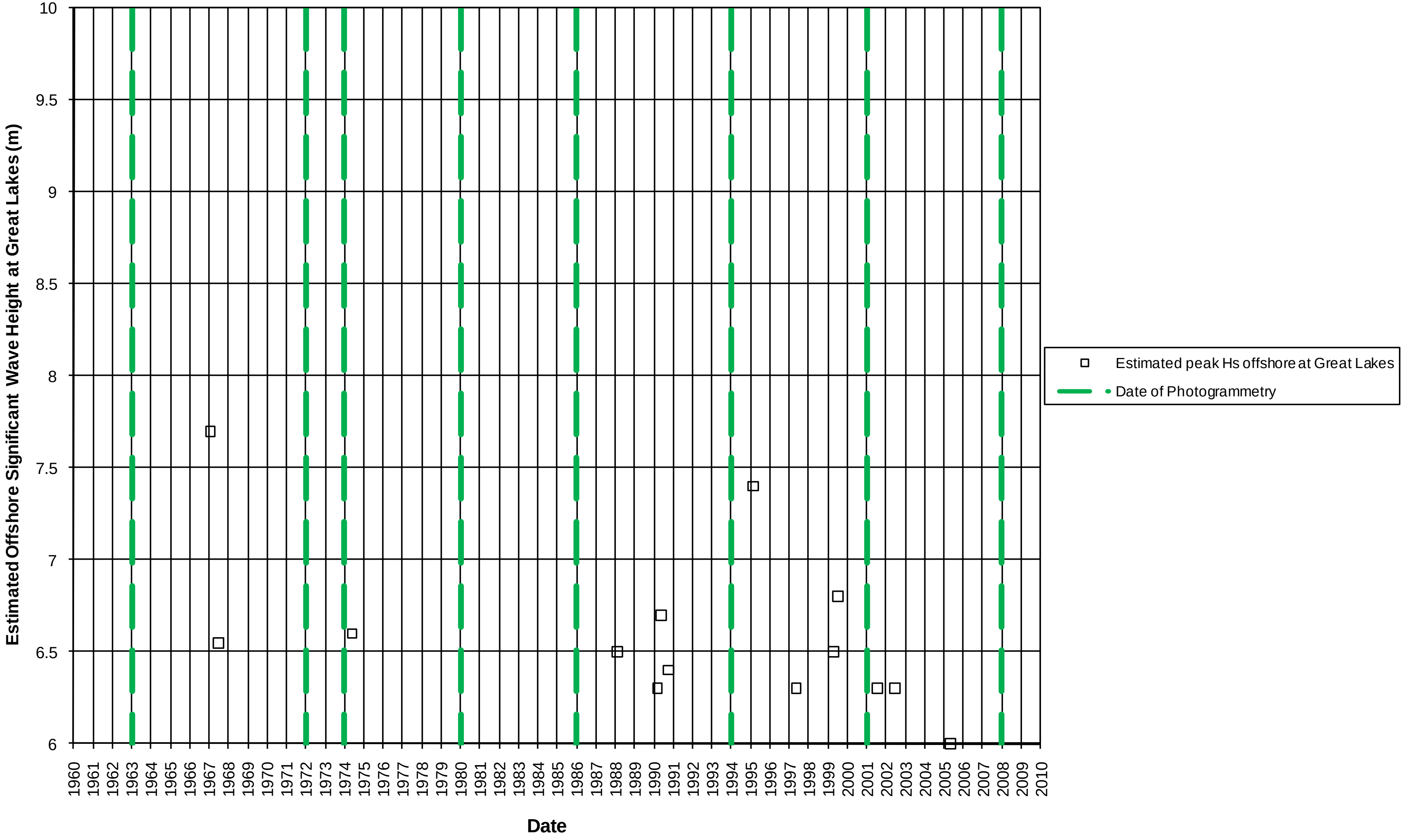
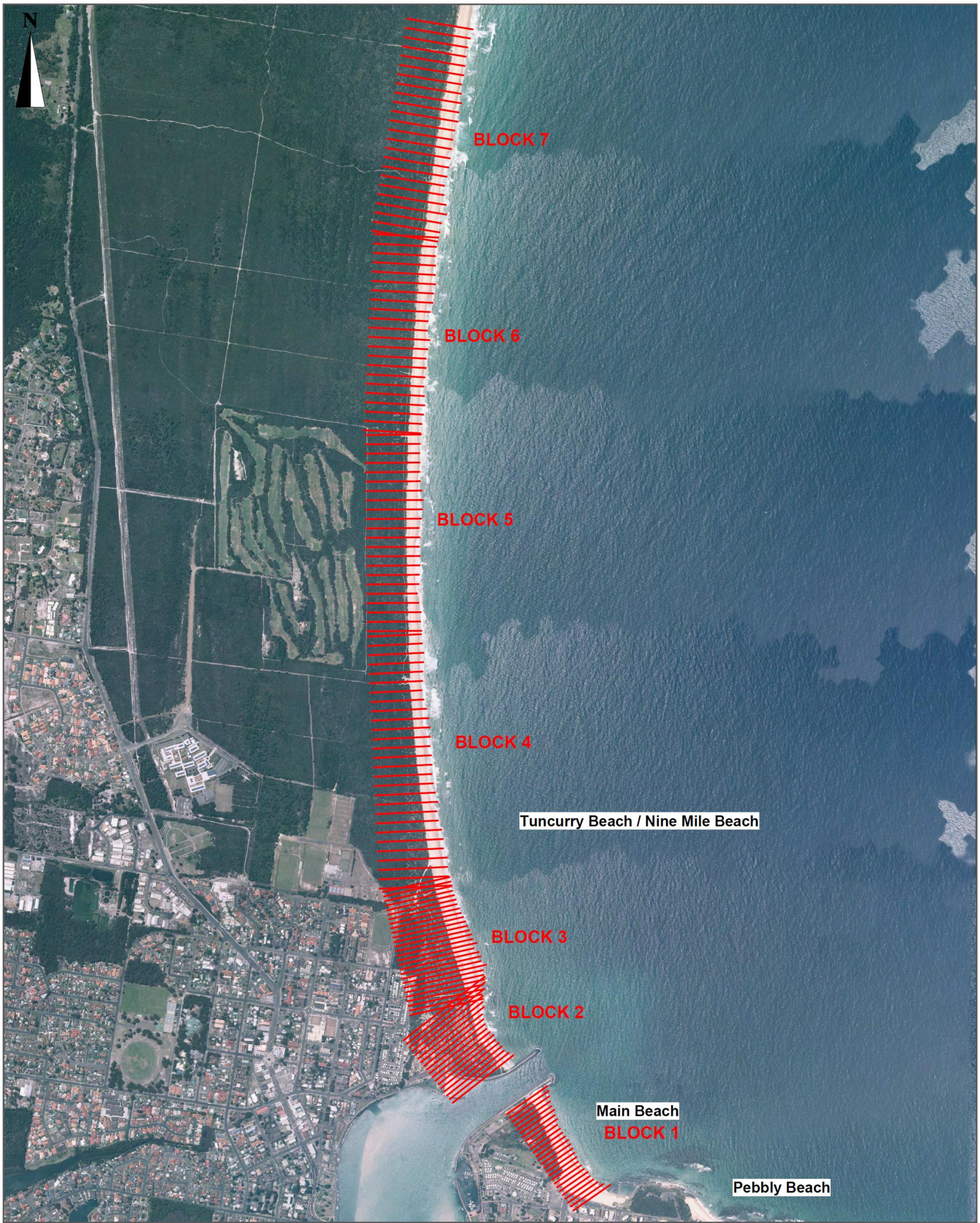


Figure B.1: Extreme Storm events vs. Photogrammetry Dates



DATE 14/03/2011	0 250 500 metres	COORDINATE SYSTEM	MGA 94 Zone 56
PROJECT NO. 3001829	PROJECT TITLE	Great Lakes Coastal Hazard Study	
FIG NO. B.2	FIGURE TITLE	Photogrammetric data location, Nine Mile/Tuncurry Beach and Main Beach	
CREATED BY M. GLATZ	LOCATION	I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS	

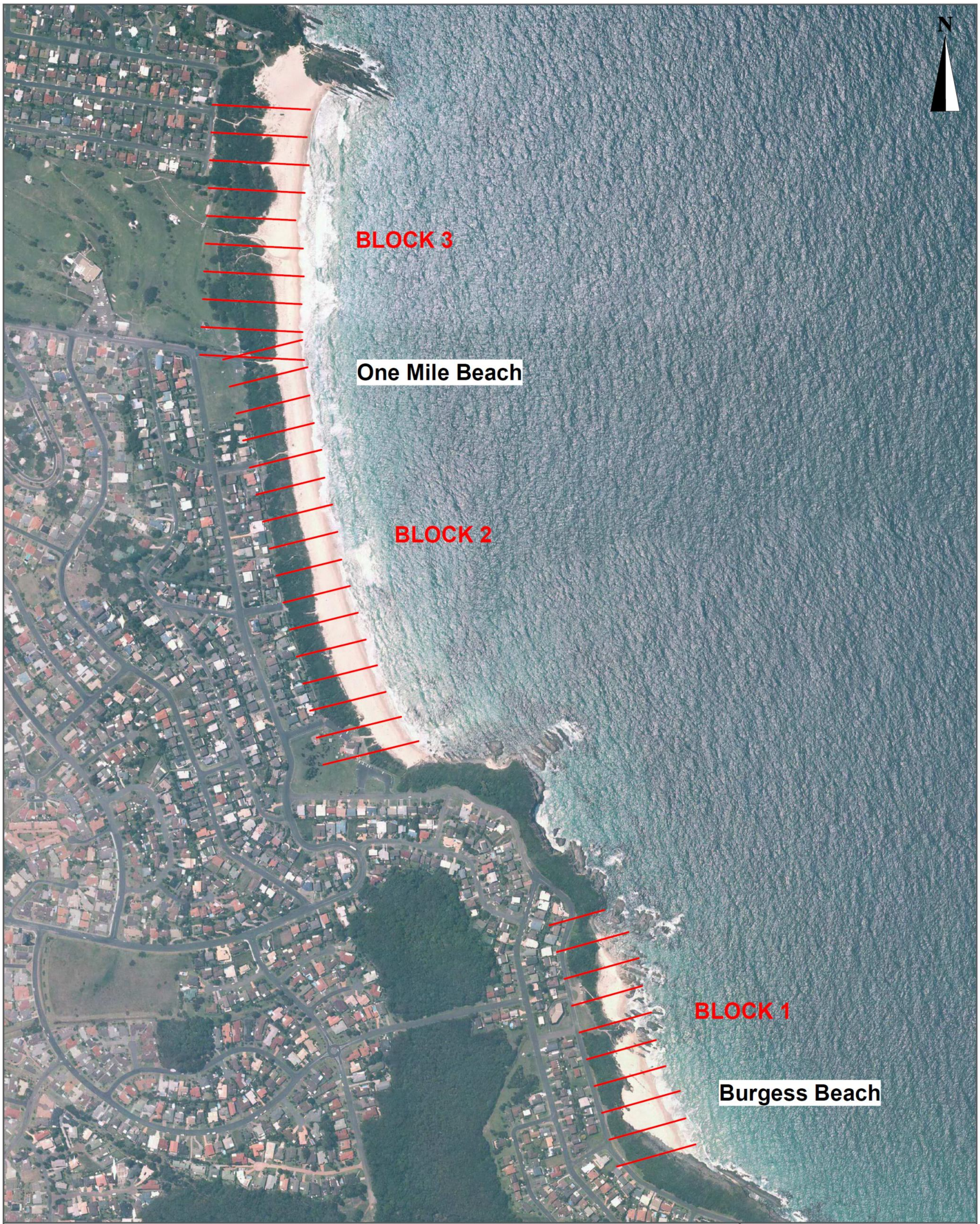


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FIG NO. B.3	FIGURE TITLE	Photogrammetric profile location, One Mile Beach and Burgess Beach	
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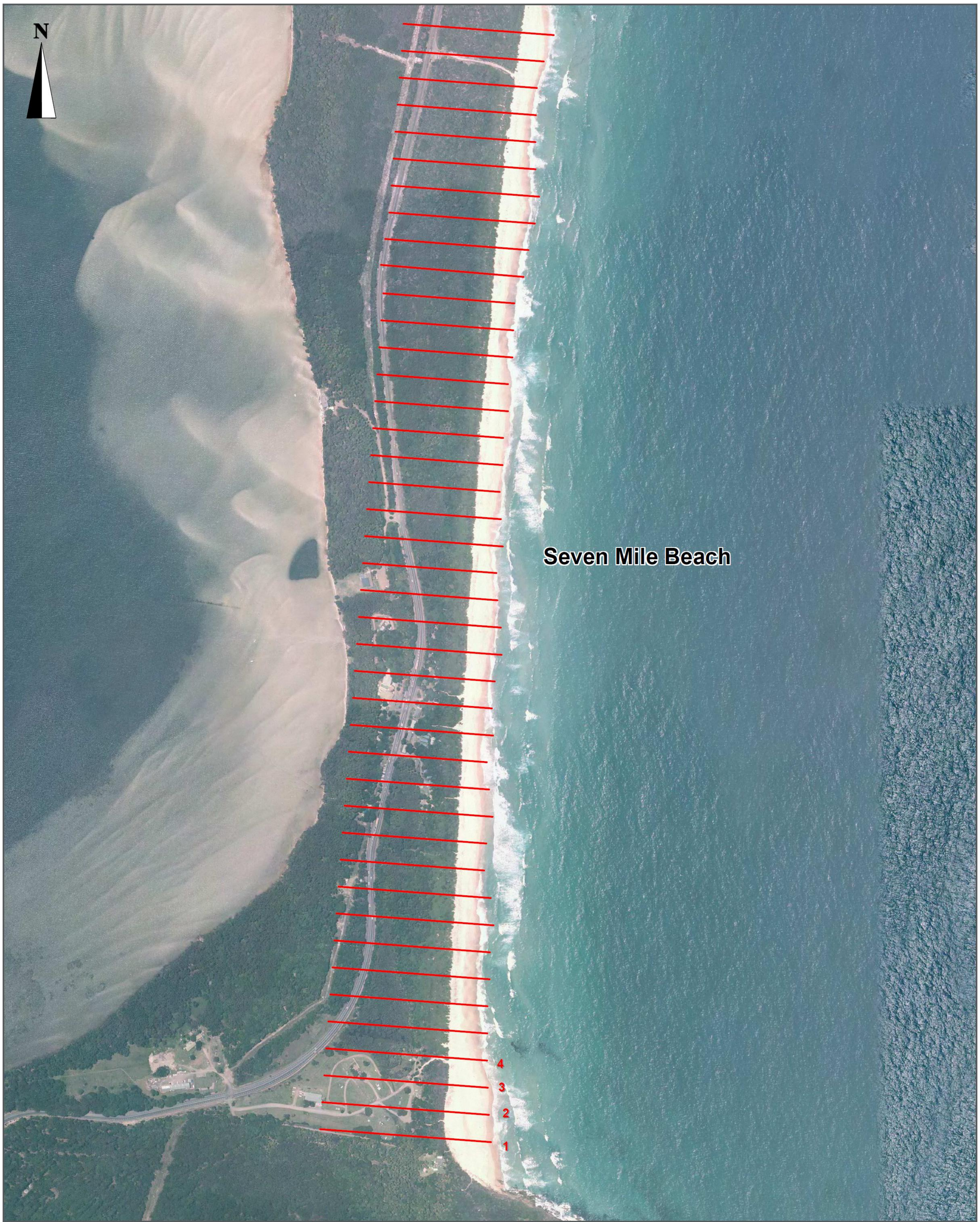

DATE 01/02/2012

COORDINATE SYSTEM
MGA 94 Zone 56

PROJECT NO. 3001829 PROJECT TITLE Great Lakes Coastal Hazard Study

FIG NO. B.4 FIGURE TITLE Photogrammetric profile locations - Seven Mile Beach

CREATED BY A.XIAO LOCATION I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Workspaces

SMEC

Great Lakes COUNCIL

DATE 24/03/2011	0 50 100 metres	COORDINATE SYSTEM MGA 94 Zone 56	FIG NO. B.5	FIGURE TITLE Photogrammetric profile location, Elizabeth Beach
PROJECT NO. 3001829	PROJECT TITLE Great Lakes Coastal Hazard Study		CREATED BY A. XIAO	LOCATION I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Workspaces

DATE 27/09/2011		COORDINATE SYSTEM	MGA 94 Zone 56
PROJECT NO. 3001829	PROJECT TITLE	Great Lakes Coastal Hazard Study	
FIG NO. B.6	FIGURE TITLE	Photogrammetric profiles location at Sandbar Beach	
CREATED BY A.XIAO	LOCATION	I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Workspaces	

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Great Lakes COUNCIL

DATE 04/08/2011	0 50 100 metres	COORDINATE SYSTEM	MGA 94 Zone56
PROJECT NO. 3001829	PROJECT TITLE	Great Lakes Coastal Hazard Study	
FIG NO. B.7	FIGURE TITLE	Photogrammetric profiles location, Number One Beach - Seal Rocks	
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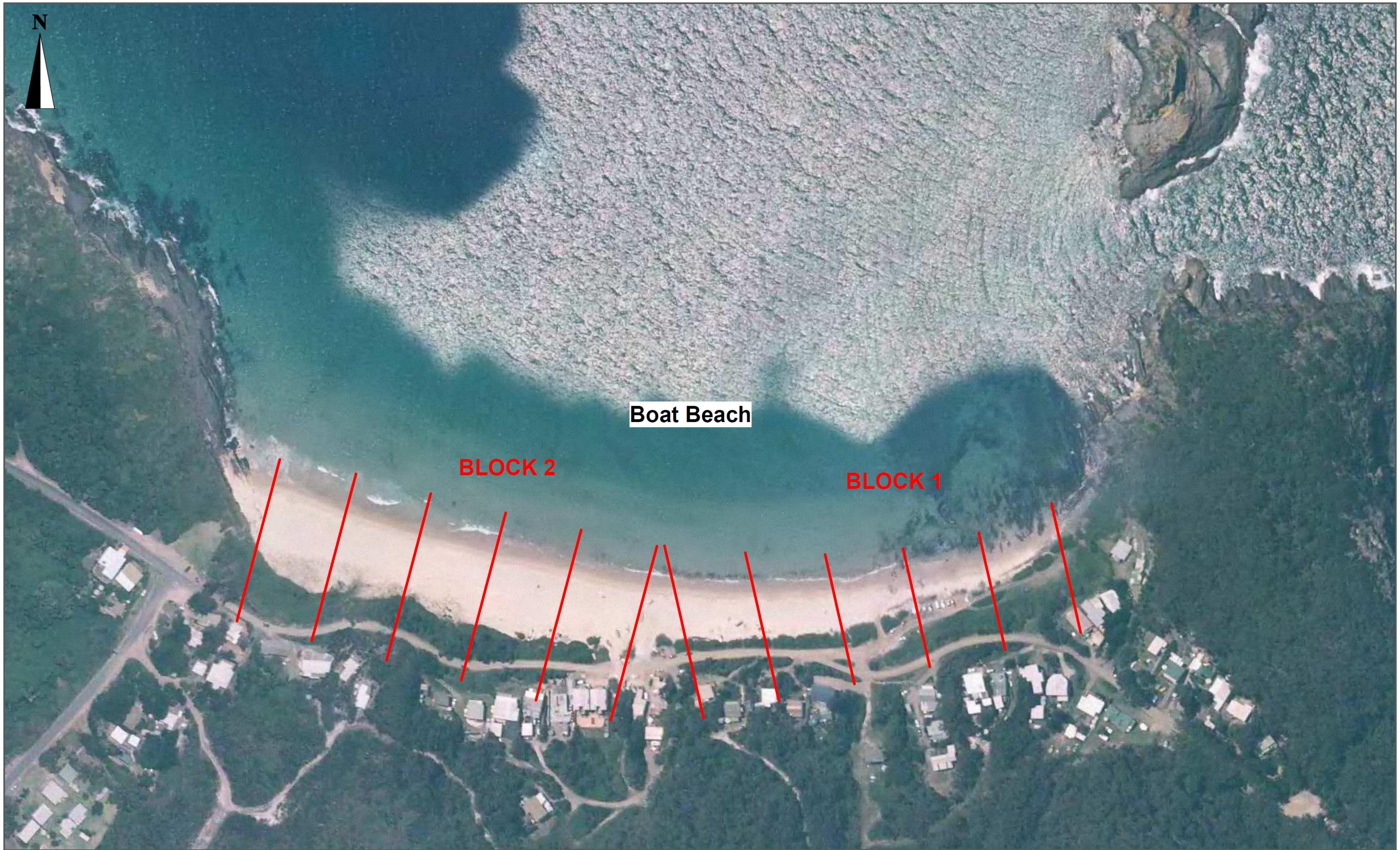

DATE 04/08/2011	0 50 100 metres	COORDINATE SYSTEM MGA 94 Zone 56	FIG NO. B.8	FIGURE TITLE Photogrammetric profile locations, Boat Beach - Seal Rocks
PROJECT NO. 3001829		PROJECT TITLE Great Lakes Coastal Hazard Study	CREATED BY A.XIAO	LOCATION I:\projects\3001829 - Great Lakes Coastal Hazard Study\009DATA\GIS\Workspaces

