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ANTARCTIC CLIMATE & ECOSYSTEMS
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TECHNICAL REPORT:

Shoreline Change at Roches Beach, South-Eastern Tasmania 1957-2010

Technical Report: Shoreline Change at Roches Beach, South-Eastern Tasmania 1957-2010.

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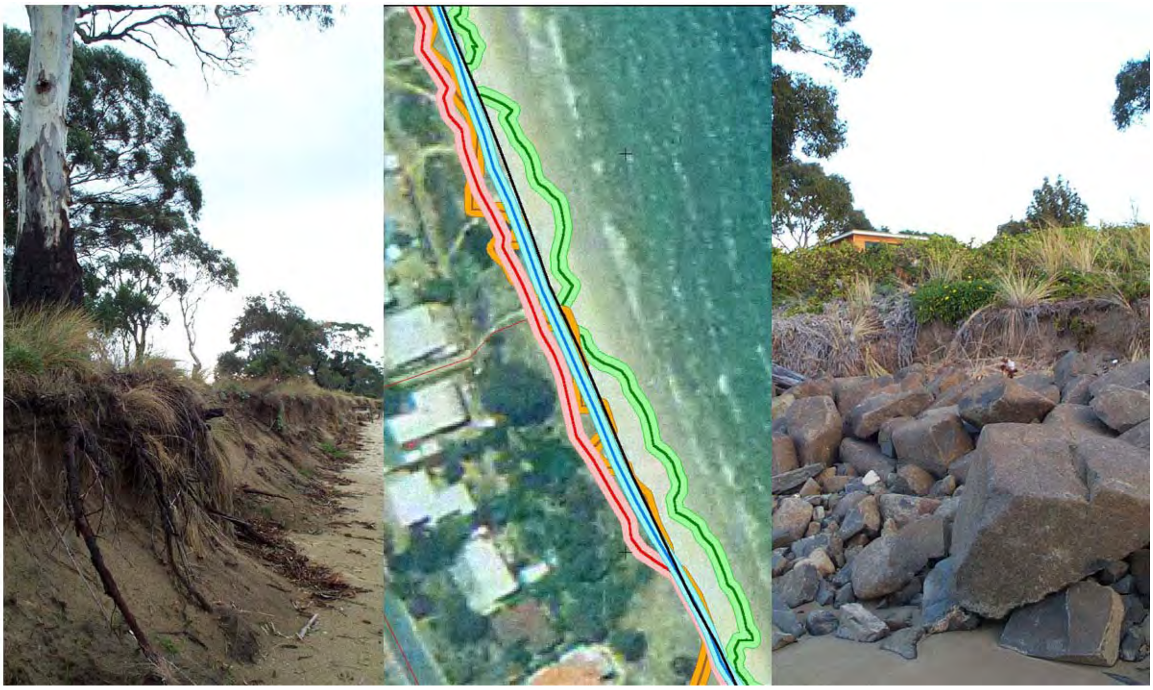
Shoreline Change at Roches Beach, South-Eastern Tasmania, 1957 - 2010



A Report to the

Antarctic Climate and Ecosystems Co-operative Research Centre

by
Chris Sharples
School of Geography & Environmental Studies,
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August 2010

Front Cover:

Left Photo: Exposure of the roots of large trees growing on the Roches Beach foredune scarp north of the canal is indicative of a degree of erosion which has not occurred at this site for decades at least. This is confirmed by the results of the study reported on here: this tree is located within net recession zone RZ3 (see Section 5.1), which has been undergoing mainly progressive erosion since prior to 1977.

Centre: Shoreline positions and error margin envelopes digitised from ortho-rectified air photos from 1957, 1977, 1987 & 2001, and from a 2005 QuickBird satellite image, demonstrate a major cut-and-fill cycle superimposed on progressive shoreline recession at recession zone RZ2, south of the Lauderdale canal. Over 15m of apparent shoreline recession occurred in places between 1957 (green envelope) & 1977 (orange envelope), after which the shoreline rebuilt prior to 2001 (black line), but without returning all the way back to its original 1957 position. Further shoreline recession occurred between 2001 and 2005 (blue envelope), and there has now been a minimum detectable net recession of around 9m in parts of this site since 1957, and probably up to 12.5m actual net recession (see Section 5.1). The base image is the 2001 ortho-rectified air photo of Roches Beach.

Right Photo: Following significant erosion during and prior to 1988, this boulder wall was constructed to prevent further shoreline recession at net recession zone RZ1, in the southern area of Roches Beach. However, foredune erosion is becoming noticeable behind the boulder wall in several places (as in this photo), indicating that storm wave run-up is overtopping the boulder wall with sufficient energy to continue eroding behind the wall.

CONTENTS

SUMMARY

Roches Beach is the eastern edge of a broad low-lying isthmus or neck of soft unconsolidated sediments connecting the South Arm Peninsula to south-eastern Tasmania. The neck is occupied by the residential township of Lauderdale, and a large number of residences have been constructed within metres of the single low foredune backing the beach. Roches Beach is an open coast sandy beach backed by a low relief beach-ridge plain of soft erodible sandy sediments extending to below present sea level. The beach is exposed to a refracted northerly-directed swell, and to locally generated wind-waves which may develop considerable erosive power when driven by easterly or north-easterly winds over the long fetch of Frederick Henry Bay.

Persistent shoreline erosion at Roches Beach has been of concern to residents and others for several decades. The present study has measured shoreline change at Roches Beach during the period 1957 to 2005, through the use of ortho-rectified air photos from 1957, 1977, 1987 & 2001 and a high resolution QuickBird satellite image from 2005. The seawards vegetation limit on the foredune front was used as a measurable indicator of shoreline position, which moves as a shoreline moves and is readily detectable on imagery. Position error margins for features on each image were determined by comparing apparent relative displacements of fixed reference features visible on all images. Shoreline positions were digitised over the imagery for each epoch, and then buffered with envelopes representing position error margins. Using this technique, any apparent movement of shoreline positions between two images that is greater than the error envelope widths must represent a minimum real shoreline movement between the times represented by the images.

Use of this method has shown that net (long term) shoreline recession has occurred along much of Roches Beach between 1957 and 2005, by minimum (demonstrable) distances of 4 – 9 metres (and probably 5 to 12.5 metres actual recession). Although several large cut-and-fill (erosion and natural swell-driven recovery of the beach) cycles are detectable super-imposed on this progressive recession trend, long stretches of the beach have never returned to their former 1957 position, but rather have exhibited net progressive recession from prior to 1977 until 2005. Subsequent field observations show the beach has remained in an erosive state up to the present (2010). The data from this study together with an earlier study by Cromer (2006) indicates the onset of progressive recession probably occurred around 1975 to 1977, representing a transition to a new style of beach behaviour at that time. Whereas the 1957 shoreline (dune front) had a notably 'ragged' planform indicative of little active erosion, subsequent to 1977 all air photo images show notably straight dune front planforms indicative of more frequent active shoreline wave erosion. Nonetheless, over the 1970's to 1990's period, several large 'cut-and-fill' cycles super-imposed on the underlying recession trend are evident in the air photo record, which are indicative of some natural shoreline rebuilding between erosion events. However from prior to 2001 until 2010 there has been no incipient dune formation or dune-front rebuilding along most of the beach, which has instead been in a persistently erosive condition over this period, suggesting more frequent wave erosion of the beach and dune front in the last decade than during the earlier period of initial shoreline recession from the 1970's to 1990's.

The explanation best fitting the observed conditions and changed behaviour of Roches Beach since the 1970's is that the shoreline is responding to global sea-level rise by receding in a fashion commensurate with the approximately 14 centimetres of sea-level rise which has been demonstrated to have occurred in south-east Tasmania since the 1800's. Other explanations, including local artificial interferences, long-term oceanographic cycles or other long term natural progressive shoreline change trends, do not appear capable of explaining the observed changes at Roches Beach. However it is noteworthy that most other swell-exposed open coast sandy beaches in south-east Tasmania (and in south-east Australia generally) are not yet showing as clear a progressive recession in response to sea-level rise, because swell-driven return of sand to the shore

face following erosion events (the ‘cut-and-fill’ cycle) is still compensating for (or ‘masking’) the recessional effects of sea-level rise, and will continue to do so until sea level rises to a threshold beyond which wave erosion events are too frequent for shores to fully rebuild in-between erosion events. That this threshold has evidently already been passed at Roches Beach is interpreted to be due to locally unusual conditions. The most likely such conditions which could explain its early response to sea-level rise is that Roches Beach is located between rocky headlands and oriented in such as way as to be subject to a persistent northerly swell-driven longshore drift. As a result the beach had some millennia ago settled into an equilibrium “zeta-form” plan shape, and indeed is the only true zeta-form beach in the South Arm – Frederick Henry Bay region.

In this light, the interpretation which appears best able to explain the observed changes in beach behaviour is that renewed sea-level rise over the last century reached a threshold around the 1970’s at which wave erosion of the upper shoreface (beach and dune-front) was occurring sufficiently frequently that the persistent longshore drift was beginning to remove eroded sand northwards faster than it could be returned to the beach by the swell or replenished by longshore drift from the south. As a result the beach system ‘flipped’ from having a balanced sand budget to having a losing budget, resulting in an onset of progressive shoreline erosion which has been most marked in the deepest (southwestern) part of the zeta-form. In other words, Roches Beach is (unusually for its region) a zeta-form beach which had settled into a planform in equilibrium with (the stable Late Holocene) sea-level some millennia ago, however the process of zeta-form deepening (shoreline recession) has now been re-started by the observed recent onset of renewed rise in sea-level. If this interpretation is correct the beach will have an ongoing tendency towards persistent shoreline recession (deepening of the zeta-form) until sea-level stabilises at some future time and the beach reaches a new zeta-planform in equilibrium with that future sea-level.

Additional future work which could further test this interpretation is described in this report. However the shoreline change detection method used in this project has proven to be a simple technique yielding reliable measures of minimum (demonstrable) shoreline changes over time, and will have utility for both assessing shoreline change at other beaches, and for future monitoring of rates of shoreline change at Roches Beach. Ideally, the remote-sensing (imagery) techniques used in this study should be tied into ground-based monitoring work such as the TASMARC shoreline monitoring program, in order to provide ground-truthing and calibration of shoreline change trends detected in aerial or satellite imagery. Monitoring of changes and trends in shoreline behaviour will be critical information for planning coastal adaptation responses to sea-level rise in residential areas such as Lauderdale.

1.0 INTRODUCTION

Roches Beach is a five kilometre long sandy beach situated at the residential satellite town of Lauderdale, about 13 kilometres east of Hobart city in south-eastern Tasmania, and lying within the City of Clarence. The beach is oriented roughly north-south with an easterly aspect facing into Frederick Henry Bay. Although the beach is located within the Frederick Henry Bay embayment, it is exposed to wave action generated by south-westerly and south-easterly swells refracting northwards into Frederick Henry Bay. Whilst the northern and southern ends of the beach are backed by rising bedrock surfaces, the major central parts of the beach are backed by very-low-lying and highly erodible unconsolidated soft-sediment plains of Holocene (recent Quaternary) age forming the Lauderdale Neck (see further geomorphic description in Section 3.0).

1.1 *The Significance of Coastal Erosion at Roches Beach*

Many houses at Lauderdale are situated on the low-lying soft sediment plain backing Roches Beach, and some of these are located only metres behind the beach, on or immediately behind the low foredune backing Roches Beach. Erosion of the low foredune by storm waves has been a concern to residents since at least the 1970's, and a boulder revetment (wall) was constructed along part of the southern section of Roches Beach circa 1988 in an effort to protect nearby houses from

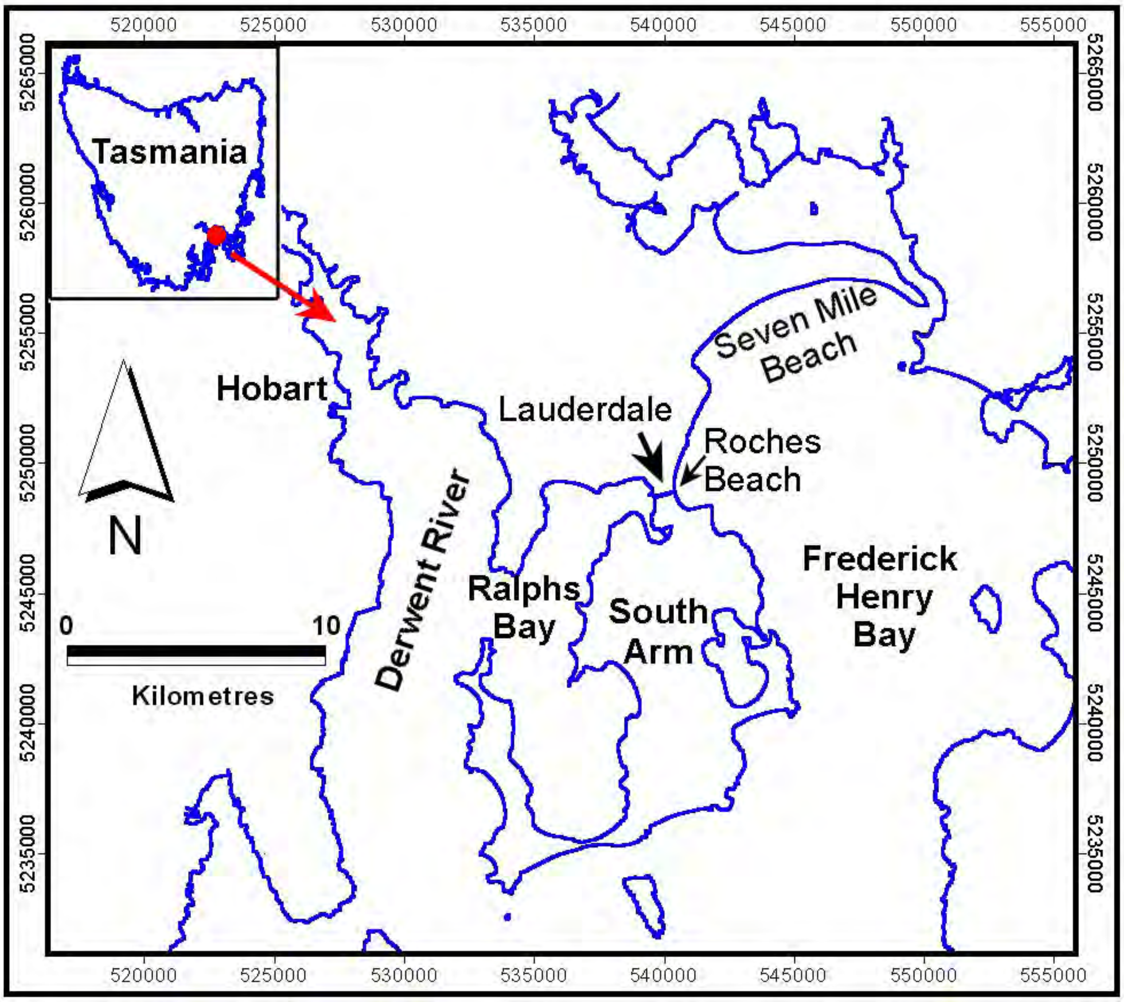

Figure 1: Locality map of Roches Beach, south-eastern Tasmania, Australia. MGA (Zone 55) map grid shown (GDA94 datum).

coastal erosion damage. This wall has largely prevented erosion of the foredune front since 1988, however the unprotected dune front adjacent the northern end of the boulder walls had by 2006 receded about 5 metres inland of the boulder wall (see Figure 31), and some wave erosion of the dune front behind other parts of the boulder wall was by then evident, as a result of storm wave run-up over-topping the boulders (Figure 30).

Sandy beaches and foredunes are highly mobile landforms which rapidly change (erode and accrete) in response to changes in wind and wave conditions. On an equilibrium beach (one that is experiencing neither a net loss or gain of sand in the long term) a cyclic pattern of change known as the "cut and fill" cycle may occur, wherein storm surge waves erode sand from the beach and dune front, dumping it in the shallow sub-tidal zone, from where is gradually returned to the beach and dune front by gentler constructive swell waves and onshore winds following the storms. A beach behaving in this fashion will show occasional erosion episodes followed by accretion, but may not show any long term net change in the shoreline position. Beaches may also show a "rotation" effect, with sand moving back and forwards along the beach in response to cyclic climatic processes including the El Nino Southern Oscillation (ENSO), but again showing no long term net change.

However, a wide range of environmental (geomorphic) variables can result in beaches being out of equilibrium, resulting in either a progressive loss or gain of sand over the long term[1]. One of the key variables in this regard is mean sea level. A large body of research shows that, whilst numerous exceptions may occur due to local variables, the general pattern is that a progressively rising mean sea level will cause sandy shorelines to progressively erode and recede in a landwards direction, in accordance with a geomorphic principle widely referred to as "The Bruun Rule" (Bruun 1954, 1962). In essence this "rule" states that – in the absence of countervailing processes – a shore subject to sea level rise will respond through increased wave erosion of the upper shoreface, and deposition of the eroded debris on the lower shoreface, so as to maintain an equilibrium profile relative to the new (rising) sea level (see Figure 2). This occurs because a rise in sea level allows more frequent wave attack on the upper shoreface than previously, resulting in accelerated erosion and landwards recession there, while the rise in sea level also raises the wave base, creating extra accommodation space on the lower shoreface into which the eroded material can settle out. This principle has been subject to considerable criticism (e.g., Cooper and Pilkey, 2004), much of which relates to the fact that other coastal processes occurring simultaneously with sea level rise (such as those relating to longshore drift and sediment supply) may over-ride this "Bruun process" and result in quite different outcomes. However, to suggest – as is sometimes done – that the Bruun Rule is 'wrong' because some shores do not behave in strict accordance with the rule (where their behaviour is dominated by other processes) is rather like claiming the Law of Gravity is false because aeroplanes fly in apparent defiance of gravity. Actually, gravity is still operating; it's just that other processes (thrust and aerodynamic lift) are dominant in this case.

There is now a broad scientific consensus that renewed global sea level rise has been in progress for about a century (Church & White 2006), with global sea levels having risen by 10 – 20 centimetres during the Twentieth Century (IPCC 2001). Tide gauge records from Port Arthur show that the mean sea level in south-east Tasmania rose by approximately 14 centimetres between 1841 and 2002, with most of the rise probably having occurred since the late 1800's (Hunter *et al.* 2003). Church & White (2006) have shown that the rate of global mean sea-level rise accelerated during the Twentieth Century and a continued rise in global sea level of between 9 and 88 cm by 2100

1 Cut and fill cycles and beach rotation cycles will still occur in such cases, but these processes will be super-imposed on a longer term trend of progressive net change.

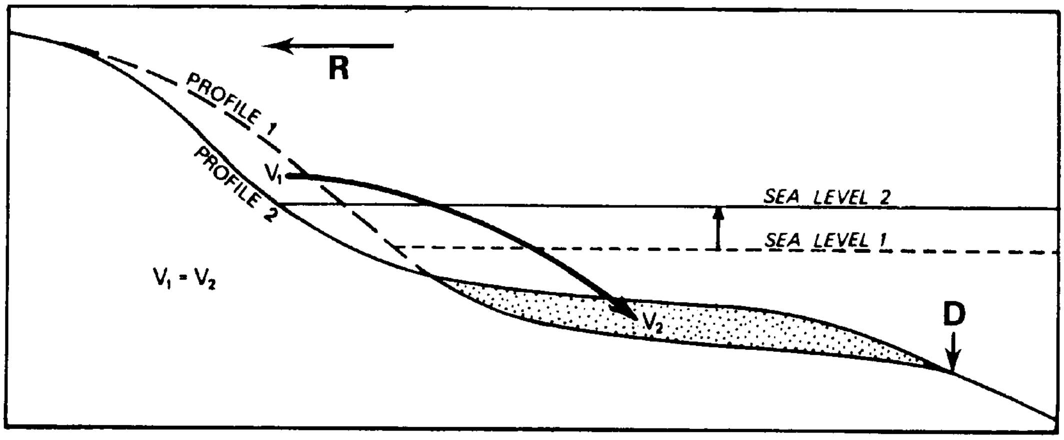

Figure 2: The Bruun Rule in its simplest form. From Bird (1993, p.57, Figure 29), whose original caption to this figure reads: "The Bruun Rule states that a sea-level rise will lead to erosion of the beach and removal of a volume of sand (v1) seaward to be deposited (v2) in such a way as to restore the initial transverse profile landward of D, the outer boundary of near-shore sand deposits. The coastline will retreat (R) until stability is restored after the sea-level rise comes to an end. The coastline thus recedes further than it would if submergence were not accompanied by erosion." It is significant that the transverse (equilibrium) profile at Roches Beach is flatter (shallower) than the profile that would be expected from the Bruun Rule (Carley *et al.* 2008, p. 61 & Fig. 13.5), which indicates that other processes are significantly modifying the effects of the Bruun Rule in that coastal process system (see also discussions in Section 3.3 & 5.2).

relative to 1990 is now projected (Church & Gregory 2001, IPCC 2001, 2007)[2], with even larger rises of between 1.0 – 2.0 metres by 2100 being possible owing to uncertainties about the response of the Antarctic and Greenland ice sheets to global warming (Pilkey & Young 2009). Whilst these rises may at first sight seem small, one implication of the Bruun Rule is that typical sandy shores backed by soft sediments may recede landwards by distances in the order of 50 – 100 times the vertical rise in sea level (Bird 1993, p. 56). This means that, for example, the 0.14m of sea level rise that has occurred in SE Tasmania over the last century or so could have resulted in roughly 7 – 14 metres of shoreline recession on some susceptible Tasmanian beaches. The same consideration indicates that an additional predictable sea level rise of (say) 0.5m by 2100 could result in a further horizontal sandy shoreline recession of 50 metres in susceptible locations[3].

The recognition that global sea level rise is now an observed reality gives rise to the concern that the coastal erosion which has been and is currently being observed at Roches Beach may not be merely part of a long term “cut and fill” cycle, but may be – at least in part – a progressive net recession of the shoreline in response to sea level rise which has already occurred over the last century. Given that global sea level rise is expected to continue – and probably to accelerate – for

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[2] More recent sea-level rise projections (IPCC 2007) appear to give a narrower range of projected sea-level rise over the next century (0.18 – 0.59m rise by 2090-2099 compared to 1980-1999), however these figures were calculated over a slightly different time frame to the 2001 projections, and moreover exclude uncertainties relating to land-ice and permafrost, which were included in the 2001 projections. When presented in the same fashion as the earlier projections, the 2007 projections give similar median and upper sea-level projections to the 2001 figures (John Hunter *pers. comm.*), hence this report continues to quote the IPCC (2001) sea-level rise projections.

[3] It should be carefully noted that the "50 – 100 x sea-level rise” rule of thumb application of the Bruun Rule is an indicative figure only, based on "typical” beach and subtidal gradients, and that the actual degree of erosion (or even accretion) at particular sites may vary considerably depending on a wide range of local conditions including substrate gradient, dune height, longshore drift and sediment budget. As discussed further in Section (5.2), it is probable that significant longshore sediment transport and a flatter-than-equilibrium profile significantly modify the effects of the Bruun Rule on the Roches Beach system.

at least the next century, it is further implicit that coastal erosion and shoreline recession may continue in a progressive fashion at Roches Beach for at least the next century (and probably more).

However, shorelines may erode for a range of reasons other than global ('eustatic') sea-level rise. One common cause of shoreline erosion in places such as the eastern USA and south-east England is ongoing subsidence of the land which causes a local sea-level rise *relative* to the land; however this is a process only experienced in a few locations on Australia's mostly tectonically-stable coasts. Nonetheless, where persistent open coast sandy shoreline erosion and recession has been observed on Australian coasts to date, it can generally be largely attributed to processes other than sea-level rise, including long-term ongoing coastal change processes (e.g., at Ninety Mile Beach in Victoria or Ocean Beach in western Tasmania), and human interferences (as for example at Portland, Victoria). It is notable that progressive coastal erosion clearly attributable to sea-level rise has not yet been identified on most open coast sandy beaches in south-eastern Australia (Church *et al.* 2008). This is attributed to the continuing ability of swell-exposed beaches to rebuild (by means of the 'cut-and-fill' cycle) following storm erosion, and it is expected that such beaches will not begin progressively receding in response to sea-level rise until additional sea-level rise has reached a threshold at which erosive wave attack on the upper shoreface becomes sufficiently frequent that there is insufficient time between erosion events for the beaches to fully rebuild.

Notwithstanding the above however, there are a few open coast sandy beaches in south-eastern Australia which are subject to special local conditions and which have begun to display progressive shoreline recession of a sort which appears difficult to explain other than as the effects of sea-level rise. One example is the very high-energy beaches of far south-west Tasmania, which have been progressively receding for some decades now (Cullen 1998), and whose erosion is likely to be a response to sea-level rise because their exposure to a very high energy wave climate and frequent storm events means they have passed a sea-level rise response threshold earlier than most other open coast beaches. The conclusions of the present report suggest there are also other special local process conditions under which beaches exposed to lower energy wave climates may begin responding to sea-level rise with progressive recession earlier than is the case for most 'typical' open coast beaches, and that Roches Beach is indeed one such special case (see Section 5.0 Discussion and Conclusions).

Because many beaches world-wide are currently both receding (for a range of reasons not limited to global sea-level rise), and have valuable infrastructure or other assets close to their shorelines which are potentially at risk from erosion, there is now considerable interest world-wide in measuring and monitoring shoreline change, including recession. A large literature exists on methods of defining shoreline positions and measuring their change over time (see for example the recent review by Boak & Turner 2005). In some parts of the world such as the USA and UK, where some shorelines have receded significantly over the last few centuries for reasons such as land subsidence, and where useful historical data on shoreline positions is available, shoreline movements over the last century or more have been mapped and shoreline monitoring by a variety of methods is ongoing (e.g., Morton *et al.* 2005, Pye & Blott 2006).

Reliable data on past and ongoing rates and patterns of shoreline change is critical for identifying those shorelines most at risk from erosion related to sea level rise, and in modelling the likely future rates of shoreline erosion at those sites. In other words, the ability to measure the past and present rates of shoreline change at critical coastal locations will be of enormous value for developing improved risk assessments and management response options for vulnerable coastlines having valuable assets such as residential areas.

Because of its history of shoreline erosion, and the existence of a large residential area very close to the eroding shore, Roches Beach is one Tasmanian site where measuring and monitoring of shoreline change will prove very valuable for risk assessment purposes, and for informed decision-making in regard to appropriate responses to the erosion issue.

1.2 *Purpose of this Work*

The primary purpose of this project has been to test several potential methods for detecting and measuring historical and ongoing shoreline position changes in Tasmania, using Roches Beach as a case study because it is both a readily accessible shoreline close to Hobart for which a range of potentially-useful data exists, and also because it is a location where concern over the possible future impact of shoreline movement on housing and infrastructure already exists.

Outcomes of this project include not only the identification of several successful methods of usefully measuring shoreline change (see Sections 4.0 & 5.0), but also a history of shoreline changes at Roches Beach over the last 50 years (Section 5.1) which will provide a basis for ongoing attempts to model and understand the coastal geomorphic processes that are operating at Roches Beach.

This project has additionally collated the available topographic, bathymetric and geomorphic information for Roches Beach (section 3.0), as a starting point for future more detailed investigations of the Holocene and ongoing geomorphic development of the beach, and for more detailed modelling of beach processes and response to sea-level rise.

The GIS datasets which accompany this report provide baseline data on shoreline positions at Roches Beach up to 2005, against which future shoreline measurements can be compared. In addition, the locations of three State Permanent Markers (SPM) installed at Roches Beach as part of the TASMARC beach monitoring project (Section 4.5) have been digitised, and provide benchmarks against which to plot future shoreline movement.

The work described in this report is primarily concerned with coastal erosion, however flooding of low-lying residential areas is a related concern at Roches Beach / Lauderdale, not least because the same storm surge events which cause shoreline erosion at Roches Beach have also been responsible for coastal flooding at Lauderdale in the past, and are likely to cause increased flooding in future with ongoing climate change and sea level rise. The issue of coastal flooding at Roches Beach / Lauderdale is not directly addressed in the present report, however Cromer (2006) and Sharples (2006a) provide discussions of the flooding issue at Lauderdale, and Carley *et al.* (2008) have more recently provided flood inundation modelling using a high resolution digital elevation model and several future sea-level rise and storm surge scenarios.

1.3 *Work Undertaken*

Ortho-rectified air photo imagery used in this project was prepared and supplied by the Information & Land Services Division of the Tasmanian Department of Primary Industries & Water (DPIW). DigitalGlobe Inc. QuickBird satellite imagery was prepared by Sinclair Knight Merz Pty. Ltd., and a clipped portion covering the Roches Beach area was supplied to this project by the University of Tasmania (Centre for Spatial Information Science). Digital recording and analysis of shoreline position information from this imagery was undertaken by Chris Sharples using ESRI Arcview 3.2a software.

An earlier version of this report was prepared (but not published) in October 2007. Subsequent informal peer review, combined with ongoing field observations at Roches Beach by the writer up to 2010, and new information (especially Carley *et al.* 2008), have led to some revision here of the preliminary conclusions provided in the earlier report. However the air photo and satellite imagery analysis has not been extended to 2010, with the data provided remaining the same as that provided in the original 2007 version of this report.

1.4 *Acknowledgements*

This project was initiated, and funding organised, by Dr John Church and Dr John Hunter of the Antarctic Climate and Ecosystems CRC at the University of Tasmania. Dr Werner Hennecke provided access to previous air photo ortho-rectification work at Roches Beach by Honours student Michael Walsh. Chris Stone (Information Land Services, DPIW) organised ortho-rectification of air photos from 1957, 1977 and 1987, and supplied existing ortho-rectified photos from 2001 to the project. Alasdair Wells (DPIW) assisted with organising for the ortho-rectification work to be undertaken, and gave useful suggestions that improved the outcomes of the project. Dr Richard Mount (University of Tasmania) assisted with obtaining QuickBird satellite imagery and metadata of Roches Beach, and Dr Vanessa Lucieer (Tasmanian Aquaculture and Fisheries Institute SEAMAP project) provided access to bathymetric and subtidal substrate mapping of the Roches Beach region. Discussions with Dr Peter Cowell (Sydney University) and Dr James Carley (Water Research Laboratory, Sydney University) have also been helpful in clarifying some issues regarding coastal processes at Roches Beach. Thanks are also extended to local Lauderdale residents Michael & Susanne Hovington, whose volunteer surveying work for the TASMARC project has been used in this report.

All these people are thanked for their kind assistance, without which this project could not have proceeded successfully.

1.5 *Abbreviations and Acronyms Used*

ACE CRC	Antarctic Climate & Ecosystems Co-operative Research Centre (based at University of Tasmania, Sandy Bay, Hobart).
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia).
DPIW	Tasmanian Department of Primary Industries & Water (2006)
DPIWE	Tasmanian Department of Primary Industries, Water & Environment (until early 2006)
ENSO	El Nino Southern Oscillation (large scale global climatic cycle occurring on a multi-year time scale)
ILS	Information & Land Services Division of the Tasmanian Department of Primary Industries & Water (DPIW).
LIDAR	Light Detection And Ranging. Laser – based remote sensing technique capable of measuring topographic profiles from an airborne platform (aircraft).
LIST	Land Information System Tasmania (administered by the Tasmanian Department of Primary Industries & Water (DPIW)).
TASMARC	Tasmanian Shoreline Monitoring and ARChiving project. Long term projected initiated by University of Tasmania and Antarctic Climate & Ecosystems Co-operative Research Centre (Hobart) to monitor shoreline movements in Tasmania using data collected by volunteers and community groups.

2.0 PREVIOUS STUDIES

To date, the only significant study of the Holocene (geologically-recent) geomorphic (landform) development of the Lauderdale Neck and Roches Beach area has been that of Davies (1959, 1961). Details of Davies conclusions are provided in Section (3.2).

In response to increasing concern over erosion at Roches Beach during the 1970's and 1980's, Foster (1988, p. 3) attempted to assess long term erosion at Roches Beach by comparing aerial photographs from January 1948 and January 1984, enlarged to a common scale of 1:5000[4]. Foster stated that within the accuracy of the analysis no significant long term erosion or accretion could be detected over the 36 year period[5]. However, this conclusion is at odds with the results of the present analysis which has demonstrated significant shoreline change (>10m) on some parts of Roches Beach within the same period (specifically, between 1957 and 1977). However, at the 1:5000 scale at which Foster examined the air photos, 1 millimetre on the photos represents 5 metres on the ground. Combined with the presumed lack of ortho-rectification of the air photos, shoreline movements of 5 – 10m scale may not have been detectable using Foster's method. It is also possible that the timing of shoreline "cut & fill" processes at Roches Beach may have been such that, fortuitously, little difference in shoreline position was evident between the air photo dates chosen, whilst significant differences were present between other dates within the 36 year period. This highlights the need to use imagery from more than just two dates in order to form a picture of shoreline change over time.

More recently, Michael Walsh (Spatial Science honours student, University of Tasmania) conducted an analysis of dune-front recession at three locations along Roches Beach, using ortho-rectified air photos from 1957, 1986 and 2001 (Walsh 2004, p. 60-62). Walsh's three locations included portions of recession zones RZ1, RZ3 and RZ5 as defined in the present study (see Figure 18), and yielded results comparable to the present study for those locations. In particular, Walsh identified a net landwards migration of the dune scarp by 6 metres from 1957 to 2001 for part of RZ3, which – given that Walsh did not use error margin buffers around his dune scarp lines - compares well with the results of the present study and that of Cromer (2006, see below) for the same part of Roches Beach.

Cromer (2006, attachment 3) undertook an analysis of 1957, 1975 and 2002 air photos of a portion of Roches Beach north of the canal (around MGA grid 540 400mE 5249 550mN (GDA94 datum), near Balook and Nerang Streets). Cromer found no net recession between 1957 and 1975, but demonstrated a net foredune[6] recession of 5 metres between 1975 and 2002. This result is consistent with the findings of the present report (see further discussion in Section 5.1). The area examined by Cromer falls within the foreshore area designated RZ3 in this report (see Figure 18), at a location in which ortho-photo analysis during the present project has demonstrated a minimum of at least 2 – 4m of landwards shoreline recession between 1957 and 2001 – and potentially up to 4 metres more given the positional error margins of the ortho-photos used for the analysis (see Section 4.2).

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[4] Foster makes no mention of ortho-rectification of the air photos, and it is unlikely that this was done given the difficulties that probably would have been experienced in finding adequate control points in the 1948 image.

[5] This raises an interesting question as to why Foster's report nevertheless proceeded to recommend coastal protection structures...

[6] Cromer measured foredune recession based on the vegetation limit at the seawards scarp of the foredune, which is the same method used in the present work.

A cursory assessment of erosion at Roches Beach by Byrne (2006, p. 11) suggested that “the erosion is much more likely to be part of a long term cyclical phenomenon rather than an ongoing recession of the coast”; however Byrne surprisingly provided no evidence supporting this assertion, which is not consistent with the findings of the present project.

Subsequently – and partly driven by awareness of erosion hazards at Roches Beach - Clarence City Council commissioned a major study of coastal erosion and inundation hazards for the Clarence City beaches which was undertaken by the Water Research Laboratory at the University of NSW. The technical results of this study are detailed by Carley *et al.* (2008), and have provided a wealth of new data on the Clarence beaches, some of which are relevant to and cited in the present study.

3.0 GEOLOGY AND GEOMORPHOLOGY OF ROCHES BEACH

Roches Beach forms the eastern edge of a broad low-lying isthmus or neck of soft unconsolidated sediments connecting the South Arm Peninsula to south-eastern Tasmania (Figure 1). The low neck is occupied by the town of Lauderdale, and is often referred to as the Lauderdale Neck. For the purposes of this study, Roches Beach is considered to comprise the series of nearly-continuous sandy shores extending over about five kilometres from south of Single Hill Point to just west of Mays Point (see Figure 8). Rocky outcrops occur on and backing the northerly and southernmost parts of the beach, however the main southerly part of the beach is backed by the low sandy Lauderdale Neck on which the township of Lauderdale is situated.

3.1 *Bedrock Geology*

The bedrock geology of the lower Derwent River region of southeast Tasmania (including the South Arm Peninsula) is structurally disrupted by generally N-S to NW-SE trending normal faults produced by extensional rifting during the Tertiary-age separation of Tasmania and Antarctica (Baillie & Leaman in Burrett & Martin 1989, p. 365). The South Arm peninsula comprises several up-standing fault blocks (horsts) of hard lithified Permian – age sedimentary rocks intruded by the Jurassic-age igneous rock dolerite. These are separated by low fault basins (grabens) which are infilled by semi-lithified (relatively soft) Tertiary-age sediments (circa 30 million years old) including gravels, sands and clays of fluvial and lacustrine origin. One of these grabens underlies the low region of eastern South Arm extending from Clifton Beach northwards through Pipe Clay and Rushy Lagoons, and Tertiary – age sediments are exposed around the shores of Pipe Clay Lagoon (Gulline 1982). The low-lying Lauderdale Neck is inferred to be underlain by the north-wards extension of this graben, and Leaman (1976, Fig. 10) infers the Lauderdale Neck to be underlain by a graben infill of soft Tertiary sediments. Tertiary sediments are exposed on the northern shore of Ralphs Bay, at the northwest margins of the Lauderdale Neck (Leaman 1972).

Relatively soft Tertiary – age sediments are thus inferred to underlie most of Roches Beach, however these are nowhere exposed along the Roches Beach shoreline, being completely mantled by geologically – young Quaternary-age sediments of coastal origin. However, at the southern end of Roches Beach, dolerite bedrock is exposed on rising slopes behind the beach at Mays Point (Gulline 1982). This dolerite bedrock forms part of the horst block bounding the eastern side of the Clifton Beach – Lauderdale Tertiary Graben. Dolerite and Permian-age sedimentary rocks are also exposed along and behind the northern parts of Roches Beach, similarly forming part of an upstanding bedrock horst block adjoining the northern end of the graben that underlies most of Roches Beach.

It is important to note that, whereas the northern and southern extremities of Roches Beach are backed by hard lithified dolerite and Permian-age sedimentary bedrock which rises above the back of the beach and limits potential for geologically-rapid landwards erosion of the shoreline in those areas, the main central part of Roches Beach is underlain by softer Tertiary-age sediments which lie below the present sea level, and are instead mantled by soft geologically-recent sediments that are highly susceptible to erosion by wave action. A small rocky dolerite point (or “salient”) referred to by Carley *et al.* (2008) as ‘Bambra Reef’, at the north end of the main southern part of Roches Beach appears to be an isolated patch of higher bedrock relief, since the shorelines to north and south of this point are evidently backed by low-lying plains of soft unconsolidated sediment.

Compared to many coastlines elsewhere in the world, the Tasmanian coast including Roches Beach area is tectonically stable. This is relevant to the present study, since high rates of coastal subsidence can result in rapid coastal erosion through the relative rise of sea levels against sinking land. However, although no long term high-precision geodetic measurements of vertical coastal land movement are yet available for Tasmania, modelling of known geological and glacio/hydro-isostatic factors indicates that parts of the south-eastern Tasmanian coast could theoretically be experiencing a low rate of vertical tectonic uplift of the order of 0.2 ± 0.2mm /year (Hunter *et al.* 2003). There is no evidence of detectable subsidence (e.g., through sediment compaction) in the Roches Beach area.

3.2 *Geomorphic History*

To date, the only significant study of the geomorphic (landform) development of the Lauderdale Neck and Roches Beach area has been that of Davies (1959, 1961).

Davies (1959) considered the South Arm peninsula to have been a series of islands at the end of the post-glacial marine transgression, which has been dated to mid-Holocene times circa 6,500 years ago (Thom & Roy 1985). Davies (1959) considered the Lauderdale Neck area to have then been a shallow narrow strait separating South Arm from the Tasmanian mainland, and he identified a low (~0.5m high) scarp at the northern end of the Neck as the mainland shoreline at that time. This shoreline is depicted as the "Milford HWM" on Figure 3 (after Davies 1959). Davies (1959) considers that two spits subsequently developed across the strait, comprising a shingle and shell spit on the western (Ralphs Bay) side, and a sand spit on the eastern (Frederick Henry Bay) side. Greater exposure to wave action on the Frederick Henry Bay side resulting in a series of beach ridges[7] being built there as the sandy spit grew (prograded). See Figure 3. Davies (1961) notes that the average height of each beach ridge behind the Frederick Henry Bay side decreases gradually to seawards, and he interprets this is indicating a slight fall in sea level following the highest level of the post-glacial marine transgression 6,500 years ago, before the late Holocene sea level finally stabilised at roughly its present level[8]. Progradation of the sand spit ultimately closed the gap to the South Arm Peninsula, and combined with the infilling of salt marsh areas west of the sand spit, produced the present day Lauderdale Neck. The former sand spit is no longer prograding towards Frederick Henry Bay, and the seawards margin of the beach ridges is now marked by a single foredune behind Roches Beach which has developed by accumulation of windblown sand off Roches Beach, and stands over a metre higher than the older beach ridges on its landwards side (see Figure 4 & Figure 6)[9].

The existence of a single larger foredune behind Roches Beach marking the seawards margin of the series of lower beach ridges implies that progradation of the former sand spit ended some millennia ago, and that the position of the shoreline has been generally stable since that time. A significant foredune would not have developed until the rapid progradation indicated by the beach ridges had ceased, and if subsequent shoreline development had involved large variations (especially recession) in the shoreline position then it is likely that exposure of older deposits under parts of the foredune might be expected in places (if the shoreline had been receding prior to development of the current foredune), whilst remnants of more than one foredune ridge might be preserved along at least some portions of the beach (where additional progradation occurred). Due to the lack of

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7 Davies (1961) considers these beach ridges to have been wave-built berms on which a low wind-blown dune began to accumulate as shoreline progradation continued and each berm became progressively separated from continuing wave action.

8 A similar slight fall in sea level following the end of the post-glacial marine transgression has been noted on mainland Australia, and is attributed to hydro-isostatic adjustment of the continental shelf in response to loading of the shelf by the higher post-glacial seas (Lambeck & Nakada 1990).

9 The beach ridges to landwards of the single foredune were mapped and measured by Davies (1959, 1961), but are difficult to identify today. This is probably due to subsequent disturbance by road making and housing construction at Lauderdale, which has been particularly concentrated on the area of beach ridges. The beach ridges have clearly been favoured development sites since they provide slightly higher and better drained ground than other parts of the Lauderdale Neck (which is mostly very low-lying and poorly drained).

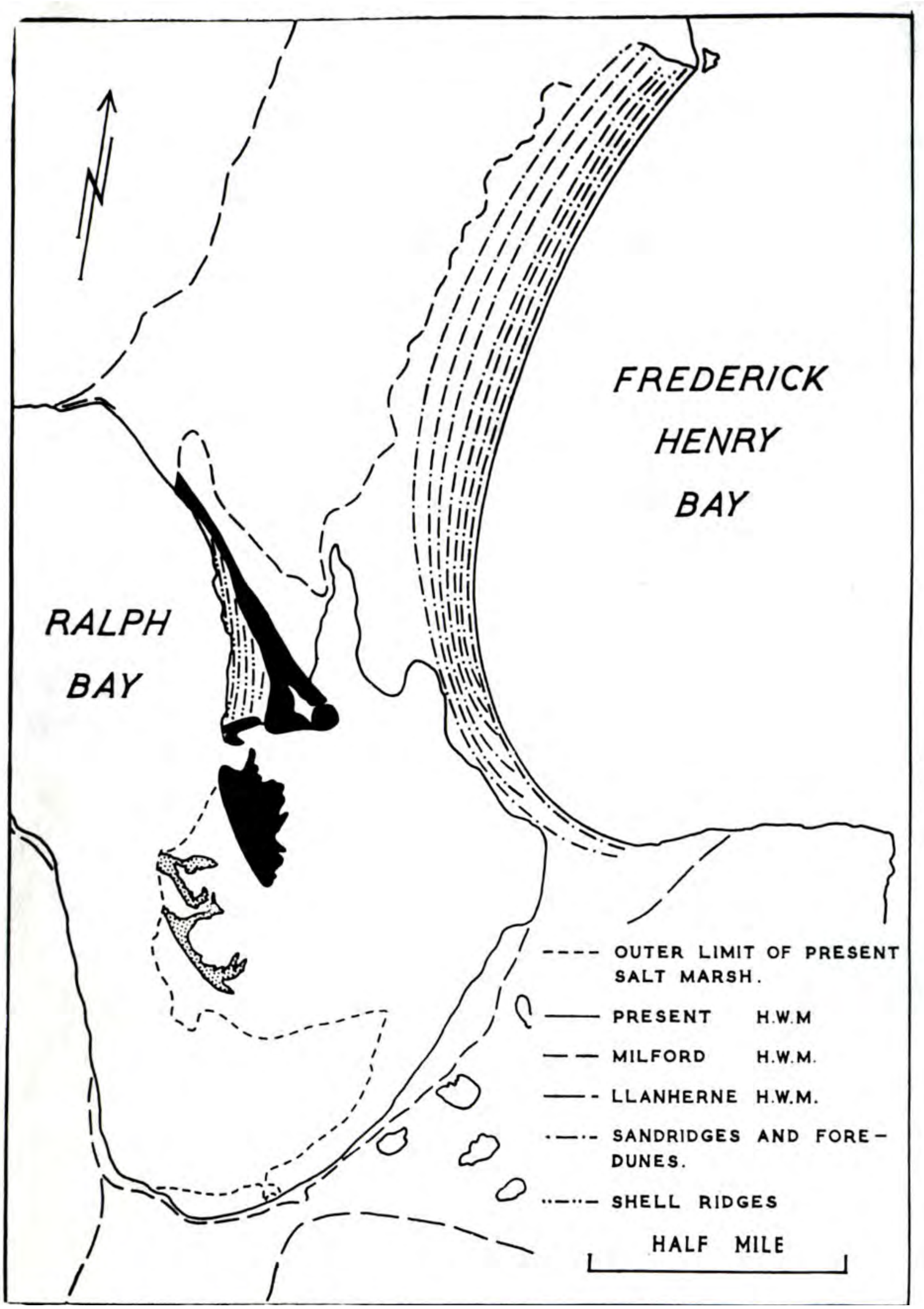

Figure 3: Geomorphic features identified at Roches Beach – Lauderdale by Davies (1959). Shingle structures are shown in black, shell structures are stippled. "Sand ridges" behind Roches Beach comprise a single foredune backed by low beach ridges. Most of the low beach ridges behind the foredune have been disturbed by roading and housing construction subsequent to 1959, and are generally difficult to discern today (see also Figure 6 & Figure 4). Davies considered the Milford HWM to represent a shoreline formed during a slightly higher mid-Holocene sea-stand following the last post-glacial marine transgression. The Llanherne HWM is likely to be a Last Interglacial shoreline. (Reproduction of Fig. 3 of Davies 1959).

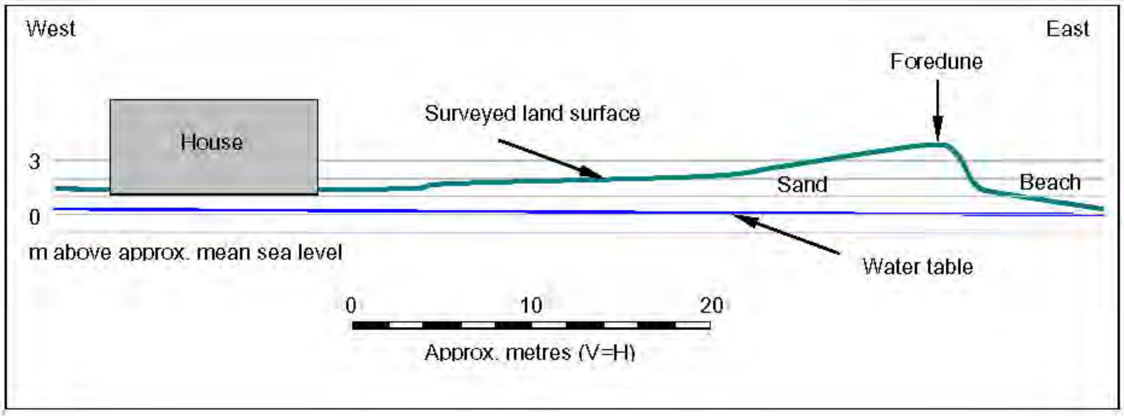

Figure 4: Surveyed profile of the foredune at the end of Aragoon Street, Roches Beach, reproduced from Cromer (2006, Fig. 2). A single foredune with a scarped seawards face is evident, and similar profiles are typical for much of Roches Beach. A series of low beach ridges mapped by Davies (1959) inland of the foredune (see Figure 3) are very subtle and virtually indiscernible today, probably largely due to ground disturbance associated with the building of the roads and houses of Lauderdale on the beach ridge area subsequent to 1959. As noted by Cromer (2006), this profile highlights the fact that many houses behind the foredune at Lauderdale are only about 1 metre above mean sea level, even though the foredune crest itself rises up to 3 metres above mean sea level. This location is at MGA (Zone 55) 540 369mE 5249 152mN (GDA94), about 200 metres north of the canal.

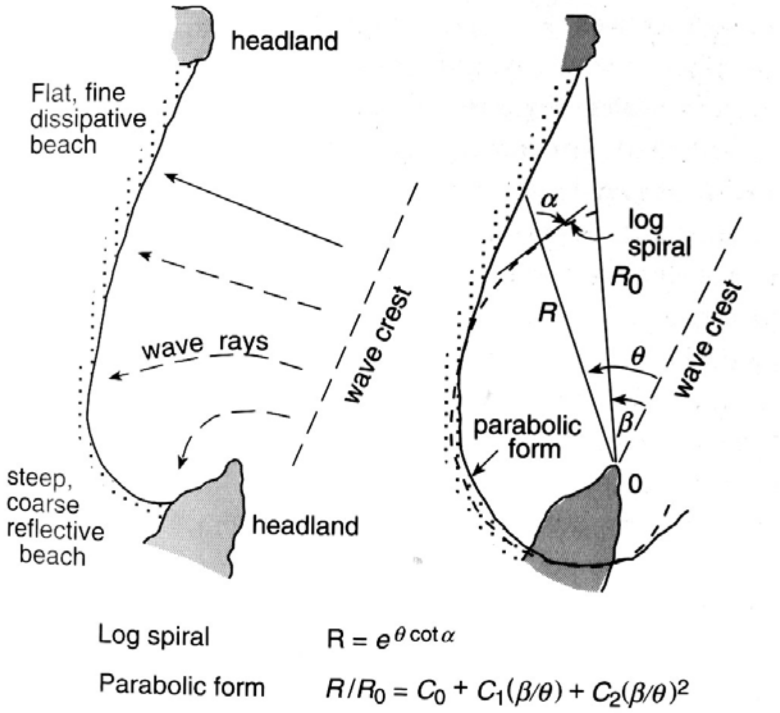

Figure 5: Diagram of a "Zeta-form" beach planform (Figure reproduced from Woodroffe 2003, after Hsu *et al.* 1989). Subsequent to Holocene progradation of the Lauderdale Neck and Roches Beach (Davies 1959), the main southern part of Roches Beach has settled into an equilibrium zeta-form plan controlled by the generally northwards – directed swell in Frederick Henry Bay (see Figure 9), the southern rocky headland of Mays Point, and the rocky point of Bambra Reef at the northern end of the main beach (compare also Figure 8).

pertinent dating studies at Roches Beach, no information is available regarding the timing of the end of the phase of shoreline progradation and beach ridge formation at Roches Beach. However, many Australian beaches show a similar pattern of rapid shoreline growth or progradation for a period after the end of the post-glacial marine transgression (circa 6,500 years BP), followed by a stabilisation of shoreline positions around 3000 – 4000 years ago (Thom 1974, p. 205-206: Thom & Roy 1985, p. 261-262).

It is notable that the main southern part of Roches Beach north from Mays Point to the small rocky point of Bambra Reef roughly 3km further north exhibits a smooth curving planform known as a "zeta-form" (see Figure 5). This is a beach form that develops where an embayed sandy beach (between rocky points) is shaped by swell waves arriving at the beach predominantly from a somewhat oblique direction rather than directly onto the beach. Roches Beach is the only well-developed zeta-form beach in the South Arm – Frederick Henry Bay region (whilst Cremorne Beach to the south is somewhat similar, the tidal channel linking Cremorne Beach to the sediment-filled Pipe Clay Lagoon results in significantly different processes dominating that beach). At Roches Beach, the zeta-form is evidently a response to the predominating south-westerly swell which refracts into Frederick Henry Bay from the south, arriving obliquely at Roches Beach from a southerly direction (see Figure 9). Because a zeta-form is produced by swells arriving obliquely to the beach embayment, there is generally a net longshore drift of sand of shallow subtidal sand through the embayment, driven by the oblique wave directions. If a ready supply of subtidal sand is capable if being driven into as well as out of the embayment by this process, then the beach planform may remain in equilibrium as long as the sand supply persists, however if there is a deficit in the sand supply into the embayment, then ongoing drift of sand through the embayment may cause progressive loss of sand at the shoreline at the up-drift end, driving the shoreline into a progressively "deeper" zeta-form and causing progressive recession of the shoreline.

This latter process is likely part of the explanation of recently renewed erosion at Roches Beach (see Section 5.2), although the shoreline position has probably been mostly stable for some millennia (as indicated by the presence of a single foredune fronting a series of progradational beach ridges; see above) suggesting that drift of sand both into and out of the embayment has probably been in balance until recent decades. Rather, the Roches Beach zeta-form is probably that stable form which the beach settled into after mid-Holocene progradation reached a point where the beach planform was in equilibrium with the alongshore sand drift and predominating swell regime. Subsequent recent shoreline erosion at Roches Beach is likely to be the result of more recent disturbance of the equilibrium by a different factor, namely sea-level rise, which has restarted the process of zeta-form deepening described above (see Section 5.2).

3.3 *Description and Geomorphic Processes*

The present day distribution of coastal sediments and landforms of recent (Holocene) origin at Roches Beach is mapped on Figure 6 (onshore) and Figure 7 (offshore), and is indicated as line maps in Figure 8.

Roches Beach comprises mainly fine- to medium-grained sand forming a gently-angled beach terrace. A sand sample taken near the Low Tide Mark south of Bambra Reef by Carley *et al.* (2008, p. 54-55) had a measured median sand grainsize of 0.150mm (i.e., fine – grained), with a small proportion of medium – sized grains. Most of the beach is backed by a single foredune rising 2 or up to 3 metres above sea level in places, which in turn is backed by lower subdued beach-ridges (see Section 3.2) except behind the northern-most and southern-most parts of the beach where a bedrock slope rises directly behind the beach (see Figure 8). However, most of Roches Beach is backed by a low profile plain of soft sandy Holocene sediments extending below present sea level (see Figure 6).

Roches Beach has a microtidal tide range of approximately 1.2m and 0.3m for spring and neap tides respectively (Short 2006, p. 126), and receives a refracted open coast swell wave regime. Under normal conditions the wave climate at Roches Beach is dominated by south-westerly swells which refract northwards up Frederick Henry Bay and arrive obliquely at Roches Beach (see Figure 9), producing mainly low wave energies at the shore, and driving a gentle northwards longshore drift along most of Roches Beach except at the sheltered southernmost end of the beach in the lee of Mays Point. Visual observation shows that the small fair-weather swell received at Roches Beach is adequate to disturb and move sand in the near-shore zone.

Roches Beach has been described by Short (2006, p. 126) as a series of five distinct beach segments separated by small rocky outcrops, and increasing in length southwards to the main southern beach which is about 3.5 km long (see "upper intertidal" beach map, Figure 8). Short classifies all five beach segments as Low Tide Terrace (LTT) beaches, switching to a short reflective beach at the southern corner of the main southern beach segment. A Low Tide Terrace beach (Short 2006, p. 37) is a wave-dominated low energy beach which typically forms on open coasts where sand is fine to medium-grained (as at Roches Beach) and wave height averages between 0.5 and 1 metre. Low Tide Terrace beaches typically have a steeper upper beach face and a broad gentler-angled low tide sand terrace or bar that may be 20 – 50m wide (Short 2006, p.37). On this type of beach, low waves pass over the submerged terrace at high tide and break on the upper beach face, behaving like a reflective beach (see below). However, at spring low tides the low tide terrace is exposed, and waves break more heavily on the outer edge of the terrace. At mid-tide, waves break right across the low tide terrace, forming a surf zone.

The southernmost (longest) section of Roches Beach has a well developed low tide terrace in its northern parts, which narrows southwards as average wave height decreases to less than 0.5m in the more sheltered lee of Mays Point, and the beach switches to a reflective beach at its southern corner (Short 2006, p. 126). Reflective beaches are low energy wave-dominated beaches that typically form at the more sheltered end of beaches, as is the case at Roches Beach, and exhibit somewhat steeper narrower beaches than Low Tide Terrace beaches. Since these beaches lack a low tide bar, waves move unbroken to the shore, and collapse or surge up the upper beach face (Short 2006, p. 38). Due to the short distance over which the waves break and run up the beach face, the wave energy is not fully expended in the run-up, and waves may reflect back out to sea, hence the term "reflective" beach.

Much of the area of the broad low Holocene Lauderdale Neck behind (west of) Roches Beach) was inferred by Leaman (1972) and Gulline (1982) to be blanketed by windblown sand, and the beach ridges mapped by Davies (1959, see Figure 3) probably also have a veneer of aeolian sand. Extensive saltmarsh – partly reclaimed by landfill – is also present across the southern part of the neck behind Roches Beach (see Figure 6). Little stratigraphic or sedimentological information is available for most of the Holocene deposits forming Lauderdale Neck; however some data is available from shallow drilling undertaken in the saltmarsh area surrounding the Lauderdale tip (landfill). See Figure 6. Cox (1990) records that 23 shallow boreholes around the landfill (on existing or disturbed saltmarsh), drilled to depths of between 2 and 6 metres, yielded similar stratigraphies comprising an uppermost horizon about 1.3m thick of fine sand with shell fragments, overlying at least several metres of interbedded sands and sandy clays including glauconitic beds. However, drilling to date at Lauderdale Neck has mainly been undertaken for reasons of groundwater and landfill leachate assessment, and there is scope for future drilling to contribute useful dating and palaeo-environmental data which will illuminate the Holocene development and history of Roches Beach and Lauderdale Neck.

Directly offshore from Roches Beach, Frederick Henry Bay has a broad shallow low-gradient seabed reaching 5 metres depth directly off Mays and Single Hill Points, but only reaching 10 metres depth several kilometres offshore (see Figure 7). Carley *et al.* (2008, Fig. 13.5) measured transverse profiles (dune to subtidal) for a range of beaches in Clarence Municipality and found

Roches Beach (offshore from the canal area) to have the flattest (shallowest) profile of any open coast (swell-exposed) beach in Clarence[10]. This is probably a significant factor in understanding the behaviour of Roches Beach, and is further discussed in Section (5.2).

With the exception of a few isolated rocky reefs, the subtidal region of the Roches Beach embayment is mantled by sand from the Low Water Mark offshore (Figure 7), and indeed the sandy subtidal substrate is visible in shallow water when viewed from the rocky shorelines at Mays and Single Hill Points. Shallow subtidal sand is continuously present immediately below LWM from south of Mays Point northwards around Single Hill Point to Seven Mile Beach (Figure 7), implying that there is no impediment to swell-driven longshore currents driving subtidal sand both into Roches Beach embayment from the south and out of the embayment to the north. Foster (1988) and Byrne (2006) have previously made order-of-magnitude estimates that the rate of littoral drift of sand past Roches Beach has historically been of the order of 60,000 to 70,000 cubic metres sand per year northwards, based on estimated accumulation of sand at Seven Mile Beach over the last 6000 years (see also Carley *et al.* 2008, p. 57). Indeed, the western end of Seven Mile beach is currently characterised by incipient foredunes indicative of ongoing sand accretion in that part of the beach (C. Sharples *personal observations* 2009), for which the most likely source is sand drifting north from Roches Beach as proposed by Foster & Byrne. Results obtained during this work from historic air photo analysis also confirm that a general northwards longshore drift of sand has been operating at Roches Beach over recent decades (see Figure 13 and Section 5.1).

Roches Beach has an easterly aspect, facing Frederick Henry Bay, and is therefore relatively protected from westerly and south-westerly storms. However, the fetch across Frederick Henry Bay facing the beach is of the order of ten kilometres (Figure 1), providing potential for the beach to be directly impacted by large wind waves generated across the bay during easterly or north-easterly storms of the sort which episodically affect eastern Tasmania during Tasman Sea low pressure storm events. This suggests that significant erosion events at Roches Beach might be expected to be more likely driven by easterly or north-easterly storms than by westerly or south-westerly ones.

Foster (1988, p.1) collated records of dates on which erosion events are "stated"[11] to have occurred at Roches Beach prior to 1988. The dates cited were:

4-6 December 1968
3-5 August 1974
23-25 April 1978
1-3 December 1979
18-20 July 1983
15-18 October 1984
2-5 March 1985
3-5 June 1985

Foster was unable to determine what characteristics of the wind, wave and tide conditions on the days concerned it was that caused erosion to occur. Sharples (2006a) and Cromer (2006) have also collated newspaper and some anecdotal records of storm surges which caused flooding (and possibly erosion) at Lauderdale / Roches Beach, which resulted in a different list of known storm dates as follows:

[10] Nearby swell-sheltered sandy shores in Pittwater (Five Mile Beach) and Ralphs Bay (e.g., Gorringes Beach at Mortimer Bay) also have very flat, shallow transverse profiles, however this is unremarkable for these beaches, which are tidal re-entrant shores subject to a different suite of geomorphic processes to swell-exposed open coast beaches such as Roches Beach.

[11] Information source not cited by Foster, but assumed to be local anecdotal reports.

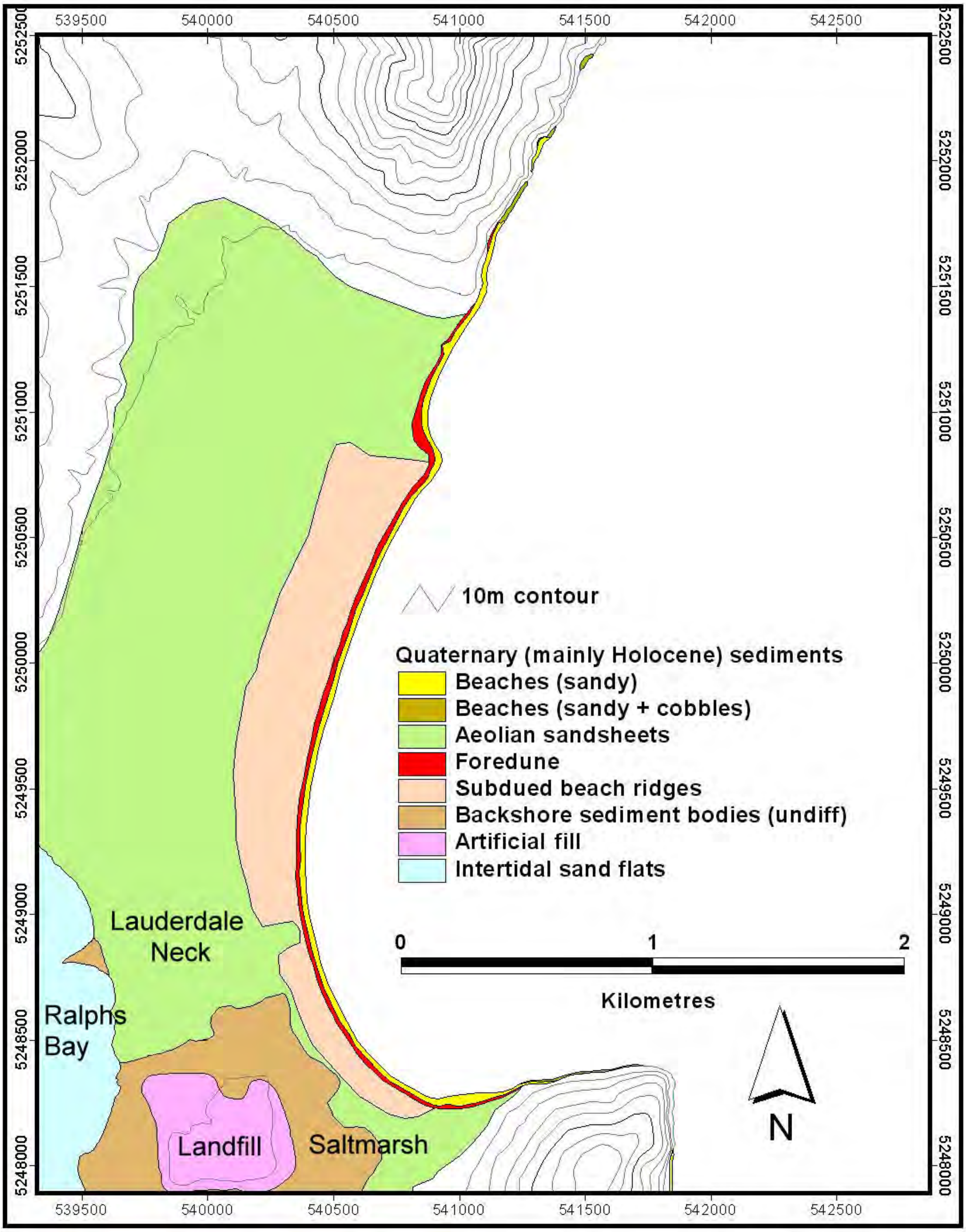

Figure 6: Onshore Quaternary (mainly Holocene) coastal soft sediment deposits and landforms at Roches Beach. This map is reproduced from a portion of the *tascoastsed_v4gda* Tasmanian Quaternary Coastal Sediments map held by DPIW (Sharples 2006c), and is based on information from Davies (1959), Leaman (1972) and field observations by C. Sharples. Map grid is Map Grid of Australia (MGA) Zone 55, based on the GDA94 datum.

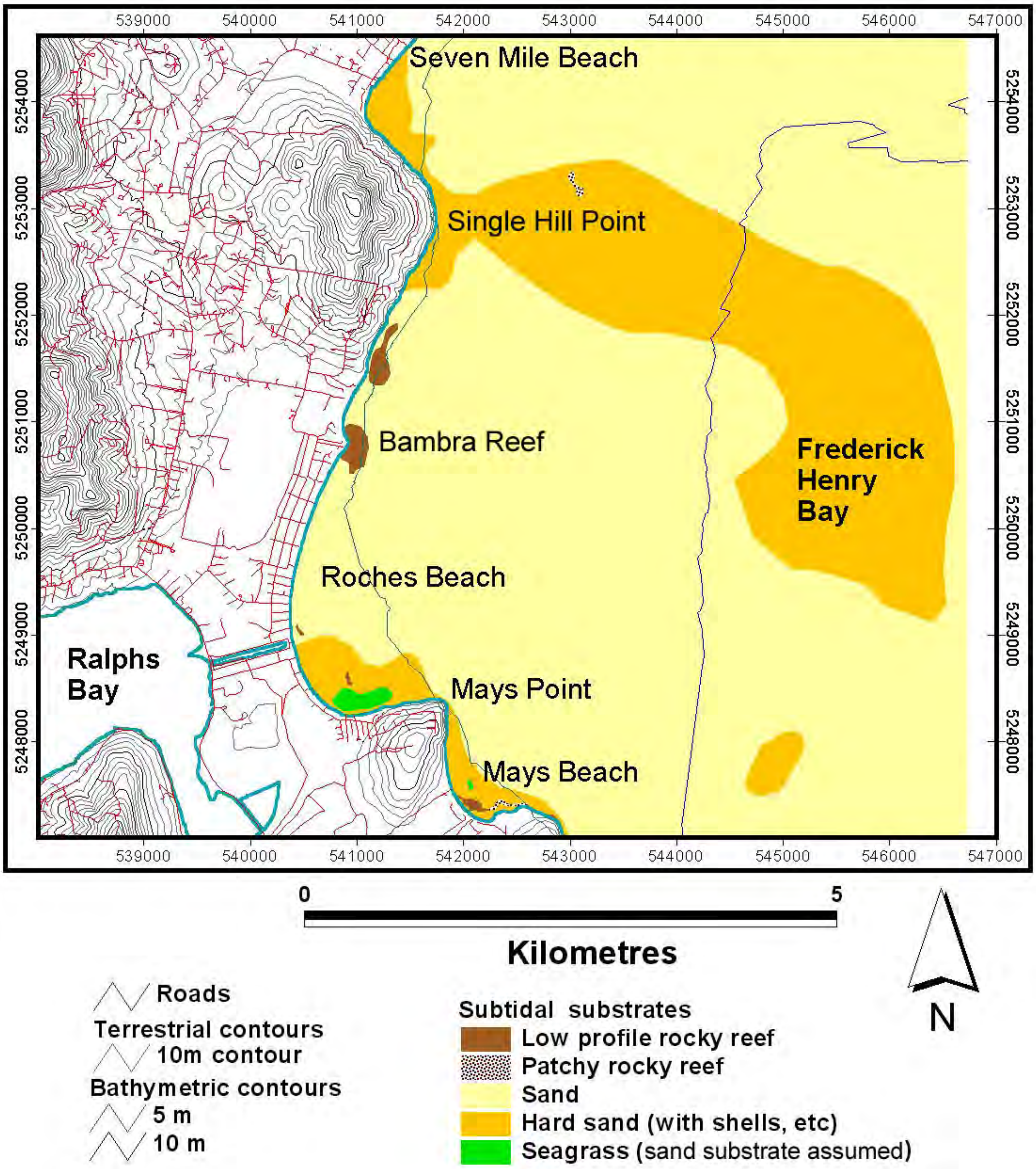

Figure 7: Offshore (subtidal) sediments and bathymetry in the Roches Beach – Seven Mile Beach – Frederick Henry Bay area. The subtidal bathymetry and substrate data shown is copyright © the SEAMAP Tasmania Project (Tasmanian Aquaculture and Fisheries Institute, University of Tasmania), and is reproduced here with permission. Map grid is Map Grid of Australia (MGA) Zone 55, based on the GDA94 datum.