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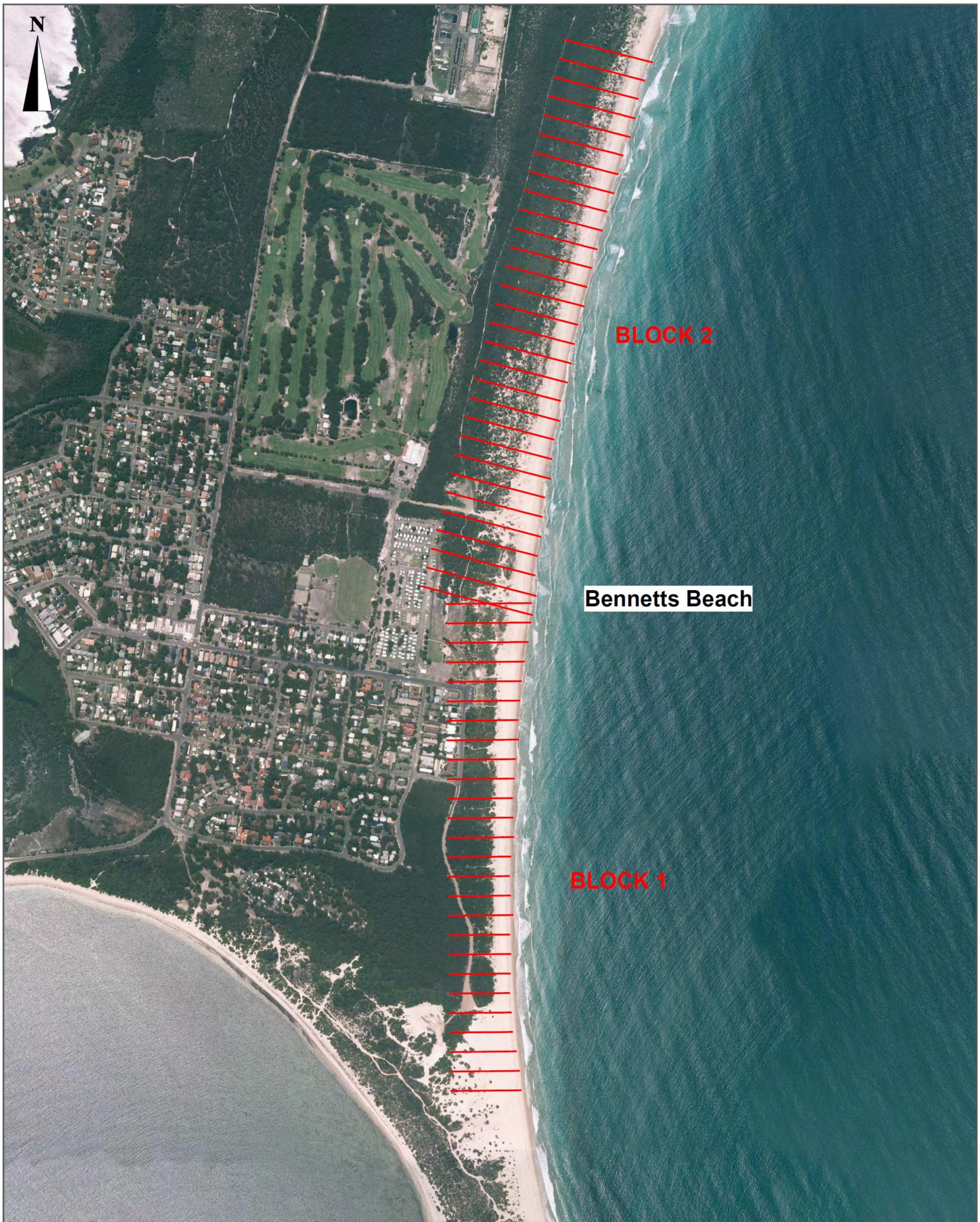

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FIG NO. B.9	FIGURE TITLE	Photogrammetric profiles location at Bennetts Beach	
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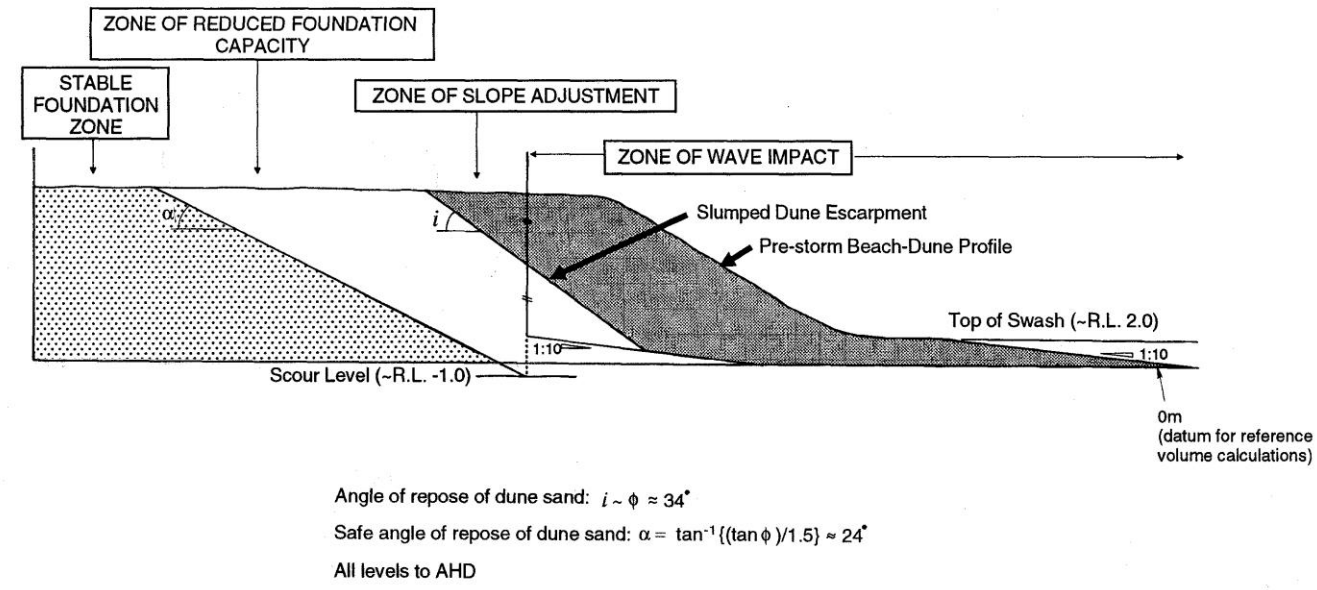


Figure B.10: Dune stability schema (after Nielsen et al., 1992)

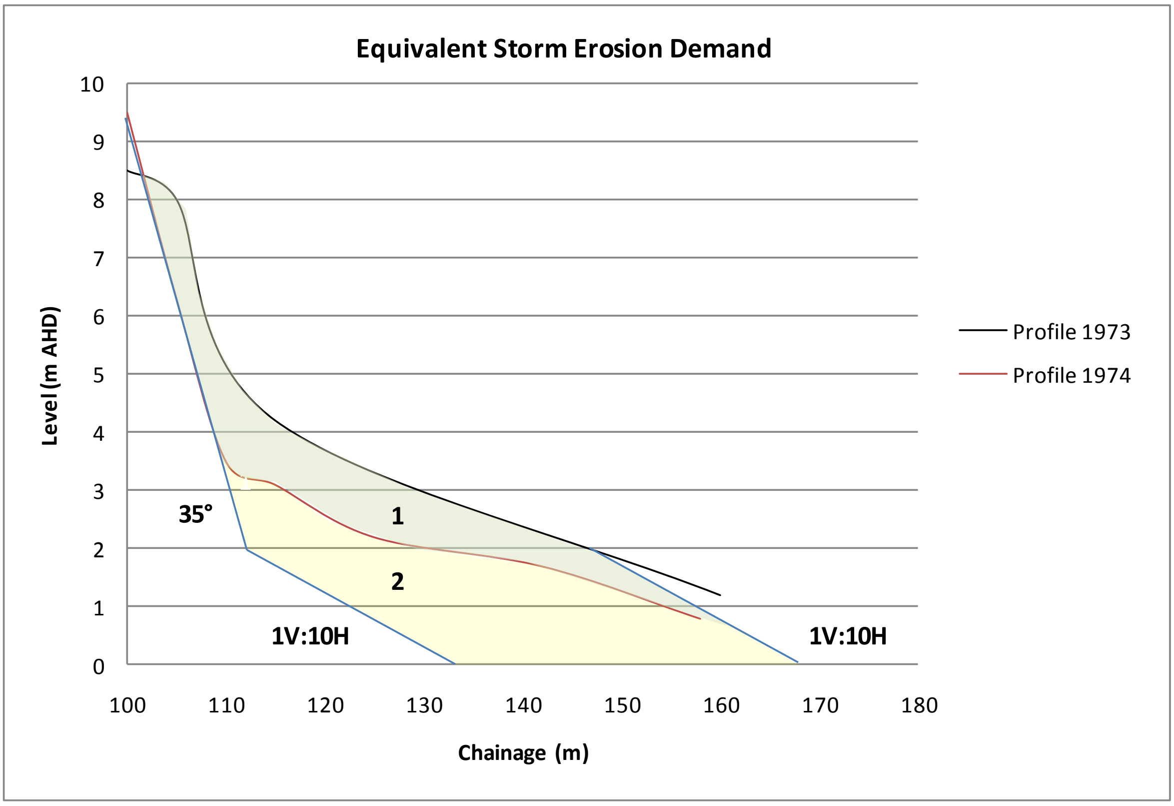
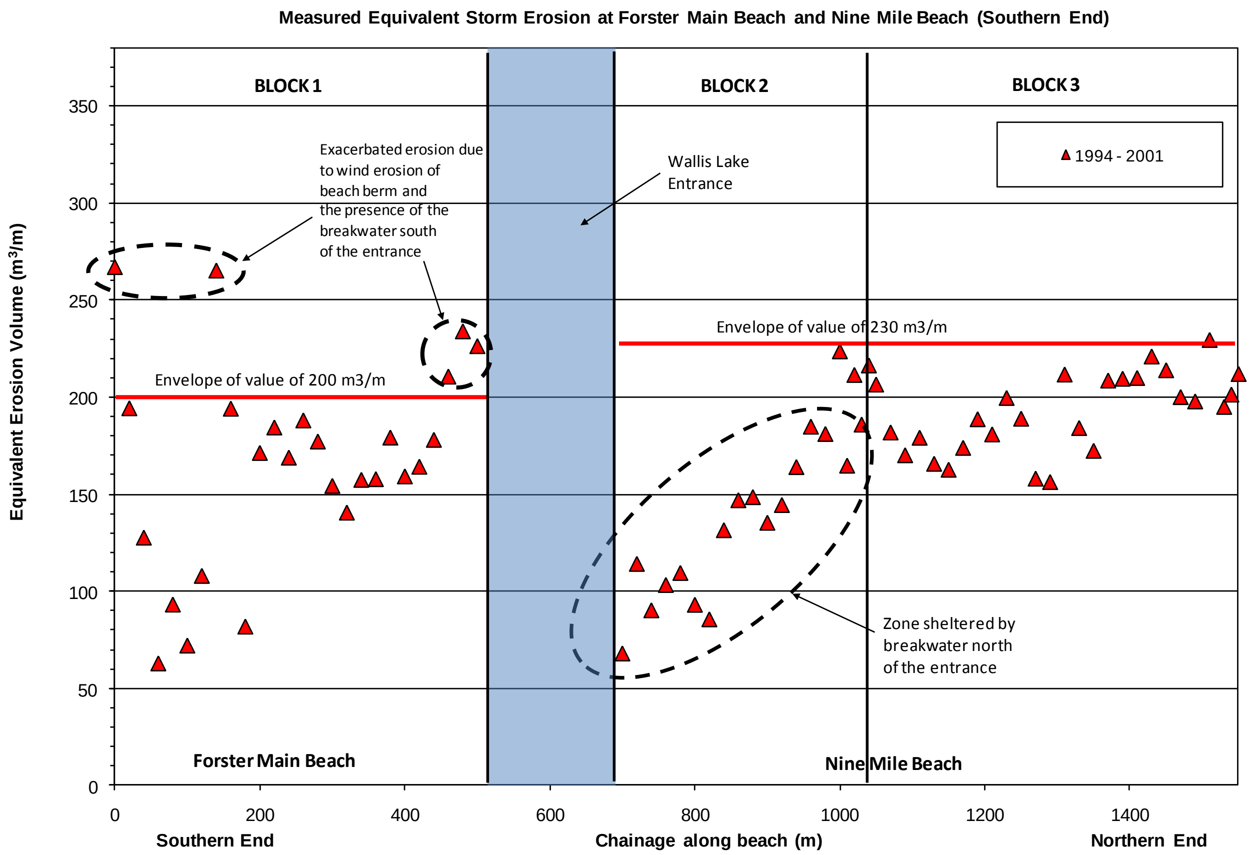


Figure B.11: Determination of Equivalent beach erosion, 1972 – 1974



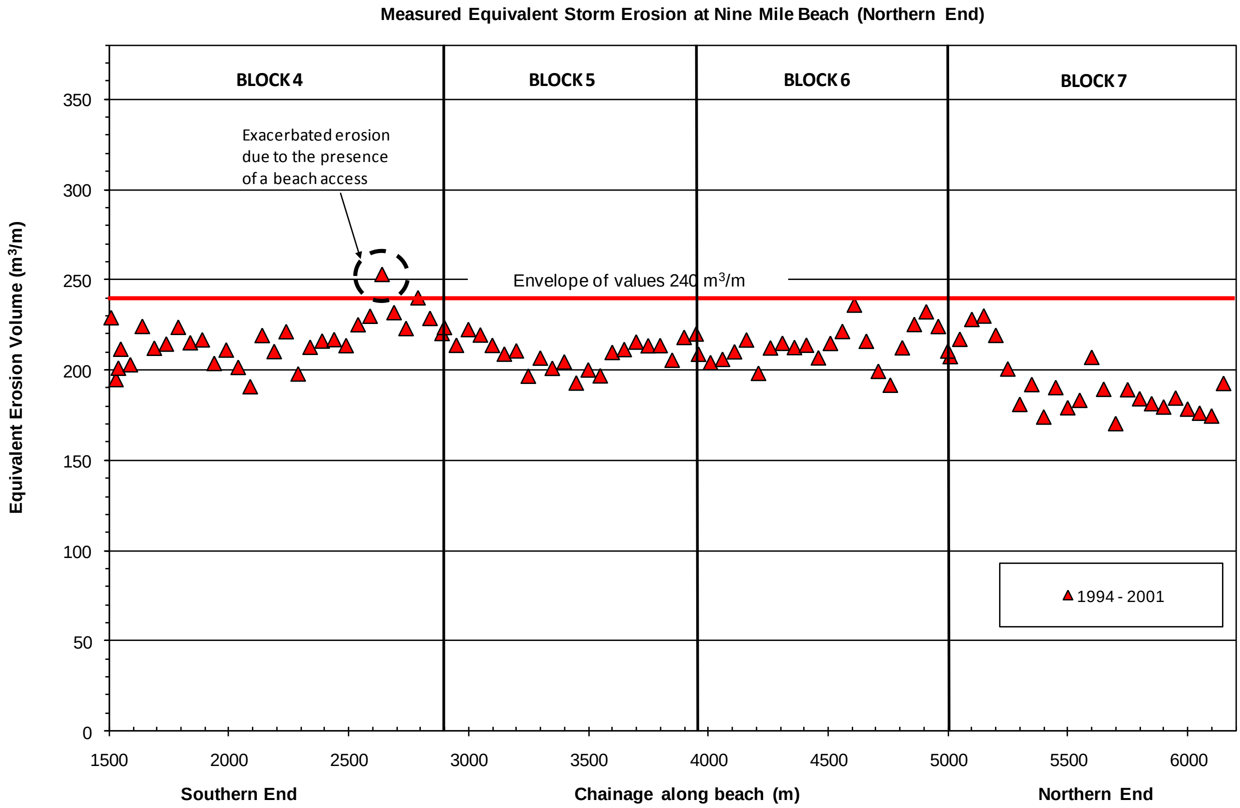


Figure B.12: Estimated beach erosion Demand for the May 1997 storm event and March 1995 Cyclone Violet at Nine Mile / Tuncurry Beach and Main Beach

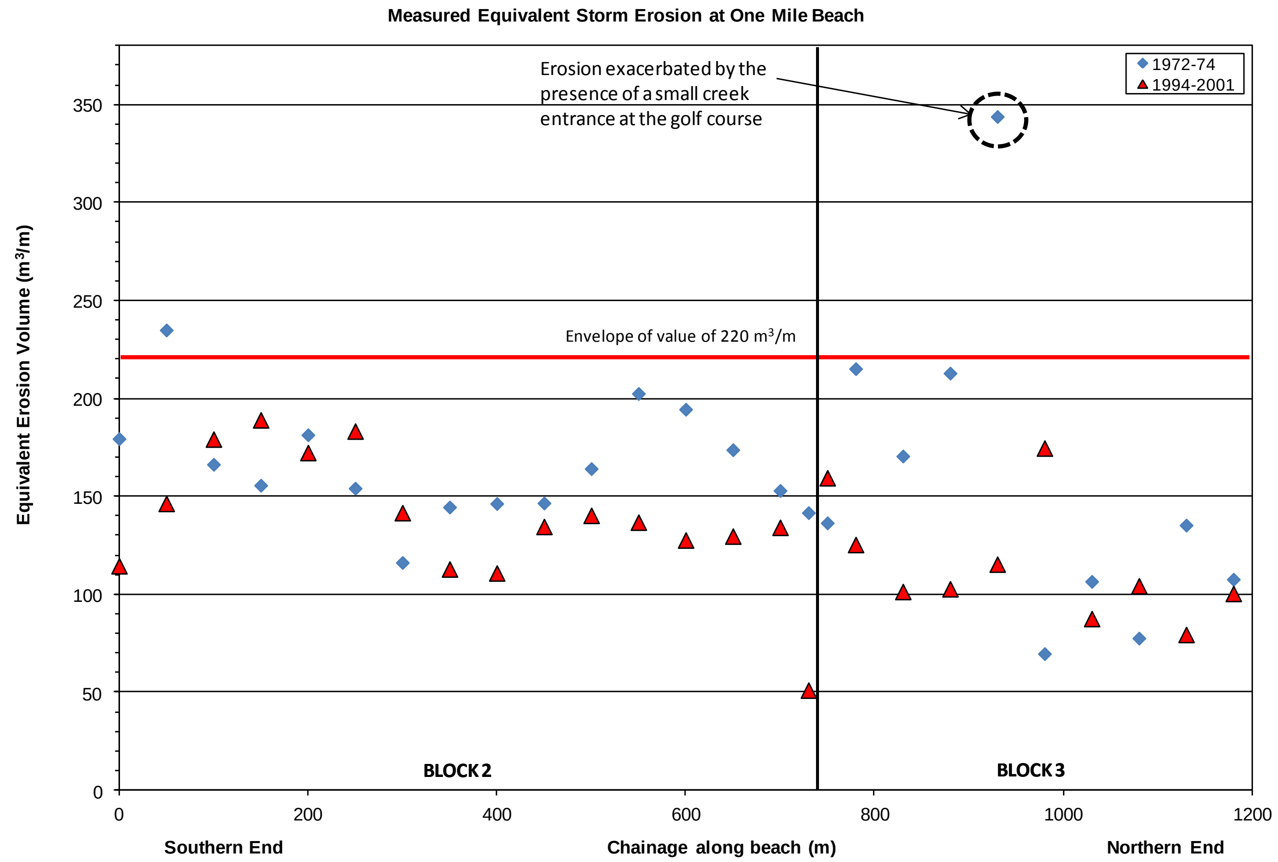


Figure B.13: Estimated beach erosion Demand for the May – June 1974 and May 1997 storm events at One Mile Beach

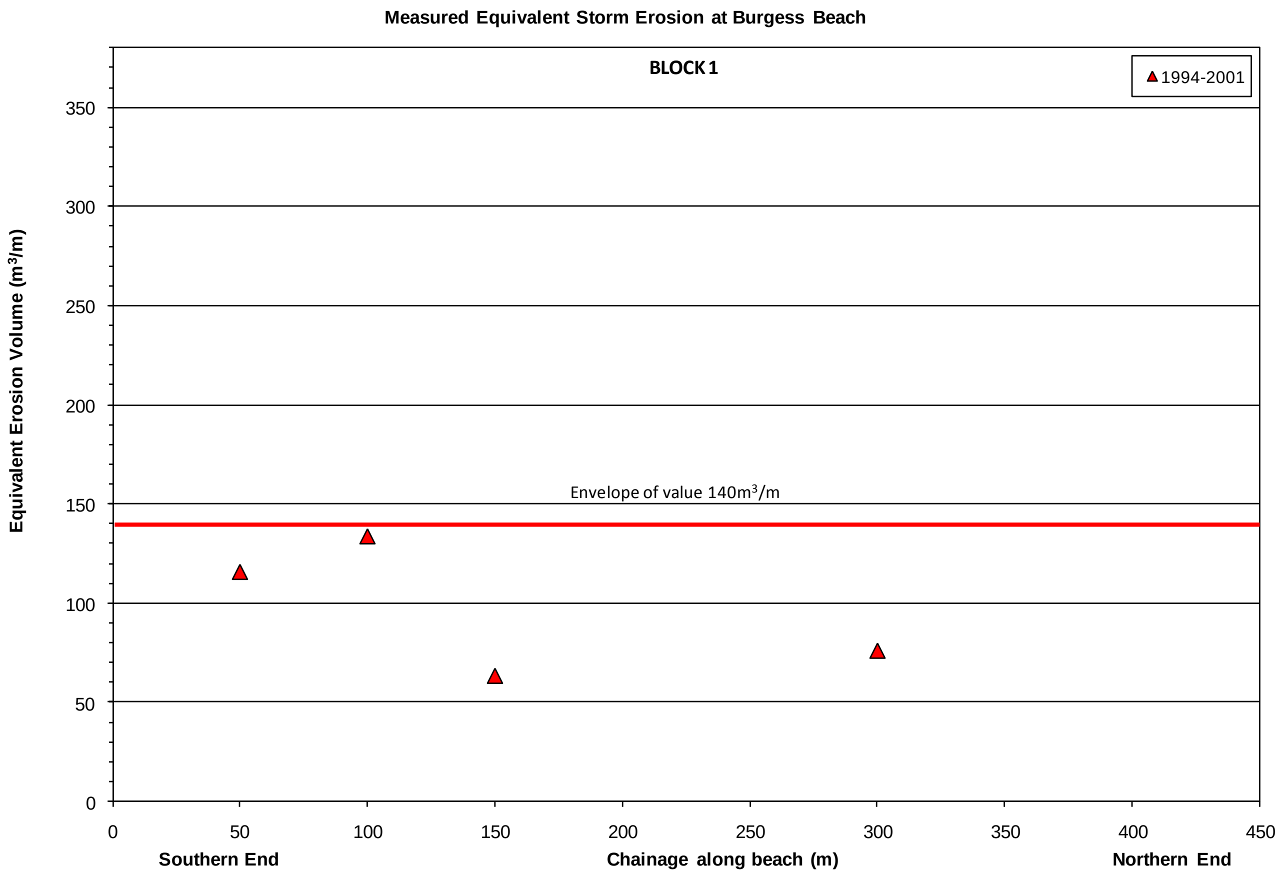


Figure B.14: Estimated beach erosion Demand for the May 1997 storm event at Burgess Beach

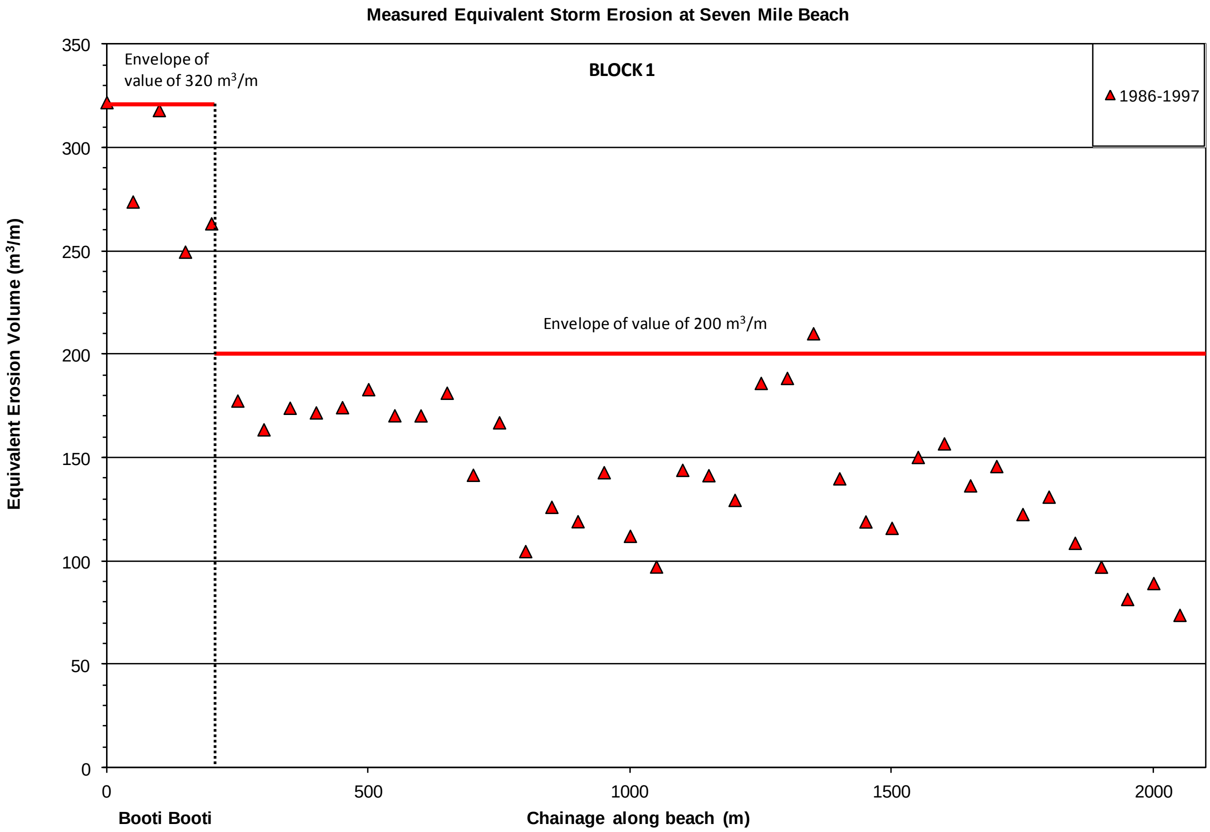


Figure B.15: Estimated beach erosion Demand for the May 1997 storm and March 1995 Cyclone Violet at Seven Mile Beach

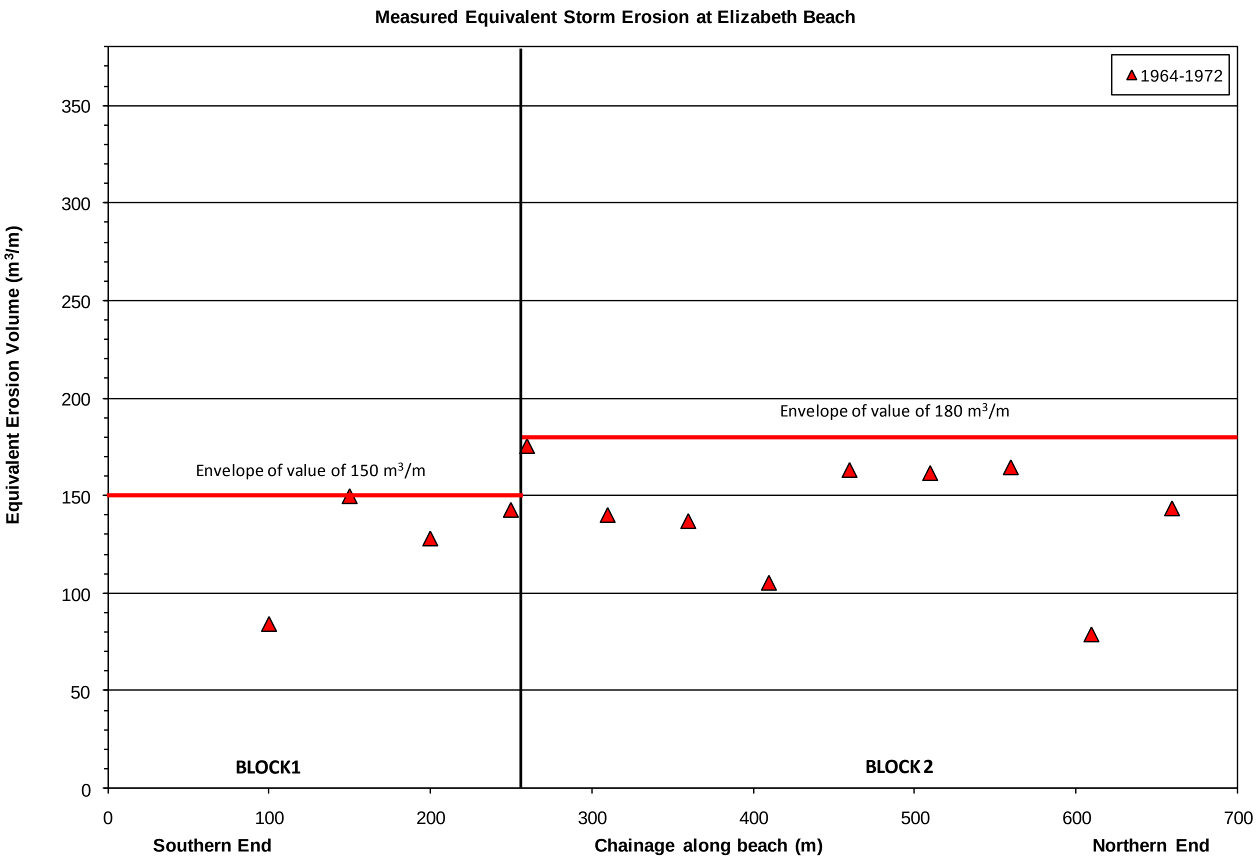


Figure B.16: Estimated beach erosion Demand for the June 1967 storm event at Elizabeth Beach

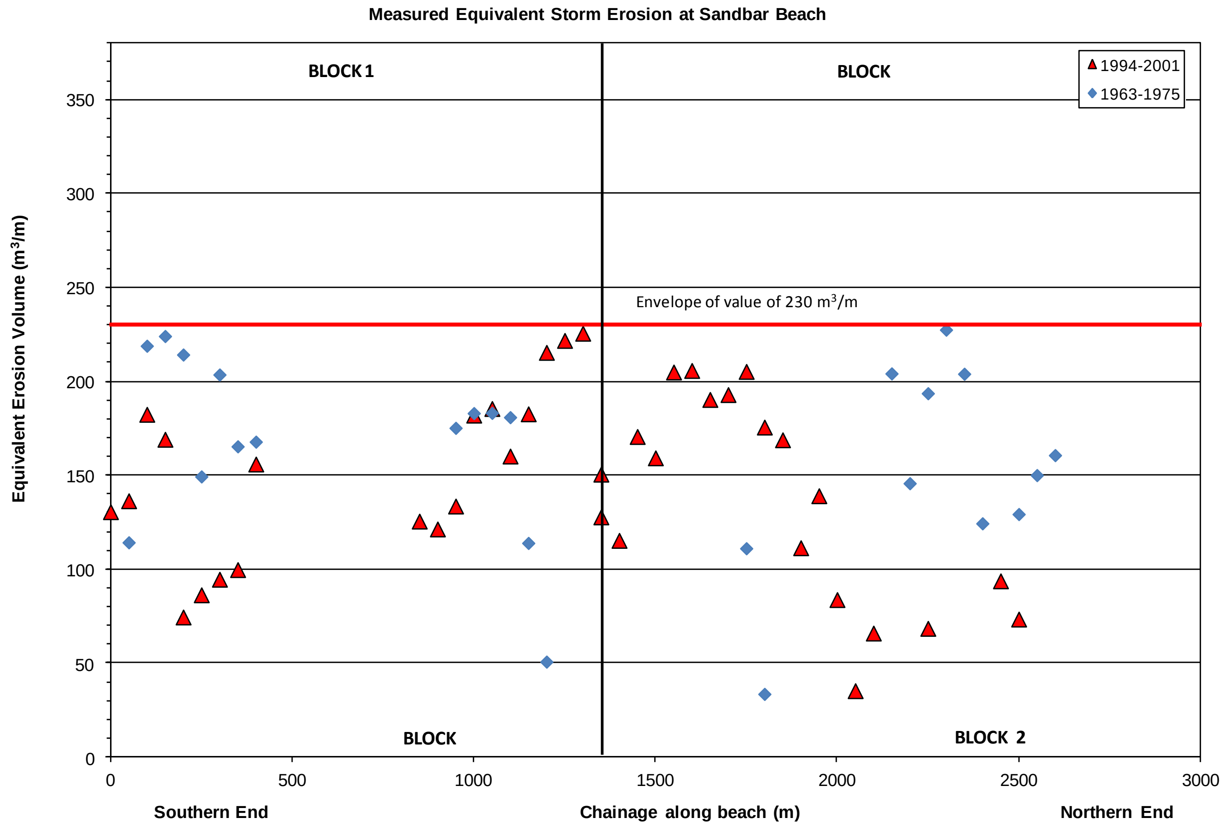


Figure B.17: Estimated beach erosion Demand for the May 1997 storm and March 1995 Cyclone Violet at Sandbar Beach

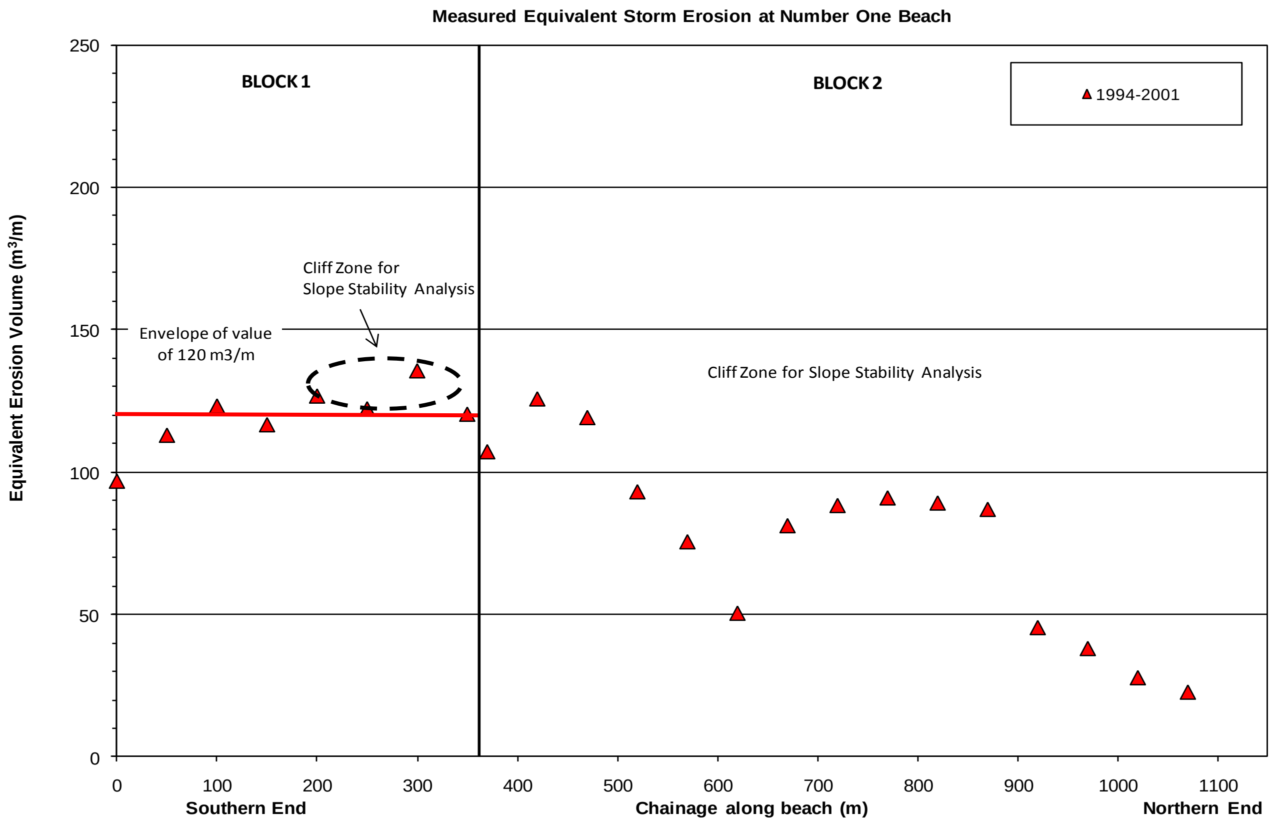


Figure B.18: Estimated beach erosion Demand for the May 1997 storm and March 1995 Cyclone Violet at Number One Beach

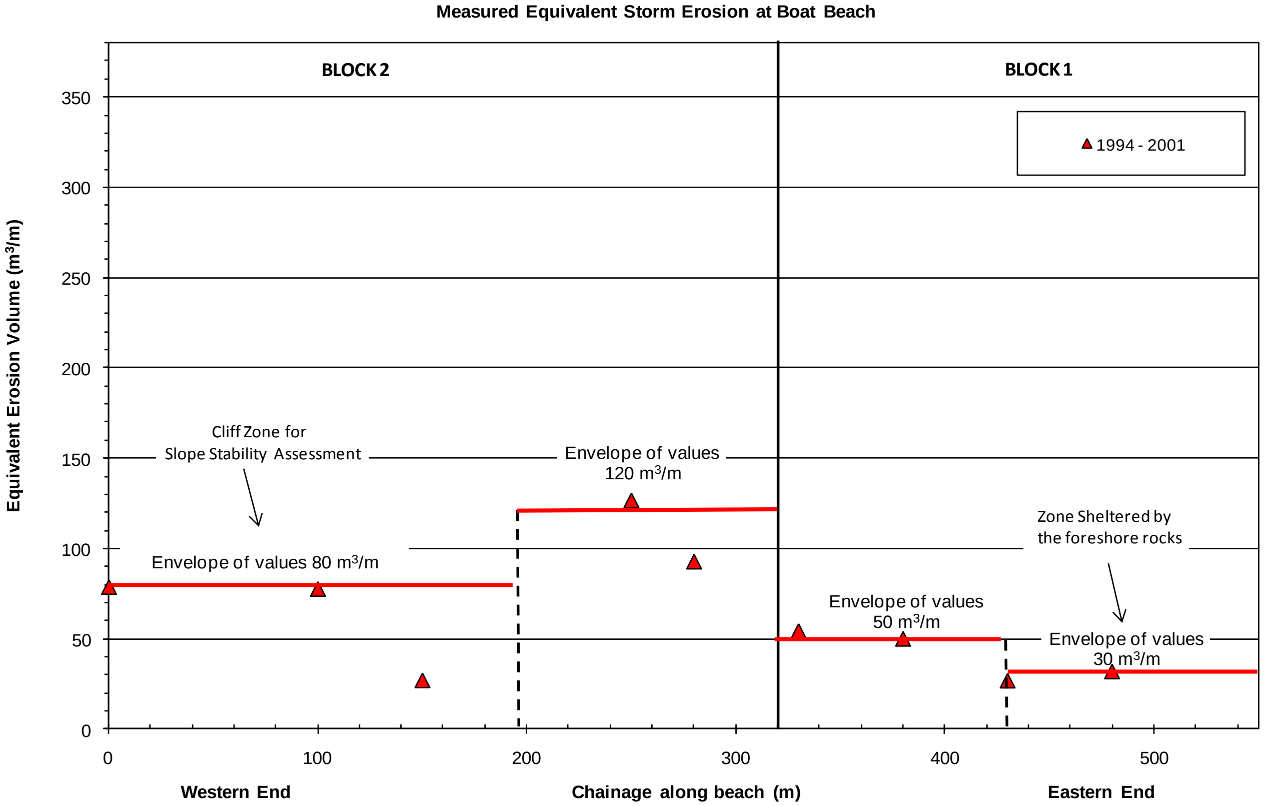


Figure B.19: Estimated beach erosion Demand for the May 1997 storm event and March 1995 Cyclone Violet at Boat Beach

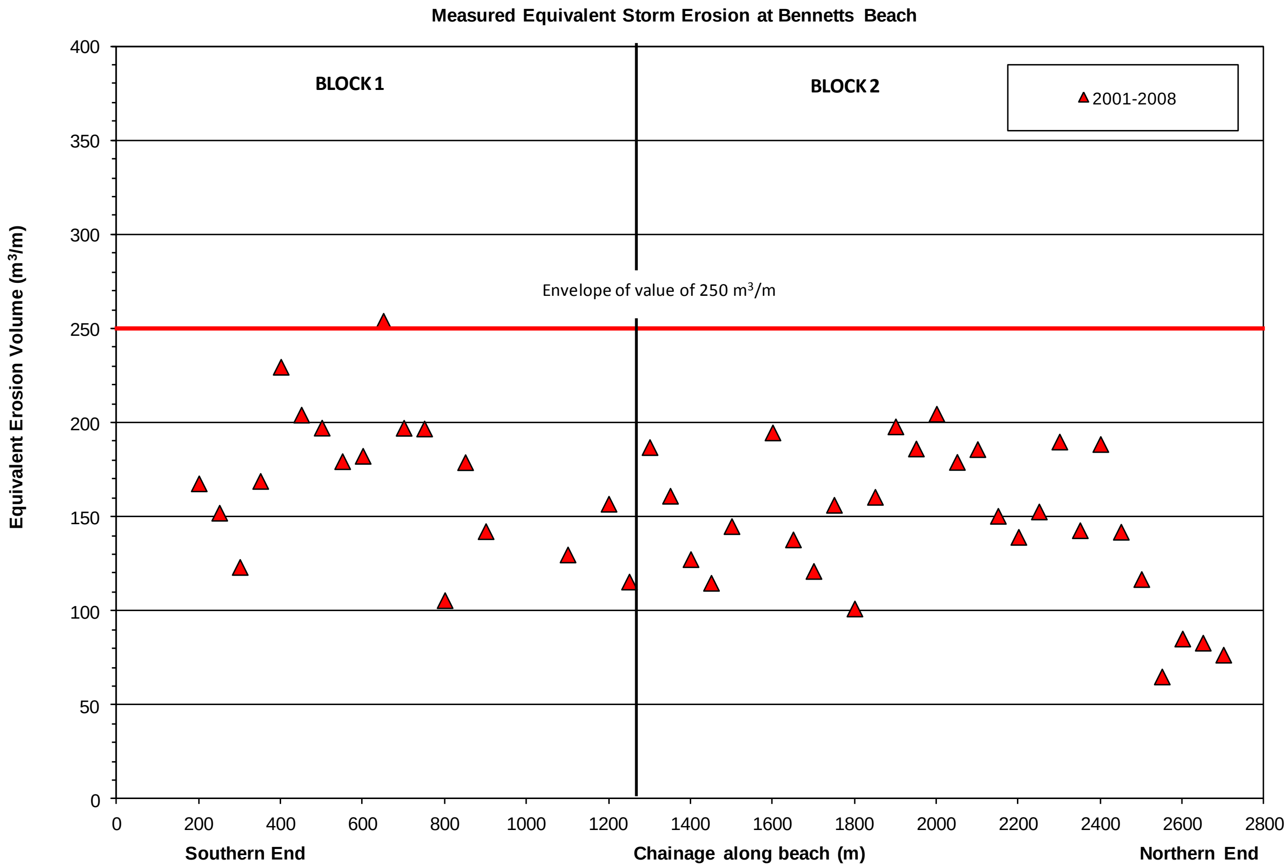


Figure B.20: Estimated beach erosion Demand for the June 2007 storms at Bennetts Beach