Nov 1967
Oct/Nov 1970
Early 1980's
Jan 1986
July 1988 (highest storm surge recorded to date at Hobart tide gauge)
Aug 1991
May 1994
Nov 1994
June 2005
Sept 2005

Despite partly overlapping time frames these two lists record different storm dates. The weather conditions associated with these storm surges may not have always caused erosion at Roches Beach (depending for example on wind directions), and it is unclear which did. The differences between the two lists – which include anecdotal reports of unknown accuracy - also suggest that there could have been other erosive storms on dates not included in either of these lists.

It will clearly require further work, including a systematic examination of weather records, particularly wind and tide conditions, to determine the dates and types of weather events that have resulted in significant erosion at Roches Beach. Such investigations would be of considerable value in better understanding erosion processes at Roches Beach (see Section 5.4).

3.4 *Artificial Modifications at Roches Beach*

No effort has been made in this study to reconstruct the history of settlement and artificial beach modification at Roches Beach in detail; however several notable events are well known and pertinent to understanding erosion processes and implications at Roches Beach.

The most prominent artificial modification of natural landforms at Roches Beach is the Lauderdale Canal, which was originally cut though the beach, albeit natural longshore drift of sand quickly repaired this gap, much to the canal proponent's chagrin! Alexander (2003, p. 161) records that the Lauderdale Canal was cut through the neck from Ralph's Bay to Frederick Henry Bay during 1924. However, shortly after completion of the canal to the High Water Mark on the Frederick Henry Bay side (Roches Beach), a storm filled the mouth of the canal with sand. This was cut through, and then another larger storm filled the mouth of the canal with even more sand. It was then realised that training walls would be needed to keep the mouth clear of sand, and a start was evidently made on constructing wooden training walls, whose remains are still visible on Roches Beach today. However, it was realised that even with these structures, continual dredging of the canal would still be needed, and a parliamentary committee ultimately recommended that the likely usage of the canal would not justify such ongoing expense. The canal project was abandoned, and Alexander (2003, p. 161) records that only one boat is reputed to have actually sailed through the canal during the brief period it was open at the eastern end.

Recent high resolution LIDAR Digital Elevation Models of the Lauderdale area demonstrate that slightly raised ground parallels the canal to both north and south, and this is undoubtedly spoil from the canal excavation. A small sandy spit immediately north of the canal entrance at its western (Ralphs Bay) end, now colonised by saltmarsh, is also understood to have originated as a spoil dump during the excavation work.

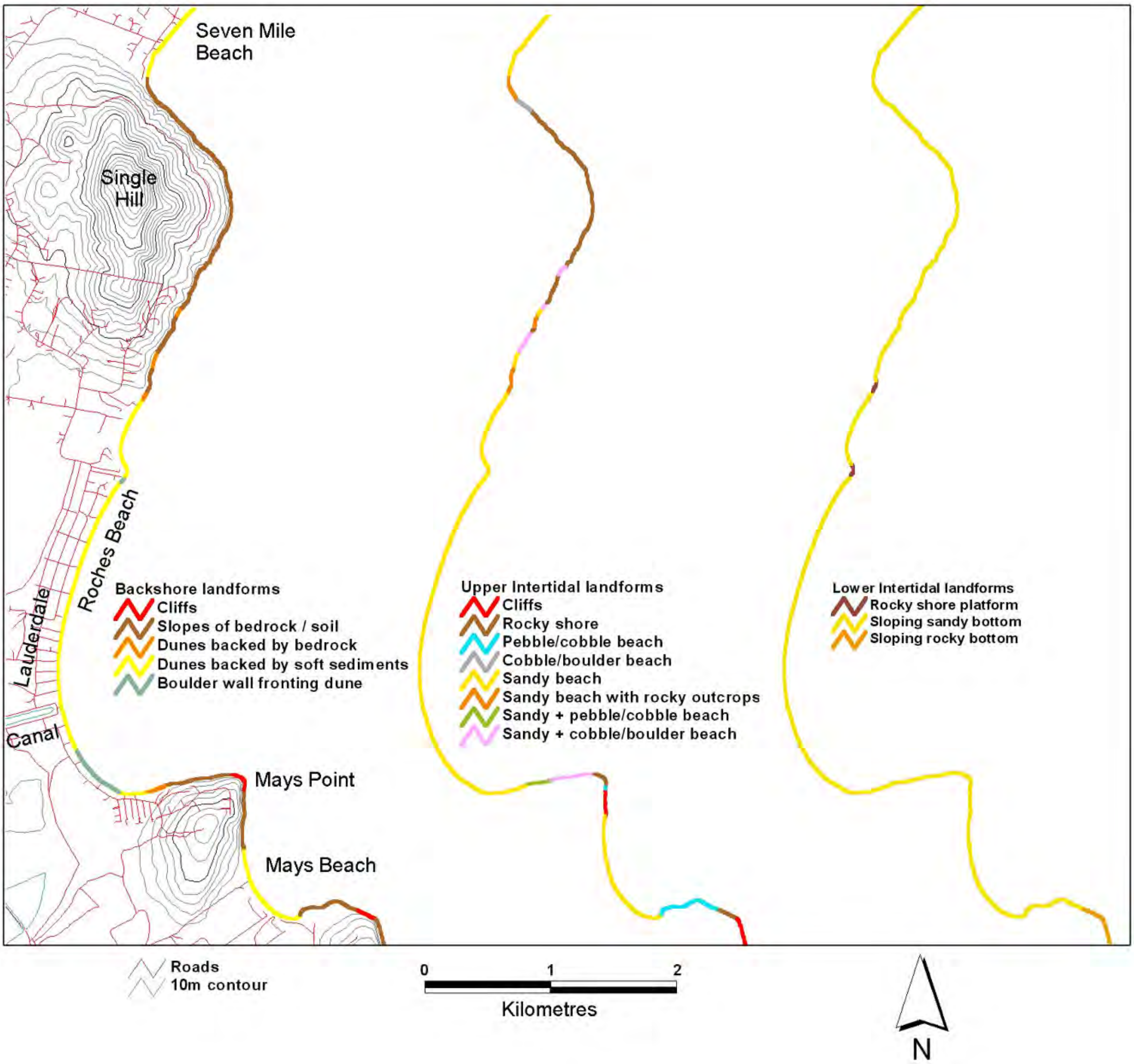

Figure 8: Coastal landform types at Roches Beach and adjacent areas. This map is reproduced from a portion of the *tascoastgeo_v4gda* Tasmanian Shoreline Geomorphic Types line map held by DPIPWE (Sharples 2006b), and is based on field observations by C. Sharples. Note that the information depicted here has now been incorporated into a similar but reclassified national coastal geomorphic map known as the 'Smartline', which is held by Geoscience Australia and is described in full by Sharples *et al.* (2009).

A number of unsealed roads and houses were present behind the beach by 1957, although most residential development at the time was close to the canal. A number of walking tracks eroded through the foredune are visible on the 1957 air photos. However, residential development has increased significantly since 1957, and by 2001 there was virtually continuous residential development behind nearly all of the main part of Roches Beach, with many houses being situated partly on or only metres behind the foredune.

Because of the proximity of houses to Roches Beach, by the 1980's there was considerable concern about the potential effects of beach and dune erosion on residences close to the beach, particularly south of the canal where the results of this study indicate that the largest erosion events occurred during the 1970's and 1980's (see Section 5.1). In response to this concern, a study of the erosion problem was commissioned by the Lands Department (Foster 1988). Despite concluding that an analysis of air photos from 1948 and 1984 showed "no significant long term erosion or accretion could be detected over this 36 year period" (Foster 1988, p. 3)[12], the report nonetheless went on to discuss design parameters for a revetment to protect the beach from further erosion. A boulder revetment (wall) was constructed along much of the beach south of the canal during the 1980's, and horizontal shoreline movement in that part of the beach has subsequently ceased, although the dune behind the wall has recently begun showing renewed erosion as a result of over-topping by storm waves (see Figure 30). The extent of the boulder wall is indicated on Figure 8 & Figure 10.

Anecdotal evidence from Clarence Council officers (verbal advice to C. Sharples 2007) indicates that at around the same time that the boulder revetment was constructed (circa 1987-88), roughly 105,000 m^2 of externally-sourced sand was dumped in the shallow subtidal or lower intertidal part of Roches Beach adjacent the canal, in an effort at beach replenishment. It is conceivable that this

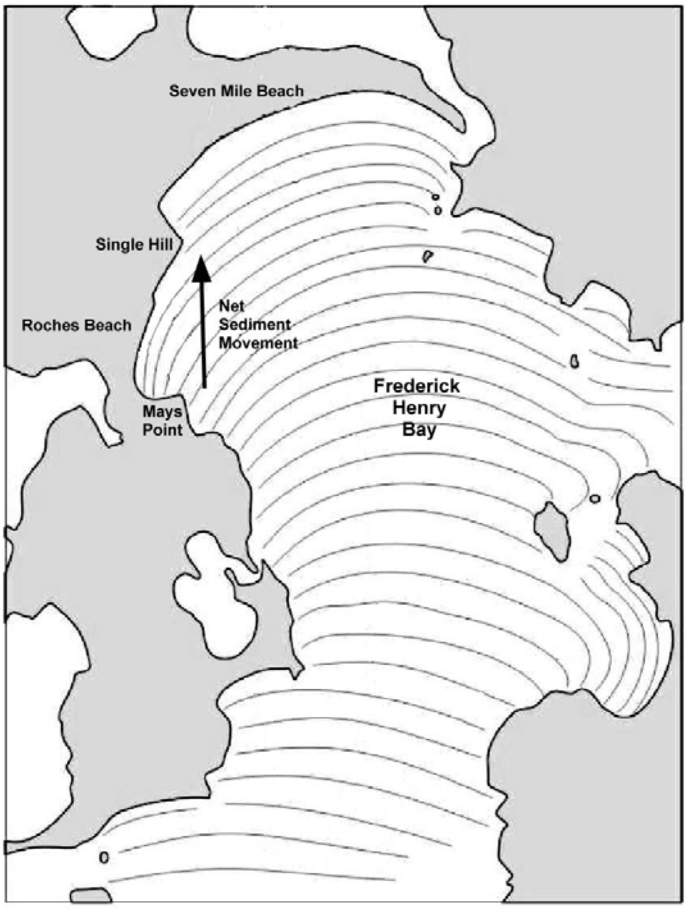

Figure 9: Swell wave refraction diagram for Frederick Henry Bay, showing how the predominating south-westerly swells produce a dominantly northwards longshore drift along the western side of Frederick Henry Bay (figure adapted from Byrne 2006). Although the southern end of the zeta-form Roches Beach embayment (in the lee of Mays Point) is relatively sheltered and may act as a sediment trap under normal swell conditions, the shallow bathymetry of the western side of Frederick Henry Bay and the presence of continuous shallow subtidal sands from south of Mays Point to Seven Mile Beach (see Figure 7), implies that this normal swell wave action is capable of driving a net northwards littoral drift of sand from south of Mays Point, through the Roches Beach embayment, and onwards around Single Hill Point to Seven Mile Beach.

[12] As noted in Section (2.0), this conclusion is contrary to those of the present study. It is difficult to assess the accuracy of Foster's study, since no information was provided regarding the methods used in Fosters analysis.

sand may have contributed to the partial re-building of the beach and foredune that occurred in areas immediately north and south of the canal between 1987 and 2001 (see Figure 18), however the extent of post-1987 shoreline accretion north of the canal was very limited, and both areas have subsequently exhibited renewed recession since before 2001.

During May 1998, sand-trapping fabric fences were installed immediately in front of eroding dune scarps for several hundred metres along the beach near the canal (Walsh 2004). These did not prevent storm waves impacting on the dune front and did not halt the erosion, with up to several metres of dune front recession having subsequently continued to occur behind the fences (as reported anecdotally by local residents, and as indicated by the results of the present study). The fences were removed subsequent to 2006.

3.5 *Current (2006 - 2010) Shoreline Condition at Roches Beach*

The condition of the shoreline at Roches Beach (defined as the seawards vegetation limit, which is typically but not always a scarp at the foredune front) was systematically assessed in the field and recorded on 11th – 14th August 2006 by C. Sharples, who has also less systematically observed the beach on numerous other occasions between 2001 and 2010. "Condition" here refers to the degree of active erosion or otherwise, and was determined according to the criteria defined in Appendix A1.3 (condition look-up table). No storms or unusual tides occurred during or immediately prior to the days these observation were made. The results were recorded in a shapefile (*2006_rochescondition_gda.shp*) which is described in Appendix A1.2 and is provided with this report. A series of reference photos of the shoreline were taken at the same time; these are described in Appendix Three and are provided with this report in JPEG format.

The results of the 2006 condition assessment are graphically represented on Figure 10. An active or recent erosion scarp was present along most of the main part of the beach, from a few hundred metres south of the canal to Bambra Reef several kilometres north of the canal (encompassing recession zones RZ1 to RZ5 as depicted on Figure 19). No incipient foredune growth was observed along this stretch, and the present writer's repeated field observations since 2001 are that this long part of the beach has been in a similar actively erosional state, with minor scarp slumping but no incipient or 'embryo' dune growth, from at least 2001, through 2006 and up to 2010 (See Figure 11). The findings of this project (Section 5.1) are that this long stretch of Roches Beach experienced significant net recession between 1957 and 2005 (apparently commencing circa 1975-1977), and the field evidence indicates this is ongoing at present (2010). Most of the boulder revetment (wall) south of the canal showed no sign of active erosion in 2006, although it is noteworthy that a small recent erosion scarp was evident on the foredune above and behind the revetment in at least one place (see Figure 30). This indicates that the revetment is not entirely halting shoreline erosion, and may require repair at some future time.

The southernmost end of the beach (east of the boulder revetment and in the lee of Mays Point) exhibited both active sand accretion and old inactive erosion scarps during 2006. This is consistent with the findings of this project (Section 5.1) that this part of the beach has experienced both episodic accretion and erosion since 1957, but no detectable net long term shoreline change.

North of the rocky Bambra Reef point at the north end of the main part of Roches Beach, the 2006 shoreline was exhibiting minor recent erosion in parts, sand accretion with incipient dune growth in other parts, and no apparent shoreline change in other parts. This behaviour is again consistent with the finding of this project (Section 5.1) that this area has experienced both erosion and accretion events since 1957, but has shown no long term net recession to date and indeed has exhibited some net shoreline accretion in two areas.

It will be useful to continue to observe the condition of Roches Beach in future years, with these 2006 observations as a baseline to compare with.

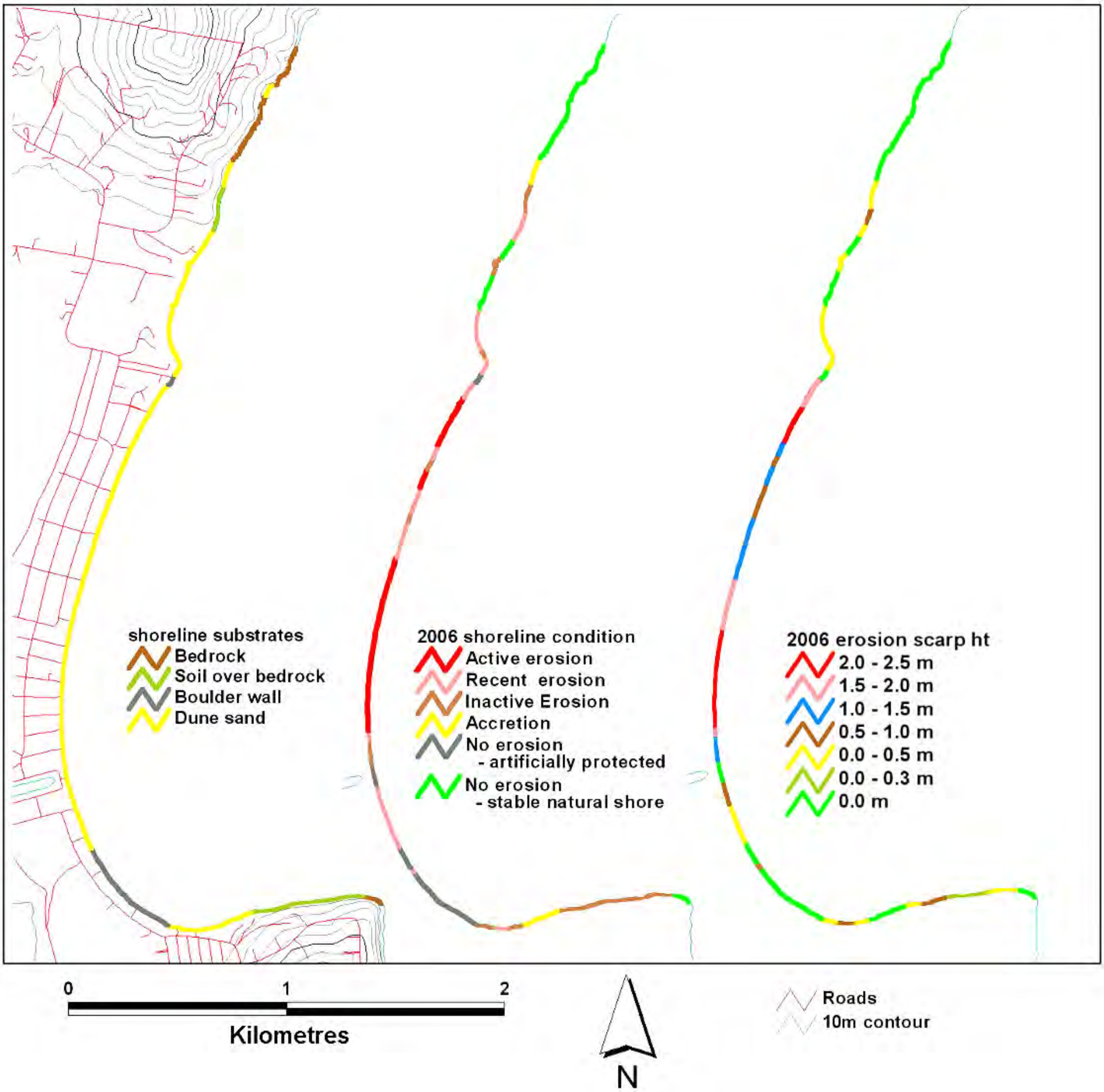

Figure 10: Shoreline condition (i.e., erosion status) at Roches Beach as at August 2006. This map shows the erosional status of all shoreline types in the study area, including sandy shores, artificial shores and bedrock shores. Shoreline "substrate" (LHS) refers to the substrate at the seawards vegetation boundary, which is taken as "the shoreline" for the purposes of this study. "Erosion" refers to recent (last few decades) or accelerated erosion (i.e., the "stable" bedrock shores are also eroding, but at a rate which is negligible for the purposes of this study). The information provided on these maps is encoded in the shapefile *2006_rochescondition_gda.shp*. See also Figure 8 which indicates the distribution of the different (geomorphic) shoreline types at Roches Beach.

Figure 11: An example reference point on the Roches Beach dune front erosion scarp, photographed in 2001, 2005 and 2010. This is Viewpoint 26 (in Recession Zone RZ3: see Figure 19) as documented in Appendix Three (also depicted as a 2006 image in Figure 32). The crooked background tree on the RHS of the 2001 image provides a comparable reference feature in all three photos, which were taken from just slightly differing viewpoints. These photos illustrate that this location – in common with most of the main part of Roches Beach – has been in a continually erosive state from at least 2001 until the present (2010). Whilst some slumping of the erosion scarp has occurred between erosion events, there has been no incipient dune formation in front of the scarp, which has receded more than a metre over the period of these photos at this particular location, as indicated by progressive exposure of the roots of a large tree which was cut down in late 2005 (shortly after the photo shown here was taken) for safety reasons.

4.0 MEASUREMENT OF SHORELINE CHANGE AT ROCHES BEACH

4.1 *Introduction*

The monitoring and measurement of shoreline change over time requires the ability to repeatedly measure and compare a physical indicator of shoreline position over time. The chosen indicator must be a feature whose position or form changes in a fashion directly correlated with recession or progradation of shores.

Shoreline indicators can be one-dimensional (e.g., a point marking a shoreline scarp or beach height at one location along a shore), two-dimensional (a vertical profile at one point along a beach, or a plan line representing an indicator such as high water mark or a shoreline scarp), or three dimensional (e.g., a series of beach profiles or a mapped surface representing the shoreline form).

Whereas one-dimensional shoreline change monitoring yields only very limited useful information, repeated mapping of a three-dimensional shore surface is the ideal indicator of shoreline change since it can yield information about shoreline changes vertically, along-shore and in the onshore-offshore direction. However in practice three-dimensional shoreline change monitoring requires considerable resources for repeated measurements.

The approach adopted in this project has been the mapping of two-dimensional shoreline indicators, which provide considerable useful information yet can be measured repeatedly in a relatively cheap and simple fashion.

4.1.1 Available Methods

A variety of techniques are available for mapping and measuring indicators of shoreline position. Methods considered – and in several cases used or investigated during this project – include the following:

Photogrammetric Methods:

Ortho-rectification of Historic Air Photos
Aerial photography at good scales (up to 1:10,000 or better) is available for most Tasmanian shorelines dating back to around 1946, and much of Tasmania has been re-photographed several times since that date. This aerial photography constitutes the best source of objective historical information on the form and condition of Tasmanian shorelines over the last 50 to 60 years. Photogrammetric software is now readily available to cheaply remove inherent distortions from air photo images and correctly position the air photo images with respect to standard map projections and grids in a GIS system. This “ortho-rectification” process can produce “ortho-photos” which accurately depict the horizontal spatial relationships between ground features with accuracies of ±2 metres or better.

Ortho-rectification of historic air photos was the primary technique of shoreline movement measurement adopted for the present project, and is further discussed in Section (4.2).

Satellite Imagery
In recent years, and particularly since the launch of the QuickBird satellite in 2002, satellite imagery with resolution (pixel sizes) comparable to good air photos has become available. Satellite imagery is of comparable usefulness to air photos for shoreline mapping, and indeed has the advantage that, being taken from a much higher platform than air photos, contains a lesser

distortion due to parallax errors, and can therefore be ortho-rectified to higher levels of accuracy. Although satellite imagery of sufficient resolution for shoreline monitoring has only recently become available, this is a technique that will clearly be very useful in future. An ortho-rectified QuickBird image of Roches Beach captured in 2005 was used in the present project, and found to yield results as useful as those obtained from air photos (see Section 4.3).

Cadastral High Water Mark (HWM) mapping
Digital cadastral mapping incorporating a HWM line determined in 1987 is available for Tasmania (LIST mapping), and was investigated as a possible baseline shore position map against which to compare shoreline position mapping from other epochs. A number of uncertainties regarding the exact features used by photogrammetrists to define the cadastral HWM, together with the fact that a different shoreline position indicator was adopted for use with ortho-photos in this project, means that the cadastral HWM cannot be directly compared with other shoreline position data obtained during this project (see Section 4.4). However, potential remains to compare the LIST HWM map with older (paper) historic property boundary surveys incorporating a surveyed HWM line (see below).

Historic Ground Photography
Where historic ground-based photos of a shoreline can be confidently compared with recent conditions, it may be possible to determine whether significant shoreline change has occurred. In order to allow useful comparison with recent conditions, it is generally essential that archival photos used for this purpose show reference features that can still be identified at the site today, or else that the photos are taken from a precisely known viewpoint. As an example, Lord (no date, p. 10-11) provides photos of a shoreline at Impression Bay (Premaydena, Tasman Peninsula) taken in 1873 and 1991 from what is clearly virtually the same viewpoint, which demonstrate a significant amount of shoreline erosion between the two photos.

Due to the time involved in archival research, no attempt was made during this project to locate early photos of Roches Beach, although this could potentially yield useful information if undertaken in future. However, representative photos were taken during this project at points along Roches Beach, for later comparison with future shoreline conditions. These photos are listed in Appendix Three, and are provided as accompanying JPEG files. Although many of these photos do not show fixed reference features likely to be identifiable decades hence, they have been taken from viewpoints fixed by hand-held GPS measurements which it is hoped will provide a reasonable basis for comparison with future photos taken from the same viewpoint co-ordinates.

Ground-based surveys:

Historic (Paper) Property Boundary Surveys
Many surveyed coastal property plans exist in Tasmanian archives dating back over a century. In many cases the old property boundaries included a High Water Mark line that was determined by the surveyor. Although uncertainties exist over exactly how HWM was defined on old property surveys, it is likely that HWM was generally defined on a similar basis to that used by photogrammetrists to determine the LIST digital HWM cadastral line (above), namely features such as beach wetting lines and flotsam lines. Although it is inevitable that there are significant uncertainties involved in using surveyed "HWM" lines as a basis for comparing shoreline positions, it is possible that if significant shoreline movement has occurred over the last century or more, then comparison of digitised and geo-registered historic coastal property boundary survey plans with the LIST HWM line may provide a useful indication of significant shoreline change – or alternatively, provide a useful indication that little change occurred over the time period concerned.

No effort was made during this project to search out historic coastal property boundary plans for Roches Beach; however this is a potential future investigation that may usefully extend knowledge of shoreline change to earlier times than the 1957 limit of the present project.

Theodolite and Tape Surveys
A useful method of shoreline monitoring which has been widely employed is the repeated measurement of shoreline profiles using tape and theodolite survey methods tied into fixed benchmarks. This method can not only monitor the position of a shoreline indicator such as a dune scarp, but can also identify episodes of beach lowering and accretion. If several profiles are measured along a beach, it is possible to monitor three-dimensional shoreline changes. Beach profile surveys of this sort are relatively cheap and can provide high-accuracy results, however their main drawback is that regularly repeated measurements may be time-consuming.

Local volunteers have undertaken tape and theodolite beach profile surveys at three locations along Roches Beach since 2005, and some initial results of this survey program have been incorporated into this report (see Section 4.5).

Differential Kinematic GPS Surveys
Shoreline surveys using high-precision differential kinematic GPS equipment can repeatedly measure both beach profiles and three-dimensional shoreline forms to a high level of accuracy, and can be performed relatively quickly. However, the equipment required is expensive to deploy repeatedly, and this method was not investigated during the present project.

Other methods:

LIDAR
LIDAR (Light Detection And Ranging) is a laser – based remote sensing technique capable of measuring topographic profiles and mapping three-dimensional surfaces at high resolution from an airborne or ground platform. LIDAR is capable of quickly mapping ground surfaces at high resolution, and is perhaps the ideal shoreline monitoring and change detection technique available with present technology. LIDAR was not used in this project, however at least one LIDAR-derived high resolution DEM is now available for Roches Beach (captured 2008), and it will be useful to compare this with future LIDAR data as a means of detecting and monitoring shoreline change.

4.1.2 Definition of "Shoreline Position"

A crucial issue in monitoring shoreline change is the definition of the shoreline features that are to be used as a basis for comparing shoreline positions over time. An idealised definition of shoreline position is the physical interface of land and water (Boak & Turner 2005), however this definition is difficult to apply in practice. In reality, the physical location of that interface changes significantly on all time scales from seconds (wave action) and hours (tides), to days and months (seasonal and storm – related shoreline changes), to years and decadal time scales (due to long term climatic variations such as ENSO, coastal subsidence, eustatic sea level rise). Thus, whereas the purpose of shoreline movement monitoring is generally to identify the long term shoreline position movements due to such causes as sea level rise or subsidence, the short term movements of the land-water interface will introduce a great deal of "noise" into any measurements unless a method of shoreline position detection is used which filters out short term movements.

Boak & Turner (2005) provide a recent review of the many shoreline features that have been used as mappable proxies for "shoreline position" in the wide range of shoreline movement studies that have been and are been undertaken globally. Commonly used proxies for shoreline position on sandy beaches include the High Water Line (HWL) or the Mean High Water (MHW) line (e.g., Moore *et al.* 2006). However, although the (most recent) High Water Line can sometimes be recognised on aerial photography (and other remote sensing) by indicators such as a tonal contrast between the wet intertidal beach and the dry upper beach, or by a line of flotsam, there are significant difficulties in using HWL or MHW as a proxy for monitoring shoreline position changes over time on aerial or satellite images (Moore *et al.* 2006). Difficulties arise because, firstly, indicators such as those noted above may not always be clearly identifiable on remote sensing imagery, and secondly, because the position of either the HWL or MHW line on a beach can vary markedly from day to day or seasonally as a result of differing tide levels or because of short-term beach lowering and rebuilding in response to seasonal weather patterns and storm wave activity

A similar problem also occurs with techniques involving measuring the actual shoreline profile (whether by ground-based surveying or remote-sensing methods such as LIDAR), and locating a datum-based shoreline position (such as the elevation representing the local MHW or mean sea level datum) on this profile (e.g., Morton *et al.* 2005). Short term seasonal or storm-related changes to the shoreline profile (if it is a sandy beach) may cause the shoreline position (defined as the intersection of the datum level and the shore profile) to move back and forwards horizontally by many metres over relatively short periods of time.

Nonetheless, many methods of shoreline position measurement are used which do rely on measuring the position of shoreline position proxies such as the HWL or MHW. These methods allow for the problems identified above by applying a variety of analytical techniques to filter out the "noise" (Boak & Turner 2005).

However, the work described in this report takes an alternative approach of using a shoreline position indicator (or proxy) which does not normally change significantly over short periods of time (hours or days), and thus is not normally subject to the "noise" problems related to short-term movements of the land-water interface. Instead, a shoreline position indicator is used which generally only changes measurably over longer periods (months or years), and in ways that reflect the longer term trends in shoreline movement that are of most interest in shoreline monitoring:

For the purposes of this work, *shoreline position* is defined as the seawards limit of growing vegetation on the shore[13]. On sandy shores, this is typically on the seawards ("stoss") face of the foredune at the back of the beach, which is a position above the Mean High Water Mark, and generally represents the limit of wave action sufficiently recent as to prevent vegetation establishment[14]. Where recent wave erosion of the foredune has occurred, this shoreline position is the position of the foredune erosion scarp. Shoreline position defined in this way provides a

[13] Note that this shoreline position indicator can indeed change its position significantly over a few hours, by receding during a severe erosive storm. However a storm sufficiently severe to cause recession of the seawards vegetation line at the back of a sandy beach will generally result in a beach profile change that will persist for months if not years before the beach rebuilds to its former state (if it does so). In the case that the beach rebuilds back to its former state, so too the dune-front will slowly rebuild and be recolonised by vegetation. Thus, although the vegetation line may change rapidly during individual storms, such change will persist for some time (or be permanent), and so does not reflect short term beach changes but rather is part of longer term "cut-and-fill" cycles, or even longer-term net recession of the shoreline. These are precisely the sorts of change that the shoreline position measurements investigated in this project are intended to capture.

[14] Note that exceptions may occur where extensive active blowouts (wind erosion hollows) are present on foredune faces, in which case bare sand will persist many metres inland of the limits of wave action. Blowouts are generally recognisable on aerial photos by their morphology, and where they are present the seawards vegetation limit cannot serve as a shoreline position proxy. No blowouts of any significant size are currently present on Roches Beach, nor have any been noted in the historic air photos used in this project. This is likely to be related to the fact that Roches Beach has both an easterly aspect (sheltered from prevailing westerly winds) and a low foredune (rising only about 3 metres above mean sea level) which is thus minimally exposed to wind erosion. Thus, whereas the vegetation limit might fail as a shoreline position proxy on some more wind-exposed Tasmanian beaches with large foredune blowouts (e.g., Nye Bay, Peron Sands), it works well at Roches Beach because the latter is much more vulnerable to wave erosion than it is to wind erosion.

distinct line which is nearly always readily identifiable on air photos of sandy beaches, and which is not affected by merely day-to-day variations in tide levels. A shoreline defined in this way allows measurement of shoreline erosional recession over time (as the vegetated dune front is progressively cut back in occasional large storms), or of shoreline accretion or progradation (as the foredune front rebuilds with sand blown from the beach and is recolonised by dune vegetation when no wave erosion has affected the dune front for a significant period). Thus, this shoreline position proxy is a good indicator of medium-term "cut-and-fill" cycles and longer term net recession or progradation of a shoreline, but is unaffected by the "noise" of day-to-day tidal changes or wave movements.

Successful Identification of Shoreline Position on Imagery
"Shoreline position" defined as the seawards vegetation limit was generally easily identified on images of the sandy Roches Beach where it is backed by the low foredune, due to the high contrast between the bright sandy beach and the darker vegetation on the sandy dune. The low dune height at Roches Beach is also a factor in the success of this method there, since erosional scarping of high dunes may be followed by slumping, producing a wide sandy slope on which the position of the original erosion scarp is hard to define.

However, difficulty was experienced where the beach is backed by bedrock and soil, whose dark tones make it more difficult to clearly identify the vegetation limit as distinct from exposed rock or soil erosion scarps; results from these areas have lesser confidence. Even more difficult were rocky shoreline segments (such as at either end of Roches Beach), due to the lower visual contrast between bare (dark-toned) rocky shores and adjacent dark soil and vegetation. This resulted in some apparent shoreline movements being measured in rocky shoreline areas that are probably artefacts of the method used, rather than real shoreline movements (see Figure 18).

Nonetheless, since the key focus of this project was identification of shoreline movement in areas of soft (highly erodible) sandy shores, the method adopted has worked well since in these areas the shoreline position as defined above was generally clearly identifiable on the satellite and air photo imagery. Nonetheless, experience showed that some problems may arise where tree canopies overhang or shade the vegetation limit as viewed from the air, where accumulations of dead sea-grass washed up onto the beach make the edge of the dune vegetation difficult to differentiate on air photos, or where walking tracks or other physical disturbances on the foredune result in patchy foredune vegetation that makes the vegetation edge (and dune scarp) difficult to define clearly. In most cases, it is considered that these problems have been largely resolved as a result of using field visits to Roches Beach to identify areas of the beach where sea grass debris tends to accumulate (mainly at the southern end of the beach), and by allowing for the irregular localised "bulges" in the apparent shoreline position that occur where large trees growing on the foredune overhang parts of the shoreline. In many cases, large tree canopies and sea grass accumulations on the beach are recognisable from textural differences visible on air photos. Whilst it remains possible that instances may occur where the shoreline position has been incorrectly interpreted for reasons such as these, in most sandy-shore areas of Roches Beach the shoreline position as defined here was considered by the writer to be clearly and unambiguously identifiable on the imagery used.