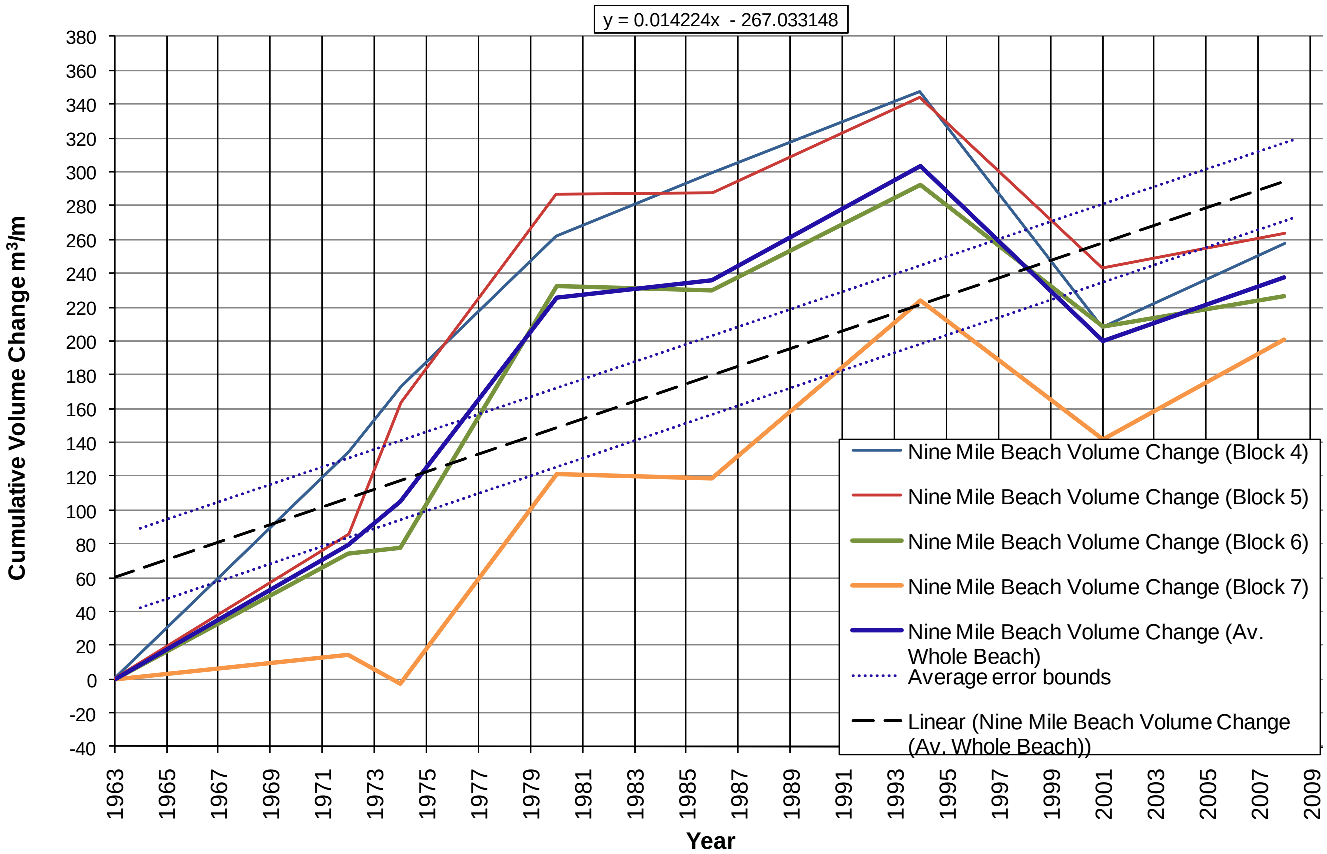


Figure B.21: Cumulative change in beach volume in cubic metres per metre length of beach at Nine Mile Beach

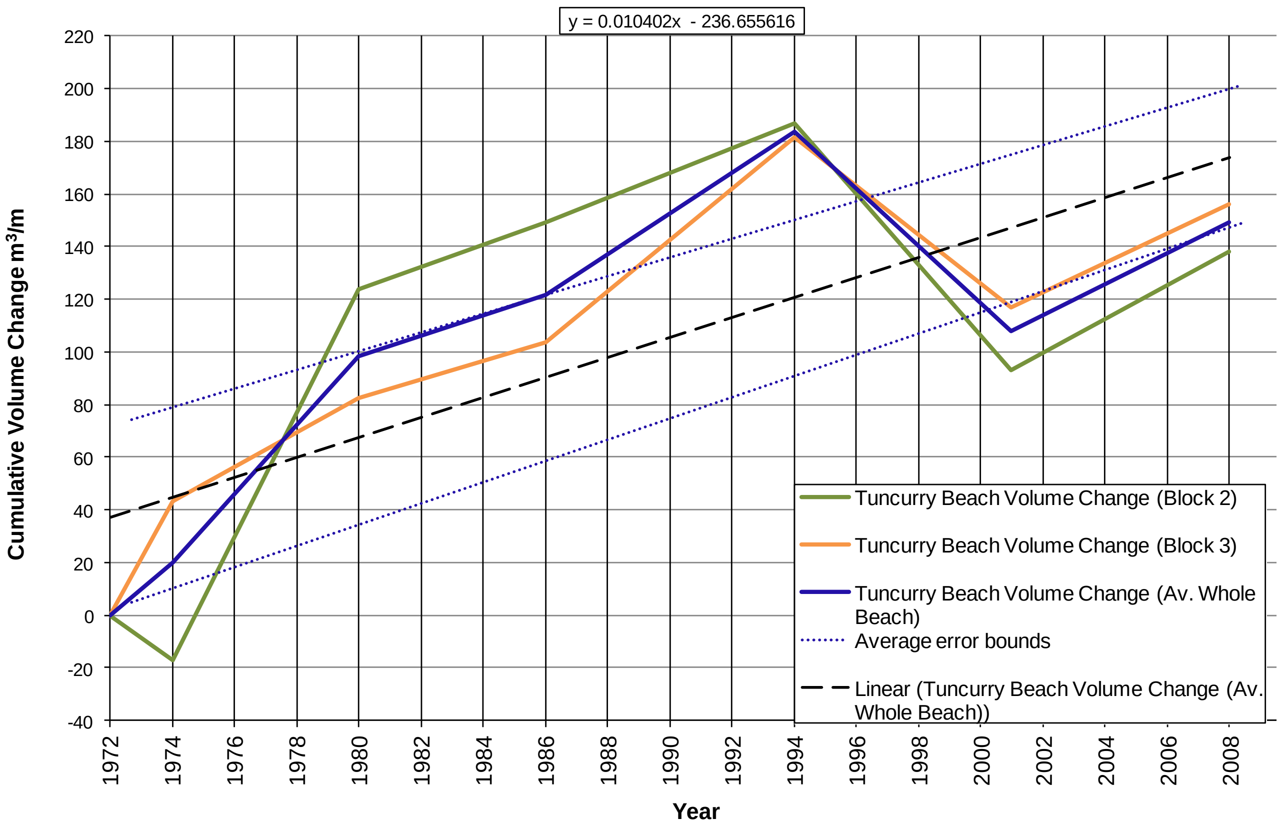


Figure B.22: Cumulative change in beach volume in cubic metres per metre length of beach at Tuncurry Beach

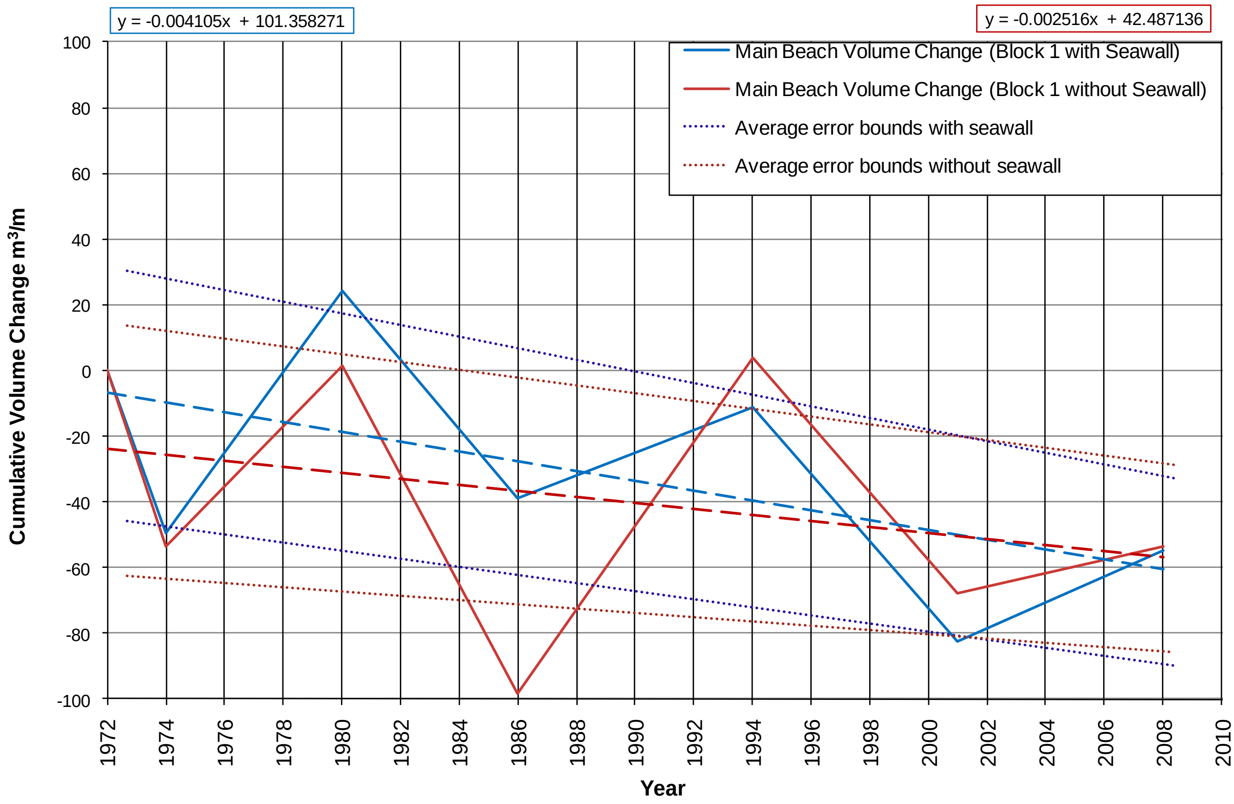


Figure B.23: Cumulative change in beach volume in cubic metres per metre length of beach at Main Beach

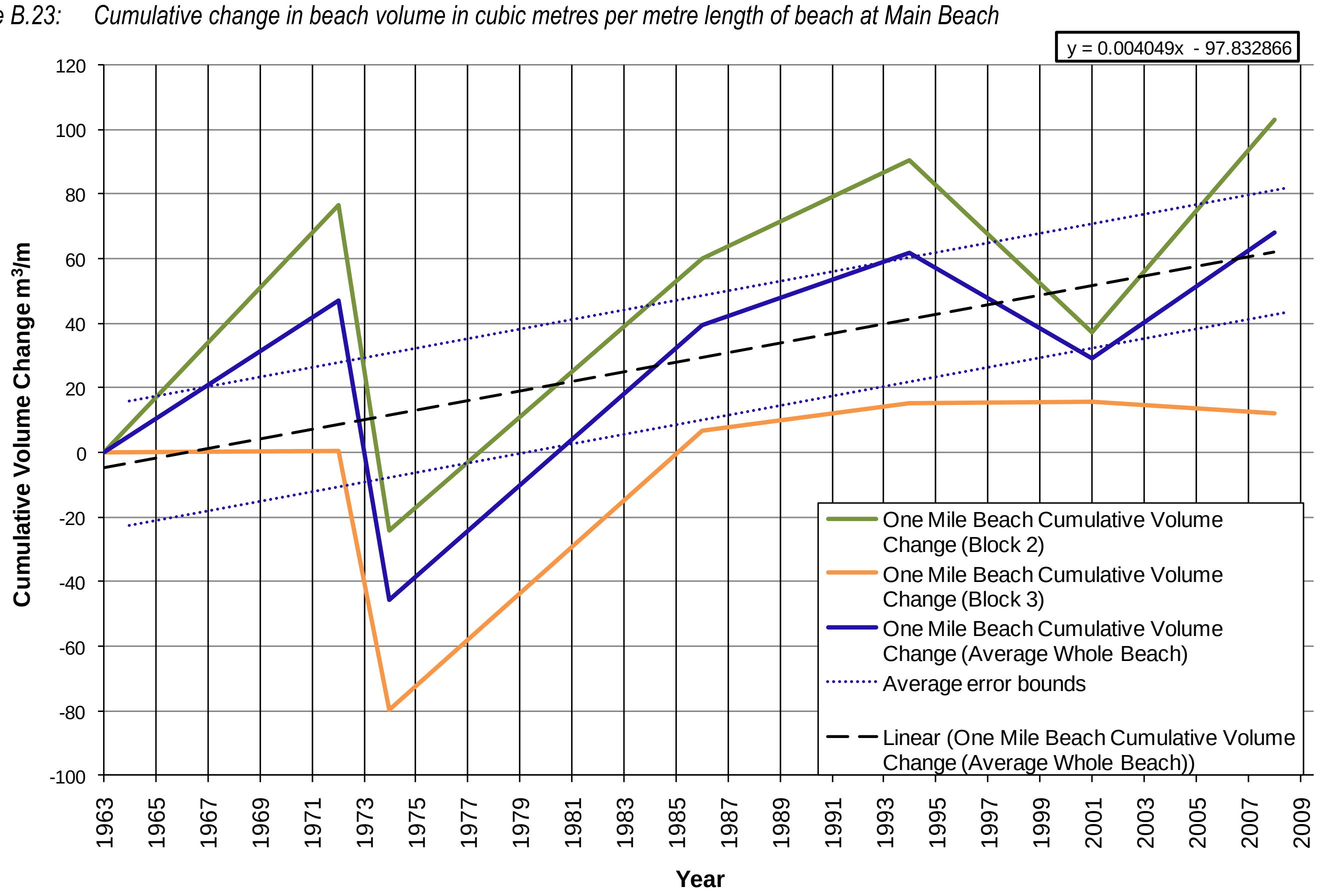


Figure B.24: Cumulative change in beach volume in cubic metres per metre length of beach at One Mile Beach

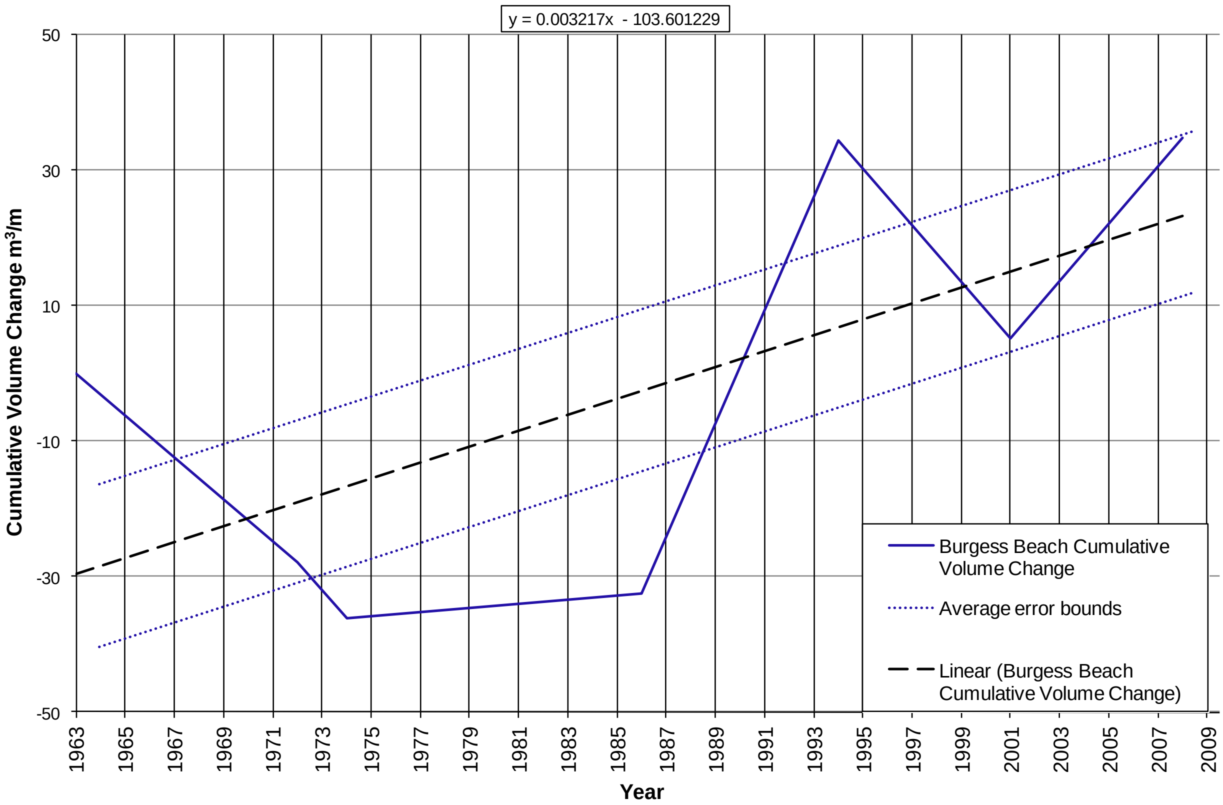


Figure B.25: Cumulative change in beach volume in cubic metres per metre length of beach at Burgess Beach

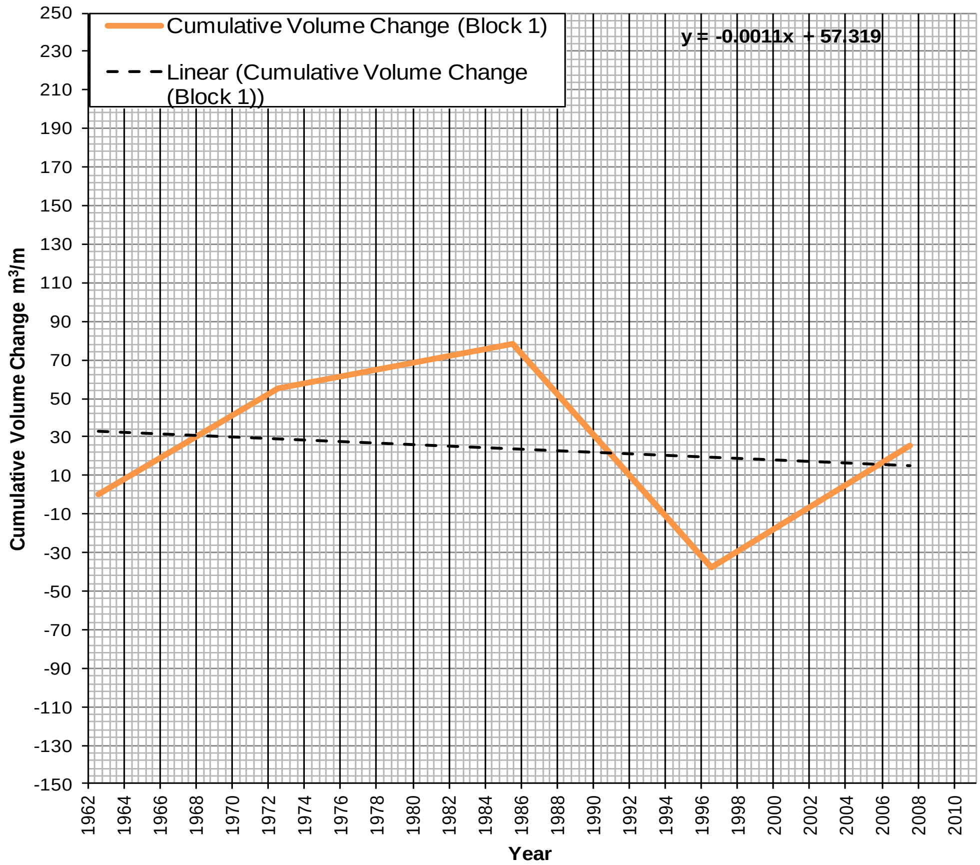


Figure B.26: Cumulative change in beach volume in cubic metres per metre length of beach at Seven Mile Beach

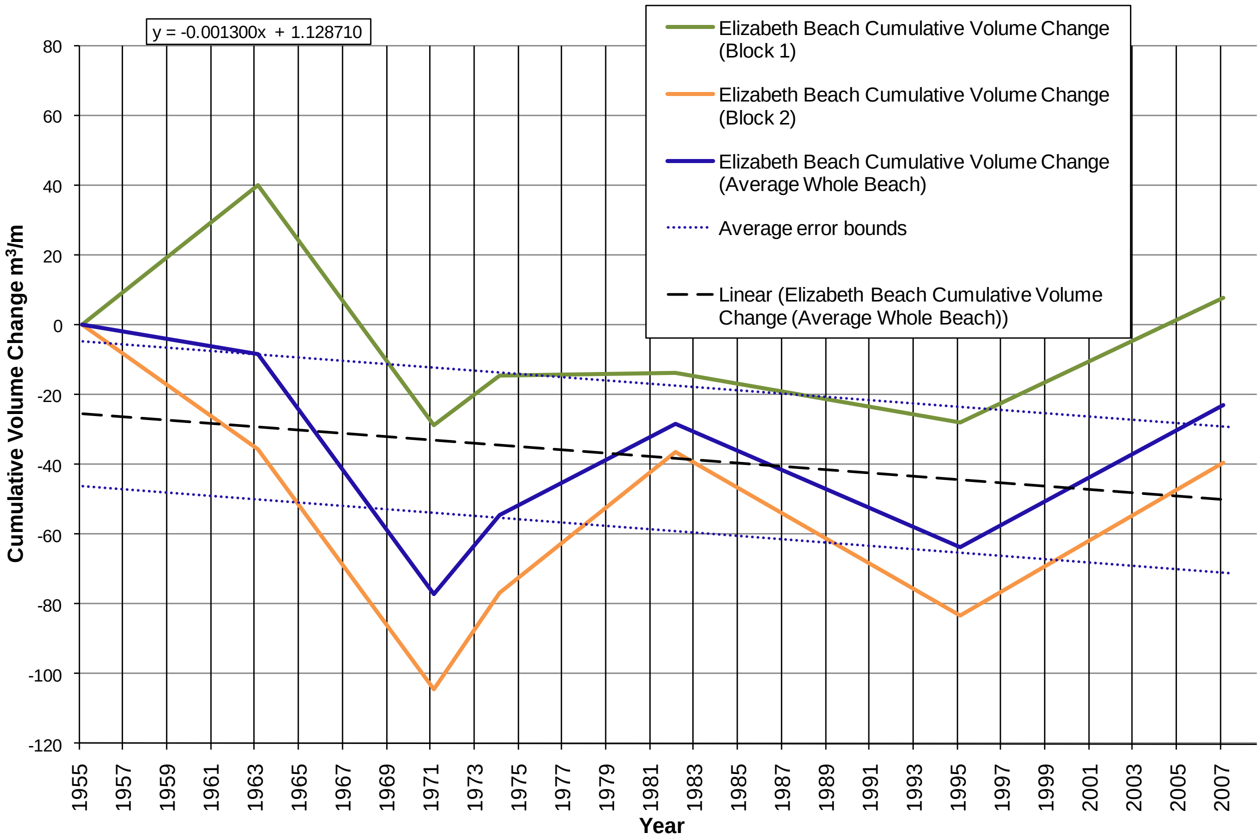


Figure B.27: Cumulative change in beach volume in cubic metres per metre length of beach at Elizabeth Beach

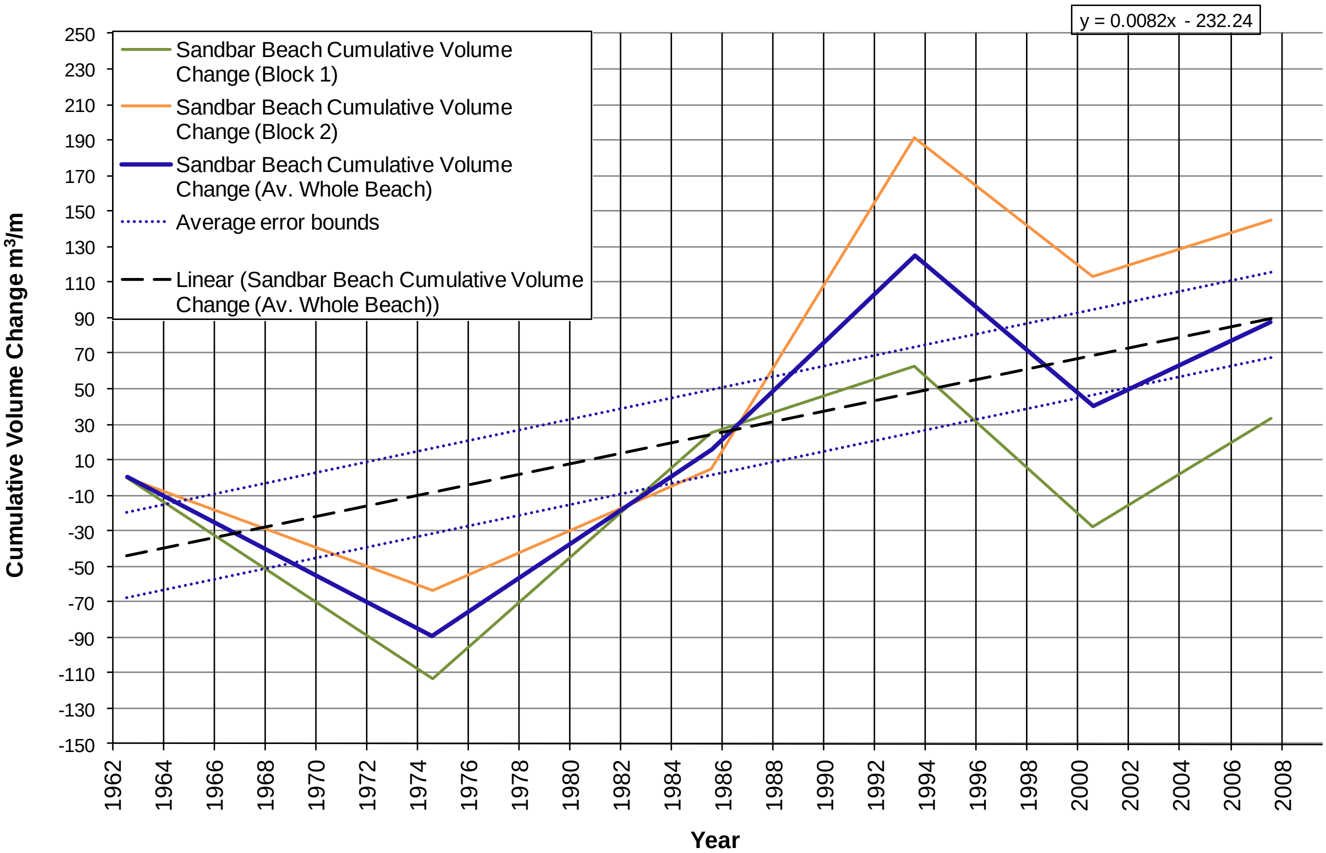


Figure B.28: Cumulative change in beach volume in cubic metres per metre length of beach at Sandbar Beach

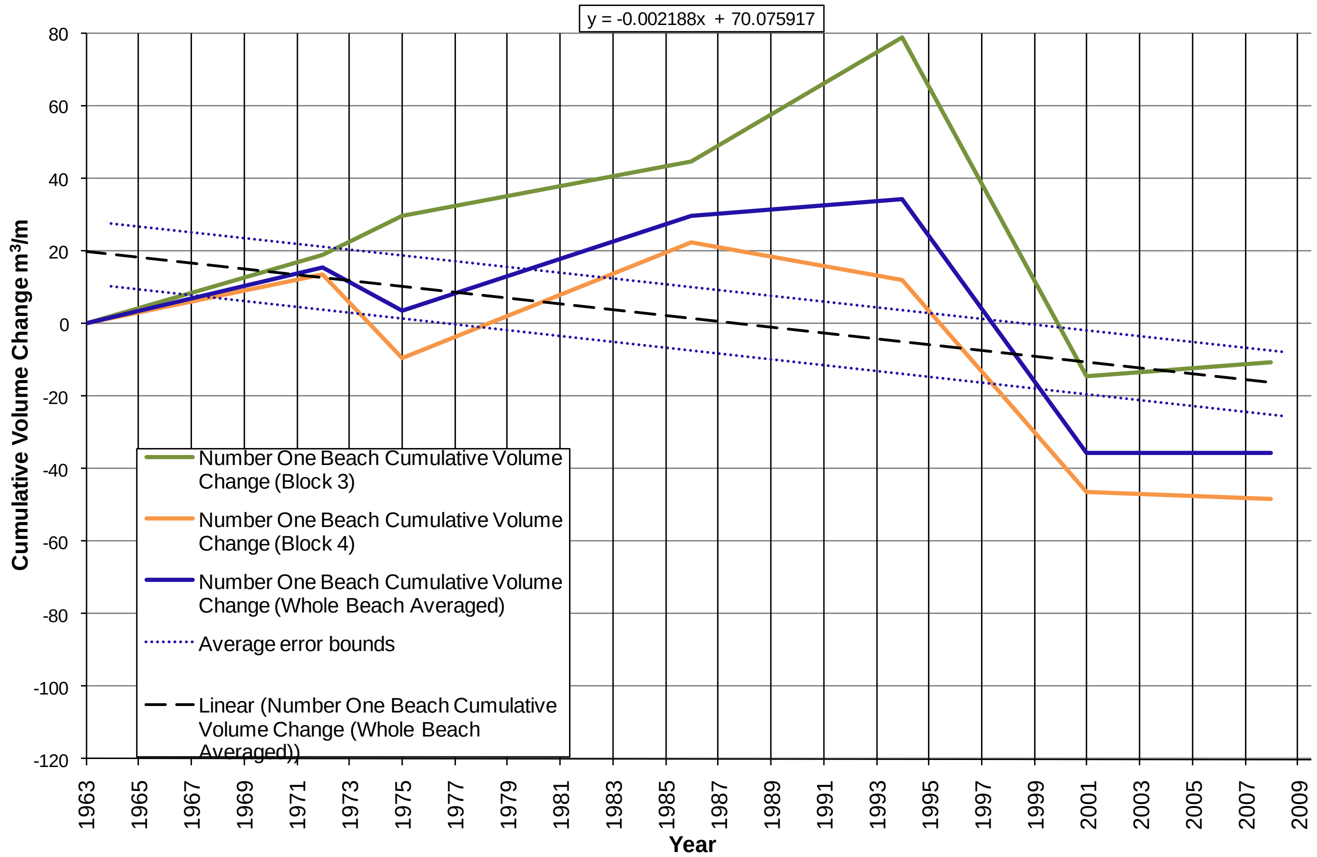


Figure B.29: Cumulative change in beach volume in cubic metres per metre length of beach at Number One Beach

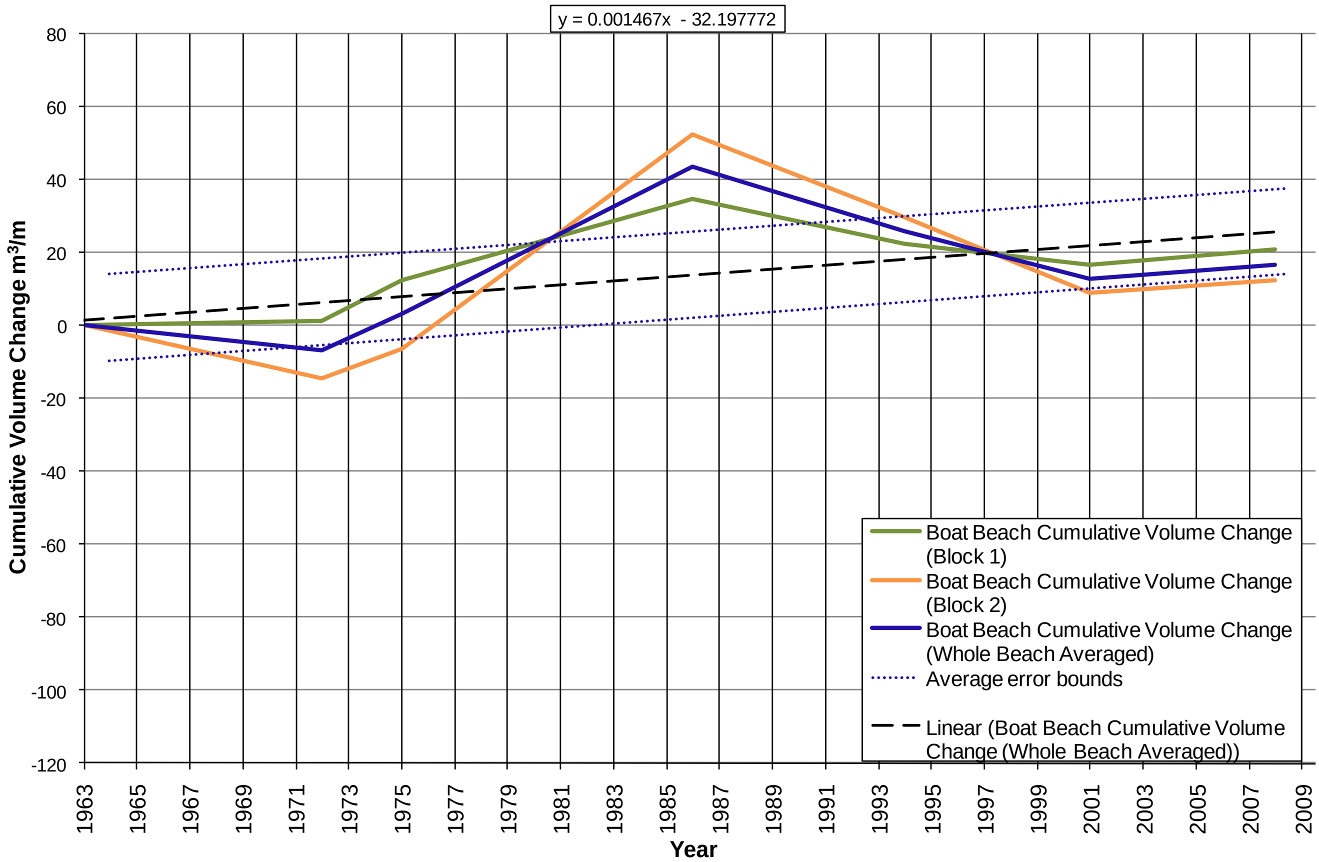


Figure B.30: Cumulative change in beach volume in cubic metres per metre length of beach at Boat Beach

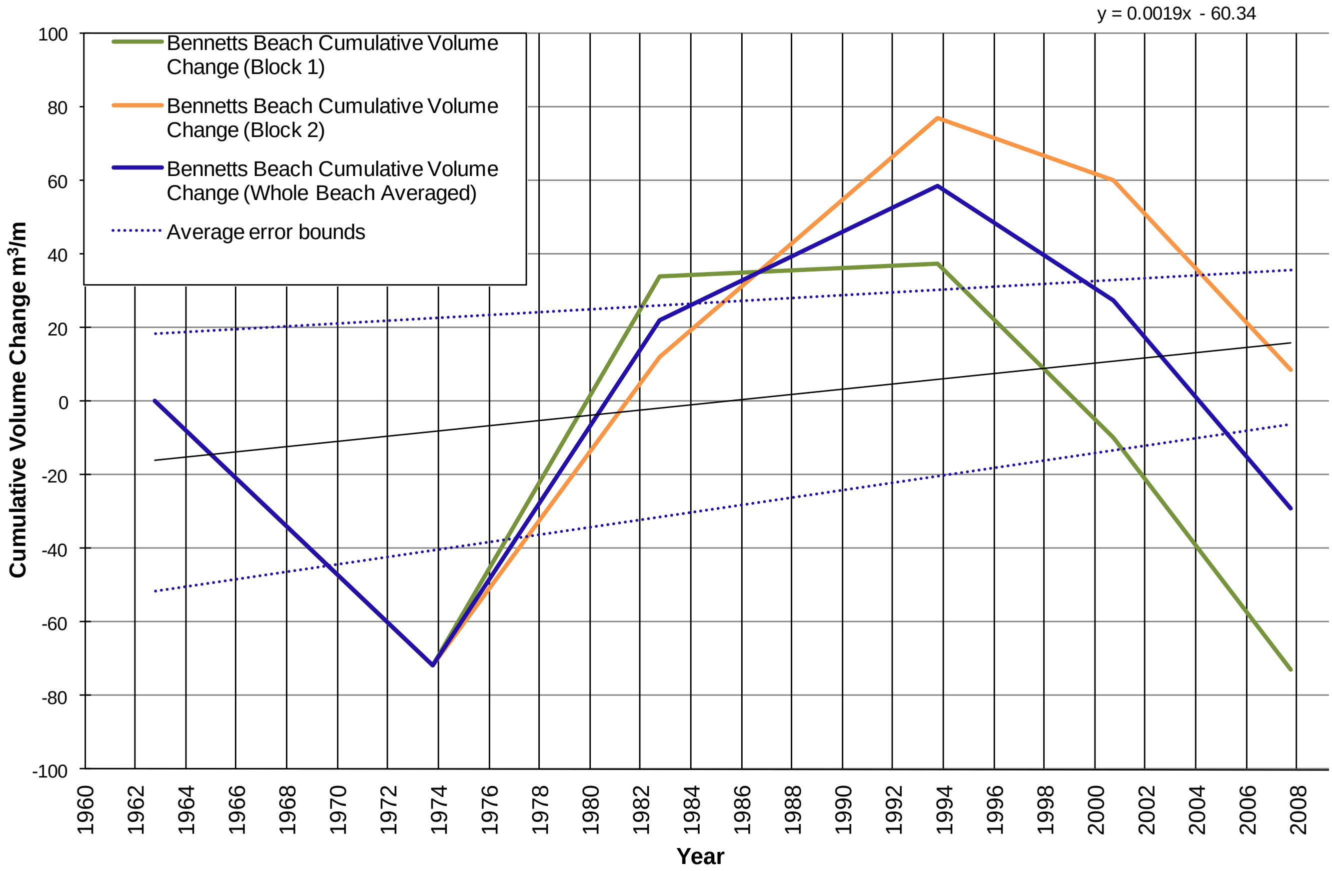


Figure B.31: Cumulative change in beach volume in cubic metres per metre length of beach at Bennetts Beach