4.2 *Ortho-Rectified Historic Air Photos*

4.2.1 Introduction

In the absence of long term beach monitoring based on ground surveys and/or ground-level photography, the most reliable source of data for determining past shoreline changes at Roches Beach is vertical aerial photography (high resolution satellite imagery and systematic ground monitoring of the Roches Beach shoreline have only been available since 2005). The oldest available aerial photography of Roches Beach dates from 1946, and subsequent aerial photography is available for a number of times up to the present, giving the potential to determine shoreline changes over the sixty five year period up to the present. The earlier photos are monochrome images whilst the more recent are colour, however on both types of photography the shoreline position (defined as the beach-vegetation boundary) is clearly visible. Image scales range from 1:14,000 to 1:30,000 (see Appendix 2).

Aerial photography cannot be used in its “raw” form to compare the position of ground features to accuracies of metre scale, due to inherent distortions in the photos resulting from parallax and variable ground surface elevation effects. However, with the digital ortho-rectification techniques now available, it is possible to correct the raw aerial photo images to produce map-like images giving the positions of ground features to within ±2 metres (or better) of their true horizontal ground positions. Whilst ortho-rectification may leave some residual image distortion in aerial photos – for example, an apparent “leaning” of tall objects such as buildings close to the edges of air photo images – the distortion of images of low-lying ground features can be largely corrected, and this is particularly the case for horizontal shorelines lying within a metre or two of mean sea level.

Based on anecdotal reports, it was thought that shoreline movements of significantly greater than ±2 metres had occurred at Roches Beach over the last fifty years. Hence, given the positioning accuracies obtainable from ortho-rectification of air photos as described above, it was expected at the outset that ortho-rectification of a time series of historic air-photos ought to be capable of unequivocally demonstrating shoreline movements of this scale. This has proven to be the case, as described in the following sub-section.

4.2.2 Shoreline Positions from Aerial Photography 1957 to 2001

Scanned, geo-referenced and ortho-rectified aerial photo images of Roches Beach dating from 1957, 1977, 1987 and 2001 were prepared and provided in digital (ERmapper .ecw) format by the Information & Land Services (ILS) Division of the Tasmanian Department of Primary Industries & Water (DPIW). See Appendix 2 for image metadata. Unfortunately, older existing air photos dating back to 1946 could not be ortho-rectified due to technical issues with the existing photo prints including a lack of fiducial marks (Chris Stone, ILS, *pers. comm.*); however the images that have been used cover a 44 year period. The pixel size (resolution) for all images supplied is 0.5 metres. This pixel size normally provides clear definition of the shoreline position (vegetation limit) to ±0.5 metre.

The 2001 aerial photos were ortho-rectified by control point transfer from existing controlled photography used to produce the 1:5,000 Urban Ortho Photo series. The 1957, 1977 and 1987 aerial photos were ortho-rectified by using common detail (ground control) points measured from the 2001 ortho-photos. ILS quoted a horizontal accuracy for the 2001 ortho-images of generally ±2 metres, with possible position errors of up to ±5 metres in places, relative to the actual location of features on the ground. Horizontal accuracy (feature position error margins) for the 1957, 1977 & 1987 ortho-photos was quoted by ILS as ±2 metres relative to the 2001 ortho-photo. The quoted error margins include the “pointing error” (ability to locate a specific feature point on the image) that results from the 0.5m pixel size of the images.

Since the 1957, 1977 & 1987 air photos were ortho-rectified using control points from the 2001 images, for the purposes of this exercise the 2001 images are taken to be the correctly positioned baseline images (irrespective of any displacement of features in the 2001 images from their true ground positions), and the horizontal error margins for the other images are relative to the 2001 baseline image (not relative to actual feature locations on the ground). That is, for the purposes of this exercise the shoreline position on the 2001 ortho-photos is taken to be correct (to within the

0.5m pixel size limit), and the ±2 metre error margin for shoreline positions on the 1957, 1977 & 1987 photos is *relative* to that "correct" 2001 baseline shore position.

The ILS-quoted error margins of ±2m for the 1957, 1977 & 1987 ortho-photos relative to the 2001 baseline ortho-photos were checked by C. Sharples by comparing fixed reference features visible in each photo and in the 2001 photos[15]. Feature positions were compared in Arcview 3.2a by digitising lines over their edges and comparing the positions of these lines using the Arcview measuring tool. Apparent displacement of fixed features on the older photos from their positions on the 2001 images ranged up to ±1.9 metres in the onshore – offshore direction (normal to the closest part of the shoreline), which confirmed the ±2 metre error margin quoted by ILS[16]. In a handful of cases, apparent position errors of up to ±3m were noted in directions other than the onshore-offshore direction, however these were discounted on the grounds that (a) they were found in only a small number of cases and are probably anomalous, and (b) no errors greater than ±2m were found in the onshore-offshore direction, which is they critical direction for measurement of shoreline movement in the sense of shoreline erosion or accretion. See Appendix 2 metadata for further details of this error margin checking procedure.

Shoreline positions were digitised in ESRI Arcview 3.2a as GIS line themes (shapefiles) traced over the shoreline positions visible on the 2001, 1987, 1977 and 1957 ortho-photos. Details of the shapefiles digitised for each shoreline epoch are provided in Appendices 1 and 2. Since the quoted position error margins of ±2m include the pointing error determined by the 0.5m pixel resolution of each image, the shoreline digitised over the 2001 image is taken as correct (to within the ±0.5 m pixel size resolution limit of that image) and the shorelines digitised over the 1957, 1977 & 1987 images are taken to have error margins of ±2.0m relative to the 2001 shoreline, as quoted by ILS.

The ability to define error margins for the shoreline positions observed on the ortho-rectified air photos allows minimum actual ("detectable") shoreline movements over time to be determined, provided that the observed apparent shoreline movements are greater than the error margins. This is the case for much of the apparent shoreline movement observed at Roches Beach between 1957 and 2001; hence this method has been used in this work, and is described below.

Comparison of shoreline positions based on image positioning error margins

The shoreline position (line theme) traced from the 2001 ortho-images was taken as the baseline shore position and as such is not considered to have an error margin (other than that imposed by the ±0.5m pixel size). The ILS-quoted horizontal position error margin of ±2 metres for the 1957, 1977 & 1987 images relative to the 2001 ortho-image was confirmed during this work as described above. Hence, ±2 metre (4m total width) buffer polygons were created around the line themes representing the 1957, 1977 & 1987 shoreline positions, to indicate the error envelope within which the actual position of those shorelines lies relative to the baseline 2001 shoreline theme.

Using this method, if the 2001 shoreline position lies within the shoreline position error envelope for any of the other epochs, then it is possible that no shoreline position change has occurred between those times (although it is possible but not demonstrable that up to 2m of change could have occurred). However, where the 2001 shoreline position lies outside the shoreline error

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[15] For the 1957 photo these were mainly a number of long-standing buildings and rock features on the shore, but for the more recent photos increased numbers of (more reliable) flat low-lying and clearly-defined features such as concrete road kerbs were available. Features used were mostly within 100 metres horizontally and 5 metres vertically of the Roches Beach shoreline, and were distributed along the full length of the beach. The apparent positions of between 20 and 27 clearly defined features were compared between the 2001 images and the older images.

[16] The error margins refer to the maximum observed position errors, not to the average or standard deviation of the position errors. In many cases, observed position errors were as little as 0.5m (i.e., the pixel size or "pointing error").

Figure 12: An example of detectable net shoreline recession at Roches Beach between 1957 and 2001 that can be demonstrated using the error envelope method described in this section (south of the canal). Both ortho-rectified air photo images (LHS: 1957, RHS: 2001) show the current LIST road lines for comparison, and the 1957 (green) and 2001 (black) shoreline positions (vegetation limits) that were mapped from these photos. The 2001 ortho-photo (RHS) also shows the ±2m shoreline position error envelope around the mapped 1957 shoreline position. This error envelope is based on taking the 2001 image as the "correct" baseline, and allowing a ±2m position error for the 1957 ortho-image relative to the 2001 ortho-image. On this basis the parts of the 2001 shoreline position line falling outside the 1957 shoreline position error envelope represent a real detectable movement of the shoreline position between 1957 and 2001, whilst those parts falling within the error envelope may or may not represent actual movement of the shoreline.

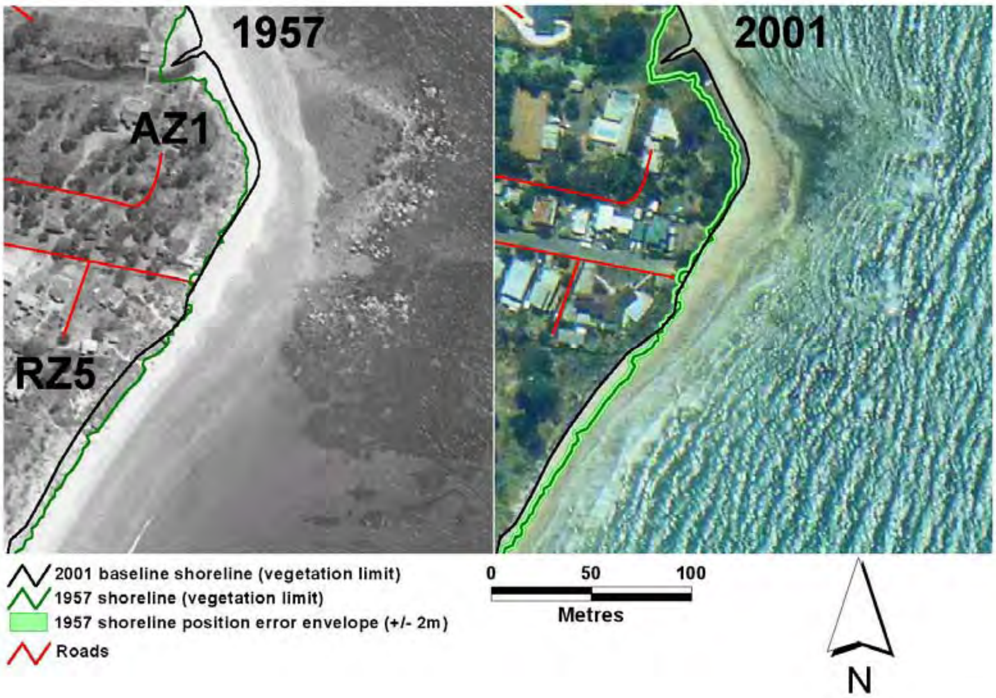

Figure 13: Net detectable shoreline recession and accretion between 1957 & 2001 that can be demonstrated using the error envelope method near Bambra Reef, a rocky point in the northern part of Roches Beach (see also Figure 18). Discussion as for Figure 12 above (zones AZ1 & RZ5 refer to Section 5.1 discussion).

envelope for 1957, 1977 or 1987, then the distance from the 2001 shoreline position to the nearest outer edge of the other shoreline error envelope represents a minimum horizontal change in shoreline position that must have occurred between the earlier epoch and 2001. This is the minimum demonstrable or "detectable" shoreline movement. See Figure 12 & Figure 13, which illustrate examples of significant detectable shoreline movements on two sections of Roches Beach between 1957 and 2001 that can be demonstrated to have occurred using this method.

Similarly, where the position error envelopes for any of the 1957, 1977 or 1987 shorelines overlap, there may have been no shoreline position change between those times (changes are possible but not demonstrable). However, where any two error envelope edges are separated by some distance, then the separation distance represents the minimum demonstrable (or "detectable") shoreline movement that must have occurred between the two epochs.

Along much of Roches Beach, sufficient separation exists between shoreline position error envelopes for at least two (and commonly more) epochs as to allow clear demonstration of significant detectable patterns of shoreline movement over time. Section (5.0) below provides a summary and geomorphic interpretation of shoreline movements at Roches Beach that can be demonstrated by this error envelope method to have occurred since 1957 (incorporating also the results obtained from a 2005 satellite image – see below).

In summary, the method of buffering apparent shoreline positions with envelopes representing their error margins has shown that shoreline movements at Roches Beach since 1957 – and over the shorter intervals between some of the aerial photo epochs within that period – have been large enough to be clearly demonstrated by this method.

Although it is possible that the positional error margins of the ortho-rectified air photos could be improved with further image processing, it is likely that such processing would require considerable extra work for the small improvements in accuracy that are likely to be achieved. Attempting to improve the ortho-rectification accuracy beyond that which has been achieved is likely to be a "diminishing returns" process which is probably not justified given that the method of using error margin buffers, as described above, gives results which are useful and accurate to a degree sufficient to clearly demonstrate detectable shoreline movement trends and patterns between 1957 and 2001.

Notes that this method of determining 'minimum demonstrable' shoreline position movements is a conservative or 'worst case' method. An alternative method commonly used is to determine shoreline positions by statistical analysis based on standard deviations, however the method used here gives a clearly definable measure of minimum actual movement which must have occurred.

4.3 *Satellite Imagery – 2005*

The results from the 1957 to 2001 ortho-rectified air photos described above were supplemented with use of 2005 QuickBird satellite imagery which is available for the Hobart region including Roches Beach.

A clipped portion of DigitalGlobe Inc. QuickBird satellite imagery covering the Greater Hobart Region was obtained for the Roches Beach area (see details in Appendix 2). The image has a resolution (pixel size) of 0.6m – which is close to the 0.5m resolution of the older air photos used in this project – and was captured on 2nd May 2005. The 2005 QuickBird imagery was ortho-rectified by Sinclair Knight Merz to the same control points as used for 2001 Urban Ortho air photo (as described above), hence the shoreline position identifiable on the 2005 QuickBird image can be compared to the 2001 "baseline" image in the same fashion as described above for the earlier air photos.

Figure 14: Detail of net recession zone RZ3 at Roches Beach (centred at MGA 540 370mE 5249 257mN GDA94 datum, 330 metres north of the canal; see also Figure 18). The left hand and centre images show the unbuffered mapped shoreline positions for 2001 and 2005 overlain on the ortho-rectified images from which they were mapped (2001 ortho-image 1342-48 and 2005 QuickBird satellite image). Current LIST road lines are shown for comparison. On the right hand image, the 2001 baseline shoreline position is plotted against the 2005 shoreline position with its ±1.6m position error envelope. Measuring the separation of the 2005 error envelope's nearest edge from the baseline 2001 shoreline position, a minimum detectable shoreline recession of typically 1.5m (and conceivably up to 3.2m more) has occurred between 2001 and 2005 in this area. Compare Figure 18.

Figure 15: Detail of same portion of net recession zone RZ3 at Roches Beach that is depicted in Figure 14 above (centred at MGA 540 370mE 5249 257mN GDA94 datum, 330 metres north of the canal; see also Figure 18). These images show the mapped shoreline positions for 1957 and 2005 plotted over the ortho-rectified images from which they were mapped (1957 ortho-image 326-40 and 2005 QuickBird satellite image). The 1957 shoreline is shown with and without its position error envelope, which is slightly wider than the 2005 shoreline position error envelope (see text). Current LIST road lines are shown for comparison. Comparing the nearest edges of the 1957 and 2005 shoreline position error envelopes to the baseline 2001 shoreline, it is apparent that in this area a minimum net detectable shoreline recession of typically 3.3m (and conceivably up to 4.0 + 3.2 = 7.2m more) has occurred between 1957 and 2005. It is notable that about half of this recession has occurred subsequent to 2001 at this location. Compare Figure 18.

The position error margin for the QuickBird image was quoted as ±3 metres by Sinclair Knight Merz; however comparison of 38 features between the 2005 QuickBird image and 2001 "baseline" ortho photo by C. Sharples yielded a maximum position error of only 1.6m in the onshore-offshore direction along Roches Beach (see Appendix 2 details), hence 1.6m has been used as the position error buffer for the QuickBird image in this project[17].

As a result of the high resolution of the QuickBird image, the shoreline position (seawards vegetation limit) at Roches Beach was readily identifiable on the image. The Roches Beach shoreline position for 2005 was mapped from the QuickBird image in the same fashion as described above for the older air photos, however given the better position error margins determined for the QuickBird image, the 2005 shoreline position was buffered with a narrower 1.6m buffer polygon (3.2m total width polygon) representing the possible range of shoreline positions relative to the 2001 baseline shore.

The 2005 shoreline position determined in this fashion is directly comparable to those determined from 2001 and earlier air photos as described in the previous section, and has been used along with these to determine the history of shoreline change at Roches Beach over the 48 year period from 1957 – 2005; see further discussion in Section (5.0).

It is likely that the smaller position error margin for the QuickBird image (±1.6m compared to the ±2m margin determined for the air photos used – see above) is at least partly due to the smaller parallax error in the satellite imagery which results from it having been captured from a much greater height than the air photos. Combined with the fact that the resolution of the QuickBird images is nearly as good as that of the air photos used in this work (0.6m as compared to 0.5m for the air photos), it is evident that new-generation satellite imagery provides a powerful tool for ongoing shoreline movement monitoring using the techniques described in this report.

4.4 *Digitised (LIST) "High Water Mark" Cadastral Mapping*

LIST 1:25,000 scale cadastral High Water Mark (HWM) line mapping is available for Tasmania, and was investigated as a potential indicator of an earlier shoreline position against which to compare shoreline positions from other epochs. Many coastal freehold properties and crown coastal reserves of various sorts have a seawards boundary defined as the "High Water Mark", hence this boundary has been mapped on coastal cadastral maps for much of Tasmania.

Information on the LIST cadastral HWM line was obtained from Chris Stone and Andrew Tomes (DPIWE). The current LIST cadastral HWM line was digitised from previous mapping derived from 1987 air photos, and at Roches Beach was originally prepared for the Urban 1:5,000 Ortho-map series. However, surveyed "HWM" lines in Tasmania are virtually never determined using tide gauge records to identify the intersection of the actual Mean High Water Mark with the shore; rather they are determined by a surveyor or photogrammetrist using indicators of recent high tides such as flotsam lines or beach wetting lines. Such indicators are inherently subject to uncertainties including the difficulty of precisely identifying such features on air photos, and the uncertainty over whether the features visible on any day actually represent the MHWM, or some other feature such as a recent storm flotsam line which may lie a considerable distance from actual MHWM.

In addition to uncertainties over how the HWM was actually determined, the LIST cadastral mapping as a whole contains internal inconsistencies since it has been compiled from a variety of different surveys conducted to different standards (Chris Stone *pers. comm.*). In areas where the

[17] The error margins refer to the maximum observed position errors, not to the average or standard deviation of the position errors.

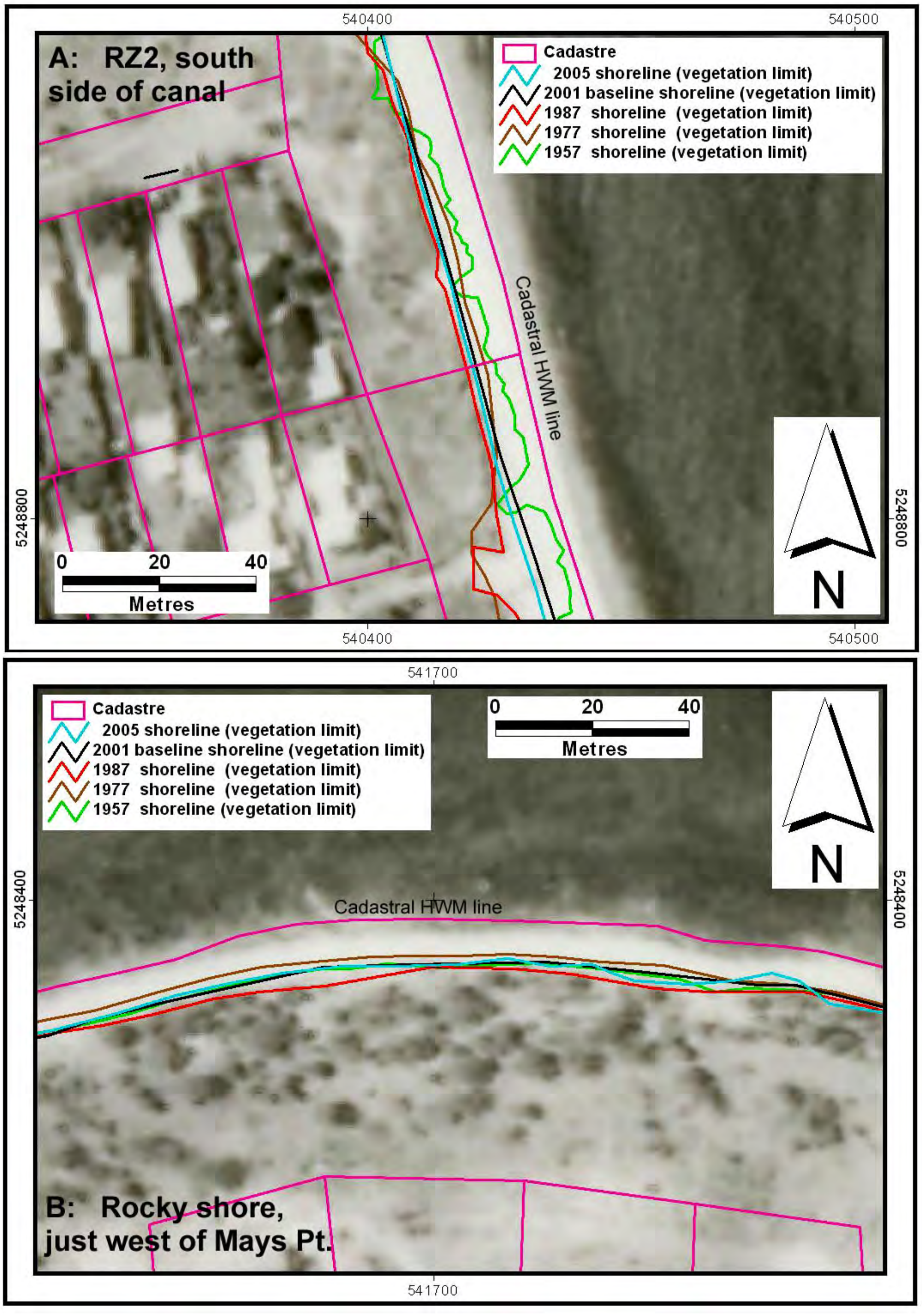

Figure 16: Comparison of the LIST cadastral HWM (High Water Mark) line with measured shoreline positions (seawards vegetation limits) at 1957, 1977, 1987, 2001 and 2005, at two locations at Roches Beach. Location A (top) shows a portion of the sandy beach immediately south of the canal, whilst B (bottom) shows a mainly rocky shoreline section immediately west of Mays Point. The background image is the 1987 ortho-image. The LIST cadastral HWM line is understood to have been drawn from a 1987 air photo. It is clear that the cadastral line is intended to be the High Water Mark (and not the vegetation limit, as used to define "shoreline position" for the present project), however note the difficulty of defining the HWM line precisely from photography such as this. Both images are same scale, map grid is MGA Zone 55 based on the GDA94 datum.

cadastre is derived from 1:5000 mapping (as at Roches Beach) the quoted positional accuracy is that 90% of cadastral features are within 3.5 metres of true position. This is sufficient to produce significant mis-matches, and comparison of the LIST cadastral mapping with property boundaries (fences) visible behind Roches Beach on ortho-photos used in this project indicates position errors of several metres are common, and also unsystematic (i.e., displacement from correct position may occur in different directions in different parts of the map).

In summary, the LIST cadastral HWM line for Roches Beach has likely position errors of ±3.5 metres plus an additional uncertainty over the identification of the HWM by photogrammetrists.

Because of the uncertainties involved in determining HWM on air photos, it was decided not to attempt to map this feature from air photos as a shoreline position indicator for the purposes of the present project, but rather to use the more clearly defined seawards vegetation limit as a shoreline indicator (see Section 4.1.2). This means that the cadastral HWM line – even if it is assumed accurate – is not directly comparable with the shoreline positions mapped from ortho-rectified air photos during this project, since HWM is always some metres (at least) to seawards of the vegetation limit. See Figure 16, which plots the LIST HWM over a 1987 ortho-photo representing shoreline condition during the year the LIST HWM was mapped. The HWM is indeed well to seawards of the 1987 shoreline vegetation limit; however it is also noteworthy that there are few clear features visible that could have been used by a photogrammetrist to define the HWM precisely.

Nevertheless, some as-yet unexplored potential may exist for identifying large scale shoreline changes over the twentieth century if older historic (especially pre-1900) land title surveys showing "HWM" exist and can be found. Many surveyed coastal property plans exist in Tasmanian archives dating back over a century. In many cases the old property boundaries included a High Water Mark line that was determined by the surveyor. Although uncertainties exist over exactly how HWM was defined on old property surveys, it is likely that HWM was generally defined on a similar basis to that used by photogrammetrists to determine the LIST digital HWM cadastral line (above), namely using features such as beach wetting lines and flotsam lines. Thus, some basis for a direct comparison exists, allowing for significant uncertainties in the positional accuracy of surveyed "HWM" lines. It is possible that if significant shoreline movement has occurred over the last century or more, then comparison of digitised and geo-registered historic coastal property boundary survey plans with the LIST HWM line may provide a useful indication of significant shoreline change – or alternatively, provide a useful indication that little change occurred over the time period concerned.

No effort was made during this project to search out historic coastal property boundary plans for Roches Beach; however this is a potential future investigation that may usefully extend knowledge of shoreline change to earlier times than the 1957 limit of the present project.

4.5 *Ground-based Survey Methods – TASMARC Project*

The TASMARC project (Tasmanian Shoreline Monitoring and ARChiving project) is a long term projected initiated by University of Tasmania and Antarctic Climate & Ecosystems Co-operative Research Centre (ACE CRC), to monitor shoreline movements in Tasmania using data collected by volunteers and community groups. At each monitoring site, a State Permanent Marker (SPM) benchmark has been installed by DPIWE surveyors behind the shoreline, and its position surveyed accurately. Volunteer surveyors then use tape and theodolite survey methods to survey beach profiles from the benchmarks at regular intervals. Survey data is lodged with ACE CRC, and it is expected that this data will prove invaluable in future years as a high-resolution record of shoreline changes over time.

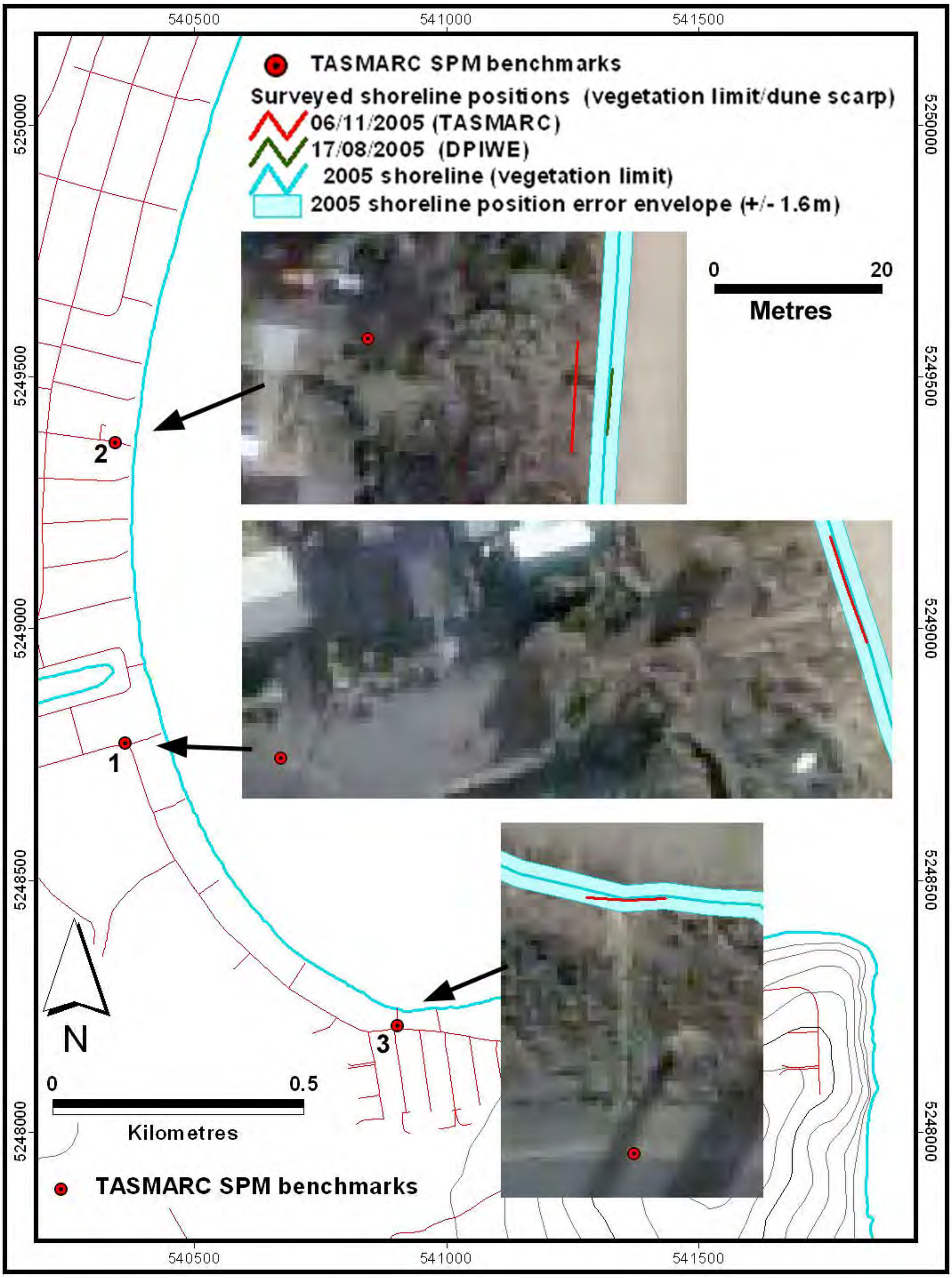

Figure 17: Comparison of the Roches Beach shoreline position for 2005 determined from ortho-rectified QuickBird satellite imagery with that measured from SPM benchmarks during late 2005 using tape and theodolite survey techniques. Upper right scale refers to inset images; lower left scale refers to base map. Survey data is provided in Appendix Four. Background images are the 2005 QuickBird image. Map grid is Map Grid of Australia (MGA) Zone 55, based on the GDA94 datum.

Three SPM markers were installed behind Roches Beach on 17th August 2005, and the DPIWE surveyors measured an initial profile over the beach from each marker at that time. Subsequently, on 6th November 2005 profile surveys were undertaken by volunteer Lauderdale community members Susanne and Michael Hovington, under the supervision of Drs Richard Coleman and John Hunter (ACE CRC). See Appendix Four for details of the SPM locations and initial surveys. Repeat surveys have continued subsequently and the monitoring program is currently (2010) managed by Nick Bowden (ACE-CRC).

The SPM locations were plotted using Arcview software (see shapefile *tasmarcs_gda.shp* accompanying this report). The initial 2005 survey data (see Appendix Four) was then used to plot the dune scarp position (seawards vegetation limit = "shoreline position") as measured from each SPM (see shapefile *tasmarcrochesveglimit_gda.shp* accompanying this report). The shoreline position determined from the 2005 QuickBird satellite image was then compared with ground-based surveys of the dune erosion scarp (vegetation limit). The results are illustrated on Figure 17.

Two of these surveyed scarp positions (for SPM Marks 1 & 3) yielded excellent agreement with the imaged 2005 shoreline position, falling with 0.5m of the apparent 2005 shoreline position on the QuickBird image, and lying well inside the 2005 shoreline position error envelope (see Figure 17). Given that the TASMARC survey results are based on accurately surveyed SPM positions, this indicates that the apparent 2005 shoreline position determined from QuickBird imagery is actually significantly more accurate than the error margin envelope suggests for these two locations, and provides high confidence that future TASMARC surveys can be directly compared with the 2005 QuickBird shoreline position to yield accurate measures of future shoreline movement relative to 2005.

However, the TASMARC surveyed position for the shoreline (scarp) position adjacent SPM Mark 2 yielded a discrepancy of about 4 metres from the 2005 QuickBird shoreline position, and in fact fell outside the position error envelope for that shoreline. However, it is likely that the initial TASMARC shoreline survey data for that location contains an error: plotting the data itself indicates a severely overhung dune scarp, which was not correct for the time the survey was undertaken (see Appendix Four). Moreover, the DPIWE survey undertaken at that site when the SPM marker was installed indicates a credible shoreline scarp position within 0.5m of the 2005 QuickBird image shoreline position. This suggests that the QuickBird image 2005 shoreline position is again accurate for this location, and suggests that the TASMARC survey data for this site should be reviewed to identify a likely data error.

5.0 DISCUSSION AND CONCLUSIONS

5.1 *Observed Shoreline Change at Roches Beach*

Introduction – minimum and most likely changes detected

The primary results of this study are summarised in Figure 18, which plots the apparent position of the Roches Beach shoreline (defined as the seawards vegetation limit) evident on ortho-rectified air photos and satellite imagery from 1957, 1977, 1987, 2001 and 2005. For ease of comparison the earliest (1957) shoreline is represented as a straight line, with shoreline positions at later epochs plotted relative to that. The sizes of the shoreline position error margins for each year are indicated by error bars on the key. Whereas the shoreline positions plotted on Figure 18 are the apparent and most likely shoreline positions at each epoch (representing the mid-line of error margin envelopes for each epoch), these apparent shoreline movements between each epoch (represented by the distance between each shoreline position) are greater than the minimum shoreline movements that can actually be demonstrated taking into account position error margins. Hence, Figure 19 plots the minimum net shoreline movement between 1957 and 2005 that can actually be demonstrated (see discussion in Section 4.2.2). The information represented by these figures is derived from shapefiles accompanying this report, which plot the apparent shoreline positions determined from ortho-photos and also the error margin envelopes for each epoch (see Appendix One).

Along the greater part of Roches Beach where the sandy beach is backed by soft sandy sediments and a dune, examination of the results presented in Figure 18 reveals systematic changes in shoreline position over time. It is evident that the method adopted to determine shoreline position in these areas has worked well due to the high contrast between bright beach and dune sands, and dark-toned vegetation, and because the relatively low dune scarp (typically 1 – 2m) means that any scarp slumping causes little change in the apparent shoreline position. However, shoreline positions plotted at the northern and southern extremities of Roches Beach where the beach is directly backed by bedrock and derived soils showed complex and apparently random position changes that were mostly of smaller scale than the ortho-photo position error margins. Taking into account position error margins, these areas showed no detectable net change between 1957 and 2005. Upon re-examination of the imagery for these areas it was evident that the apparent small-scale shoreline changes were mostly artefacts of the difficulty of clearly defining a vegetation limit on the imagery against dark-toned soil and bedrock. Hence the small scale apparent shoreline movements for these areas should be disregarded, and this has been indicated by pink shading on Figure 18.

Summary of changes detected

Based on evidence from air photo and satellite imagery for the period 1957 to 2005 (as described above), together with the writers own field observation from 2001 to 2010 (see Section 3.5), the following is a summary outline of observed changes to Roches Beach from 1957 until 2010. Some of the observed changes are described with reference to numbered recession and accretion zones indicated on the following map figures.