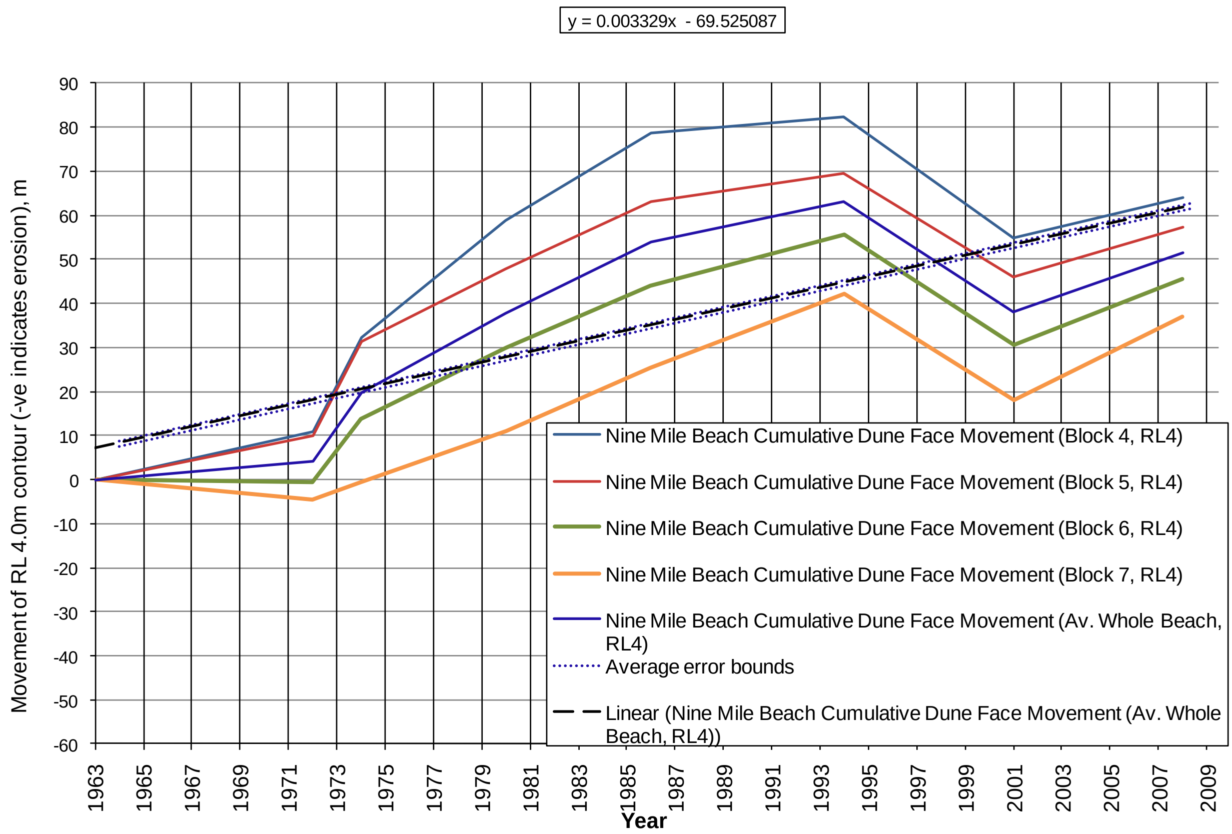


Figure B.32: Cumulative dune face movement in metres at Nine Mile Beach

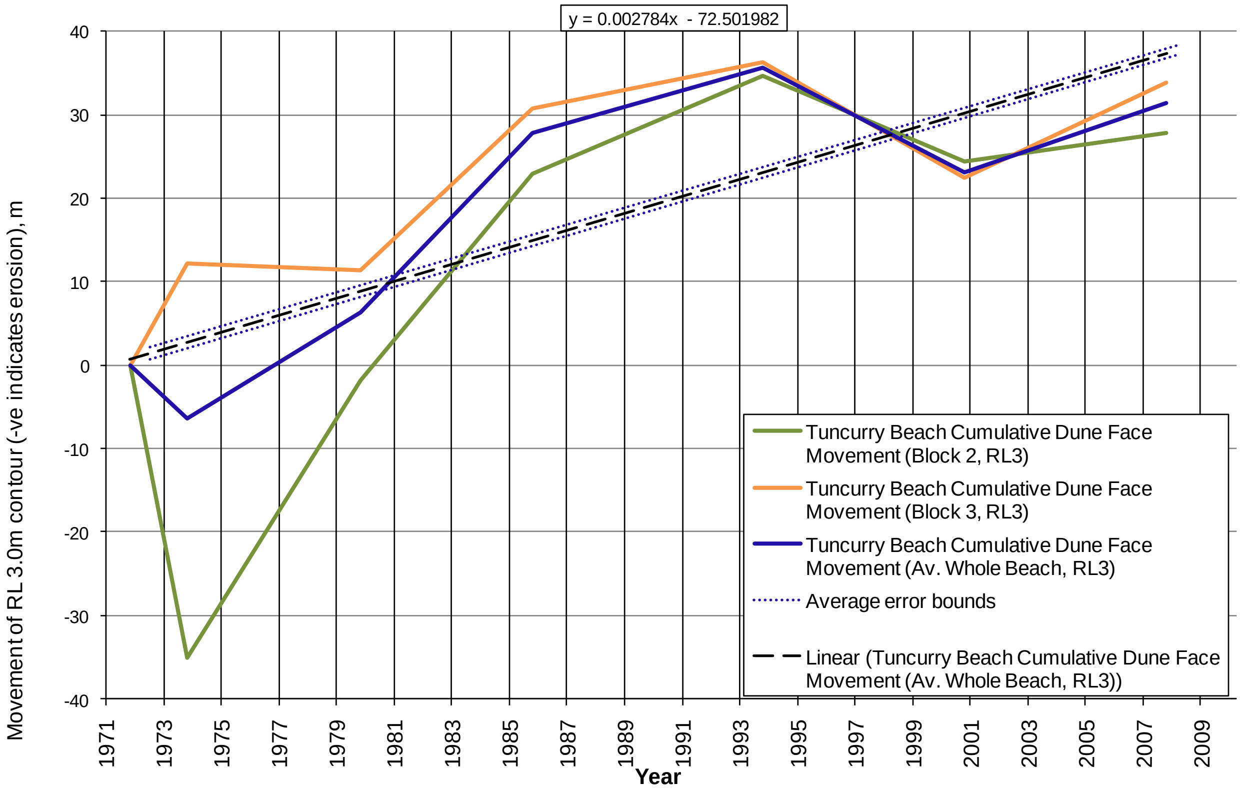


Figure B.33: Cumulative dune face movement in metres at Tuncurry Beach

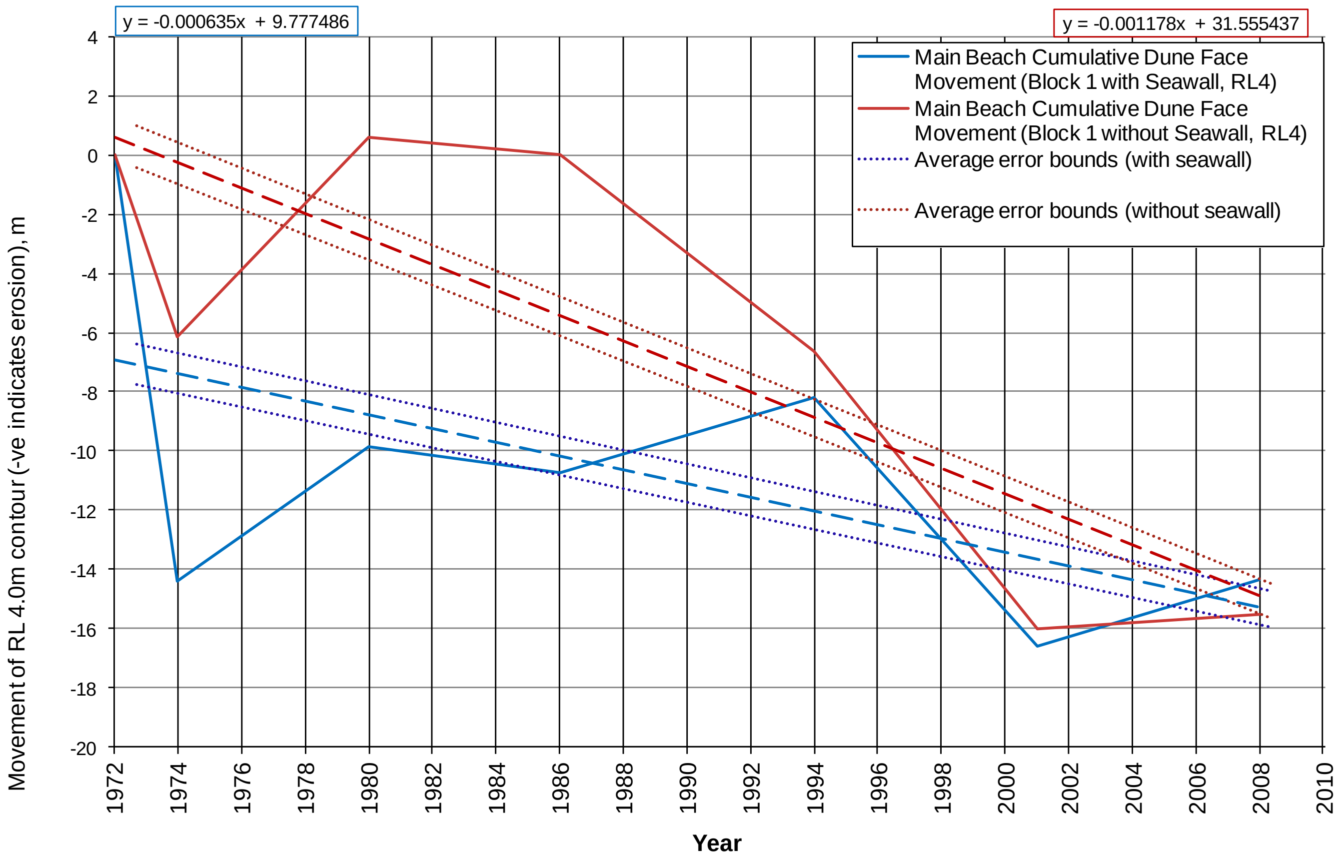


Figure B.34: Cumulative dune face movement in metres at Main Beach

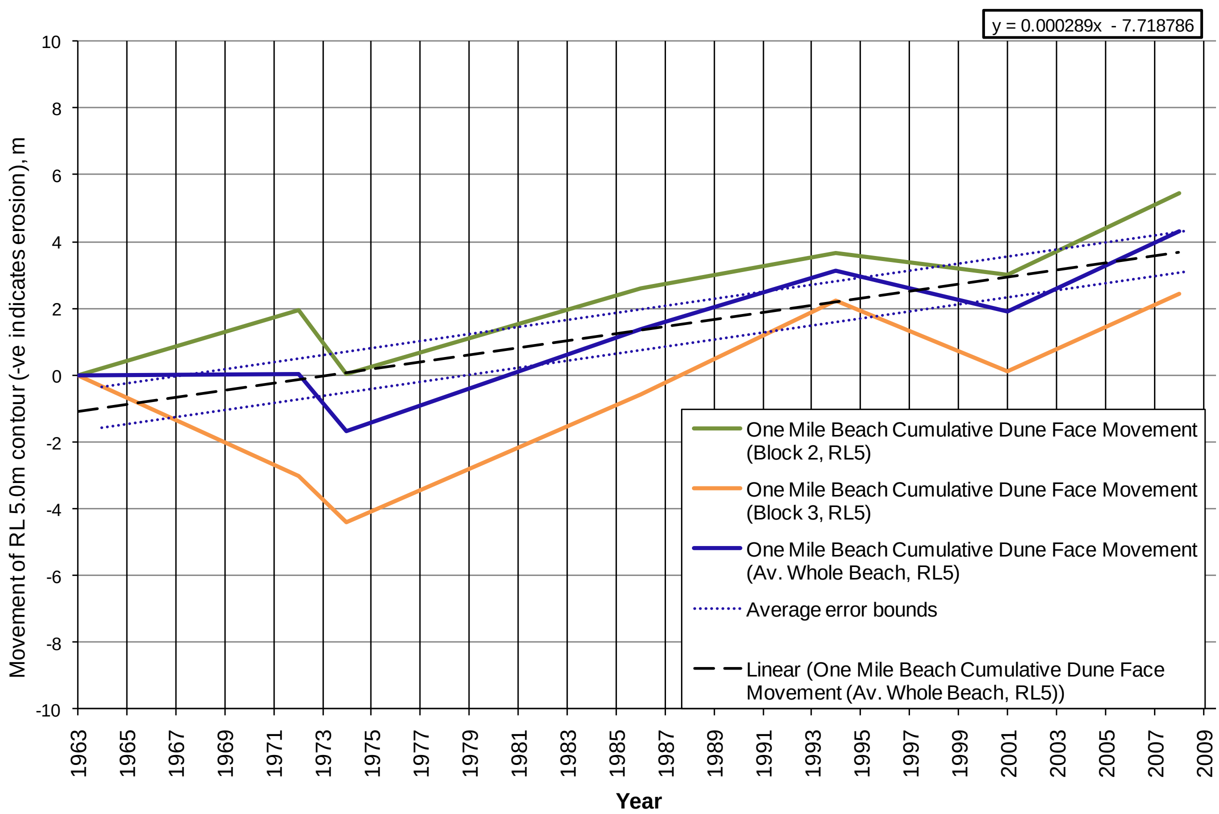


Figure B.35: Cumulative dune face movement in metres at One Mile Beach(RL5.0m AHD)

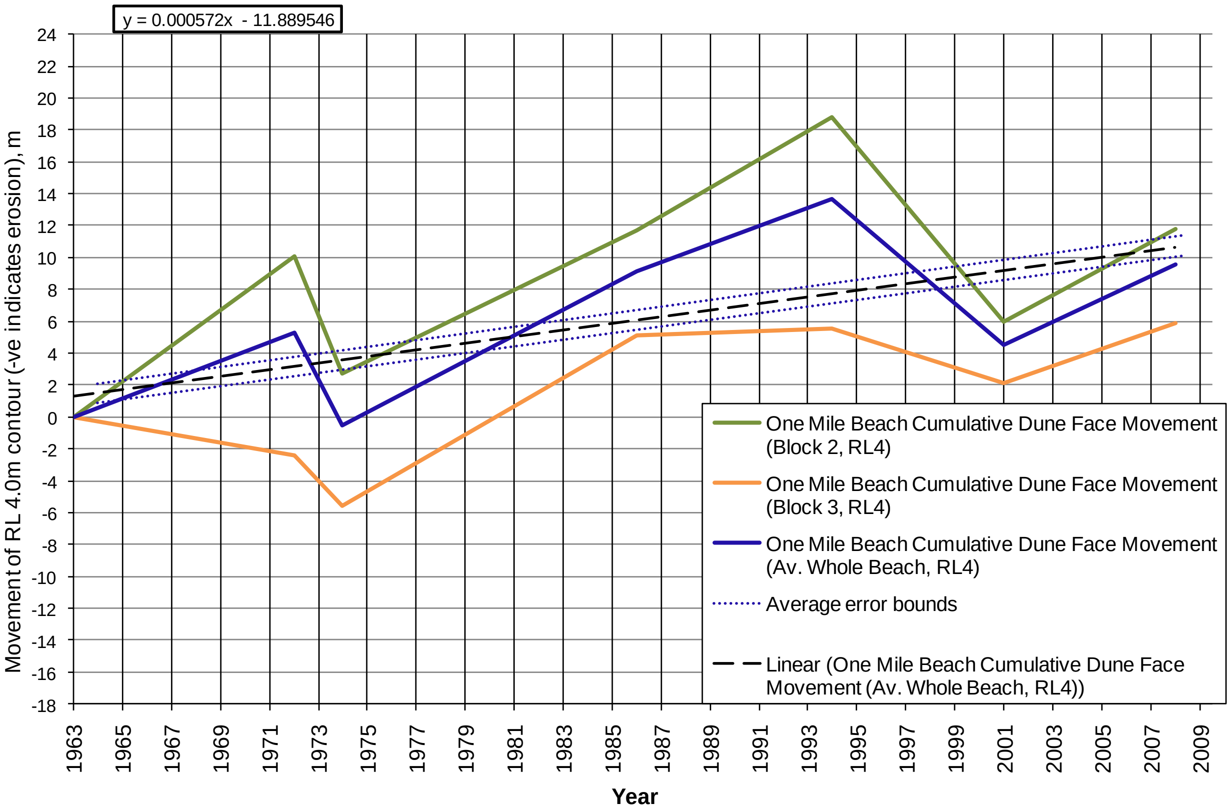


Figure B.36: Cumulative dune face movement in metres at One Mile Beach(RL4.0m AHD)

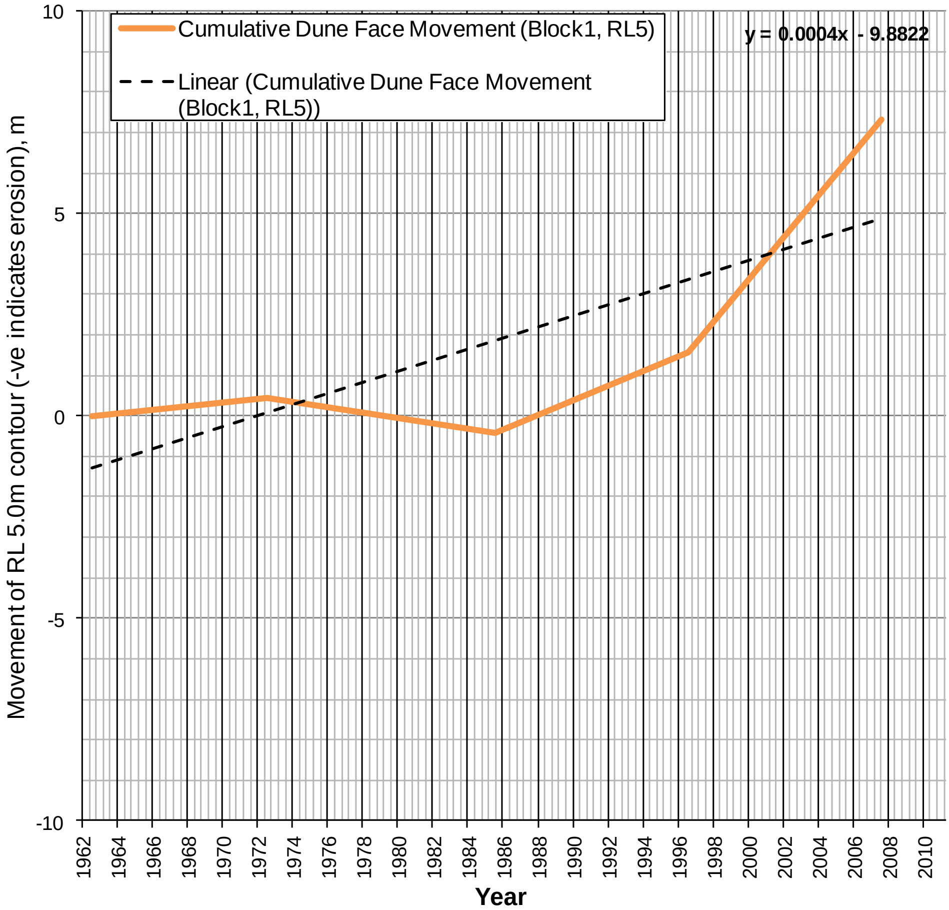


Figure B.37: Cumulative dune face movement in metres at Seven Mile Beach

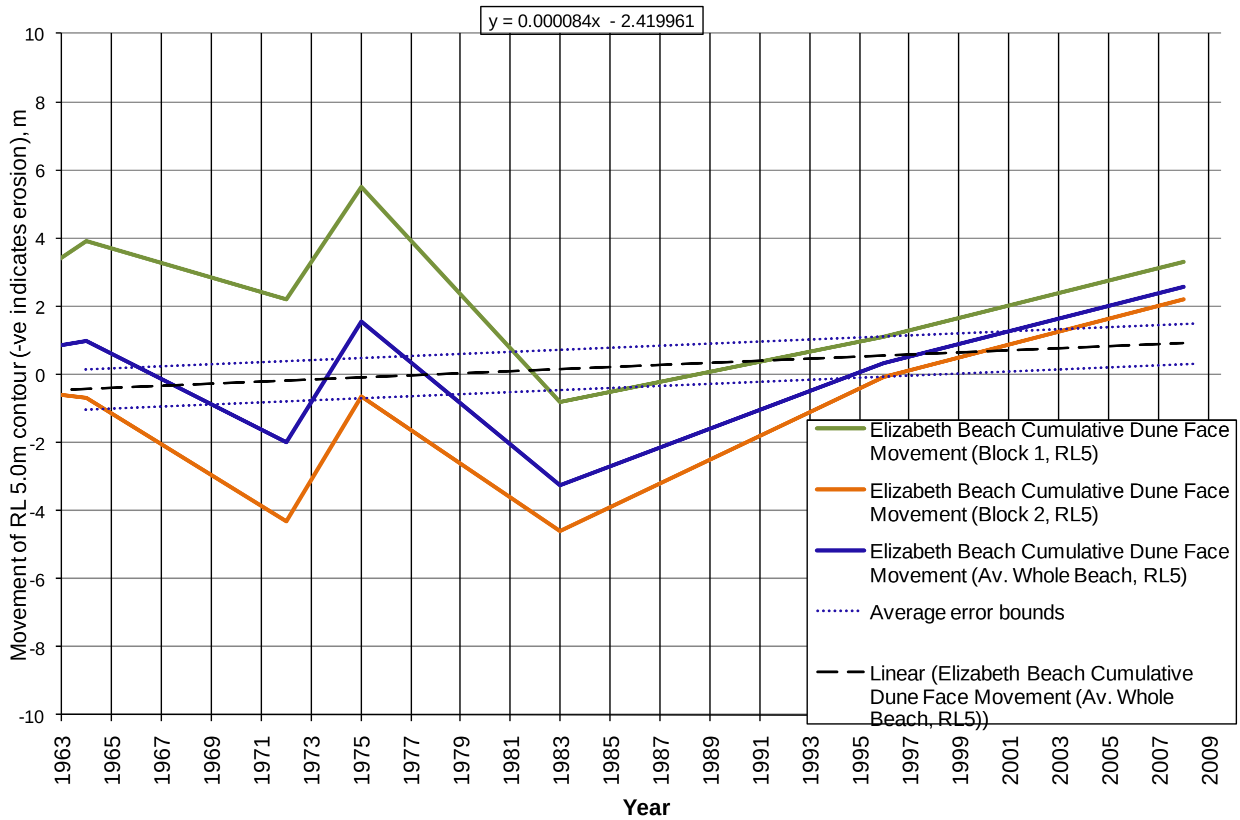


Figure B.38: Cumulative dune face movement in metres at Elizabeth Beach

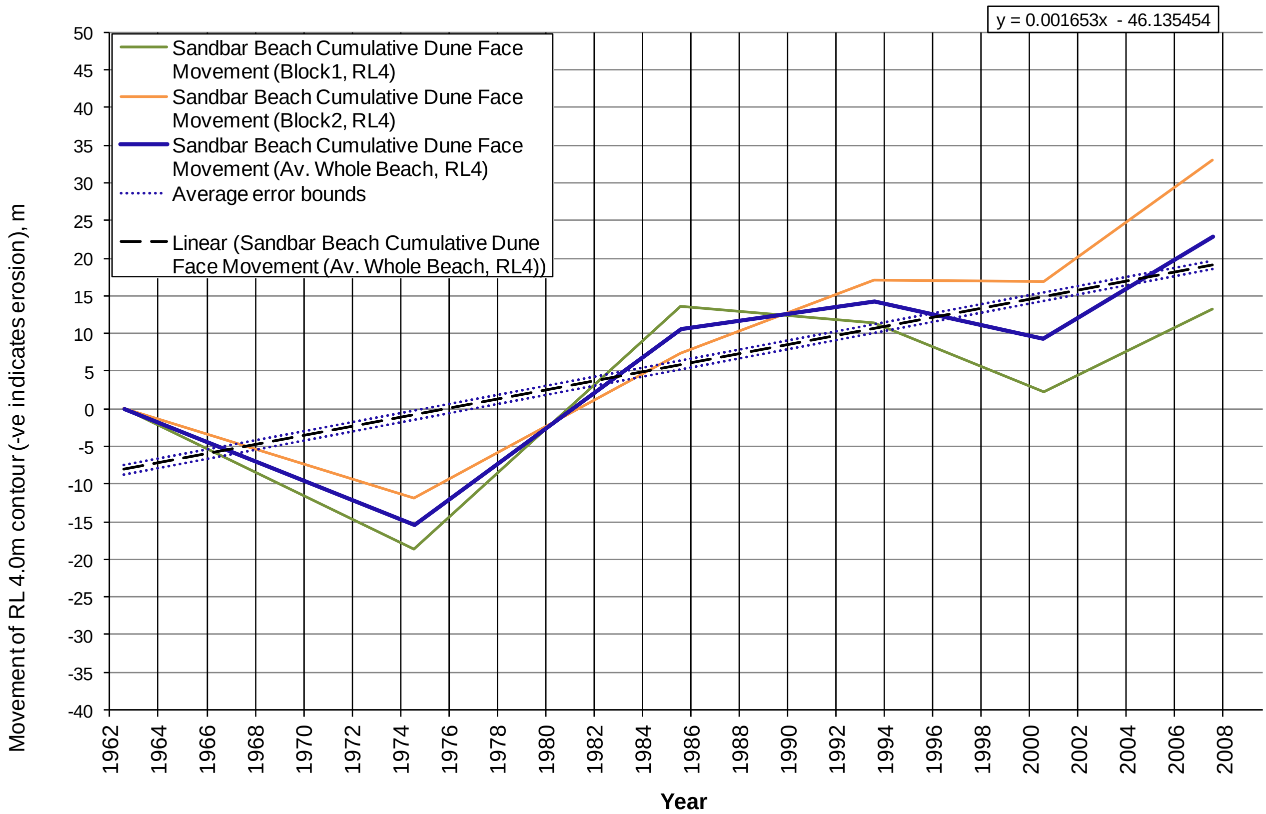


Figure B.39: Cumulative dune face movement in metres at Sandbar Beach

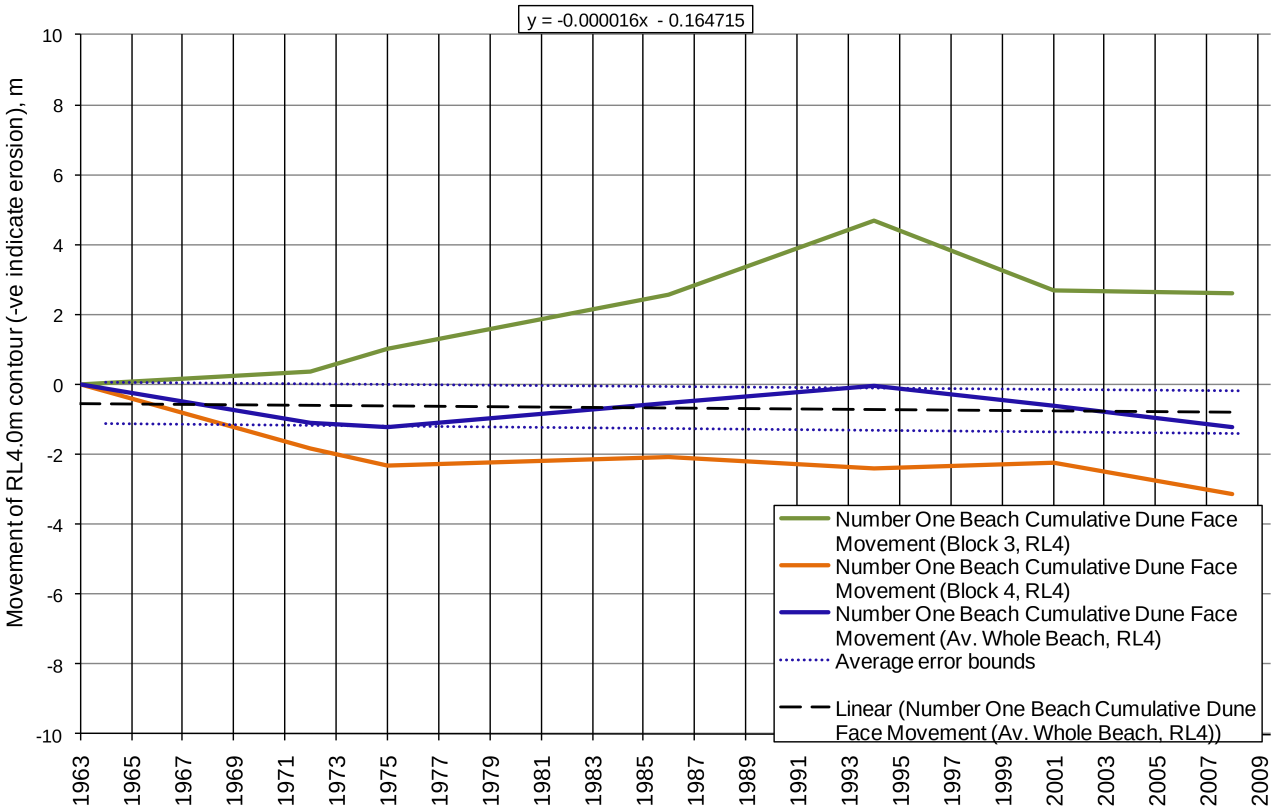


Figure B.40: Cumulative dune face movement in metres at Number One Beach

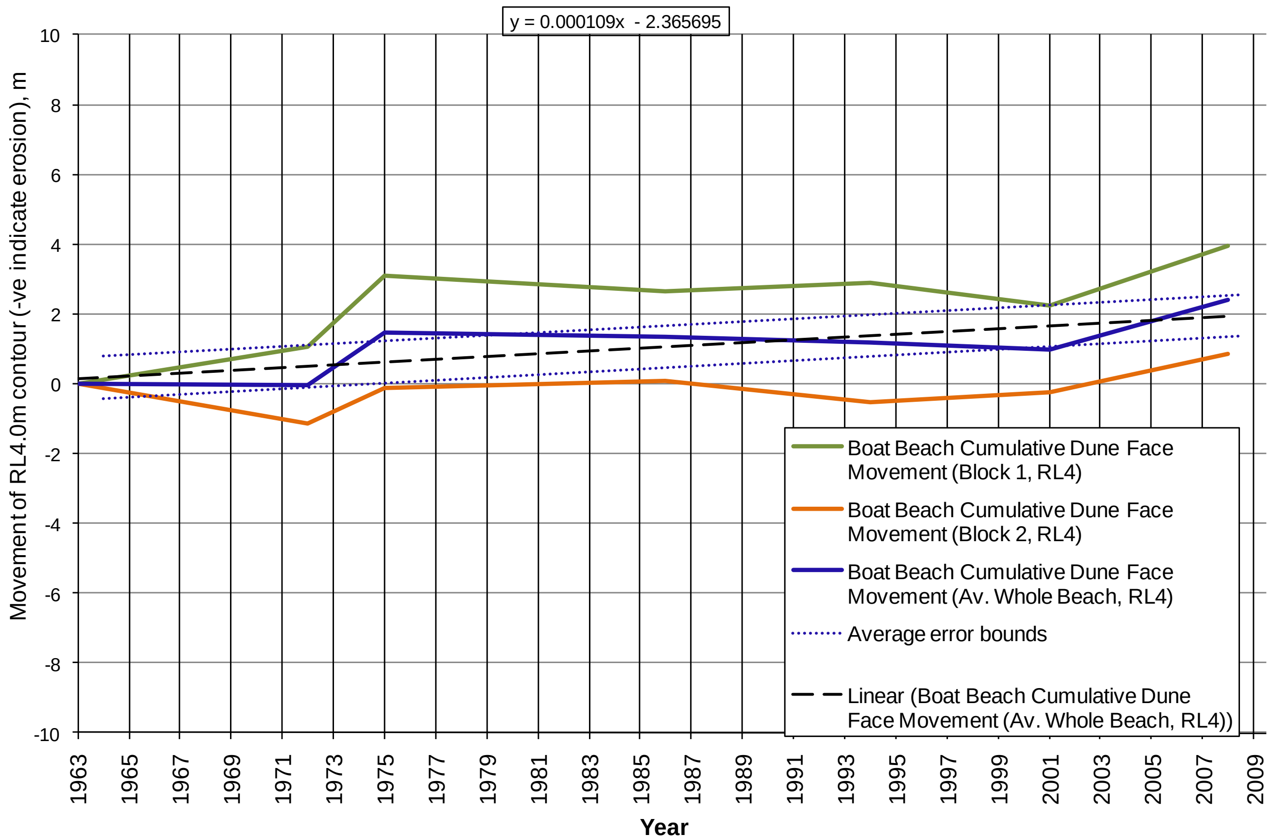


Figure B.41: Cumulative dune face movement in metres at Boat Beach

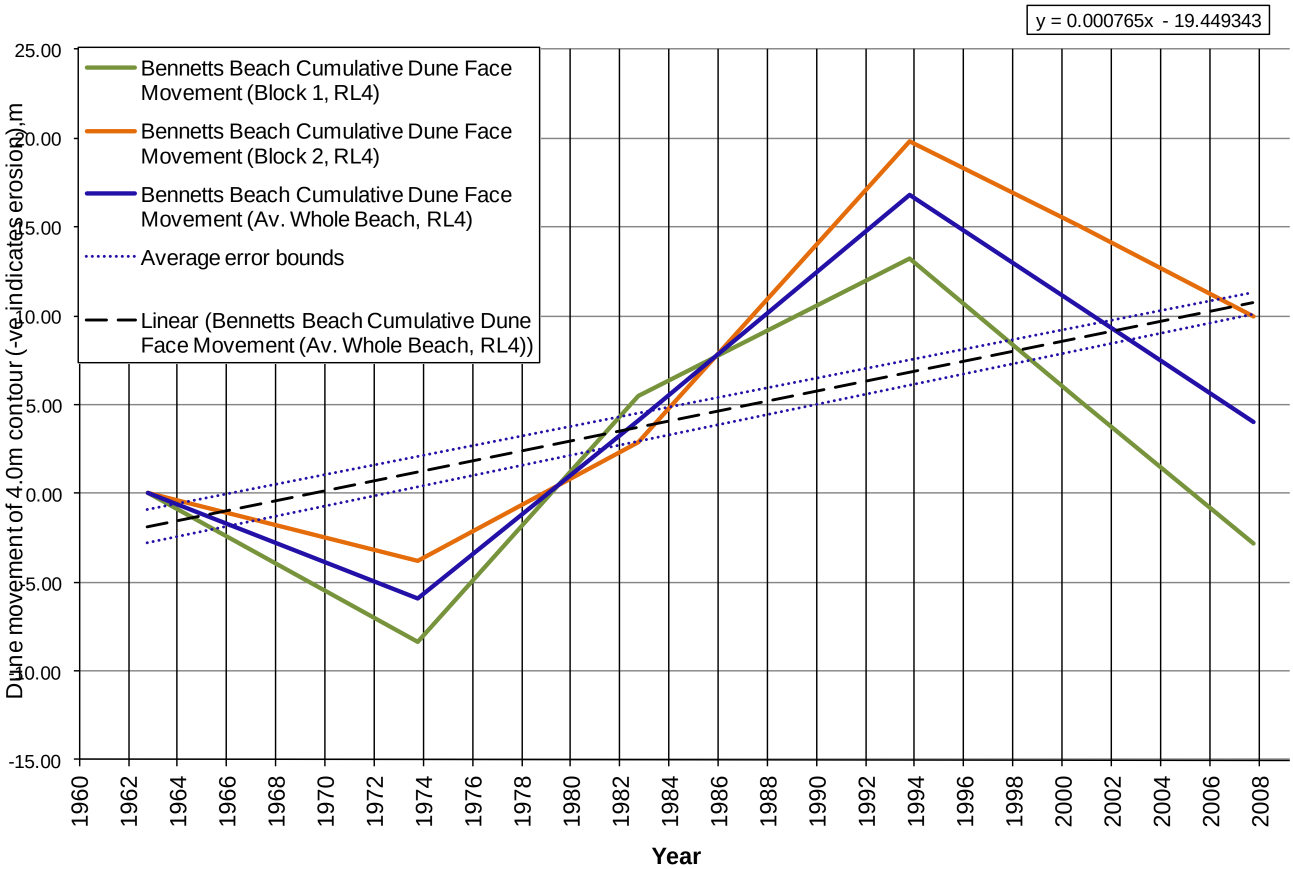


Figure B.42: Cumulative dune face movement in metres at Bennetts Beach

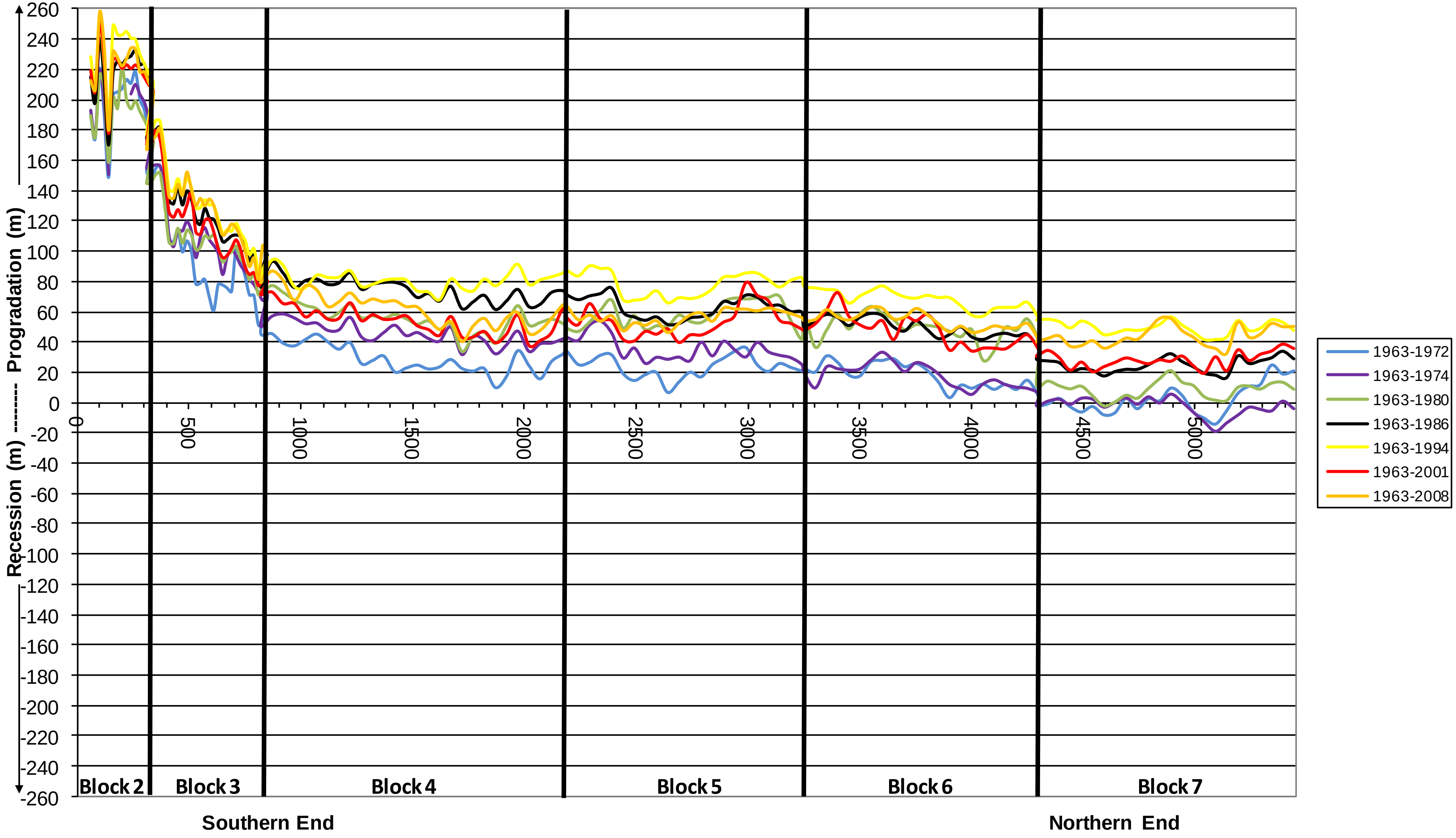


Figure B.43: General Movement of the RL 3.0m contour for Tuncurry / Nine Mile Beach between 1963 and 2008
N.B.: the effect of the construction of Wallis Lake training wall is noticeable between 1963 and 1972

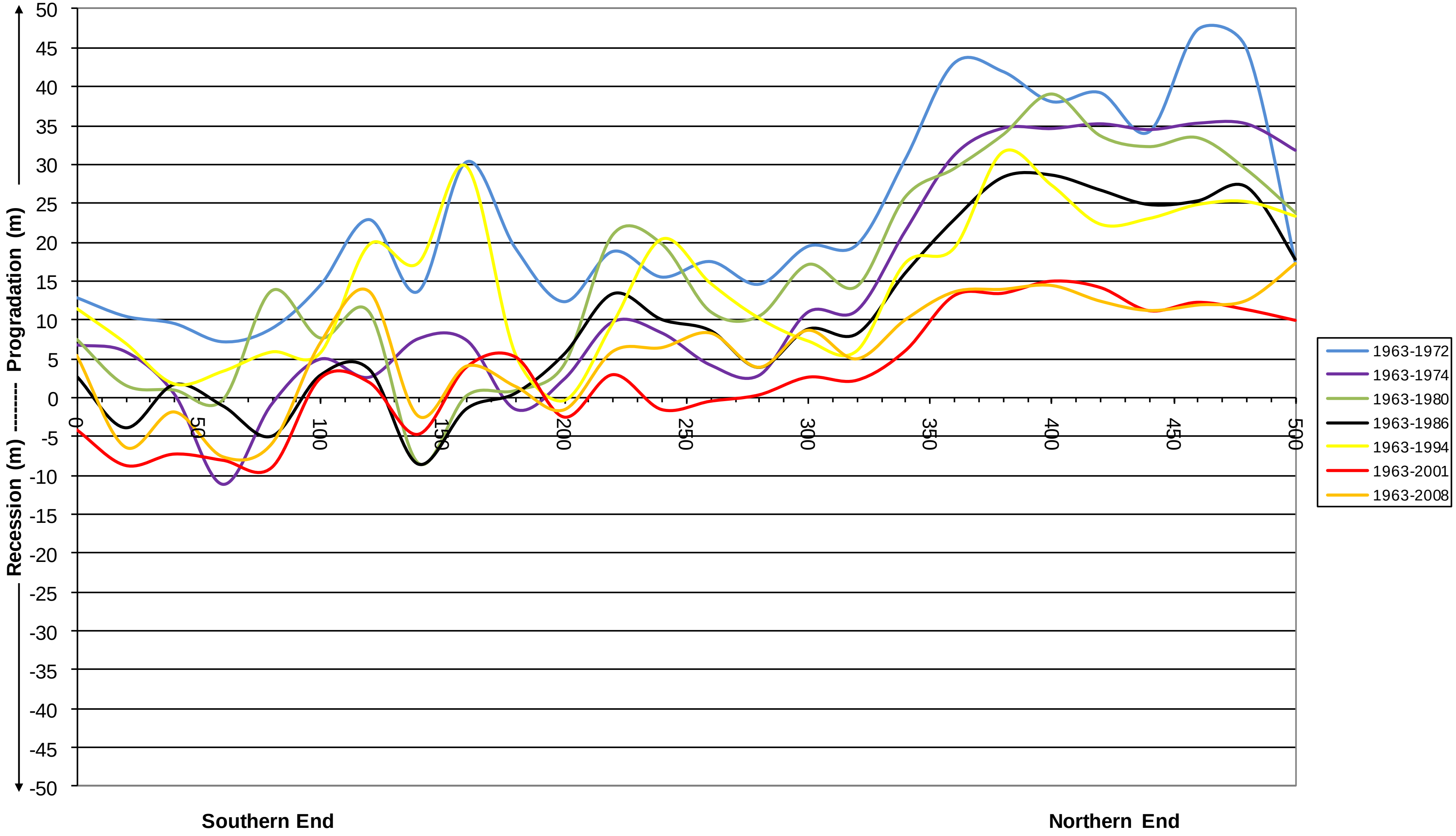


Figure B.44: General Movement of the RL 3.0m contour for Main Beach between 1963 and 2008
N.B.: the construction of Wallis Lake training wall is noticeable between 1963 and 1972

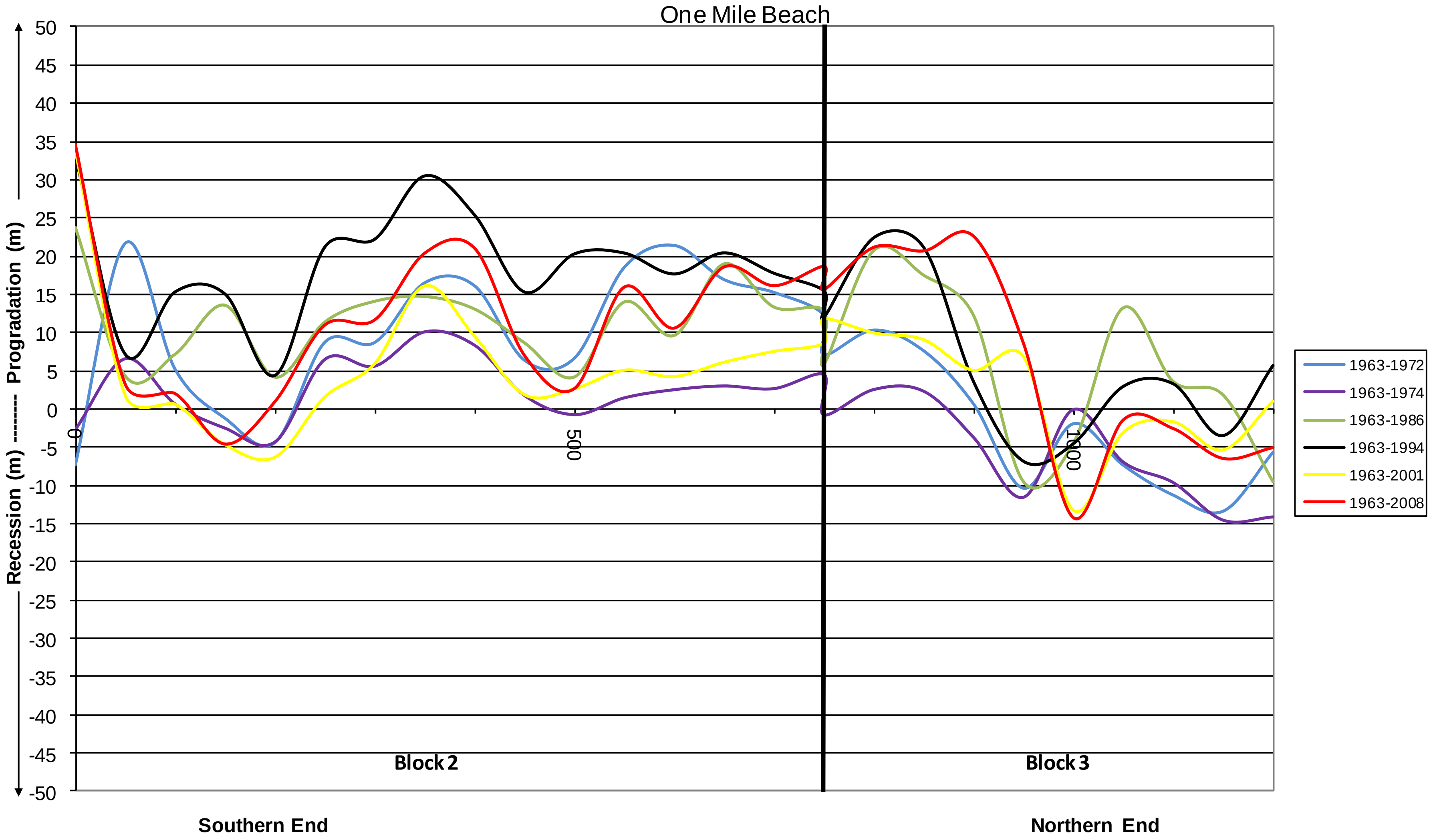


Figure B.45: General Movement of the RL 4.0m contour for One Mile Beach between 1963 and 2008