1957 The shoreline was located to seawards of its present – day position along most of the beach, particularly in the southern and central parts of the beach. The dune front (seawards vegetation limit) had a notably 'ragged' plan-form along most of the shore (see for example Figure 12), indicating that significant erosion of the dune front had not occurred for some years (at least) prior to 1957.

Significant erosion and recession of the beach and dune front occurred at some time after 1957 and prior to 1977 (probably commencing around 1975 – 1977; see below), and from that time onwards the dune front has exhibited a notably straighter planform indicative of more frequent wave erosion

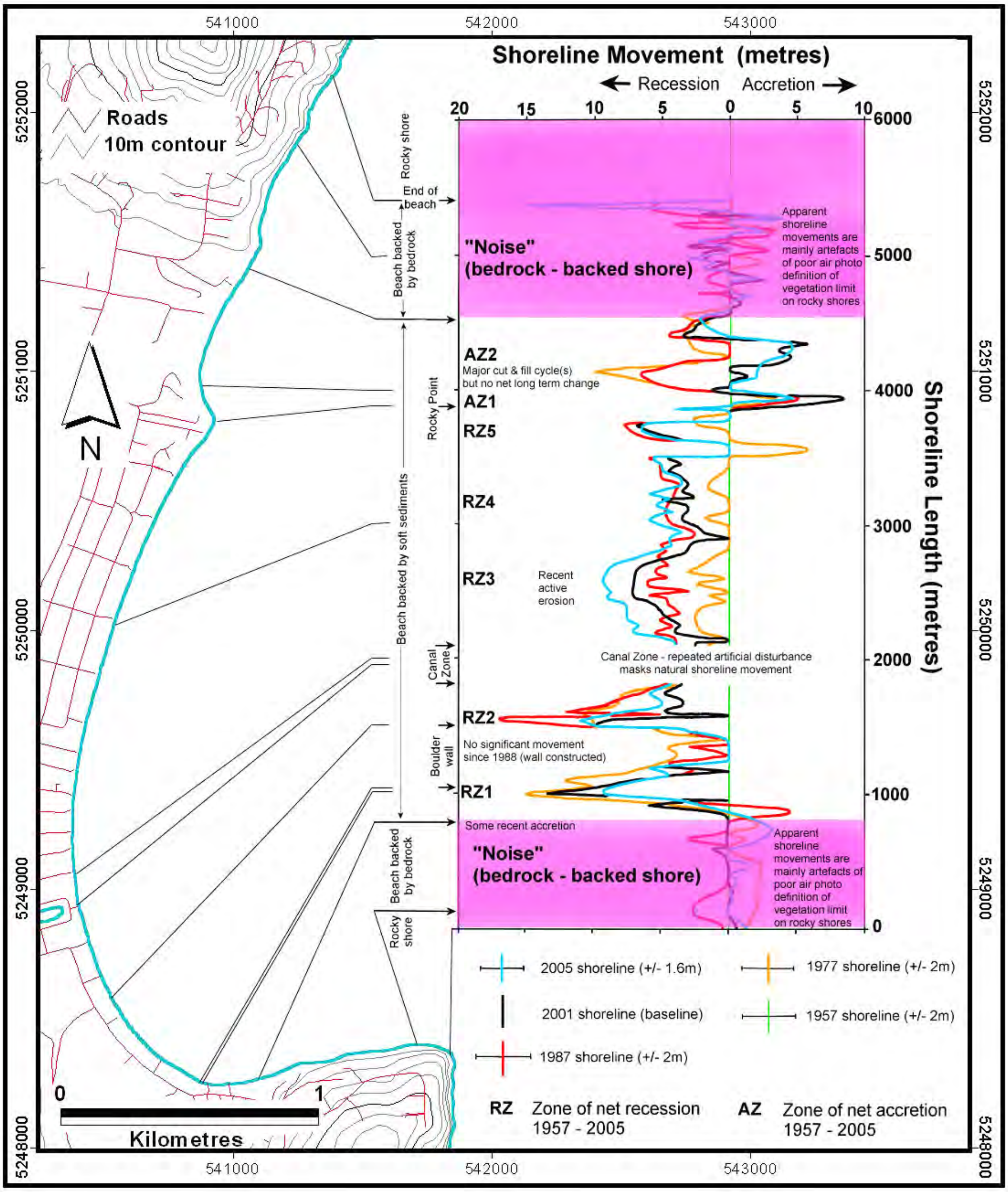

Figure 18: Apparent shoreline movement at Roches Beach, 1957 to 2005, as traced from ortho-rectified air photos from 1957, 1977, 1987 & 2001, and from a rectified 2005 QuickBird satellite image. For ease of comparison, the 1957 shoreline is depicted as a straight line, with later shoreline positions depicted relative to the 1957 position. The coloured lines represent the *apparent* shoreline positions at each epoch; however these are not the minimum *detectable* shoreline change positions, which would be represented by the separation between shoreline position error envelopes. See also Figure 19, which depicts the minimum detectable shoreline position changes based on the separation between the error envelopes. Error envelopes for each shoreline position are represented on this figure by bars on the figure key. Nonetheless, the *apparent* shoreline positions depicted here represent the centre of the position error envelopes, and therefore represent the most *likely* shoreline positions at each epoch. The shaded portions of the shoreline movement graph are those areas in which sandy beach is backed by bedrock; in those areas shoreline position could not be reliably determined by the method used in this project due to poor definition of the vegetation limit on air photos in areas of dark-toned bedrock and bedrock-derived soil backshores. The map grid is the MGA (Zone 55) grid (GDA94 datum). Note that the scale of the "Shoreline Length" axis on the graph is not the same scale as the map. An enlarged version of this figure is also provided in Appendix Five (Figure 37).

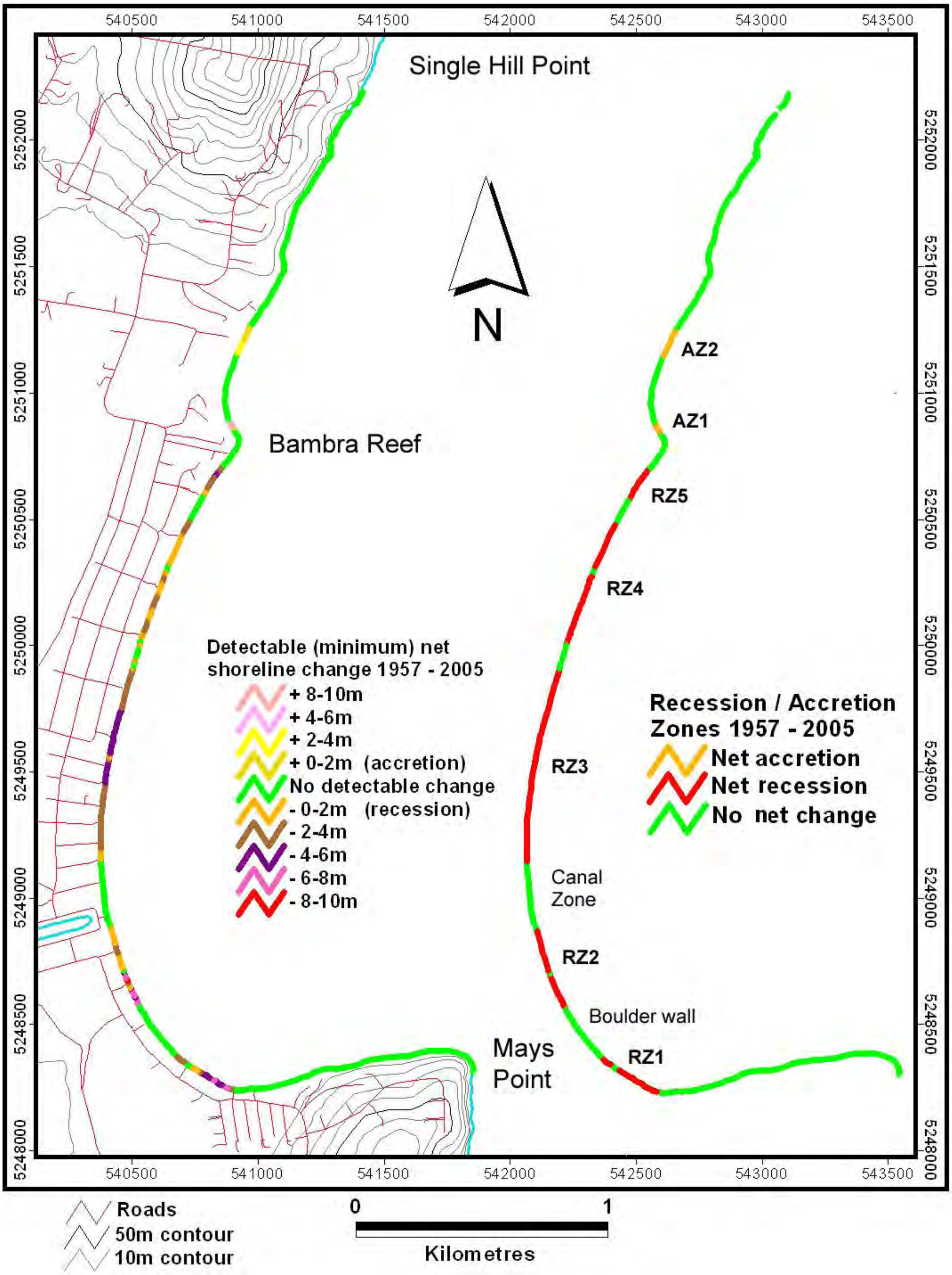

Figure 19: Detectable (minimum) net shoreline movement at Roches Beach between 1957 and 2005. This figure depicts the minimum net shoreline change that can be demonstrated to have occurred between 1957 and 2005, based on the separation between the edges of position error envelopes for the apparent 1957 and 2005 shoreline positions (as shown on Figure 18). Actual net shoreline change over that period is almost certainly greater than these minimum changes, but cannot be unequivocally demonstrated due to the position errors inherent in the ortho-rectified photos. However, the most likely actual shoreline changes are those depicted as apparent shoreline position changes in Figure 18, and are 3.6m greater than the minimum detectable changes depicted in this figure (1.6m 2005 error margin + 2m 1957 error margin). The map grid is the MGA (Zone 55) grid (GDA94 datum), and relates to the left-hand map.

events. Along most of the beach the shoreline has never returned to its 1957 position but rather has receded landwards and is continuing to do so as of 2010.

1977 – 1990s From prior to 1977 until the 1990s marked erosion and recession of the shoreline occurred along most of the beach, resulting in progressive recession of the shoreline of net apparent (most likely) distances ranging between 5 to 12.5 m relative to its 1957 position in recession zones RZ1 to RZ5. However over this period at least two major cut and fill cycles (erosion & rebuilding) events were superimposed on the overall recession trend[18], with some erosion cuts extending over 17m landwards of the 1957 shoreline position (in RZ2) before being rebuilt to seawards by subsequent sand accretion ('fill'). Most parts of the dune front are notably straighter in the 1977 and 1987 air photos than it was in 1957, indicating more recent active erosion had been occurring by 1977 and 1987.

A boulder revetment (wall) was constructed along part of the southern end of the beach during 1988 to halt erosion along part (but not all) of the southernmost recession zones (RZ1 & RZ2) which had experienced the most extensive erosion cuts prior to that date.

Significant erosion also occurred at the northern end of the beach (north of Bambra Reef) during this period, however unlike the main parts of the beach to the south of Bambra Reef subsequent rebuilding fully returned these areas to the 1957 shoreline position (see Figure 24), and by 2001 net accretion (shoreline progradation) relative to 1957 had occurred at accretion zones AZ1 & AZ2.

2001 – 2010 By 2001 all dune front rebuilding in recession zones RZ1 to RZ5 had ceased and the dune front was a fresh erosion scarp in all those zones. Measurable erosion occurred between 2001 – 2005 along most of the beach (recession zones RZ1 to RZ5). From 2001 until 2010 repeated field inspections have shown no evidence of beach rebuilding or incipient dune accumulation within these recession zones (see Section 3.5); only some minor dune scarp slumping has occurred. Recession Zones RZ1 to RZ5 have thus been in a progressively eroding state throughout this period with notably straight erosion scarp planforms indicative of fresh erosion, and no evidence of a new 'fill' cycle of sand accretion commencing. Some evidence of erosion above and behind the boulder revetment wall has appeared during this period (see Figure 30).

However, accretion (including incipient dune formation) has continued in the northern parts of the beach (accretion zones AZ1 & AZ2) over this period, and is indicative of continued northwards longshore drift of sand from the main (central-southern) part of the beach.

Along the main part of Roches Beach (recession zones RZ1 – RZ5) the available evidence is indicative of a change from a phase of little or infrequent erosion (pre-1970's) to one of mainly progressive recession with some rebuilding (cut and fill cycles) from (shortly?) before 1977 until the 1990s, to the current phase of progressive recession with no fill (rebuilding) from prior to 2001 up until the present (2010). Longshore drift of sand to the northern parts of the beach has continued over the period from probably before 1977 onwards, resulting in net accretion (seawards progradation) of some northern parts of the beach (north of Bambra Reef) relative to the 1957 shoreline position (see Figure 13).

The following sub-sections discuss key aspects of these changes in more detail.

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[18] Although no air photos for the 1990s decade were obtained and ortho-rectified, it can be assumed that some dune and beach rebuilding after 1987 continued into the 1990s as it would have taken some years to rebuild parts of the beach to its 2001 position following the degree of recession that had occurred in some places by 1987.

Progressive net recession with super-imposed cut-and-fill cycles

The results of this study show that significant progressive shoreline recession occurred along much of Roches Beach between 1957 and 2005, which is continuing as of 2010 (see Section 3.5). Allowing for air photo position error margins, minimum (demonstrable) net shoreline recession of 4 to 6 metres has occurred along much of the main beach, and a minimum demonstrable net recession of up to 9 metres has occurred in part of recession zone RZ2, south of the canal (see Figure 18). However, most likely net recession distances (measured apparent movement) between 1957 and 2005 are greater, averaging about 5 to 10 metres north of the canal (recession zones RZ3, RZ4 & RZ5), and up to 12.5m in recession zone RZ2 (south of the canal). See Figure 19**.**

It is also significant that the air photo analysis demonstrates that at least two major "cut-and-fill" cycles are superimposed on the progressive net recession of the shoreline at Roches Beach between 1957 and 2005. These are evident from examination of Figure 18, and are shown on Figure 20 & Figure 21 for recession zones RZ2 & RZ3 by plotting shoreline positions against time. See also Figure 23. This is most obvious south of the canal, where major erosion events evidently occurred prior to both 1977 and 1987, with apparent shoreline recession of over 17m occurring by 1977 and 1987 relative to 1957 at some points in RZ2, after which the shoreline rebuilt considerably prior to 2001, before receding again after 2001 (see Figure 21). At least one similar but smaller cut-and-fill cycle is evident in the central and northern parts of the main beach (RZ3 (Figure 20), RZ4 & RZ5). It is likely that other smaller cut and fill cycles have also occurred, although the frequency of air photos used for this study is too coarse to reveal these.

Overall however, it is significant that - despite large detectable cut-and-fill cycles having occurred within the 53 year period from 1957 to 2010 - much of the main beach has never returned to its 1957 shoreline position but rather has exhibited a net progressive recession underlying the shorter term cut-and-fill cycles within this period, and that since at least 2001 recession has been dominant with no further 'fill' or rebuilding since that time.

The southern half of the boulder revetment (wall) constructed along part of Roches Beach south of the canal circa 1988 protects an area (designated recession zone RZ1 on Figure 19) which experienced considerable erosion prior to 1977. Although the dune front had again rebuilt seawards some metres by 1987, the large scale of the erosion events in this area no doubt played a role in pressures to build the boulder wall. Subsequent to construction of the boulder revetment there has been no detectable movement of this part of the shore, although erosion is now beginning to impact the dune behind the wall in at least one place, presumably due to over-topping by storm waves (see Figure 30). It is probable that without construction of the wall, this area would have continued to exhibit significant recession after 1988, as has RZ2 to its immediate north.

Timing and possible causes of onset of progressive recession

A previous study by Cromer (2006) suggested that most detectable shoreline recession at Roches Beach since 1957 has occurred after 1975 (see Section 2.0). Cromer undertook an analysis of 1957, 1975 and 2002 air photos of a portion of Roches Beach north of the canal (around MGA grid 540 400mE 5249 550mN (GDA94 datum), near Balook and Nerang Streets). Cromer found no net recession between 1957 and 1975, but demonstrated a net foredune[19] recession of 5 metres between 1975 and 2002. This is of particular interest in the light of a study of shoreline recession at Cornelian Bay (Hobart) by Sharples (2003), which similarly found that, whilst the Cornelian Bay shoreline has receded landwards by 2.0 to 3.5m since circa 1900, virtually all of that recession has occurred in the period since 1973. These two results from the Hobart region are both consistent with onset of a phase of net shoreline recession on at least some shores around or after 1975, following a long period of apparent near-equilibrium shoreline conditions prior to that date.

[19] Cromer measured foredune recession based on the vegetation limit at the seawards scarp of the foredune, which is the same method used in the present work.

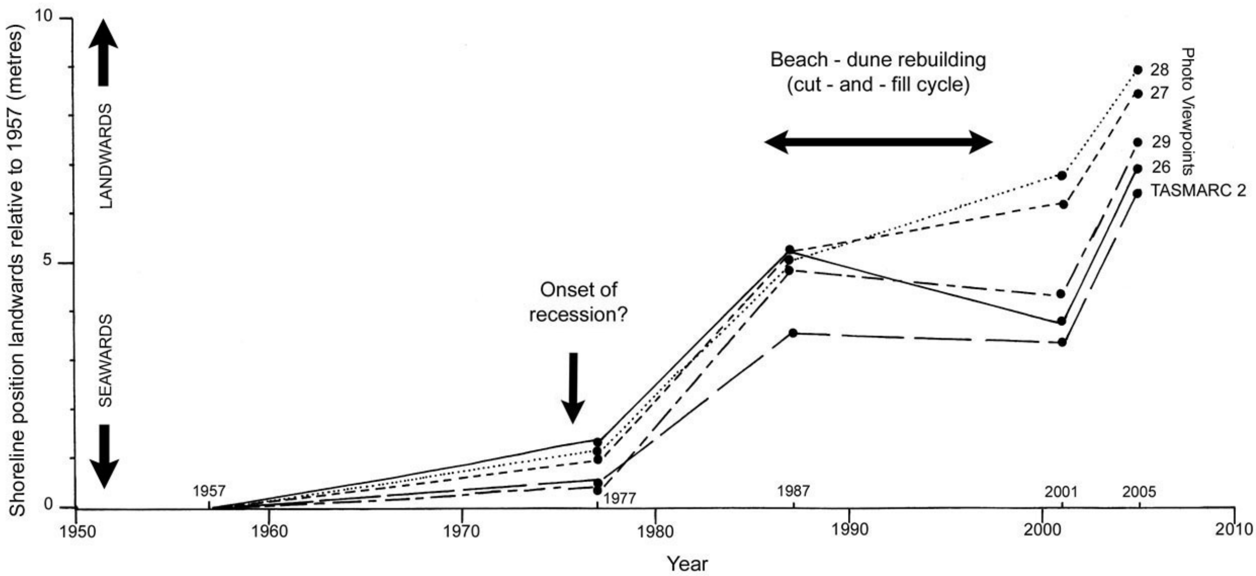

Figure 20: Shoreline recession plotted against time for the central part of Roches Beach (recession zone RZ3). This part of the beach shows the least effect of cut-and-fill cycles (compare Figure 18), although at least one such cycle is evident. Apparent (most likely) shoreline positions (vegetation limits) in metres landwards relative to the 1957 shoreline position were manually measured in Arcview from the ortho-rectified imagery time series (1957, 1977, 1987, 2001 & 2005) at four numbered photo viewpoints as specified on the RHS of the figure (see Appendix 3) and at the position of the TASMARC 2 monitoring profile (see Appendix 4). Although more data points are desirable (particularly in the 1960s, 1970s and 1990s intervals), this figure clearly indicates a substantial shoreline recession trend beginning with a marked change in shoreline behaviour that probably commenced in the mid - 1970s.

Taking data from the present project together with Cromer's (2006) results, there appears to be good evidence that there was a significant onset of erosion at Roches Beach around the 1975 to 1977 period:

Firstly, Cromer's results using 1957, 1975 and 2002 air photos indicated that no recession was apparent between 1957 and 1975, and that recession occurred after the 1975 photo. Given that the results of the present project using 1977 imagery indicate significant recession had commenced prior to 1977, this appears to constrain onset of significant recession at Roches Beach to sometime in the 1975 – 1977 period. It must be noted however that Cromer's study only considered one location at Roches Beach, and the behaviour of the whole beach between 1975 and 1977 should be considered in future studies.

Secondly, it is probably significant that the ortho-photos from 1957 show a noticeably "ragged" dune-front vegetation limit planform in 1957, whilst 1977 & 1987 ortho-photos show a significantly straighter dune front, and those from 2001 and 2005 show a very much straightened dune front planform. This is particular evident in the areas designated RZ1 and RZ2 (e.g., see Figure 12). The more recent straight dune fronts are indicative of relatively recent active wave erosion (which tends to straighten dune scarps), whereas the ragged 1957 dune front is indicative of a long preceding period without significant wave erosion, during which minor scarp collapses, sand accretion and erosion of walking tracks through the dune had created a complex ragged dune front planform. This evidence that little recent erosion had occurred at Roches Beach prior to the 1957 air photo but was clearly evident by 1977 is consistent with a mid - 1970s onset of recession.

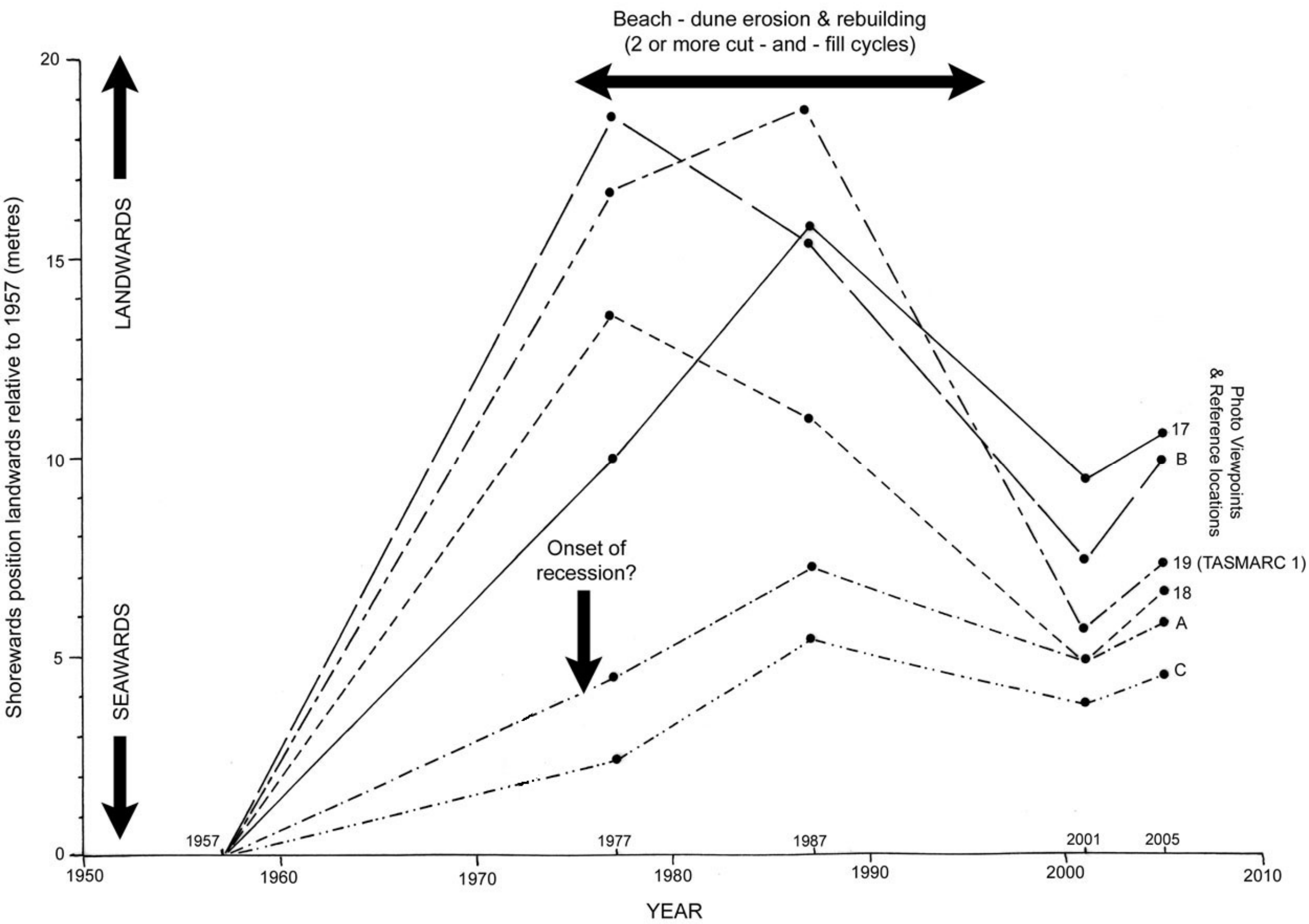

Figure 21: Shoreline recession plotted against time for Roches Beach south of the canal and north of the boulder wall (recession zone RZ2). This part of the beach shows several large cut-and-fill cycles super-imposed on an overall recession trend comparable to that at recession zone RZ3. At least two cut-and-fill cycles are evident – erosion occurred at all sites before 1977, with several areas then showing significant rebuilding prior to 1987, however some sites show further erosion between 1977 and 1987. All sites show rebuilding after 1987 & prior to 2001, and all sites then show only progressive erosion without rebuilding after 2001. This figure was derived by measuring apparent (most likely) shoreline positions (vegetation limits) in metres landwards relative to the 1957 shoreline position in Arcview from the ortho-rectified imagery time series (1957, 1977, 1987, 2001 & 2005) at six locations spread along recession zone RZ2, as specified on the RHS of the figure. These locations comprised three of the numbered photo viewpoints (17, 18 & 19) as listed in Appendix 3 (one of which is also the TASMARC 1 monitoring profile as described in Appendix 4), and three new reference locations whose positions are as follows: A = 540 430mE 5248 821mN; B = 540 476mE 5248 691mN; C = 540 418mE 5248 871mN (all MGA, GDA94 datum). Although more data points are desirable (particularly in the 1960s, 1970s and 1990s intervals), this figure clearly indicates a substantial shoreline recession trend beginning with a marked change in shoreline behaviour that probably commenced in the mid - 1970s.

Thirdly, the air photo evidence shows that whilst major erosion occurred at RZ1 & RZ2 in the southern part of the beach (shortly?) prior to 1977 - with more major erosion following subsequently (see Figure 18 & Figure 21) - in the central part of the beach (RZ3) only relatively limited erosion had occurred by 1977 with a significantly greater scale of erosional recession occurring following that time (see Figure 20). This is suggestive that by 1977 significant erosion in the central part of the beach had only recently commenced, and that it only accelerated subsequent to that date. This would be compatible with the greater early erosion at the southern end of the beach if the initial major mid-1970s erosion events were driven by north-easterly storm winds driving wind waves generated across the large north-easterly fetch of Frederick Henry Bay predominantly onto the north-east facing southern part of the beach, so that the initial erosion was most intense at that end of the beach (and has continued to be so since – see below).

It is potentially significant in this regard that the mid - 1970s were a period of unusual storminess on NSW beaches, which resulted in severe erosion of many NSW beaches such as Moruya Beach in large storms from May-June 1974 through 1978 (Thom & Hall 1991, McLean & Shen 2006). Most of the affected open coast NSW beaches have ultimately rebuilt to their former positions, and as such have not yet exhibited a net progressive recession. It is possible that related mid - 1970s east coast - Tasman Sea storms (driving strong north-easterly winds across Frederick Henry Bay) may also have triggered significant erosion at Roches Beach (and no doubt other eastern Tasmania beaches). However, whilst most affected beaches have subsequently fully rebuilt, Roches Beach has not.

It is recommended that future work include air photos from within the 1957 to 1977 time gap (especially the 1975 image), examining changes (or lack of) along the whole beach, in order to better constrain times and rates of shoreline change at Roches Beach (see Section 5.4).

Spatial variation in shoreline change patterns

The patterns of cut-and-fill, and progressive net recession, at Roches Beach have not been uniform along the beach, but rather exhibit distinct spatial patterns. Although natural beach and dune processes have been artificially modified over the 1957 to 2005 period by continual artificial dune disturbance adjacent the canal, and by construction of a boulder revetment along a large southern part of the main beach circa 1988, nonetheless several clear shoreline change patterns are evident along Roches Beach as a whole (compare Figure 18 & Figure 19):

The southernmost extremity of Roches Beach (east of RZ1 & sheltered in the lee of Mays Point) has exhibited no net recession from 1957 to 2005, although cyclic shoreline movement has occurred here, with sand accretion being evident in 1987 and at the present time (2006-2010), and with an inactive erosion scarp also being currently present behind part of the beach.

Northwards, the main part of Roches Beach (recession zones RZ1 – RZ5) has nearly all experienced net recession between 1957 and 2005 and has been in a continually erosive state from at least 2001 up to 2010 (see Section 3.5) except where this has been masked by continual artificial disturbance (canal area and boulder revetment). Erosion events have been of largest scale south of the canal, but so too have the cut-and-fill cycles superimposed on the net recession there also been of larger scale (Figure 21, Figure 23). Northwards from the canal, a lesser but still significant progressive net shoreline recession has dominated as far north as Bambra Reef at the north end of the main beach, with only small cut-and-fill cycles superimposed on the general recession trend (Figure 20, Figure 22).

There is clear evidence of long term sand movement northwards around the rocky point of Bambra Reef, where for much of the 1957 to 2005 period the southern side of the rocky point has been receding (RZ5) and the northern side accreting sand (AZ1). See Figure 13. North of Bambra Reef large scale cut-and-fill cycles have occurred but there has been negligible net shoreline change (see Figure 24), except in two small zones where minor net sand accretion has occurred (AZ1 & AZ2).

These patterns indicate that erosion has occurred episodically along most of Roches Beach, with the greatest amount of erosion occurring episodically south of the canal (suggesting that it is exposure to north-easterly storm wind-waves - which would impact most directly in that area – that has produced the largest erosion events at Roches Beach). Sand eroded from the southern part of the beach has probably been redistributed within the southernmost sheltered part of the embayment in the lee of Mays Point, which evidently acts as a partial sand trap causing occasional beach accretion in that area, but this sand has ultimately been recirculated northwards, replenishing and

Figure 22: Shoreline change between 1957 and 2005 for a central portion of recession zone RZ3 (area shown is centred at 540 390mE 5249 480mN (MGA co-ordinates, GDA94 datum), about 550 metres north of the Lauderdale Canal). Background image is the 2005 QuickBird satellite image. Shoreline position error envelopes around the mapped shoreline positions show a minimum detectable net shoreline recession between 1957 & 2005 typically of the order of 4 to 6 metres in this area. Although small scale cut-and-fill cycles are likely to have occurred, no large scale cut-and-fill cycles are detectable along this central part of Roches Beach; instead the general pattern here over the period 1957 to 2005 has been one of progressive net shoreline recession (compare Figure 18).

partly rebuilding the beach south of the canal and resulting in no long-term net shoreline change in the southernmost extremity of the embayment. However, the eroded areas south of the canal (RZ1 & RZ2) have never rebuilt completely, indicating that a further net loss of sand has occurred.

The main beach north of the canal has experienced less intense erosion episodes, but there has also been less rebuilding of the shoreline, resulting in progressive net shoreline recession and indicating a continuous loss of sand from this area, either offshore and/or through northwards littoral drift. This area has now been in a continually erosive state from at least 2001 up to 2010 (see Section 3.5). That at least part of the sand loss has been due to northwards littoral drift is indicated by the erosion and accretion patterns around the rocky point at Bambra Reef, at the north end of the main beach.

Figure 23: Shoreline change between 1957 and 2005 for a portion of recession zone RZ2 (area shown is centred at 540 505mE 5248 612mN (MGA co-ordinates, GDA94 datum), about 340m south of Lauderdale Canal). Background image is the 2005 QuickBird satellite image. Shoreline position error envelopes around the mapped shoreline positions show a minimum detectable net shoreline recession between 1957 & 2005 typically of the order of 6 to 7 metres in this area. In contrast to RZ3 (Figure 22 above) this area shows evidence of large cut and fill cycles, however these are also superimposed on a long term net recession trend as at RZ3. At least two very large erosion events (prior to 1977, and again between 1977 & 1987) have occurred at this site, however the shoreline has subsequently re-built (accreted seawards) prior to 2001, before again receding landwards between 2001 & 2005 and has remained in a continually erosive state with no incipient foredune growth up until the present (2010). Despite the cut and fill cycles, the beach has never rebuilt to its 1957 position, and the overall trend has been one of net erosional recession.

Large erosion events have also occurred along the beach north of Bambra Reef, however there has been no net long-term shoreline recession in this area, indicating that the continuous northwards littoral drift of sand from receding areas south of Bambra Reef has been sufficient to fully replenish sand eroded during storms (Figure 24), and indeed some minor net shoreline accretion has occurred along a few parts of the beach in this area (see Figure 18).

Even further north, the current presence of incipient dunes at the western end of Seven Mile Beach (see Section 3.3 & Figure 9) strongly suggests that sand is actively accreting in that area. The most likely source is sand is being driven northwards from the north end of Roches Beach by longshore drift, as previously stated by Foster (1988) and Byrne (2006).

Figure 24: Shoreline change between 1957 and 2005 for an area between accretion zones AZ1 and AZ2 (area shown is centred at 540 863mE 5251 022mN (MGA co-ordinates, GDA94 datum), about 200 metres north of Bambra Reef at the north end of the main part of Roches Beach. Background image is the 2005 QuickBird satellite image. Shoreline position error envelopes around the mapped shoreline positions show evidence of at least one major erosion and shoreline recession event (demonstrable recession up to 8m) prior to 1977 (similar to RZ2; see Figure 23 above), however the shoreline has subsequently rebuilt (accreted seawards) back to its 1957 position. Thus, whilst this part of Roches Beach shows evidence of at least one major cut-and-fill cycle – probably contemporaneous with that evident at RZ2 – no net shoreline recession is detectable between 1957 & 2005 and this part of the beach is behaving as an equilibrium shoreline subject only to short-term cut and fill cycles, but not as yet subject to long term net erosional recession.

5.2 Explaining the Observed Historic Shoreline Changes at Roches Beach

In the only significant study to date of the Holocene (geologically-recent) geomorphic development of Lauderdale Neck and Roches Beach, Davies (1959, 1961) concluded that the present neck and beach prograded (grew) following the mid-Holocene end of the post-glacial marine transgression when sea level settled at roughly its present level about 6,500 years ago. Although further geomorphic studies are desirable, on existing knowledge it is likely that progradation ended some thousands of years ago when Roches Beach settled into a zeta-form plan in equilibrium with northwards longshore drift of sand on the eastern side of Frederick Henry Bay, driven by the prevailing northwards refraction of south-westerly swells into the bay (see Section 3.2).

However, the evidence provided by this study indicates that Roches Beach has not been in equilibrium between 1957 and 2010, but rather has exhibited net progressive shoreline recession over that period, probably commencing around 1975-1977. The question which arises is whether the observed recession is simply part of a longer term cycle within a generally equilibrium shoreline history, part of a longer term progressive trend in shoreline evolution at Roches Beach unrelated to sea-level rise, the result of the relatively recent onset of a new recessive phase in the beaches history related to sea-level rise, or some other cause such as artificial disturbance of beach processes?

Observations to date indicate that most open coast (swell-exposed) sandy beaches in south-eastern Australia (at least) have not yet begun to show detectable progressive recession attributable to the physical effects of sea-level rise (Church *et al.* 2008). This is because the “noise” of other coastal processes including the swell-driven ‘cut-and-fill’ process (rebuilding of the beach and dune-front after storms) combined with a positive sand supply from the lower shoreface; continue to mask the signal of underlying recession due to sea-level rise. Sea-level rise has yet to reach a threshold level above which storms will erode beaches too frequently for beaches to rebuild in-between those events, resulting in shoreline recession becoming a dominant process[20]. An important focus for ongoing research is to determine the sea-level at which this threshold will be crossed, initiating widespread progressive recession of open coast sandy beaches.

Roches Beach is an open coast beach exposed to a refracted swell which – even in calm weather – has sufficient power to move sand shoreward onto the beach and thus rebuild the beach and dune after storms. It therefore seems anomalous that – in contrast to most south-east Australian open coast swell-exposed sandy beaches, including most of those in south-east Tasmania - Roches Beach has nonetheless been in a state of overall recession since sometime prior to 1977 (probably circa 1975 – see Section 5.1 above).

[20] At current sea-levels, smaller and more frequent storms cause little erosion of beaches, with only the larger and more infrequent storms causing significant erosion. Such infrequent erosion is then ‘repaired’ in the long intervals between large storms, as the calm-weather swell pushes the eroded sand back onto the beach and wind blows exposed sand landwards from the beach to rebuild the dune front. However with continued sea-level rise – and even without any change in the frequency of storms of any given magnitude – smaller storm waves, which previously caused little damage, will reach further landwards over the deepened water to cause more erosion than they were previously capable of. At a certain (as yet unknown) sea-level, the increased frequency of such erosion events will pass a threshold beyond which insufficient time is available between erosion events for beaches to fully rebuild, and progressive recession of the beach and dune-front will start to become apparent above the ‘noise’ of swell-driven beach rebuilding and other coastal processes.

As noted above, the historic air photo evidence does show that swell-driven shoreline rebuilding has indeed occurred at Roches Beach in the past, in particular since major erosion events prior to 1977 and 1987; however those processes have never fully rebuilt the shoreline to its former 1957 position. Even more anomalously, no significant shoreline rebuilding (including formation of incipient foredunes) has occurred at all over the period from at least 2001 until 2010 (based on the writers own repeated field observations since 2001: see Section 3.5). Over at least the last decade, most of Roches Beach (especially the central part north of the canal) has been in a continually erosive state, with occasional slumping of foredune erosion scarps but no accumulation of incipient foredunes indicative of beach rebuilding[21].

Possible causes of the observed shoreline behaviour at Roches Beach between 1957 and 2010 are considered below:

Artificial disturbances

Artificial disturbances that have occurred at Roches Beach (Section 3.4) do not appear capable of explaining the observed patterns of shoreline change. The Roches Beach end of the Lauderdale Canal was notoriously closed by longshore sand drift within days of its construction (see Section 3.4), and has had negligible effect on shoreline processes. Significant recession at the south end of Roches Beach occurred prior to construction of the boulder revetment in that area circa 1988, and although the revetment has subsequently exerted local control on shoreline processes – primarily by isolating dune sand from further erosion and thus removing it from the beach process system – this does not appear capable of explaining the broader pattern of shoreline recession along the major part of Roches Beach extending for several kilometres north of the revetment. Artificial replenishment of beach sand in the canal area circa 1988 is not a likely cause of shoreline erosion; if anything it may have locally slowed the progress of shoreline recession. No other artificial disturbances are known to have occurred that might explain the observed shoreline changes at Roches Beach.

Cyclic oceanographic processes

In a cursory assessment of erosion at Roches Beach, Byrne (2006, p. 11) suggested that “the erosion is much more likely to be part of a long term cyclical phenomenon rather than an ongoing recession of the coast”; however Byrne provided no evidence supporting this assertion. Nonetheless a number of coastal geomorphic processes are known to cause cyclic erosion and rebuilding of beaches. These include cut-and-fill cycles associated with individual storms or stormy periods, seasonal (annual) weather cycles, and longer term cycles including the El Nino Southern Oscillation or ENSO (which has been shown to cause beach rotation on inter-decadal cycles in NSW: Short *et al.* 2000) and the Pacific Decadal Oscillation (PDO). However to the extent that these cyclic beach changes are driven by cyclic changes in swell wave climate related to ENSO, PDO, etc, this means that these cycles have their strongest effect on more exposed open coast beaches where significant changes in swell direction related to these cycles may significantly affect wave directional variability at the shore. However swell waves reaching Roches are strongly refracted, hence any such directional variability is damped out.

Moreover, these cycles tend to cause beaches to oscillate around an equilibrium position on annual or decadal time-frames, whereas Roches Beach can now be demonstrated to have undergone net – and continuing - recession since at least 1977, probably commencing around 1975 (see Section 5.1 above). Whilst it remains possible that this is simply the recession phase of an even longer oscillatory cycle, it is unclear what the nature and causes of such a cycle might be.

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[21] Incipient dunes are present in a few locations at the northern and southern extremities of Roches Beach – e.g., see Figure 28 & Figure 35 – however the major erosion scarps in the central part of the beach, especially Recession Zone RZ3 (Figure 19) have shown no incipient dune formation since at least 2001.

Given that cyclic variability in swell wave direction is unlikely to be a cause of putative long-term cyclic erosion at Roches Beach because any such variability will be damped out by the long refraction pathway of swell-driven waves reaching Roches Beach up Frederick Henry Bay, the only other likely driver of long term erosion cycles at Roches Beach would appear to be the possibility of long cycles of increased storminess, which might affect both the magnitude (wave energy) of swell-driven storms and also – through increased windiness – the magnitude of locally-generated wind wave storms across the fetch of Frederick Henry Bay (which appear to be the main agent of erosion at Roches Beach). However, whilst it does appear possible that the current phase of erosion and shoreline recession may have been triggered by a period of increased storminess which affected eastern Australia during the 1970's (see discussion in Section 5.1 above), that phase of increased storminess has not persisted from the 1970's up to the present. On the other hand, erosion and progressive shoreline recession has persisted from its apparent inception during the 1970's up to the present (2010), a fact which increased 1970's storminess followed by several decades of unexceptional storminess fails to explain.

In the absence of any clear evidence that Roches Beach is simply responding to a very long-period cyclic process, the fact that the beach has now exhibited net continuing recession since at least the mid-1970's (i.e., over at least 35 years), and currently remains in an actively eroding state, diminishes the likelihood that the observed beach recession is simply a cyclic phenomenon (of some unclear nature), and makes it more probable that what is being observed is a switch of beach behaviour into a new state due to some other cause.

Long-term ongoing shoreline geomorphic changes unrelated to sea-level rise

It is evident that there is a persistent northwards swell-driven longshore drift of shallow subtidal sand through and out of the Roches Beach system, towards Seven Mile Beach (see Sections 3.3 & 5.1). If this lost sand is not replenished by an equivalent amount of sand drifting into the embayment from the south, around Mays Point, then the expected result would be a progressive loss of sand from the embayment, resulting in progressive shoreline recession and deepening of the zeta-form beach planform (Section 3.2). Indeed, this describes the current patterns of observed erosion at Roches Beach (Section 5.1), and is evidently the process which produced the zeta-form shape of the Roches Beach embayment following the initial mid-Holocene progradation of the Lauderdale Neck some thousands of years ago. If such a process has simply been ongoing for the last few thousand years up to the present, then the current observed shoreline recession might be merely a continuation of a long term (continuous or intermittent) process of progressive shoreline evolution at Roches Beach (note that this sort of ongoing long term progressive shoreline change – for reasons unrelated to sea-level rise – is indeed observed on many Australian beaches such as Ocean Beach (western Tasmania) and Ninety Mile Beach (Victoria), albeit it is likely that in these cases recent sea-level rise is probably accelerating the underlying long term recession trend).

However, the presence of a single well developed foredune backing Roches Beach – without exposure of older deposits under the dune which might imply the shoreline was receding prior to putatively recent development of the current foredune - suggests instead that the shoreline was essentially stable for some considerable time prior to the onset of the current phase of shoreline recession around the 1970's. This implies that, when the progradation (growth) of Lauderdale Neck ended some thousands of years ago (see Section 3.2), longshore drift processes must have modified the beach planform until it had settled into a stable zeta-form in equilibrium with the longshore sand drift, such that the amount of sand leaving the embayment to the north (towards Seven Mile Beach) was balanced by an equivalent amount of sand entering the embayment from the south (around Mays Point). Without this condition having been satisfied it is unlikely that the single substantial foredune backing the beach today could have formed[22].

[22] Note that it would be possible and desirable to test this assertion by dating the age of the Roches Beach foredune at several points along its length (for example, by dating the burial time of quartz sand cored from the lower buried parts of the dune using OSL (Optically Stimulated Luminescence) dating techniques). If the

If this interpretation is correct, then it implies that the current phase of shoreline recession at Roches Beach – which on available evidence appears to have commenced circa 1975 - 1977 following a long period of relative shoreline stability – is a new phase of shoreline behaviour caused by a change in coastal processes at Roches Beach, rather than simply a continuation of a long term shoreline trend of ongoing shoreline recession which – if the latter hypothesis were correct – would need to have been more-or-less continuously in progress for some thousands of years since the Lauderdale Neck ceased prograding.

Sea-level rise

The above discussions have argued that local artificial beach modifications, long term oceanographic process cycles and long term underlying coastal landform change processes do not in themselves appear capable of explaining the marked phase of coastal erosion and shoreline recession that appears to have commenced at Roches Beach sometime between 1957 and 1977 (probably circa 1975), and that has persisted until the present (2010). The only other apparent significant factor known to have changed at Roches Beach in a time frame which could explain this onset and continuation of coastal recession is the rise in mean sea-level.

It has been demonstrated that about 14cm of sea-level rise has occurred around south-eastern Tasmania since 1840, probably mostly in the last century (Hunter *et al.* 2003). As described in Section (1.1), well-established geomorphic principles show that – unless other factors have countervailing effects – sea-level rise will in general result in erosion and recession of soft sandy shores. Given that other potential processes described above appear unlikely to explain the observed shoreline recession at Roches Beach, and also given that sea-level rise is known to have occurred and would be expected to cause shoreline change of the general sort that is actually observed, it is therefore most likely that the underlying cause of the shoreline erosion and recession observed at Roches Beach since the 1970’s is the renewed sea-level rise that is known to have occurred in south-east Tasmanian coastal waters over the last century.

However as noted above, it is significant that similar recessional effects of sea-level rise are not yet identifiable on most other open coast sandy beaches in south-east Tasmania, nor are such effects yet becoming apparent on most south-east Australian open coast beaches generally (Church *et al.* 2008). Thus if the observed shoreline recession is indeed a response to sea-level rise, then there must be somewhat unusual conditions or geomorphic processes operating at Roches Beach compared to many other open coast beaches, which result in an earlier response to sea-level rise than on most open coast sandy beaches.

Two aspects of the geomorphic process system at Roches Beach can be identified as being unusual in comparison to other open coast sandy beaches in the region, namely:

- *Shallow offshore profile*: As noted in Section (3.3) above, Carley *et al.* (2008, Fig 3.5) found that the transverse seawards beach profile (dune to subtidal) at Roches Beach is notably flatter (shallower) than for any other open coast swell-exposed beach measured in Clarence Municipality, and in fact that it is flatter (shallower) than the equilibrium profile that would be expected from the Bruun Rule (see Section 1.1, Figure 2) for a beach having the median sand grainsize measured at Roches Beach. In a swell-wave dominated beach environment this would be expected to result in net onshore sand movement by

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dune is some hundreds to a thousand or more years old, then the shoreline position has evidently been essentially stable for a considerable period as suggested above. However if it turned out that the dune is only one or two centuries old, then the possibility arises that the shore may indeed still be episodically but progressively retreating as part of an ongoing long term adjustment of the zeta planform in response to longshore drift (see also Section 5.4).

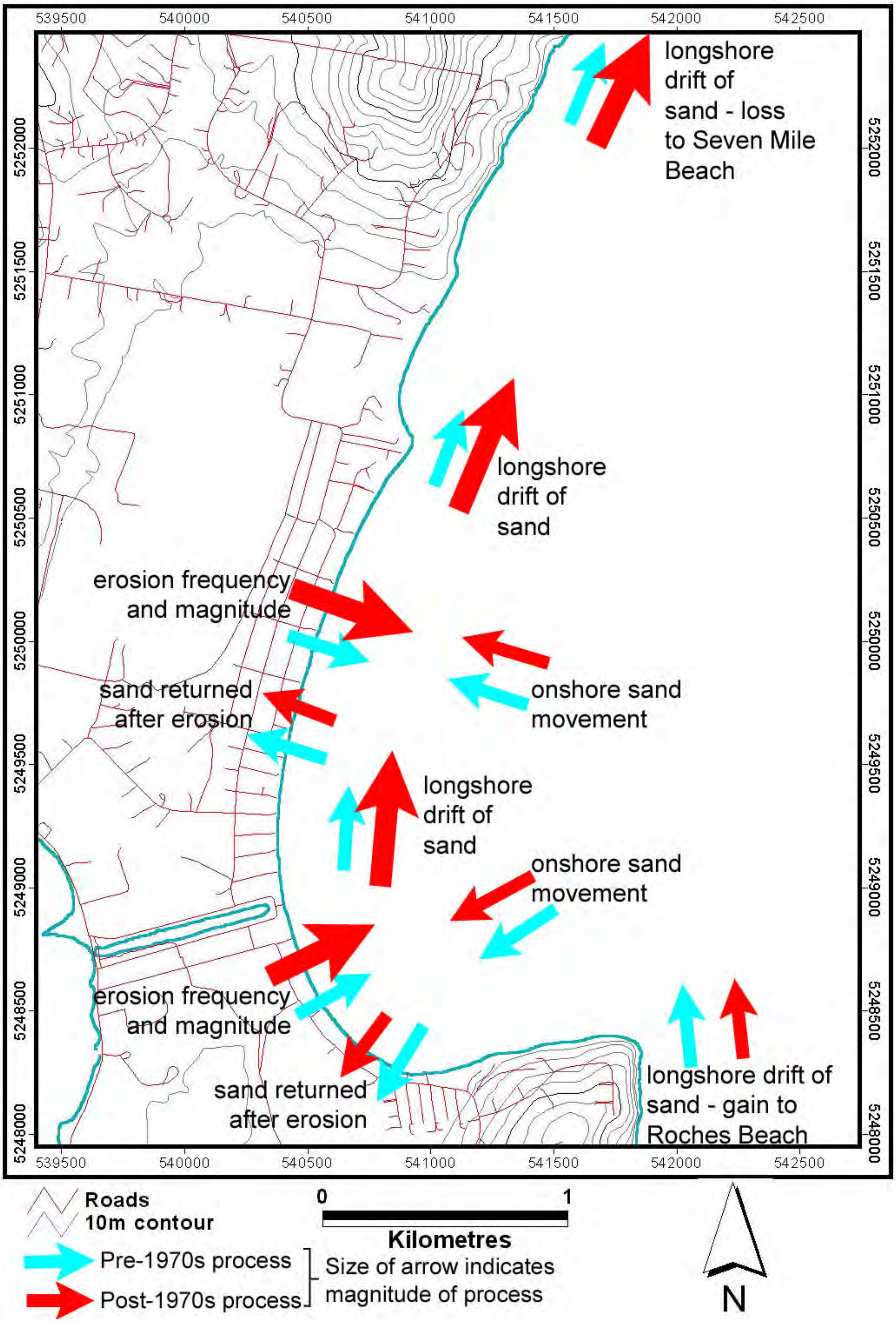

Figure 25: Diagrammatic summary of interpreted process changes at Roches Beach pre- and post-1970s. Increased erosion frequency and magnitude resulting from sea-level rise has from the 1970's onwards led to increased northwards longshore sand drift. Without counterbalancing increases in longshore sand gain from the south and onshore sand movement, the result has been a net progressive shoreline recession. The map grid is the MGA (Zone 55) grid (GDA94 datum).

constructive fair-weather swell waves resulting in beach growth (progradation) until an equilibrium subtidal profile were achieved. The fact that this has probably not been the case for some thousands of years (see Section 3.2), and certainly not in recent decades (Section 5.1), indicates that some other process or processes is dominating the system at Roches Beach[23]. The most likely dominating process known to be operating at Roches Beach which could offset shore-wards movement of sand from the shallow lower shoreface profile is a persistent swell-driven northwards longshore drift:

- *Persistent northwards longshore drift:* The Roches Beach embayment experiences a persistent unimodal northwards longshore drift of sand owing to refraction of swells moving northwards up Frederick Henry Bay and around Mays Point at the southern end of the embayment (Foster 1988, Byrne 2006; see Section 3.3). The progressive accretion of sand on the northern side of Bambra Reef, as demonstrated by comparison of historic air photos from 1957 to 2005 (see Section 5.1), and accretion of sand further north at the western end of Seven Mile Beach (Section 3.3), testify to the volume of sand being moved northwards through and out of the Roches Beach embayment by this longshore drift. Persistent northwards longshore drift is responsible for the development of the prominent zeta-form shape of the Roches Beach embayment (see Section 3.2). Roches Beach is the only well-developed zeta-form embayment in the Clarence Municipality region, which supports the observation that persistent unimodal longshore drift appears to be a much more significant process in this location than it is on other open coast beaches in the region[24].

Since these aspects of the geomorphic process system at Roches Beach are unusual in the region, it is likely that one or both of these conditions is a part of any explanation of why Roches Beach should be receding in response to sea-level rise while other open coast beaches in the region are not yet doing so. In any case a satisfactory explanation of shoreline recession at Roches Beach must at least account for these local factors.

Response of Roches Beach to sea-level rise

The following interpretation is proposed as the explanation of the shoreline erosion and recession observed at Roches Beach which appears to best account for the evidence and discussions presented in preceding sections (see summary diagram Figure 25):

Prior to circa 1975, net onshore swell-driven sand movement from the shallow offshore profile was offset by a longshore drift of sand northwards out of embayment towards Seven Mile Beach; at the same time sand lost northwards was balanced by gain of sand through longshore drift from the south around Mays Point. Thus longshore drift counterbalanced onshore sand drift, the overall sediment budget through the embayment was in balance, and the shoreline position was in equilibrium with these processes. The average time between erosive storms was long enough that sand was returned – albeit probably more slowly than on other open coast beaches lacking the persistent northwards longshore drift found at Roches Beach – to fully rebuild the beach after infrequent erosion events. Although renewed sea- revel rise had begun approximately a century prior to 1975, until that time a threshold had not yet been reached at which erosive storms were

[23] Indeed, Carley *et al.* (2008, p. 61) contend that where beaches have seaward profiles flatter than equilibrium, this is due to "a surplus of sediment, and/or headland bypassing, and/or a profile not dominated by cross shore wave action". In the case of Roches Beach, the latter explanation appears most relevant – longshore drift of sand northwards out of the Roches Beach embayment appears to be exceeding the rate at which cross-shore swell wave action can drive sand onshore to rebuild the eroded beach profile.

[24] Carley *et al.* (2008) noted that Cremorne Beach, south of Roches Beach, exhibits some zeta-form characteristics, however sand transport processes in the latter embayment are significantly modified by the tidal channel entrance to Pipe Clay Lagoon at the southern end of Cremorne Beach, which is thus not comparable to Roches Beach in this respect.

excavating the beach high enough up the profile and frequently enough that it could not fully rebuild between storms.

From circa 1975 onwards, erosion events of any given magnitude were more frequently eroding sand from higher than previously on the upper beach and dune face, due to the raised sea level. The increased frequency of such erosion events had reached a threshold at which the beach could no longer fully rebuild between these events, because longshore drift was removing the increased quantities of eroded sand to the north faster than it could be replenished by the (presumably unchanged) onshore sand movement and flux of new sand carried into the embayment by longshore drift from the south around Mays Point. Thus the sand budget in the embayment has switched from being in balance to a losing sand budget, causing the shoreline to progressively recede in response to the new budget.

Testing the interpretation
Whereas the interpretation presented above appears to provide the simplest explanation accounting for observed conditions and historical shoreline behaviour at Roches Beach, a number of additional investigations would be useful to support or refute this explanation. Key further investigations (tests of the interpretation) include the following (described in more detail in Section 5.4):

- Ortho-rectification of additional historic air photos - and mapping of shoreline positions from them - to fill in some critical time gaps in the ortho-photo time series used in the current study. Of particular interest are more air photos from the 1957 – 1977 time gap (especially the 1960’s and the 1975 air photo) to confirm that progressive shoreline recession began around the mid-1970s, and more air photos from the 1987 – 2001 time gap to narrow down when effective rebuilding of the shore after storm events ceased;

- Measurements of longshore drift / sand fluxes into, through and out of the Roches Beach embayment (it is expected that sand flux northwards out of the embayment now exceeds sand flux into the embayment from the south around Mays Point);

- Dating of the foredune at several locations along its length, ideally using OSL tests on sand samples cored from within the dune (it is expected that the current dune is several thousand years old, having been a stable feature in its current position since mid-Holocene progradation of the Lauderdale Neck ceased);

Implications of the interpretation
A number of implications of the interpretation presented above are worthy of note, including:

- As discussed above (Church *et al.* 2008), most open coast swell-exposed sandy beaches in south-eastern Australia (including the Hobart – Storm Bay region) are not yet showing obvious recession as is expected to occur as a result of sea-level rise, despite the fact renewed sea-level rise has now been in progress for over a century. Sea-level rise has yet to reach a threshold beyond which those beaches will begin to exhibit progressive recession. That Roches Beach is evidently an exception to this rule is attributable to unusual local conditions – especially a strong uni-modal longshore drift of sand which, in combination with sea-level rise, has caused the beach to switch from an equilibrium sand budget to a losing budget at a lower sea-level threshold than will be necessary for most other open coast beaches to do so.

- The net accretion of sand on north side of Bambra Reef as observed after 1957 (see Section 5.1 & Figure 13) is evidence of an increase in volume of sand being transported northwards out of Roches Beach, as required by the interpretation presented above. Prior to the onset of progressive shoreline recession it is expected that the longshore drift sand budget would have been in equilibrium - with sand from Roches Beach moving north around Bambra Reef and towards Seven Mile Beach no faster than it was being replenished from the south around Mays Point – so there would have been no net increase in accretion on the north side of Bambra Reef.

- Under this interpretation, the progressive recession observed in recent decades at Roches Beach represents a new phase in the evolution of the beach, which is a response to renewed sea-level rise which began over a century ago. The suggestion that the current phase of recession only commenced circa 1975 (see Section 5.1) is consistent with this explanation, since it is probable that there would be a lag period between the onset of sea-level rise over a century ago, and the onset of detectable shoreline changes resulting from that rise, because the onset of progressive recession could not occur until sea-level rise had reached a threshold beyond which there was insufficient time between storms to rebuild the beach.

- The spatial patterns of erosion at Roches Beach over the last few decades (as described in Section 5.1 above) imply that *both* swell waves and local wind waves generated across the fetch of Frederick Henry Bay are involved in the observed erosion process. The fact that the greatest magnitude of erosion observed has been in the deepest (south-western) part of the embayment is best explained as a result of erosion by wind-waves generated across the north-easterly fetch of Frederick Henry Bay, whilst it is the refracted swell which is driving a persistent northwards longshore drift that removes the eroded sand, causing a losing sand budget and preventing the beach from fully rebuilding after storms.

- The same observed patterns of erosion also imply that sea-level rise has in effect restarted the process of zeta-form shoreline development, which originally produced the planform of the Roches Beach embayment some thousands of years ago before it settled into an equilibrium with the sea level at that time (see Section 3.2). The planform of Roches Beach is now adjusting towards a new zeta-form in equilibrium with new higher sea-levels, and will continue to do so until sea-level rise stops (at some time at least centuries in the future).

- It is implicit in the above that the largest magnitude of ongoing erosion will continue to be in the south-west (deepest) part of the Roches Beach zeta-form, albeit this may be partially masked by the boulder revetment that has been constructed in part of that area to resist erosion.

- It was noted in Section (5.1) above that the apparent onset of recession at Roches Beach around the mid-1970's coincided with a period of unusual storminess which caused major erosion on many south-eastern Australian beaches, particularly in NSW. It is likely that the same phase of storminess caused major erosion at Roches Beach. However, whilst many of the NSW beaches which were eroded by the mid-1970s storms have subsequently fully rebuilt, Roches Beach has not and instead has settled into a new long-term phase of progressive recession. The difference in behaviour is attributed to the local conditions at Roches Beach, in particular the persistent unimodal northwards longshore drift. Thus, whilst Roches Beach has – like other open coast beaches – shown some rebuilding following initial severe erosion in the mid-1970s, those erosion events receded the shore to an extent which could not be fully rebuilt in the intervals between subsequent storms owing to the combined effects of sea-level rise (which tends to cause underlying progressive recession) and local longshore drift conditions (which tend to inhibit the beach from rebuilding at a sufficiently rapid rate as to 'mask' the recessional effects of sea-level rise). Had similar events occurred some decades earlier, when less renewed sea-level rise had occurred and the resulting magnitude of erosion would therefore have been less, then the beach may have fully recovered; however the mid-1970's erosion events occurred at a time when sufficient sea-level rise had occurred that the beach responded with greater erosion than the same events might have caused if sea-level was lower, and so was no longer able to fully recover before subsequent storms triggered additional erosion leading to the observed progressive recession trend. Conversely, had major erosion events not occurred at Roches Beach during the 1970's, then it might have taken longer before Roches Beach started to exhibit progressive recession. In effect, whilst the 1970's storms were not themselves an effect of sea-level rise, they occurred at a time when sufficient sea-level rise had happened that they had the effect of 'flipping' Roches Beach into a new state in which long-term recession in response to sea-level rise became apparent and persistent.

- A key observation report in Section (5.1) above is that, whilst some rebuilding of Roches Beach ("cut-and-fill" behaviour) occurred between 1977 and the 1990's following the onset of progressive observable shoreline recession in the 1970's, more recently from at least 2001 up to 2010 there has been no observed rebuilding at all. Rather, the beach and dune-front have settled into a persistently erosional state with no incipient dune formation in most areas. A likely explanation of this is that the observed ongoing acceleration of global sea-level rise (Church & White 2006) means that smaller storm events (with shorter Average Recurrence Intervals) – impacting the shore from a higher sea level than before - are now capable of causing more beach erosion than similar storms could do in the 1970's to 1990's period, with the result that beach rebuilding processes are now even more inhibited at Roches Beach than they were in the 1970's.

- Observed shoreline recession at Roches Beach is a good example of how the Bruun Rule (Section 1.1) is rarely the sole control over beach response to sea-level rise, but can be significantly modified by other processes such as longshore drift. At Roches Beach the shallow offshore profile means that – according to the Bruun Rule – the shoreline should be prograding rather than receding; however this is offset by longshore drift to the extent that shoreline recession in response to sea-level rise has actually occurred earlier than on other open coast beaches in the region.

5.3 *A Baseline for Monitoring Ongoing Shoreline Change at Roches Beach*

This project has demonstrated that the use of a time series of ortho-rectified air photos and high-resolution satellite imagery is a simple and effective method of monitoring shoreline change over time on shores where a clearly defined indicator of shoreline position is visible on the imagery. The seawards dune vegetation limit serves this purpose well along the major part of Roches Beach where the bright sandy beach is backed by dunes with dark-toned vegetation. However this indicator is difficult to use on sandy or rocky shorelines directly backed by bedrock and soil slopes, due to poor contrast between vegetation, exposed soil and rock.

An important element of this method is the determination of the position error margins for comparing feature positions between each ortho-rectified image in a time series. These margins can be determined if sufficient fixed reference features are visible in each image. Provided a reasonable ortho-rectification accuracy is achieved (i.e., ±2 or 3 metres position errors), and the position error margins are known, then it is possible to reliably demonstrate *minimum* shoreline movements, and in particular changing patterns of movement, where-ever these movements have been greater than the error margin. Where this method does not detect any demonstrable shoreline movement, the equally useful conclusion can be drawn that any actual shoreline movement that may have occurred is demonstrably less than the ortho-rectification error margin.

Although more accurate ortho-rectification is always desirable, beyond a certain point improving the accuracy of ortho-rectification may become an exercise of diminishing returns for increased effort, hence the use of error margins provides a simpler method which can nonetheless yield reliable information on real shoreline changes. Shoreline movements at Roches Beach between 1957 and 2005 have demonstrably been significantly greater than the error margins of the ortho-images that were used; hence this method has yielded considerable reliable information on the degree, timing and patterns of real shoreline change.

In addition, comparison of 2005 TASMARC benchmarks and ground survey results with the 2005 QuickBird ortho-image have shown a close correlation between the results of these two methods.

Ongoing future work using ground survey results such as TASMARC profiles, in conjunction with future ortho-rectified satellite and air photo imagery; will continue to provide a simple and cost-effective method of monitoring and measuring shoreline change at Roches Beach. Since ortho-rectification of all the imagery used in this project used the control points to which the 2001 ortho-image was initially ortho-rectified, it is envisaged that the 2001 shoreline position should continue to be regarded as the "baseline" against which to measure position error margins for both earlier and later imagery.

5.4 *Recommended Further Investigations on Roches Beach*

In addition to ongoing monitoring of future shoreline change at Roches Beach as outlined above, further work that could usefully be undertaken to test the causes of long-term erosion at Roches Beach proposed in Section (5.2) above include:

- Physical measurement of actual shallow subtidal sand flux (longshore drift) into, through and out of the embayment (around Mays Point, Bambra Reef and Single Hill Point respectively), to test the assumption that natural longshore replenishment of sand is now out of balance due to increased frequency of erosion events, which is causing the beach to recede with sea-level rise while other open coast beaches with more balanced sand budgets aren't yet doing so.

- Ortho-rectification and shoreline position measurement on air photos from additional epochs between 1957 and 1977 (especially 1975, but also the 1960's), along the whole length of Roches Beach, to test the proposal (Section 5.1) that significant erosion and recession at Roches Beach only commenced sometime around 1975 to 1977 (this also further tests the assessment that observed net shoreline recession is not a continuation of a long term trend, but rather a recent coastal response to sea-level rise within the last century).

- Although air photos prior to 1957 could not be ortho-rectified for this project, an older 1946 air photo exists (See Section 4.1) and should be at least visually compared with the 1957 photo to determine whether there is any indication of a change of behaviour between the two epochs, or whether the 1946 photo shows a similar shoreline position and dune front 'raggedness' to the 1957 image, which would suggest little change between the two times.

- Ortho-rectification and shoreline measurement on air photos from additional epochs between 1987 and 2001 to narrow down the time at which the current phase of continually erosive scarping without rebuilding commenced, following the episodic rebuilding of the dune front after erosion that is observable from 1977 to at least 1987.

- Historical research (primarily using Bureau of Meteorology weather records, Hobart tide gauge records and newspaper reports, but including seeking local anecdotal reports) may be useful to pin down the timing of major erosion events at Roches Beach, and the nature of the weather systems causing such events. Note that it is considered likely that major erosion events at Roches have been caused by locally-generated wind-waves driven by north-easterly winds across the fetch of Frederick Henry Bay, which may not have been recorded as storm surges at the Hobart tide gauge, but may be identifiable from weather records of east coast low pressure systems, and might possibly (although not necessarily) have been reported in local newspapers. Similar research through the 1980s until at least 1988 or later would be useful to identify any other notable erosion events at Roches Beach within that period.

- An archival search for an old (pre-1957) coastal land title surveys at Roches Beach might yield old surveyed HWM boundaries capable of being compared with LIST cadastral HWM maps, albeit at a lower level of reliability than the ortho-rectified photo analysis conducted in the present project (see Section 4.4). There is potential for such surveys to provide some evidence as to whether or not significant historical erosion has occurred at Roches Beach prior to 1957; such evidence could bear on the question of whether observed progressive net shoreline recession at Roches Beach is a relatively recent phenomenon, or part of a longer term ongoing process (see Section 5.2).

- More detailed investigations of the late Holocene geomorphic history of Roches Beach aimed at confirming or refuting the apparent stability of the Roches Beach foredune and shoreline position since progradation of the Lauderdale Neck ceased (and dating of that time) would provide key support or refutation of the proposed explanation of recent shoreline recession at Roches Beach. It is asserted in Section (5.2) above that the presence of a single well-developed foredune backing Roches Beach implies that Roches Beach probably settled into a stable zeta planform in equilibrium with longshore drift of sand through the embayment following the end of the Lauderdale Neck's progradation some thousands of years ago, and remained essentially stable until the recent onset of renewed sea-level rise upset the equilibrium. However, it would be possible and desirable to test this assertion by dating the age of the Roches Beach foredune at several points along its length (for example, by dating the burial time of quartz sand cored from the lower buried parts of the dune using Optically Stimulated Luminescence (OSL) techniques). If the dune is some hundreds to a thousand or more years old, then the shoreline position has indeed evidently been essentially stable for a considerable period as suggested above. However if it turned out that the dune is only one or two centuries old, then the possibility arises that the observed erosion may simply be part of an ongoing process of long-term progressive or episodic shoreline retreat as the zeta planform evolves in response to longshore drift causing a negative sand budget in the embayment.

However, irrespective of the causes of coastal recession at Roches Beach, the shoreline change detection techniques explored in this work will provide a simple means of continuing to reliably monitor shoreline changes at Roches Beach, in particular the ongoing use of new ortho-rectified high resolution satellite imagery as it becomes available, and continued beach profile surveying tied into the satellite imagery results (TASMARC surveys and Clarence Council Surveys).

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APPENDIX ONE: DATA DICTIONARY FOR DIGITAL MAPPING

A1.1 *Introduction*

This appendix provides metadata for the vector GIS layers created to record the results of this project. All files produced are ESRI shapefiles, created using Arcview 3.2a, projected in the Universal Transverse Mercator (UTM) system using the Map Grid of Australia (MGA) co-ordinate system (Zone 55), and based on the GDA94 datum.