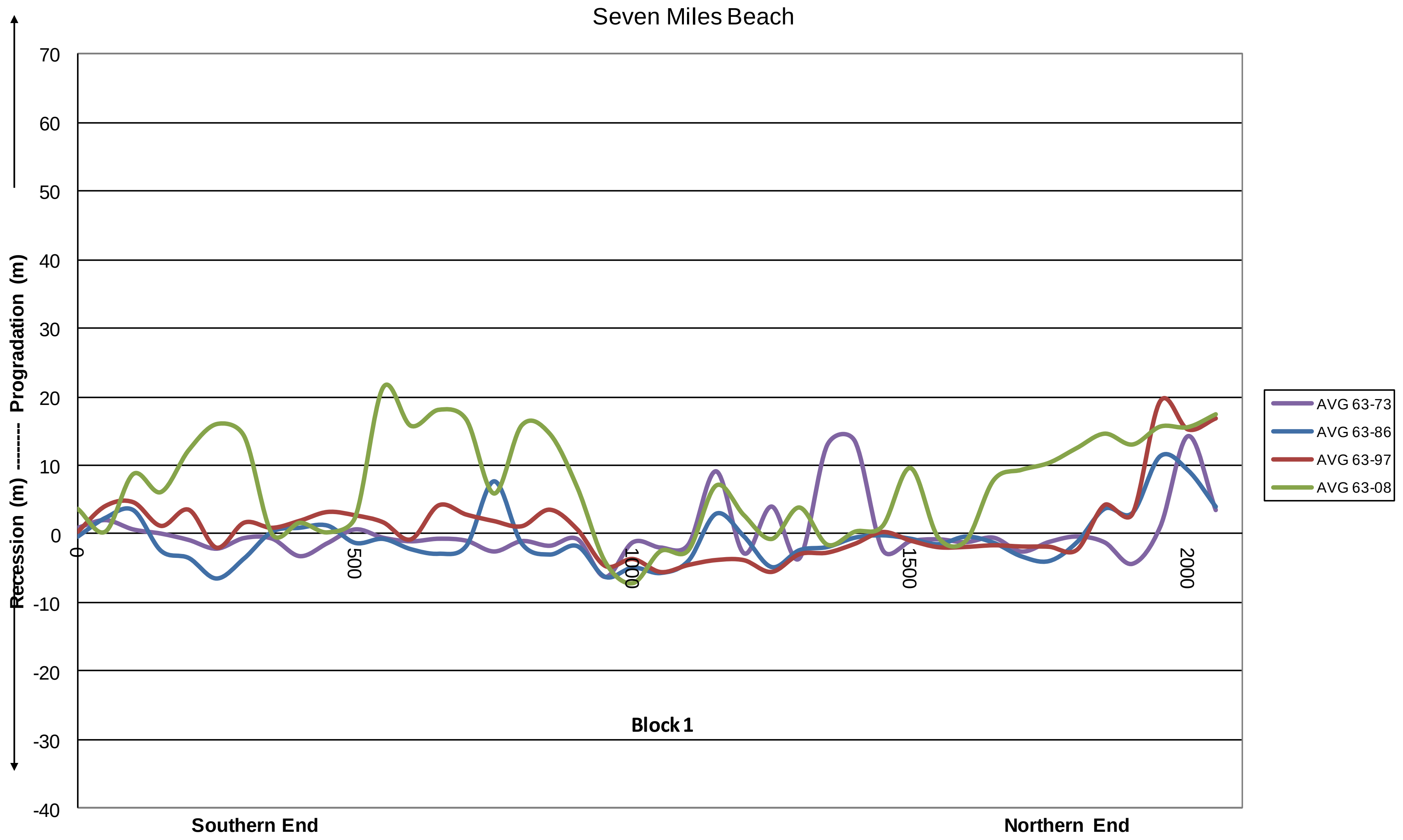


Figure B.46: General Movement of the RL 5.0m contour for Seven Mile Beach between 1963 and 2008

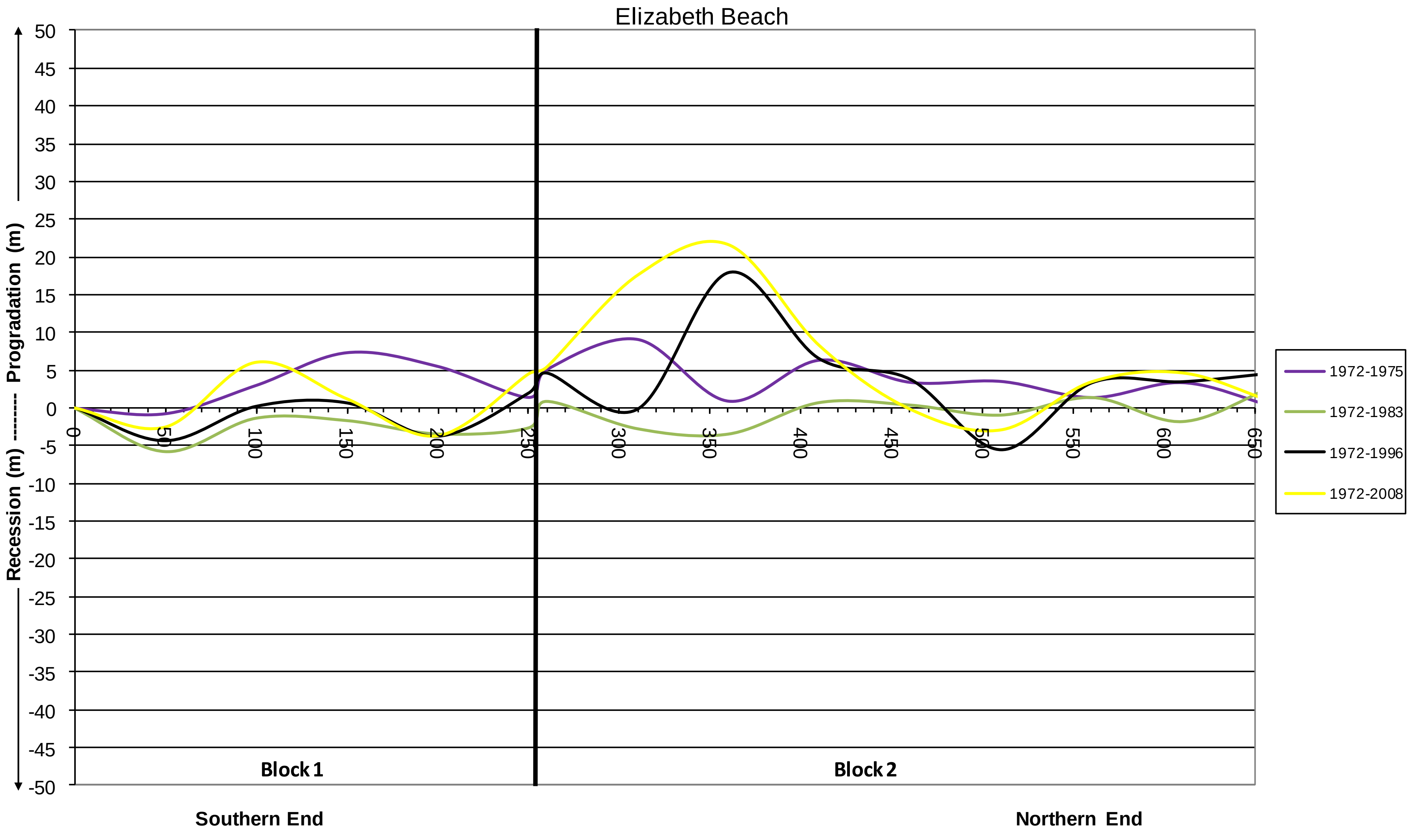


Figure B.47: General Movement of the RL 5.0m contour for Elizabeth Beach between 1972 and 2008

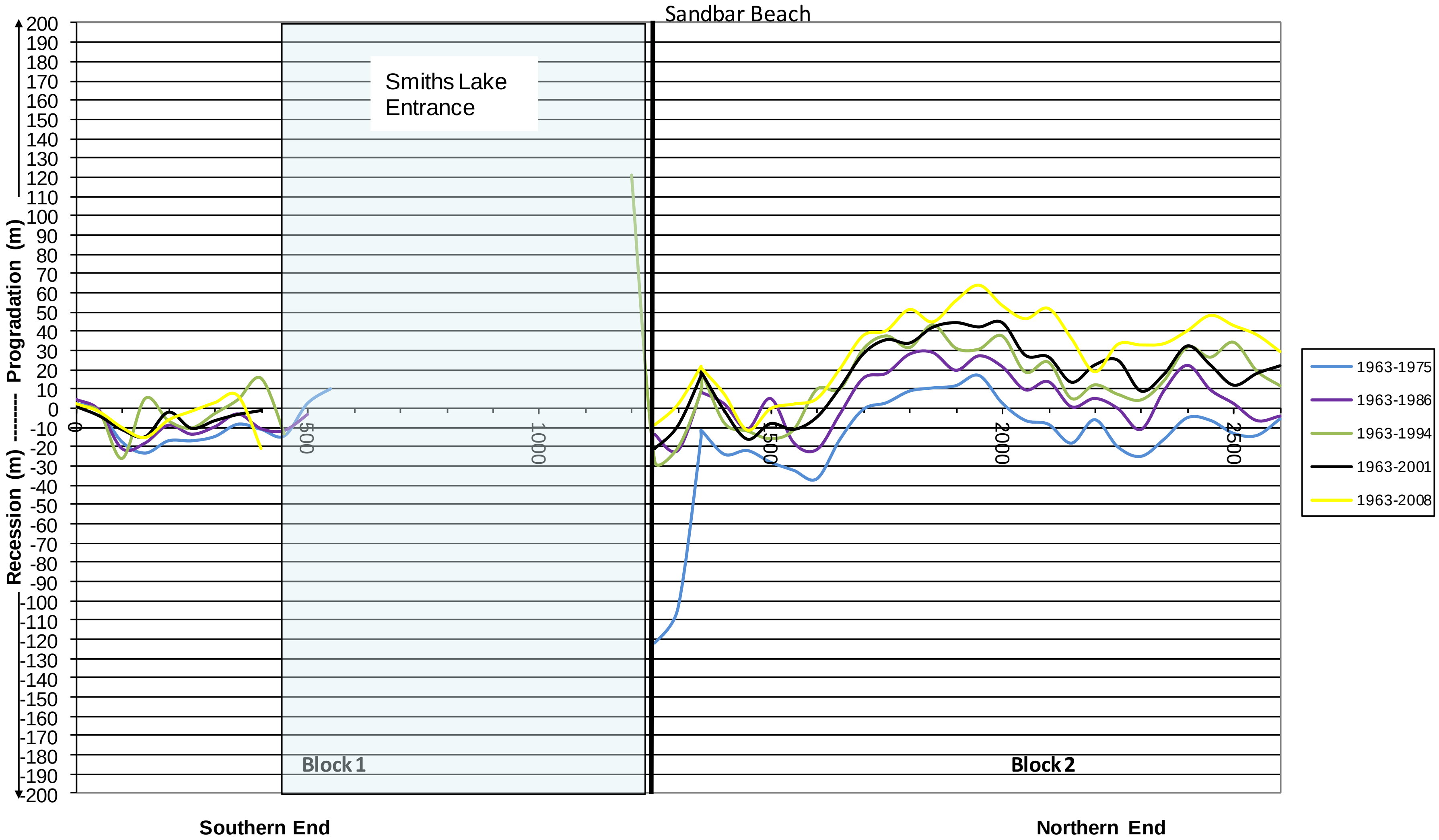


Figure B.48: General Movement of the RL 4.0m contour for Sandbar Beach between 1963 and 2008

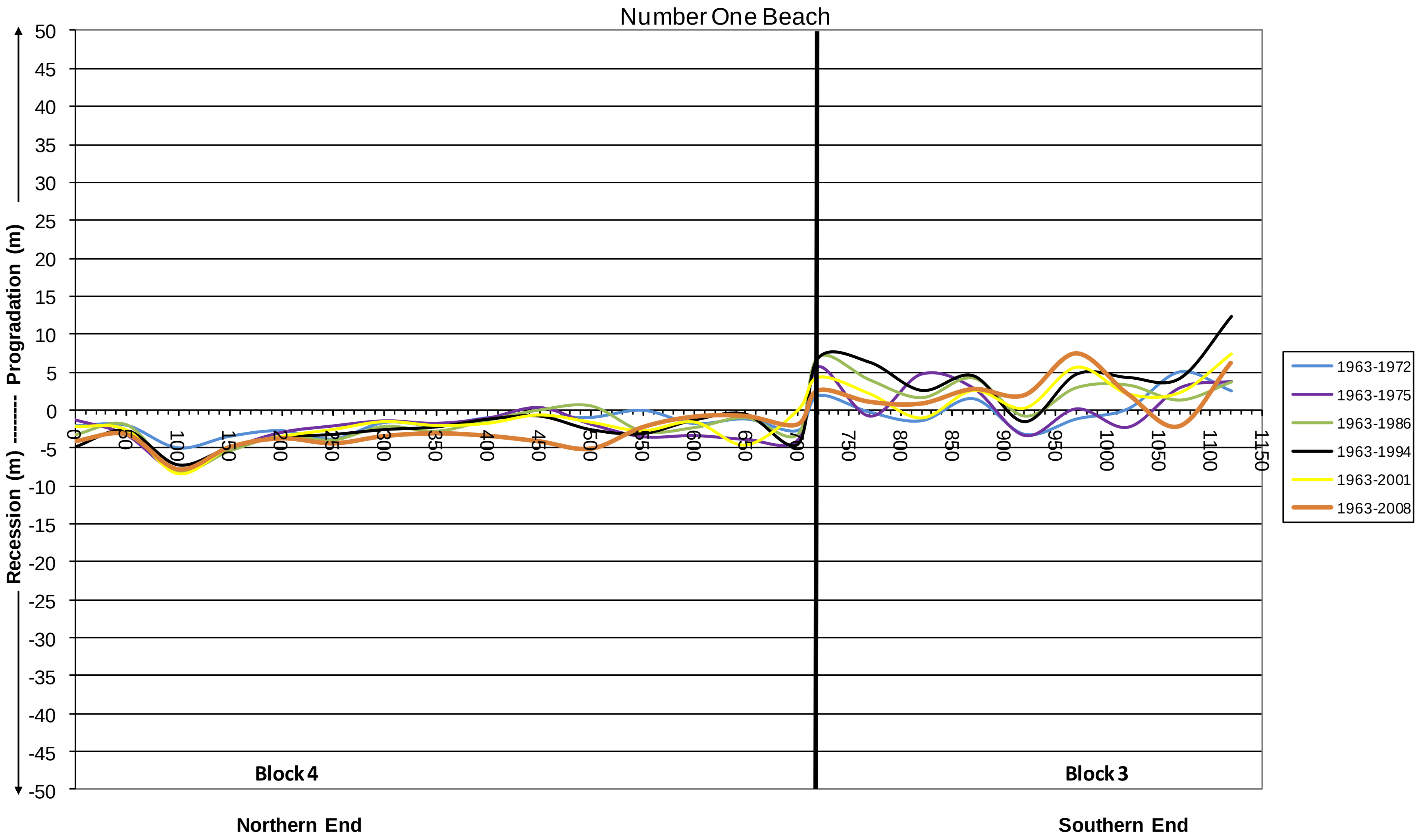


Figure B.49: General Movement of the RL 4.0m contour for Number One Beach between 1963 and 2008

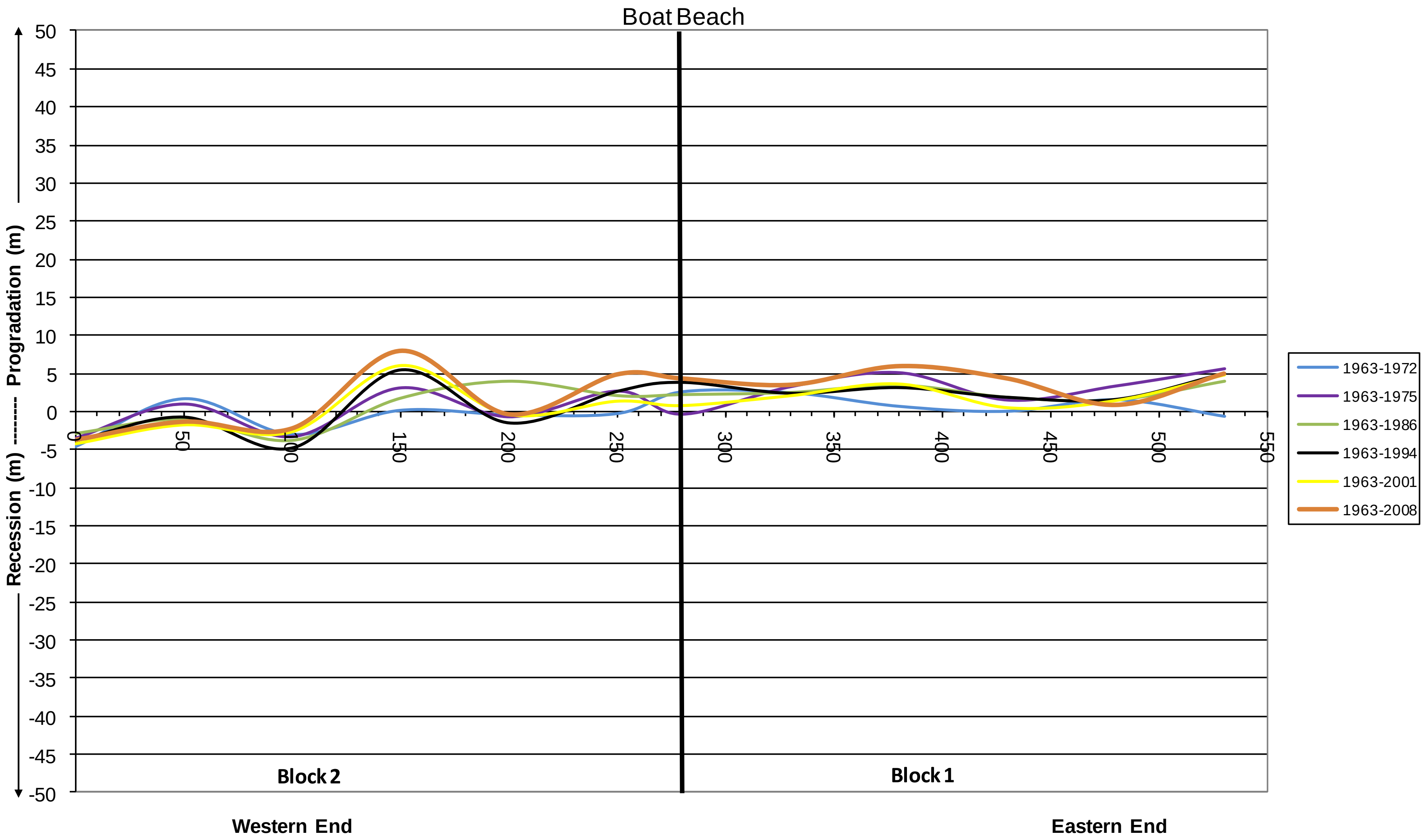


Figure B.50: General Movement of the RL 4.0m contour for Boat Beach between 1963 and 2008

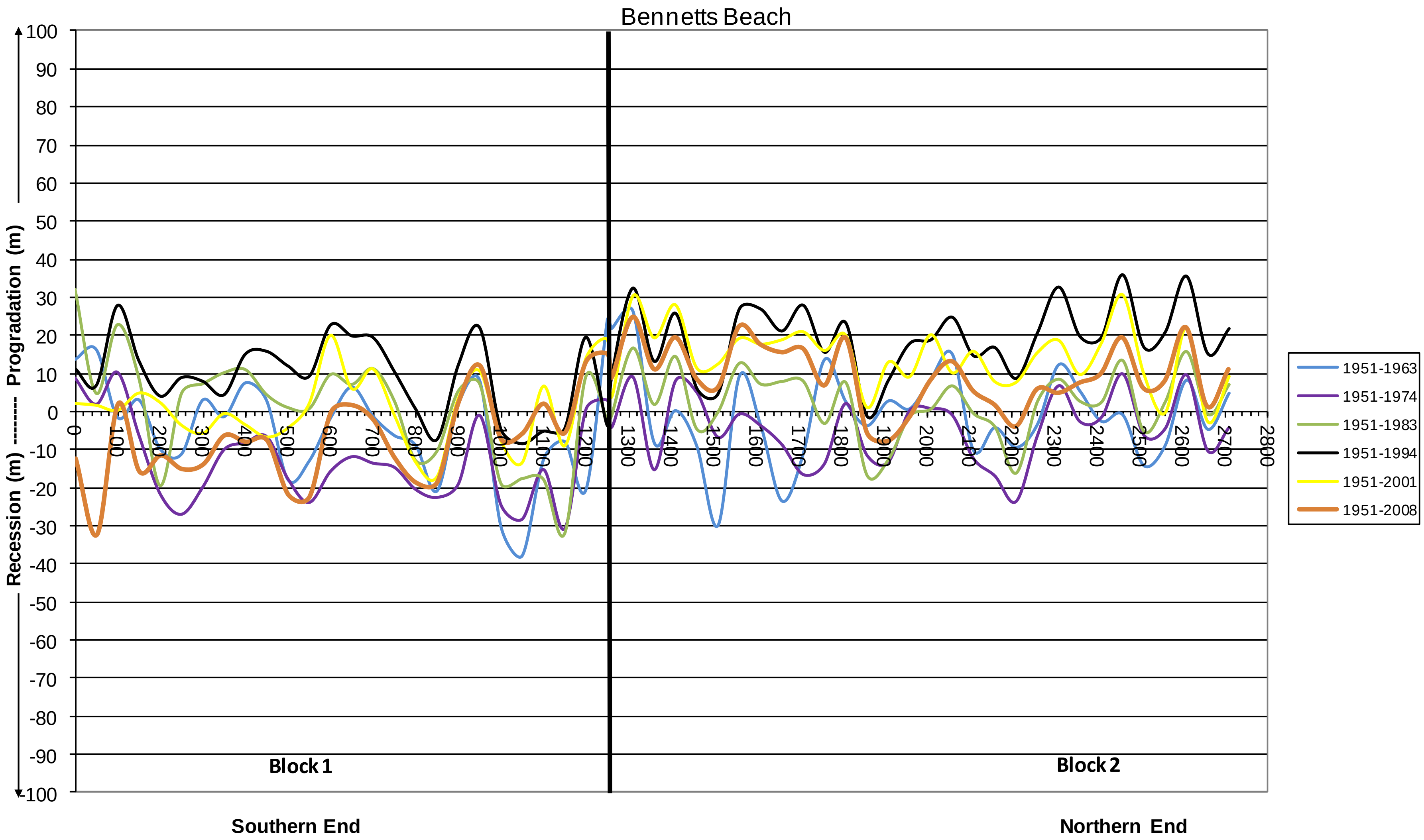


Figure B.51: General Movement of the RL 4.0m contour for Bennetts Beach between 1951 and 2008