A1.2 *Data Models*

Shapefile: *1957_rochesveglimit_gda.shp*, GDA94 datum
Type: Line
Description: Line position represents shoreline location (defined as seawards vegetation limit) at Roches Beach and adjacent rocky shorelines in 1957, and fixed reference features used to determine ortho-photo position error margins, digitised by drawing line over 1957 ortho-rectified air photos (Ortho-images 326-40 & 326-80; See Appendix Two). Shoreline is dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. In this theme, recorded attributes are based on air photo interpretation and comparison with 2006 ground truth data where appropriate.

Field	Type	Width	Attributes	Comments
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline): • bedrock • colluvium • dune sand • etc	Recorded where possible.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Recorded where possible. See attribute table in Section (A1.3)
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	Recorded where possible.
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	For this theme = Ortho-photo numbers 326-40 & 326-80
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date image taken.

Shapefile: *1977_rochesveglimit_gda.shp*, GDA94 datum
Type: Line
Description: Line position represents shoreline location (defined as seawards vegetation limit) at Roches Beach and adjacent rocky shorelines in 1977, and fixed reference features used to determine ortho-photo position error margins, digitised by drawing line over 1977 ortho-rectified air photo (Ortho-image 708-3; See Appendix Two). Shoreline is dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. In this theme, recorded attributes are based on air photo interpretation and comparison with 2006 ground truth data where appropriate.

Field	Type	Width	Attributes	Comments
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline): • bedrock • colluvium • dune sand • etc	Recorded where possible.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Recorded where possible. See attribute table in Section (A1.3)
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	Recorded where possible.
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	For this theme = Ortho-photo number 708-3
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date image taken.

Shapefile: *1987_rochesveglimit_gda.shp*, GDA94 datum
Type: Line
Description: Line position represents shoreline location (defined as seawards vegetation limit) at Roches Beach and adjacent rocky shorelines in 1987, and fixed reference features used to determine ortho-photo position error margins, digitised by drawing line over 1987 ortho-rectified air photo (Ortho-image 1092-240; See Appendix Two). Shoreline is dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. In this theme, recorded attributes are based on air photo interpretation and comparison with 2006 ground truth data where appropriate.

Field	**Type**	**Width**	**Attributes**	**Comments**
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline): • bedrock • colluvium • dune sand • etc	Recorded where possible.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Recorded where possible. See attribute table in Section (A1.3)
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	Recorded where possible.
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	For this theme = Ortho-photo number 1092-240
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date image taken.

Shapefile: *2001_rochesveglimit_gda.shp*, GDA94 datum
Type: Line
Description: **Baseline shoreline position map, used as the standard baseline against which to compare all earlier and later imagery and mapping of shoreline position.** Line position represents shoreline location (defined as seawards vegetation limit) at Roches Beach and adjacent rocky shorelines in 2001, and fixed reference features used to determine ortho-photo position error margins, digitised by drawing line over 2001 ortho-rectified air photos (LIST Digital Urban Series Ortho-images 1342-46 & 1342-48; See Appendix Two). Shoreline is dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. In this theme, recorded attributes are based on air photo interpretation and comparison with 2006 ground truth data where appropriate.

Field	**Type**	**Width**	**Attributes**	**Comments**
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline): • bedrock • colluvium • dune sand • etc	Recorded where possible.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Recorded where possible. See attribute table in Section (A1.3)
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	Recorded where possible.
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	For this theme = Ortho-photo numbers 1342-46 & 1342-48
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date image taken.

Shapefile: *2005_rochesveglimit_gda.shp*, GDA94 datum
Type: Line
Description: Line position represents shoreline location (defined as seawards vegetation limit) at Roches Beach and adjacent rocky shorelines in 2005, and fixed reference features used to determine ortho-photo position error margins, digitised by drawing line over 2005 rectified QuickBird satellite image (see Appendix Two). Shoreline is dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. In this theme, recorded attributes are based on image interpretation and comparison with 2006 ground truth data where appropriate.

Field	**Type**	**Width**	**Attributes**	**Comments**
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline): • bedrock • colluvium • dune sand • etc	Recorded where possible.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Recorded where possible. See attribute table in Section (A1.3)
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	Recorded where possible.
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	For this theme: QuickBird satellite image
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date image taken. (For this theme = 2nd May 2005)

Shapefile: *2005roches1_6mbuffergda.shp*
1987_roches_2mbuffer_gda.shp
1977_roches_2mbuffer_gda.shp
1957_roches_2mbuffer_gda.shp
Type: Polygon
Description: Buffer envelopes around measured apparent shoreline positions for 2005, 1987, 1977 & 1957 (*rochesveglimit* line shapefiles, see above), representing position error margins determined as described in text. The buffers represent the areas within which the shoreline for each epoch could potentially lie, given the measured position error margins for each ortho-rectified air photo (see Appendix Two). Buffer shapefiles generated automatically in Arcview, based on the shoreline position line theme to which each buffer envelope file relates.

Field	**Type**	**Width**	**Attributes**	**Comments**
Bufferdis	numerical	16	Buffer distance in metres around central apparent shoreline position.	Buffer distance is 1.6m either side of apparent shoreline position for 2005, and 2.0m for 1987, 1977 and 1957 files

Shapefile: *tasmarcs_gda.shp*, GDA94 datum
Type: Point
Description: Positions of State Permanent Markers (SPM) installed by DPIWE surveyors during 2005 for the Tasmanian Shoreline Monitoring and Archiving (TASMARC) project, benchmarks for beach profile monitoring surveys. Positions of SPM markers determined by accurate GPS surveys conducted by DPIWE surveyors.

Field	**Type**	**Width**	**Attributes**	**Comments**
Tasmarc	string	7	TASMARC benchmark number	Mark number assigned for TASMARC Project.
Spm	string	16	State Permanent Marker (SPM) number	Assigned by DPIWE
Eastgda	number	16 (3 decimal places)	Metric easting (Map Grid of Australia (MGA), based on GDA94 datum)	Determined by DPIWE GPS survey; metric co-ordinate quoted to 3 decimal places by surveyors.
Northgda	number	16 (3 decimal places)	Metric northing (Map Grid of Australia (MGA), based on GDA94 datum)	Determined by DPIWE GPS survey; metric co-ordinate quoted to 3 decimal places by surveyors.

Shapefile: *tasmarcrochesveglimit_gda.shp*, GDA94
Type: Line
Description: Line positions representing shoreline location (defined as dune scarp = seawards vegetation limit) at three locations adjacent TASMARC / SPM markers, obtained by ground-based TASMARC surveys. Surveys based on tape and theodolite measurements from SPM benchmarks.

Field	**Type**	**Width**	**Attributes**	**Comments**
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate at the vegetation limit (= shoreline) : • bedrock • colluvium • dune sand • etc	
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	Based on photos taken by TASMARC volunteer surveyors. See attribute table in Section (A1.3)
Scarphtm	number	4 (2 decimal places)	Height of erosion scarp where present, in metres	Based on photos and survey records by TASMARC volunteer surveyors. Automatically records as zero (0.00) where no erosion scarp present
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any.	
Notes	string	200	Verbal comments as appropriate	
Source	string	100	Source of line position data	
Date	string	10	Date line position data obtained, in format: DD/MM/YYYY	Date survey conducted.

Shapefile: *2006_rochescondition_gda.shp*, GDA94
Type: Line
Description: Geomorphic condition (erosion status, etc) of Roches Beach shoreline (defined as seawards vegetation limit) at 11th – 14th August 2006, determined by field surveys by C. Sharples. Shoreline is the seawards vegetation limit, i.e., the dune front scarp or incipient dune front in sandy areas, and landwards limit of regular wave-wash on rocky or artificial shorelines. The line position is based on *2001_rochesveglimit_gda.shp*; hence whilst condition data attributes are accurate for 2006, line position is *not* necessarily accurate for 2006.

Field	**Type**	**Width**	**Attributes**	**Comments**
Feature	string	50	Class of feature: • shoreline vegetation limit • fixed reference feature	Broadly identifies whether mapped feature is a part of the shoreline whose movement is being monitored, or is a fixed reference feature whose position should not change over time
Descrip	string	100	More specific description of what the feature is.	Verbal description of types, e.g., road edge, building edge, dune-front scarp, etc
Substrate	string	50	Shoreline substrate <u>at</u> the vegetation limit (= shoreline): • bedrock ± soil • colluvium ± soil • dune sand • boulder wall • etc	Verbal description of types.
Condition	string	1	Alphabetical qualitative classification of shoreline condition in terms of erosion or otherwise.	See attribute table in Section (A1.3)
Scarphtm	string	9	Height of erosion scarp where present, in metres, recorded in half-metre ranges (e.g., "0.5 – 1.0")	"0.0" where no scarp present, or old bedrock scarp is considered stable (see attribute table in Section A1.3).
Artificial	string	50	Artificial feature types present at shoreline vegetation limit, if any. Includes: "no" – no artificial features	Verbal description of types.
Notes	string	200	Verbal comments as appropriate	
Date	string	10	Date condition data obtained, in format: DD/MM/YYYY	Date survey conducted, etc.

Shapefile: *1957_2005_mindetectabble_changegda.shp*, GDA94
Type: Line
Description: LIST HWM line with attributes summarising the minimum shoreline position changes that can be demonstrated to have occurred at Roches Beach between 1957 and 2005, based on measuring the separation between the outer edges of the position error envelopes for the shoreline positions determined for those epochs from analysis of ortho-rectified air photos. Also provides numbering of shoreline accretion and recession zones defined in this project for convenience in describing patterns of change.

Field	**Type**	**Width**	**Attributes**	**Comments**
change	string	16	Measured 1957 to 2005 position error envelope separations, in 2 metre increments.	Net recession indicated by ‘-‘ figures, net accretion by ‘+’ figures.
zone	string	16	Recession or accretion zone name, or “no change” where no net detectable shoreline movement between 1957 and 2005 can be demonstrated.	

Shapefile: *fixedfeatures_gda.shp*, GDA94 datum
Type: Point
Description: This theme identifies the positions of fixed reference features visible in both the 1957 air photo ortho-images and in the 2001 air photo ortho-images, and records the actual ortho-rectification errors (apparent feature movement) between the 2001 and 1957 ortho-images. The outlines of the same fixed reference features have been digitised as lines in *1957_rochesveglimit_gda.shp* and in *2001_rochesveglimit_gda.shp*, and are identified with the same feature labels in those shapefiles. The point positions recorded in this theme are positions roughly halfway between the 1957 and 2001 positions of the part of each fixed feature used to measure the apparent movement (ortho-rectification error) between the 2001 and 1957 ortho-images. The position errors recorded in this theme were determined in Arcview by measuring the distance between the position of each identical fixed feature in the *1957_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp* themes. The position errors recorded in this theme are in all cases recorded as the distance and direction from the 2001 position of each feature to the 1957 position of the same feature. The accuracy of the position errors determined in this way is estimated to be ±0.5 metre, which is the pixel size of both ortho-images.

Field	**Type**	**Width**	**Attributes**	**Comments**
Fixedfeat	string	4	Feature number	Feature label, as used for same features in the *1957_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp* themes.
Eastgda	number	6	MGA easting of fixed feature location point, GDA94 datum	Feature position mid-way between the 1957 and 2001 positions of the part of each fixed feature used to measure the apparent movement (ortho-rectification error) between the 2001 and 1957 ortho-images
Northgda	number	7	MGA northing of fixed feature location point, GDA94 datum	As above
Northm	number	1 + 2 decimal places	Apparent movement of feature in northwards direction, in metres.	Apparent movement of feature from the 2001 image position to the 1957 image position.
Southm	number	1 + 2 decimal places	Apparent movement of feature in southwards direction, in metres	As above.
Eastm	number	1 + 2 decimal places	Apparent movement of feature in eastwards direction, in metres	As above.
Westm	number	1 + 2 decimal places	Apparent movement of feature in westwards direction, in metres	As above.
Offshorem	number	1 + 2 decimal places	Apparent movement of feature in offshore direction, in metres	As above. Movement normal to shoreline.
Onshorem	number	1 + 2 decimal places	Apparent movement of feature in onshore direction, in metres	As above. Movement normal to shoreline.
Notes	string	200	Notes or comments	

A1.3 *Attribute Table ("Lookup Table")*

Shoreline Condition (Condition)
Used in shapefile/theme: *2006_rochescondition_gda.shp*
Field name: Condition
Field type: String
Field width: 1
Explanation: Qualitative classification of shoreline condition (at the seawards vegetation limit) in terms of the degree of erosion evident or otherwise. Determined by subjective field classification by C. Sharples on 11th – 14th August 2006.

NOTE that for the purposes of this attribute, "erosion" refers to recent or accelerated (last few years or decades) erosion; bedrock shores showing shoreline scarps with no evidence of recent accelerated erosion are considered stable shorelines, albeit they are obviously erosional over longer time-frames.

Attribute summary:

Characters	Shoreline condition (*Condition*)
A	**Active erosion** – Fresh vertical erosion scarp, unvegetated, little slumping or rounding of scarp.
B	**Recent erosion –** Erosion scarp mainly vertical and unvegetated, with some slumping or rounding over.
C	**Inactive erosion** – Old erosion scarp, significantly collapsed or rounded over and with some vegetation growth, but generally no significant incipient dune formed to seawards of old erosion scarp.
D	**Sand accretion –** Significant fresh incipient dune with some vegetation growth (partly buried old erosion scarp may still be evident to landwards in some cases).
E	**No erosion scarp: Artificial shores –** Artificially protected shores showing no active erosion scarp behind or under protective structure. (If erosion scarp is evident despite artificial structure, shoreline segment classified A, B or C as appropriate).
F	**Stable shoreline: natural shores** - Natural shores (rocky or sandy, etc) showing neither recent accelerated erosion nor accretion of sand).
U	**Unclassified –** Shoreline condition unknown or unclassified.

APPENDIX TWO: AERIAL AND SATELLITE IMAGERY METADATA

This Appendix provides relevant metadata for imagery (including ortho-rectified air photos and a satellite image) used to produce the mapping provided with this report. The imagery is copyright data, copies of which cannot be provided as outcomes of this report, but upon which the outcomes provided with this report are based. Users wishing to view and use such imagery will need to obtain their own copies from the relevant copyright holders in each case.

2001 Ortho-rectified Air Photo Images

Imagery name: LIST Digital Urban Series Ortho-images 1342-46 & 1342-48
Copyright holder: Information & Land Services (ILS), Department of Primary Industries & Water, Hobart, Tasmania
Brief description & coverage: Scanned and ortho-rectified 2001 colour air photo images of Roches Beach, Lauderdale, southeast Tasmania (North Roches Beach: 1342-46, South Roches Beach: 1342-48)
Used for: *2001_rochesveglimit_gda.shp* (used to digitise baseline 2001 shoreline (seawards vegetation limit) position); Refer Appendix A1.2 Data Models.
Format & Mapping Standards: Supplied in ERmapper .ecw format, GDA94 datum, MGA Zone 55 co-ordinate system, UTM projection.
Image Capture date: 4th January 2001
Image & Camera details: Colour Aerial Photography Project No. A135HD, Film no. 1342, Run No. 15S, Frames 46 & 48, flown 4/01/2001, Lens 153mm, Scale 1:24,000
Rectification: Ortho-rectification process controlled by control point transfer from existing controlled photography used to produce 1:5,000 Urban Ortho Photo Series and 5m contour data from that series.
Pixel size (resolution): 0.50 metre
Absolute horizontal accuracy (positional error margins) relative to actual feature positions, as quoted by supplier: Accuracy generally in the order of ±2 metres, but can be ±5 metres in some places (includes the "pointing error" determined by pixel size limitations). When projected in Arcview, there is a 4 - 5 m (approx) north-south offset and 1.5m (approx) east-west offset between identifiable features in the shoreline region of each image, in the area of overlap between the two images. Since the shoreline runs N-S in the area of overlap, this amounts to a 1.5m (approx) offset in the shoreline position in the onshore-offshore direction. The northern part of *2001_rochesveglimit_gda.shp* was digitised from 1342-46, and southern (main) from 1342-48 (as attributed in *2001_rochesveglimit_gda.shp*), hence this offset will be inherent in a slight difference between the two.

Relative horizontal accuracy: These 2001 images are the baseline maps (images) used to compare all other images with for the purposes of this project. Hence for these purposes the "absolute" accuracy of these 2001 images with respect to actual feature locations on the ground is ignored, and the horizontal accuracy (error margin) for these 2001 images is taken to be only the "pointing error", which is the accuracy with which any feature can be pointed at on the images. This error is determined by the pixel size (0.5m).

1957 Ortho-rectified Air Photo Images

Imagery name: ILS Ortho-images 326-40 & 326-80
Copyright holder: Information & Land Services (ILS), Department of Primary Industries & Water, Hobart, Tasmania.
Brief description & coverage: Scanned and ortho-rectified monochrome 1957 air photo images of Roches Beach, Lauderdale, south east Tasmania (North Roches Beach: 326-80, South Roches Beach: 326-40).
Used for: *1957_rochesveglimit_gda.shp* (line map of 1957 shoreline (seawards vegetation limit) position); Refer Appendix A1.2 Data Models.
Format & Mapping Standards: Supplied in ERmapper .ecw format, GDA94 datum, MGA Zone 55 co-ordinate system, UTM projection.
Image Capture date: 30th January 1957
Image & Camera details: Black & White Aerial Photography, Hobart Project, Film no. 326, Run 4 Frame 40 and Run 5 Frame 80, flown 30/01/1957, Lens 152mm, Scale 1:14,000.
Rectification: Ortho-rectified by ILS using common detail (ground control) points measured from 2001 ortho-images 1342-46 and 1342-48 (described above).
Pixel size (resolution): 0.50 metre
Relative horizontal accuracy (positional error margins) quoted by supplier: Relative difference between the 2001 baseline control images (ortho-images 1342-46 & 1342-48) and 1957 ortho-images 326-40 & 326-80 is ±2 metres in some areas (includes the "pointing error" determined by pixel size limitations).
Relative horizontal accuracy (positional error margins) estimated by comparison of fixed reference features with baseline image (2001 ortho-photo): Accuracy of ±1.9 metres in directions normal to the shoreline for features on and adjacent Roches Beach, relative to the baseline 2001 ortho-photos (Ortho-images 1342-46 & 1342-48 described above).

(Positional error margins were determined by C. Sharples using ESRI Arcview 3.2a software. The edges of a total of 20 fixed reference features clearly visible in both the 1957 and the 2001 ortho-photo images were plotted against each image, and their apparent displacements between the two images were measured using the Arcview measuring tool. Fixed reference features used were mainly building edges, fences and rock outcrop features at the shoreline. Features were chosen distributed along the entire length of the study area (including both of the 1957 ortho-images), most are within 100 metres horizontally and less than 5 metres vertically of the shoreline, and all features used are within 135 metres horizontally and 15m vertically of the shoreline. The features used are digitised as line segments in the accompanying shapefiles *1957_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp*. Maximum apparent displacement in any direction of any point features (corners, etc) between the 1957 and 2001 ortho-photo images was 3.0m, however all but 3 of the 20 features compared were displaced less than 2.3m and 14 of the 20 were displaced less than 2.0m in any direction. This is reasonably consistent with the supplier's quoted accuracy of ±2 metres, with only a few features being displaced 2.0 – 3.0m and none greater than 3.0m. Maximum apparent displacement of features in either direction normal to the adjacent part of the shoreline was 1.9m, however most apparent displacements in directions normal to the shoreline were less than 1.5m. Apparent displacement of features in the 1957 images relative to the 2001 baseline images occurred variously in both onshore and offshore directions.)

1977 Ortho-rectified Air Photo Image

Imagery name: ILS Ortho-image 708-3
Copyright holder: Information & Land Services (ILS), Department of Primary Industries & Water, Hobart, Tasmania.
Brief description & coverage: Scanned and ortho-rectified monochrome 1977 air photo image of Roches Beach, Lauderdale, south-east Tasmania.
Used for: *1977_rochesveglimit_gda.shp* (line map of 1977 shoreline (seawards vegetation limit) position); Refer Appendix A1.2 Data Models.
Format & Mapping Standards: Supplied in ERmapper .ecw format, GDA94 datum, MGA Zone 55 co-ordinate system, UTM projection.
Image Capture date: 4th February 1977
Image & Camera details: Black & White Aerial Photography, Revision 1977 Project, Film no. 708, Run 6 Frame 3, flown 04/02/1977, Lens 153mm, Scale 1:30,000.
Rectification: Ortho-rectified by ILS using common detail (ground control) points measured from 2001 ortho-images 1342-46 and 1342-48 (described above).
Pixel size (resolution): 0.5 metre
Relative horizontal accuracy (positional error margins) quoted by supplier: Relative difference between the 2001 baseline control images (ortho-images 1342-46 & 1342-48) and 1977 ortho-image 708-3 is ±2 metres in some areas (includes the "pointing error" determined by pixel size limitations).
Relative horizontal accuracy (positional error margins) estimated by comparison of fixed reference features with baseline image (2001 ortho-photo): Accuracy of ±1.8 metres in directions normal to the shoreline for features on and adjacent Roches Beach, relative to the baseline 2001 ortho-photos (Ortho-images 1342-46 & 1342-48 described above).

(Positional error margins were determined by C. Sharples using ESRI Arcview 3.2a software. The edges of a total of 25 fixed reference features clearly visible in both the 1977 and the 2001 ortho-photo images were plotted against each image, and their apparent displacements between the two images were measured using the Arcview measuring tool. Fixed reference features used were mainly road kerbs, building edges, fences and rock outcrop features at the shoreline. Features were chosen distributed along the entire length of the study area, most are within 100 metres horizontally and less than 5 metres vertically of the shoreline, and all features used are within 240 metres horizontally and 10m vertically of the shoreline. The features used are digitised as line segments in the accompanying shapefiles *1977_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp*. Maximum apparent displacement in any direction of any point features (corners, etc) between the 1977 and 2001 ortho-photo images was 2.75m, however all but 2 of the 25 features compared were displaced 2.0m or less in any direction. This is consistent with the supplier's quoted accuracy of ±2 metres, with only 2 features being displaced >2.0m and none greater than 2.75m. Maximum apparent displacement of features in either direction normal to the adjacent part of the shoreline was 1.8m, however most apparent displacements in directions normal to the shoreline were less than 1.5m. Apparent displacement of features in the 1977 images relative to the 2001 baseline images occurred variously in both onshore and offshore directions.)

1987 Ortho-rectified Air Photo Image

Imagery name: ILS Ortho-image 1092-240
Copyright holder: Information & Land Services (ILS), Department of Primary Industries & Water, Hobart, Tasmania.
Brief description & coverage: Scanned and ortho-rectified monochrome 1987 air photo image of Roches Beach, Lauderdale, south-east Tasmania.
Used for: *1987_rochesveglimit_gda.shp* (line map of 1987 shoreline (seawards vegetation limit) position); Refer Appendix A1.2 Data Models.
Format & Mapping Standards: Supplied in ERmapper .ecw format, GDA94 datum, MGA Zone 55 co-ordinate system, UTM projection.
Image Capture date: 30th October 1987.
Image & Camera details: Black & White Aerial Photography, M727 Project, Film no. 1092, Run 3 Frame 240, flown 30/10/1987, Lens 153mm, Scale 1:28,000.
Rectification: Ortho-rectified by ILS using common detail (ground control) points measured from 2001 ortho-images 1342-46 and 1342-48 (described above).
Pixel size (resolution): 0.5 metre
Relative horizontal accuracy (positional error margins) quoted by supplier: Relative difference between the 2001 baseline control images (ortho-images 1342-46 & 1342-48) and 1987 ortho-image 1092-240 is ±2 metres in some areas (includes the "pointing error" determined by pixel size limitations).
Relative horizontal accuracy (positional error margins) estimated by comparison of fixed reference features with baseline image (2001 ortho-photo): Accuracy of ±1.9 metres in directions normal to the shoreline for features on and adjacent Roches Beach, relative to the baseline 2001 ortho-photos (Ortho-images 1342-46 & 1342-48 described above).

(Positional error margins were determined by C. Sharples using ESRI Arcview 3.2a software. The edges of a total of 27 fixed reference features clearly visible in both the 1987 and the 2001 ortho-photo images were plotted against each image, and their apparent displacements between the two images were measured using the Arcview measuring tool. Fixed reference features used were mainly road kerbs, building edges, fences and rock outcrop features at the shoreline. Features were chosen distributed along the entire length of the study area, most are within 100 metres horizontally and less than 5 metres vertically of the shoreline, and all features used are within 180 metres horizontally and <10m vertically of the shoreline. The features used are digitised as line segments in the accompanying shapefiles *1987_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp*. Maximum apparent displacement in any direction of any point features (corners, etc) between the 1987 and 2001 ortho-photo images was 2.7m in one anomalous case, however all other 26 of the 27 features compared were displaced 2.0m or less in any direction. This is consistent with the supplier's quoted accuracy of ±2 metres, with only 1 feature being displaced >2.0m and none greater than 2.7m. Maximum apparent displacement of features in either direction normal to the adjacent part of the shoreline was 1.9m, however most apparent displacements in directions normal to the shoreline were less than 1.0m. Apparent displacement of features in the 1987 images relative to the 2001 baseline images occurred variously in both onshore and offshore directions.)

2005 Rectified QuickBird Satellite Image

Imagery name: Clipped portion of Sinclair Knight Merz (SKM) Greater Hobart QuickBird Imagery Pilot Project Image Catalogue ID 1010010004354500
Copyright holder: DigitalGlobe Inc (QuickBird satellite imagery rectified and supplied by Sinclair Knight Merz to University of Tasmania).
Brief description & coverage: Clipped image portion covering Roches Beach, Lauderdale, south-east Tasmania.
Used for: *2005_rochesveglimit_gda.shp* (line map of 2005 shoreline (seawards vegetation limit) position); Refer Appendix A1.2 Data Models.
Format & Mapping Standards: Supplied in GeoTIFF format, GDA94 datum, MGA Zone 55 co-ordinate system, UTM projection.
Image Capture date: 2nd May 2005 (GMT 00h 23m 27s), orbit 19870.
Image & Camera details: QuickBird satellite providing images with 61cm panchromatic resolution and 2.44m multi-spectral resolution.
Rectification: Ortho-rectified by SKM using Hobart Urban Ortho Series ground control points (as used for 2001 Ortho-images 1342-46 & 1342-48 described above).
Pixel size (resolution): 0.6 metre
Relative horizontal accuracy (positional error margins) quoted by supplier: Accuracy of ±3 metres quoted by SKM, based on use of Urban Ortho Series control points.
Relative horizontal accuracy (positional error margins) estimated by comparison of fixed reference features with baseline image (2001 ortho-photo)**:** Accuracy of ±1.6 metres in directions normal to the shoreline for features on and adjacent Roches Beach, relative to the baseline 2001 ortho-photos (Ortho-images 1342-46 & 1342-48 described above).

(Positional error margins were determined by C. Sharples using ESRI Arcview 3.2a software. The edges of a total of 38 fixed reference features clearly visible in both the 2005 QuickBird image and the 2001 ortho-photo images were plotted against each image, and their apparent displacements between the two images were measured using the Arcview measuring tool. Fixed reference features used were mainly concrete road kerbs (flat, sharp-edged features), and a few building edges, fences and rock outcrop features at the shoreline. Features were chosen distributed along the entire length of the study area, most are within 100 metres horizontally and less than 5 metres vertically of the shoreline, and all features used are within 200 metres horizontally and 50m vertically of the shoreline. The features used are digitised as line segments in the accompanying shapefiles *2005_rochesveglimit_gda.shp* and *2001_rochesveglimit_gda.shp*. Maximum apparent displacement in any direction of any point features (corners, etc) between the QuickBird and 2001 ortho-photo images was 2.6m (consistent with the supplier's quoted accuracy of ±3 metres), and most apparent displacements were less than 1.5m in any direction. Maximum apparent displacement of features in either direction normal to the adjacent part of the shoreline was 1.6m, however most apparent displacements in directions normal to the shoreline were less than 1.0m. Apparent displacement of features in the 2005 QuickBird image relative to the 2001 baseline images occurred variously in both onshore and offshore directions.)

APPENDIX THREE: ROCHES BEACH REFERENCE PHOTOS 2006

This appendix provides details of a series of ground-based photos of Roches Beach that were captured during August 2006 by Chris Sharples (and some photos of SPM markers captured during February 2006). These images are provided as a set of digital images (JPEG format) accompanying this report. The purpose of these photos is to serve as a set of reference photos documenting the condition of the shoreline at Roches Beach during August 2006, which should provide useful base line information for future comparison. Photos of three State Permanent Marker (SPM) survey markers used for beach profile monitoring in the TASMARC program have also been included as reference features, partly to assist in identifying the precise location of those features on air photo and satellite imagery.

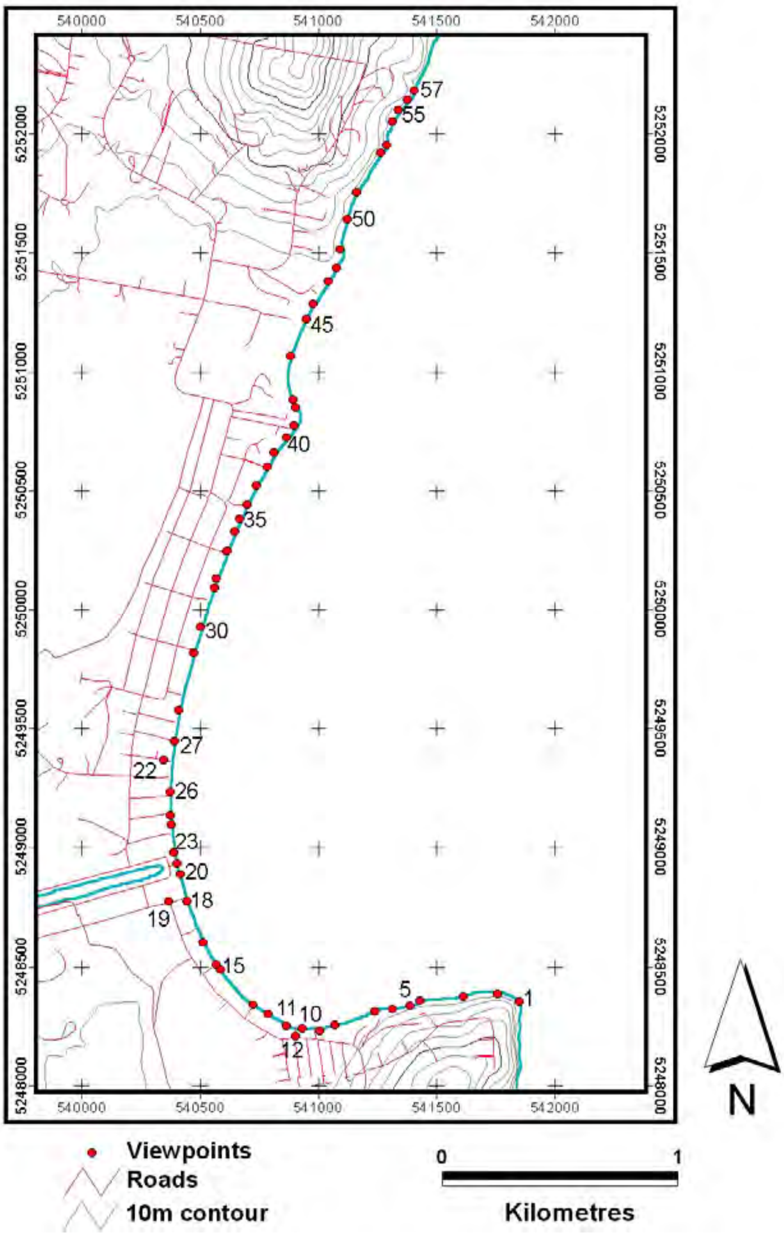


Figure 26: Location of photo viewpoints at Roches Beach, southern Tasmania, as detailed in Table 1 following. Not all photo viewpoints are numbered on this map; however the viewpoints are numbered consecutively from south to north, with the exception of the State Permanent Marker (SPM) photo viewpoints numbered 12, 19 and 22. Map grid is MGA Zone 55 (GDA94 datum).

Table 1 below provides map grid references specifying the viewpoint from which each photo was taken. These are metric UTM projection Map Grid of Australian (MGA Zone 55) co-ordinates based on the GDA94 datum. Note however that the grid references were obtained with a hand-held Garmin Etrex GPS unit having an estimated positional error of 4 metres or more. Also, some photos were taken from a few paces away from the quoted location, hence these grid references should be considered only as approximate photo viewpoints (likely positional errors of ± 5 metres or so).

A selection from the photos is provided as figures in the latter part of this appendix.

Table 1: Details of reference photos captured at Roches Beach (southern Tasmania) by C. Sharples during August 2006 (and a few photos of SPM markers captured during February 2006).

Photo number	Capture Date	View-Point No.	Viewpoint easting (MGA, GDA94)	Viewpoint northing (MGA, GDA94)	View description
RB2006_1	11/08/2006	1	541847	5248355	View to northwest from Mays Point, along rocky shore towards Roches Beach.
RB2006_2	11/08/2006	2	541755	5248385	View to west along cobble shore with soil erosion scarp at back.
RB2006_3	11/08/2006	3	541611	5248376	View to west along sand + cobble shore with soil/bedrock backshore.
RB2006_4	11/08/2006	3	541611	5248376	View to east along sand + cobble shore with soil/bedrock backshore.
RB2006_5	11/08/2006	4	541427	5248357	View to west along sand + cobble beach with soil erosion scarp & artificial wall backing beach.
RB2006_6	11/08/2006	5	541387	5248338	View to east with soil erosion scarp behind ineffective artificial wall.
RB2006_7	11/08/2006	6	541310	5248324	View to west along pebble + sand beach.
RB2006_8	11/08/2006	7	541236	5248313	View to west along broad sand beach with low partly vegetated incipient dune.
RB2006_9	11/08/2006	8	541068	5248255	View to east along broad sand beach with low incipient dune. Drain outlet to right hand side flows onto beach.
RB2006_10	11/08/2006	8	541068	5248255	View to west along sand beach without incipient dune. Minor cobbles at back of beach.
RB2006_11	11/08/2006	9	541004	5248231	View to east along broad sand beach.
RB2006_12	11/08/2006	9	541004	5248231	View to west along narrower sand beach.
RB2006_13	11/08/2006	10	540930	5248240	View to east along dune scarp. Seagrass abundant on beach in this area.
RB2006_14	11/08/2006	10	540930	5248240	View to west along sand beach and dune front. Seagrass abundant on beach in this area.
RB2006_15	11/08/2006	11	540864	5248251	View to southeast along dune scarp (artificial cutting through dune at right hand side of view).

					View includes location of southern TASMARC profile based on Mark 3 (SPM 9532RM1). Seagrass abundant on beach in this area.
RB2006_16	11/08/2006	11	540864	5248251	View to northwest along boulder wall and sand beach.
RB2006_17	03/02/2006	12	540901	5248209	View to south (from path to beach) to State Permanent Mark SPM 9532RM1 (red-painted mark in gutter). Grid reference refers to SPM position determined by Etrex GPS (position error ~3.8m by comparison with surveyed SPM position). (Arrow added to indicate SPM)
RB2006_18	03/02/2006	12	540901	5248209	View to northwest to State Permanent Mark SPM 9532RM1 (red-painted mark in gutter). Grid reference refers to SPM position determined by Etrex GPS (position error ~3.8m by comparison with surveyed SPM position). (Arrow added to indicate SPM)
RB2006_19	03/02/2006	12	540901	5248209	View to east-southeast to State Permanent Mark SPM 9532RM1 (red-painted mark in gutter). Grid reference refers to SPM position determined by Etrex GPS (position error ~3.8m by comparison with surveyed SPM position). (Arrow added to indicate SPM)
RB2006_20	11/08/2006	13	540787	5248302	View to southeast, to concrete boat ramp, showing beach level with respect to end of ramp (red notebook = 180mm high).
RB2006_21	11/08/2006	13	540787	5248302	View to northwest along boulder wall and beach.
RB2006_22	11/08/2006	14	540721	5248340	View to southeast to concrete steps (red notebook 180 mm high for scale)
RB2006_23	11/08/2006	14	540721	5248340	View to northwest along boulder wall and beach.
RB2006_24	11/08/2006	15	540584	5248487	View to northwest to dune scarp behind boulder wall.
RB2006_25	11/08/2006	15	540584	5248487	View to southeast along boulder wall and beach.
RB2006_26	11/08/2006	16	540567	5248509	View to southeast to dune erosion scarp behind boulder wall.
RB2006_27	11/08/2006	16	540567	5248509	View to northwest to boulder wall, concrete steps and concrete ramp (red notebook 180 mm high for scale).
RB2006_28	11/08/2006	17	540510	5248603	View south to north end of boulder wall, showing dune front eroded back ~5m at end of boulders.
RB2006_29	11/08/2006	17	540510	5248603	View north looking past north end of boulder wall, showing dune front eroded back ~5m

					immediately beyond end of boulders.
RB2006_30	11/08/2006	18	540445	5248775	View south along dune scarp (obscured by marram grass but fairly fresh in many parts)
RB2006_31	11/08/2006	18	540445	5248775	View north along dune scarp (higher than to south of viewpoint)
RB2006_32	05/02/2006	19	540367	5248774	View eastwards to State Permanent Mark SPM 10906 (red-painted mark on kerb). Grid reference refers to SPM position determined by Etrex GPS (position error ~2.74m by comparison with surveyed SPM position). (Arrow added to indicate SPM)
RB2006_33	05/02/2006	19	540367	5248774	View east-northeast - wards to State Permanent Mark SPM 10906 (red-painted mark on kerb). Grid reference refers to SPM position determined by Etrex GPS (position error ~2.74m by comparison with surveyed SPM position). (Arrow added to indicate SPM)
RB2006_34	11/08/2006	20	540414	5248887	View south along dune front scarp. Note wooden posts isolated seawards of scarp.
RB2006_35	11/08/2006	20	540414	5248887	View north along dune front (with low wooden structure).
RB2006_36	11/08/2006	20	540414	5248887	View north along beach showing both training walls at canal end, and low wooden structure on dune front south of canal.
RB2006_37	11/08/2006	21	540401	5248933	View to south along beach front showing low wooden wall and south training wall, from canal road access.
RB2006_38	11/08/2006	21	540401	5248933	View to north along beach showing north training wall, from canal road access.
RB2006_39	11/08/2006	21	540401	5248933	View northwards to north training wall, from canal road access.
RB2006_40	12/08/2006	22	540 344	5249 367	View west to SPM 10904 (red mark) from path to beach. Grid reference refers to SPM position determined by Etrex GPS (position error ~1.5m by comparison with surveyed SPM position). (Arrow added to indicate SPM marker).
RB2006_41	12/08/2006	22	540 344	5249 367	View east to SPM 10904 (red mark), with back of foredune beyond. Grid reference refers to SPM position determined by Etrex GPS (position error ~1.5m by comparison with surveyed SPM position). (Arrow added to indicate SPM marker).
RB2006_42	12/08/2006	23	540 388	5248 979	View south along low fence.

RB2006_43	12/08/2006	23	540 388	5248 979	View north along older dune scarp.
RB2006_44	12/08/2006	24	540 375	5249 095	View south along old erosion scarp.
RB2006_45	12/08/2006	24	540 375	5249 095	View north along fresher erosion scarp.
RB2006_46	12/08/2006	25	540 373	5249 133	View south.
RB2006_47	12/08/2006	25	540 373	5249 133	View north.
RB2006_48	12/08/2006	26	540 372	5249 234	View south.
RB2006_49	12/08/2006	26	540 372	5249 234	View north, including undermined tree stump (sawn off).
RB2006_50	12/08/2006	27	540 390	5249 445	View south.
RB2006_51	12/08/2006	27	540 390	5249 445	View north.
RB2006_52	12/08/2006	28	540 408	5249 577	View south, showing exposed tree roots and collapsing tree exposed in foredune scarp.
RB2006_53	12/08/2006	28	540 408	5249 577	View north.
RB2006_54	12/08/2006	29	540 470	5249 816	View south.
RB2006_55	12/08/2006	29	540 470	5249 816	View north.
RB2006_56	12/08/2006	30	540 500	5249 925	View south.
RB2006_57	12/08/2006	30	540 500	5249 925	View north.
RB2006_58	12/08/2006	31	540 558	5250 090	View south.
RB2006_59	12/08/2006	31	540 558	5250 090	View north.
RB2006_60	12/08/2006	32	540 568	5250 131	View south.
RB2006_61	12/08/2006	32	540 568	5250 131	View north.
RB2006_62	12/08/2006	33	540 614	5250 248	View south.
RB2006_63	12/08/2006	33	540 614	5250 248	View north.
RB2006_64	12/08/2006	34	540 644	5250 329	View south.
RB2006_65	12/08/2006	34	540 644	5250 329	View north.
RB2006_66	12/08/2006	35	540 666	5250 381	View south.
RB2006_67	12/08/2006	35	540 666	5250 381	View north.
RB2006_68	12/08/2006	36	540 697	5250 439	View south.
RB2006_69	12/08/2006	36	540 697	5250 439	View north.
RB2006_70	12/08/2006	37	540 736	5250 520	View south.
RB2006_71	12/08/2006	37	540 736	5250 520	View north to rocky point (Bambra Reef).
RB2006_72	12/08/2006	38	540 782	5250 601	View south.
RB2006_73	12/08/2006	38	540 782	5250 601	View north to rocky point (Bambra Reef).
RB2006_74	12/08/2006	39	540 812	5250 658	View south.
RB2006_75	12/08/2006	39	540 812	5250 658	View north to rocky point (Bambra Reef).
RB2006_76	12/08/2006	40	540 864	5250 723	View south.
RB2006_77	12/08/2006	40	540 864	5250 723	View north along artificial boulder wall at rocky point (Bambra Reef).
RB2006_78	12/08/2006	41	540 894	5250 771	View south along artificial boulder wall at rocky point (Bambra Reef).
RB2006_79	12/08/2006	41	540 894	5250 771	View north beyond boulder wall at small rocky point(Bambra Reef).
RB2006_80	12/08/2006	42	540 903	5250 849	View south along small erosion scarp behind beach and rocky shore platform (Bambra Reef).
RB2006_81	12/08/2006	42	540 903	5250 849	View north from rocky point (Bambra Reef) to sand accretion area.
RB2006_82	14/08/2006	43	540 891	5250 882	View south to rocky point (Bambra Reef).

RB2006_83	14/08/2006	43	540 891	5250 882	View south-west up ephemeral creek mouth.
RB2006_84	14/08/2006	43	540 891	5250 882	View north to accretion area.
RB2006_85	14/08/2006	44	540 882	5251 067	View south.
RB2006_86	14/08/2006	44	540 882	5251 067	View north.
RB2006_87	14/08/2006	45	540 947	5251 221	View south.
RB2006_88	14/08/2006	45	540 947	5251 221	View north.
RB2006_89	14/08/2006	46	540 975	5251 284	View south-west across mouth of ephemeral creek.
RB2006_90	14/08/2006	46	540 975	5251 284	View north to next rocky point.
RB2006_91	14/08/2006	47	541 041	5251 381	View south.
RB2006_92	14/08/2006	47	541 041	5251 381	View north to bedrock backshore.
RB2006_93	14/08/2006	48	541 075	5251 436	View south.
RB2006_94	14/08/2006	48	541 075	5251 436	View north across rocky point.
RB2006_95	14/08/2006	49	541 091	5251 514	View south across rocky point.
RB2006_96	14/08/2006	49	541 091	5251 514	View north.
RB2006_97	14/08/2006	50	541 120	5251 641	View south.
RB2006_98	14/08/2006	50	541 120	5251 641	View north.
RB2006_99	14/08/2006	51	541 161	5251 754	View south.
RB2006_100	14/08/2006	51	541 161	5251 754	View north.
RB2006_101	14/08/2006	52	541 261	5251 921	View south.
RB2006_102	14/08/2006	52	541 261	5251 921	View north.
RB2006_103	14/08/2006	53	541 288	5251 952	View north from Jurassic dolerite/Permian siltstone contact (siltstone to north in foreground)
RB2006_104	14/08/2006	54	541 310	5252 051	View north.
RB2006_105	14/08/2006	54	541 310	5252 051	View south.
RB2006_106	14/08/2006	55	541 337	5252 101	View south.
RB2006_107	14/08/2006	55	541 337	5252 101	View north.
RB2006_108	14/08/2006	56	541 377	5252 143	View south over northernmost end of sandy beach.
RB2006_109	14/08/2006	56	541 377	5252 143	View north from northernmost end of sandy beach.
RB2006_110	14/08/2006	57	541 402	5252 182	View south.
RB2006_111	14/08/2006	57	541 402	5252 182	View north.

Figure 27: Photo RB2006_6 (Viewpoint 5). An old erosion scarp is evident in places behind this southern part of Roches Beach, eroded into (partly) colluvial soil over weathered bedrock. The artificial wall seen here is evidently ineffective in stopping erosion, however only a small amount of net erosion has occurred here over the last 50 years, insufficient to be detectable as net recession on air photos.

Figure 28: Photo RB2006_8 (Viewpoint 7). The shoreline in this short section of southern Roches Beach has accreted in recent times, as indicated by the small incipient dune present in front of the larger established foredune on this part of the beach; however this section of the shore has shown no detectable net change between 1957 and 2005. Only a few southern and northern sections of Roches Beach show evidence of sand accretion at the present.

Figure 29: Photo RB2006_20 (Viewpoint 13). This view shows a concrete boat ramp in the boulder wall along part of the southern area of Roches Beach. Lowering of the beach surface below the lip of the ramp is probably a result of recent stormy conditions. The surface will probably grow (accrete) upwards during long calm weather periods, however it is likely that some degree of net lowering of the beach surface has occurred since the boulder wall was constructed in 1988, due to increased wave reflection off the hard wall. Red notebook is 180mm high.

Figure 30: Photo RB2006_26 (Viewpoint 16). This view of the boulder wall (revetment) shows foredune erosion above and behind a section of the wall, indicating that storm waves have begun to overtop and erode behind the boulder wall in this area.

Figure 31: Photo RB2006_28 (Viewpoint 17). View southwards from the northern end of the boulder wall along part of the southern area of Roches Beach. This photo shows a shoreline (dune – front) net recession of about 5 metres at this point since the boulder wall was constructed during 1988.

Figure 32: Photo RB2006_49 (Viewpoint 26). View north along Roches Beach erosion scarp, several hundred metres north of the canal. The sawn stump of a large eucalypt tree whose roots became exposed by erosion in the period 2001 – 2006 is visible. This view is in the area referred to as recession zone RZ3 in this report.

Figure 33:.Photo RB2006_71 (viewpoint 37). View north along the large active erosion scarp in the northerly part of Roches beach. This view looks along the area referred to as recession zone RZ5 in this report.

Figure 34: Photo RB2006_81 (viewpoint 42). View north showing Accretion Zone AZ1, immediately north of the small rocky point (Bambra Reef) at the north end of the main part of Roches Beach. This is one area where net detectable shoreline accretion has occurred at Roches Beach between 1957 and 2005. It is unlikely that the visible fence has been a major factor in the accretion, which is probably due to the location of this area on the down-drift (north) side of Bambra Reef.

Figure 35: Photo RB2006_86 (viewpoint 44). View north showing part of Accretion Zone AZ2 with low incipient foredune development. This is an area where net detectable shoreline accretion has occurred at Roches Beach between 1957 and 2005.

Figure 36: .Photo RB2006_103 (viewpoint 53). View north along part of the northernmost end of Roches Beach, where the beach is backed by a rising bedrock slope with little dune development. There is little potential for shoreline recession here, although beach lowering and loss may result from sea level rise.

APPENDIX FOUR: TASMARC SURVEY DATA (2005)

This appendix provides copies of survey data related to State Permanent Marker (SPM) benchmarks installed at Roches Beach, and the initial TASMARC shoreline monitoring project survey data based on those benchmarks, as discussed in report Section (4.5).

(A) Locations of SPM benchmarks installed by DPIWE surveyors on 17th August 2005, and initial profiles measured from the benchmarks to the beach by the surveyors on that date. Notes in red italics are annotations by C. Sharples.

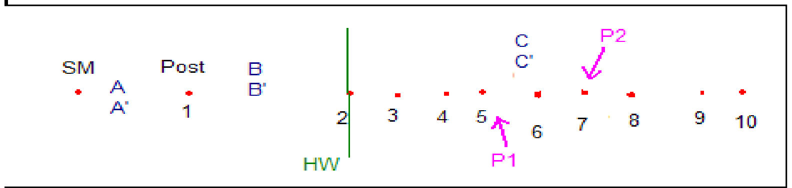
Chainage	Point	MGA East	MGA North	AHD83 Ht	Code	Remarks
730/01	***Mark 1***					**Lauderdale**
0.000	SPM10906	540364.412	5248773.101	2.973	NS001	Profile based on SPM 10906 and starts at Chainage 52.05,
52.054	101	540414.432	5248787.511	3.466	NS001	offset approx 1.0m north of pathway.
69.266	102	540431.102	5248791.797	3.200	NS001	
69.808	103	540431.623	5248791.944	3.005	NS001	
70.275	104	540432.090	5248791.923	1.891	NS001	
74.269	105	540435.930	5248793.021	1.222	NS001	
83.195	106	540444.444	5248795.702	0.244	NS001	
730/02	***Mark 2***					**Lauderdale**
0.000	SPM10904	540344.149	5249368.498	2.285	NS002	Profile based on SPM 10904 and produced along
24.926	202	540368.762	5249364.561	3.586	NS002	line of southern kerb of Coolahra Street
28.474	203	540372.296	5249364.240	3.910	NS002	
30.567	204	540374.348	5249364.651	1.767	NS002	***Dune scarp at approx. 29.5 metres indicated***
34.390	205	540378.163	5249364.408	1.248	NS002	
41.653	206	540385.422	5249364.148	0.355	NS002	
730/03	***Mark 3***					**Lauderdale**
0.000	SPM9532RM1	540903.562	5248211.835	1.795	NS003	Profile based on SPM 9532RM1, along north side of pathway.
7.318	302	540903.719	5248219.151	1.856	NS003	
19.419	303	540904.081	5248231.247	2.275	NS003	
24.726	304	540903.064	5248236.456	2.297	NS003	
27.003	305	540902.996	5248238.732	1.730	NS003	
27.416	306	540903.153	5248239.113	1.042	NS003	
28.068	307	540903.145	5248239.765	0.960	NS003	
38.142	308	540902.597	5248249.824	0.577	NS003	
45.450	309	540903.959	5248257.004	0.009	NS003	

(B) Initial TASMARC survey results for Roches Beach SPM Marks 1, 2 & 3, surveyed on 6th November 2005. In these records "HW" represents the surveyed position of the foredune scarp (seawards vegetation limit). Red roman comments are original, red italic comments are annotations by C. Sharples.

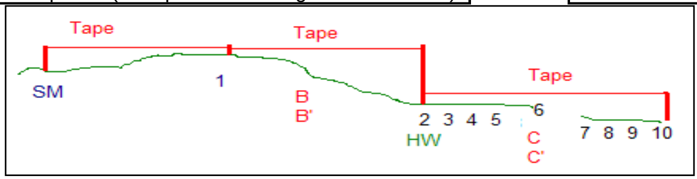
Tasmanian Shoreline monitoring and Archiving Project	Front

Date 6/11/2005	Sheet no. for this site 1	TASMARC
Time start 18:10	Time end 18:35	
Observers:- Michael Hovington, Susanne Hovington, John Hunter, etc		Circle as appropriate:
Site name:- Bayview Rd Carpark.		Weather: sunny, cloudy, rain, windy
Survey mark (SM) I.D:- Marker No.1 (SPM 10906)		
Camera serial no.		
If applicable:		
Level serial no.		Wave height: (at breaking): flat calm, 0-1 metre, > 1 metre
Staff serial no.		
Staff type		

Sketch map (for tape and levelling measurements) — To Ocean →



Sketch profile (for tape and levelling measurements) — To Ocean →



Notes	Photo no.	Full photo I.D
Low tide @ 7.25pm 0.56m		

Please return form to: John Hunter, Private Bag 80, Hobart Tasmania 7001
Ph 03 6226 7849 john.hunter@acecrc.org.au

Tasmanian Shoreline monitoring and Archiving Project	Back

Horizontal Measurements

Point from	Point to	Distance (metres)
SM	1	51.96
1	2 (HW)	18.5
2	3	3
2	4	6
2	5	9
2	6	12
2	7	15
2	8	18
2	9	21
2	10	24

Enter all horizontal measurements (i.e. for survey mark, SM, for high water mark and for all staff positions)

Fill in one (and only one) row for each staff position.

One row should contain the reading(s) for:
. one foesight, or
. one backsight, or
. one foresight and one backsight, or
. one intermediate sight.

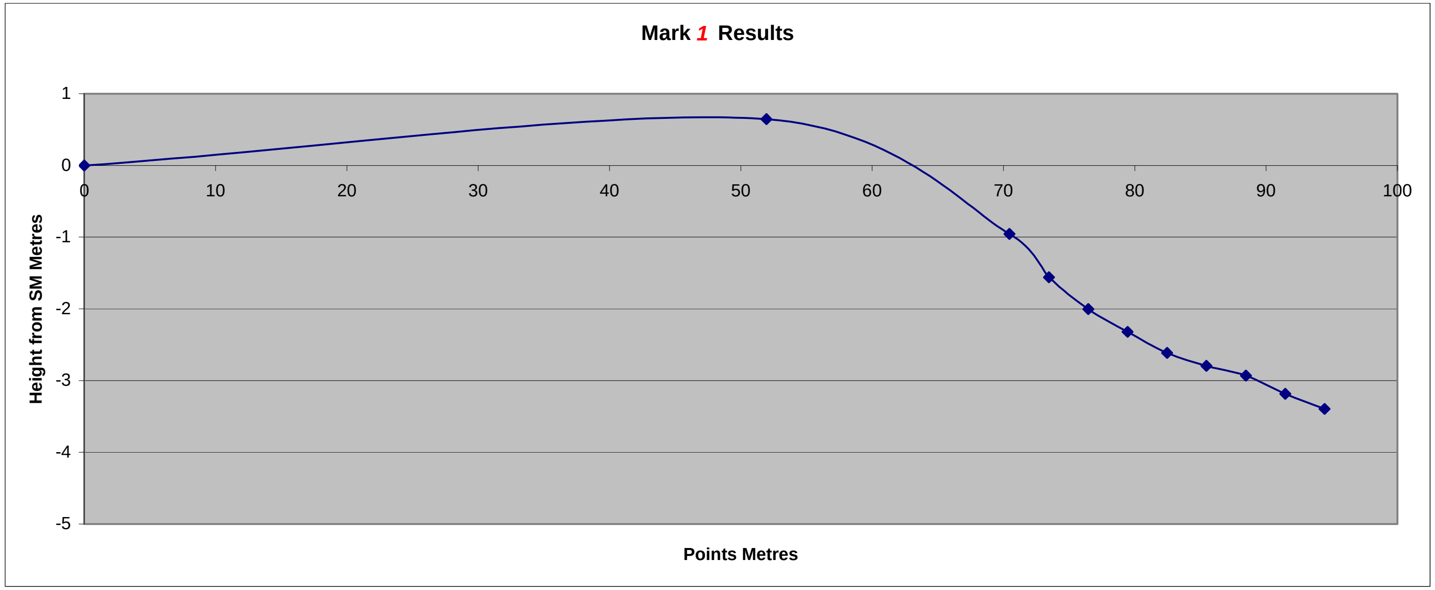
To Ocean ↓

Levelling Measurements

Locations (see sketch map and profile) Tripod	Staff	Staff readings: Backsight (metres)	Intermediate Sight (metres)	Foresight (metres)	Height above survey mark (SM) (metres)
A	SM	1.105			0.000
A,A'	1	0.450		0.460	0.645
A'	SM			1.100	-0.005
	Totals	1.555		1.560	-0.005
B	1	1.335			0.645
C, B	2 (HW)	0.175		2.935	-0.955
C	3		0.780		-1.560
C	4		1.225		-2.005
C	5		1.540		-2.320
C	6		1.835		-2.615
C	7		2.015		-2.795
C	8		2.150		-2.930
C	9		2.405		-3.185
C, C'	10	2.615		2.615	-3.395
C', B'	2	2.930		0.180	-0.960
B'	1			1.330	0.640
	Total	7.055		7.060	-0.005

If you need more space, use the back of another log sheet, remembering to fill in the date, site name, survey mark I.D. and sheet number on the front.

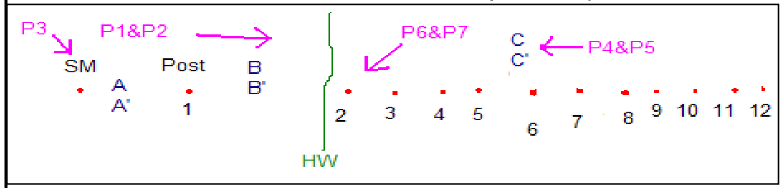
	6/11/2005		
SM	0	0	
1	51.96	0.645	
2 (HW)	70.46	-0.955	***Scarp 70.46m seawards of SM (Mark 1 benchmark)***
3	73.46	-1.56	
4	76.46	-2.005	
5	79.46	-2.32	
6	82.46	-2.615	
7	85.46	-2.795	
8	88.46	-2.93	
9	91.46	-3.185	
10	94.46	-3.395	



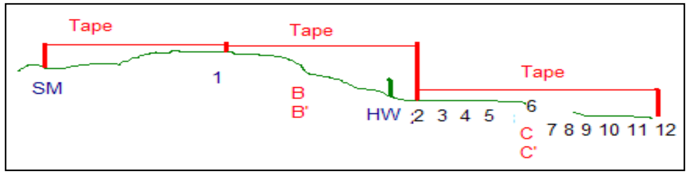
Tasmanian Shoreline monitoring and Archiving Project	Front

Date 6/11/2005	Sheet no. for this site 1	TASMARC	
Time start 15:55	Time end 16:30		
Observers:- Michael Hovington, Susanne Hovington, John Hunter, etc		Circle as appropriate:	
Site name:- Sand Dune Court		Weather	sunny
Survey mark (SM) I.D:- Marker No.2 (SPM 10904)			cloudy
Camera serial no.			rain
If applicable:			windy
Level serial no.		Wave height:	flat calm
Staff serial no.		(at breaking)	0-1 metre
Staff type			> 1 metre

Sketch map (for tape and levelling measurements) To Ocean →



Sketch profile (for tape and levelling measurements) To Ocean →



Notes	Photo no.	Full photo I.D
Low tide @ 7.25pm 0.56m		

Please return form to: John Hunter, Private Bag 80, Hobart Tasmania 7001
Ph 03 6226 7849 john.hunter@acecrc.org.au

Tasmanian Shoreline monitoring and Archiving Project	Back

Horizontal Measurements

To Ocean ↓

Point from	Point to	Distance (metres)
SM	1	25.8
1	(HW)	-0.46
1	3	4.31
2	4	3
2	5	6
2	6	7.5
2	7	8
2	8	8.5
2	9	9
2	10	12
2	11	15
2	12	18

Enter all horizontal measurements (i.e. for survey mark, SM, for high water mark and for all staff positions)

Fill in one (and only one) row for each staff position.

One row should contain the reading(s) for:
. one foesight, or
. one backsight, or
. one foresight and one backsight, or
. one intermediate sight.

Levelling Measurements

To Ocean ↓

Locations (see sketch map and profile) Tripod	Staff	Staff readings Backsight (metres)	Intermediate Sight (metres)	Foresight (metres)	Height above survey mark (SM) (metres)
A	SM	1.660			0.000
A, A'	1	0.650		0.590	1.070
A'	SM			1.735	-0.015
	Total	**2.310**		**2.325**	**-0.015**
B	1	0.025			1.070
C, B'	2	0.740		1.590	-0.495
C	3		1.160		-0.915
C	4		1.490		-1.245
C	5		1.515		-1.270
C'	6		1.555		-1.310
C'	7		1.640		-1.395
C'	8		1.705		-1.460
C'	9		1.813		-1.568
C	10		2.140		-1.895
C	11		2.390		-2.145
C, C'	12	2.495		2.580	-2.335
C', B'	2	3.270		0.650	-0.490
B'	1			1.710	1.070
	Total	**6.530**		**6.530**	**0.000**

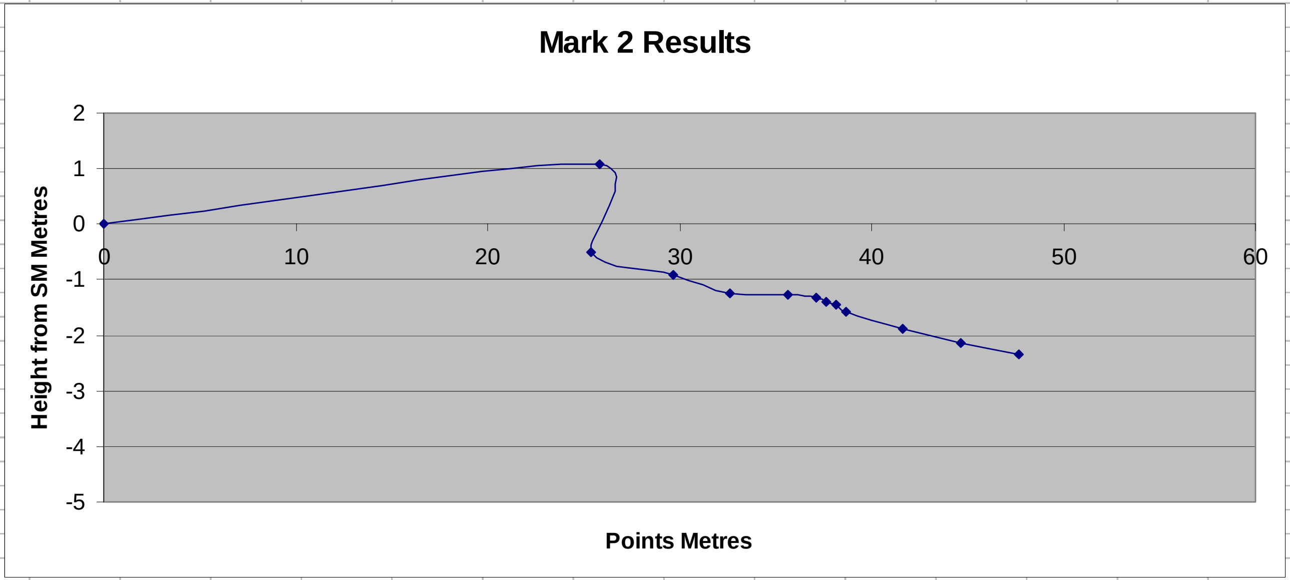
If you need more space, use the back of another log sheet, remembering to fill in the date, site name, survey mark I.D. and sheet number on the front.

	6/11/2005	
SM	0	0
1	25.8	1.07
2 (HW)	25.38	-0.495
3	29.65	-0.915
4	32.65	-1.245
5	35.65	-1.27
6	37.15	-1.31
7	37.65	-1.395
8	38.15	-1.46
9	38.65	-1.568
10	41.65	-1.895
11	44.65	-2.145
12	47.65	-2.335

Scarp (HW) indicated 25.38m seawards of SM (Mark 2 benchmark), but likely incorrect

29.65m is likely correct HW location?

(Note scarp not overhung as suggested by plot)

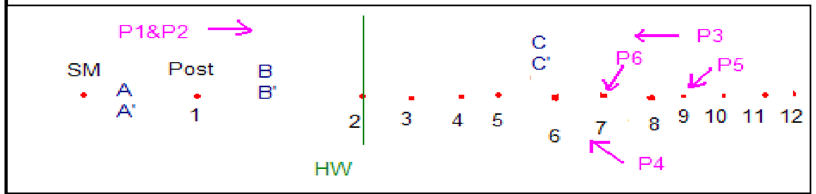


Tasmanian Shoreline monitoring and Archiving Project | Front

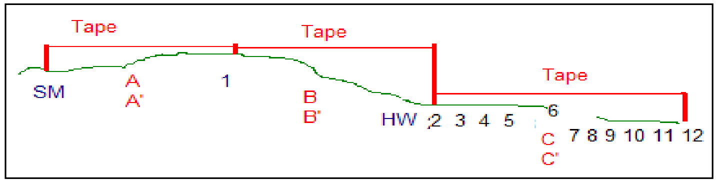
TASMARC

Date 6/11/2005	Sheet no. for this site 1		
Time start 17:00	Time end 17:35		
Observers:- Michael Hovington, Susanne Hovington, John Hunter, etc		Circle as appropriate:	
Site name:- Sand Dune Court		Weather	sunny cloudy rain windy
Survey mark (SM) I.D:- Marker No.3 (SPM 9532M1)			
Camera serial no.			
If applicable:			
Level serial no.		Wave height: (at breaking)	flat calm 0-1 metre > 1 metre
Staff serial no.			
Staff type			

Sketch map (for tape and levelling measurements) | To Ocean →



Sketch profile (for tape and levelling measurements) | To Ocean →



Notes	Photo no.	Full photo I.D
Low tide @ 7.25pm 0.56m		

Please return form to: John Hunter, Private Bag 80, Hobart Tasmania 7001
Ph 03 6226 7849 john.hunter@acecrc.org.au

Tasmanian Shoreline monitoring and Archiving Project | Back

Horizontal Measurements

To Ocean ↓

Point from	Point to	Distance (metres)
SM	1	25.8
1	2 (HW)	4.45
1	3	7
1	4	10
1	5	12.9
1	6	13.7
1	7	15
1	8	18
1	9	21
1	10	24
1	11	27
1	12	30

Enter all horizontal measurements (i.e. for survey mark, SM, for high water mark and for all staff positions)

Fill in one (and only one) row for each staff position.

One row should contain the reading(s) for:
. one foesight, or
. one backsight, or
. one foresight and one backsight, or
. one intermediate sight.

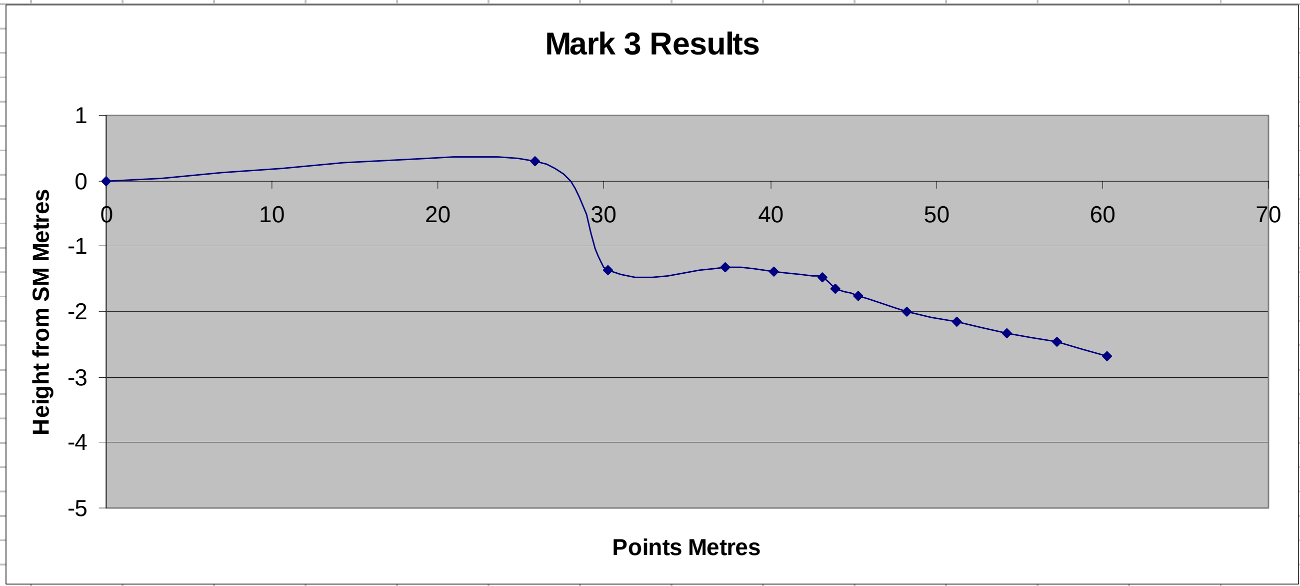
Levelling Measurements

To Ocean ↓

Locations (see sketch map and profile) Tripod	Staff	Staff readings Backsight (metres)	Intermediate Sight (metres)	Foresight (metres)	Height above survey mark (SM) (metres)	
A	SM	1.115			0.000	
A, A'	1	1.205		0.820	0.295	
A'	SM			1.970	-0.470	
	Total	**2.320**		**2.790**	**-0.470**	
B	1	0.010			0.295	
B	2 (HW)		1.680		-1.375	
B	3		1.630		-1.325	
B	4		1.690		-1.385	
B	5		1.770		-1.465	On Seaweed
B	6		1.965		-1.660	On Seaweed
B	7		2.060		-1.755	On Seaweed
B	8		2.300		-1.995	
B	9		2.450		-2.145	
B	10		2.635		-2.330	
B	11		2.760		-2.455	
B', B	12	3.375		2.975	-2.670	
B'	1			0.405	0.300	
	Total	**3.385**		**3.380**	**0.005**	

If you need more space, use the back of another log sheet, remembering to fill in the date, site name, survey mark I.D. and sheet number on the front.

	6/11/2005		
SM	0	0	
1	25.8	0.295	
2 (HW)	30.25	-1.375	***Scarp ("HW") 30.25m seawards of SM (Mark 3 benchmark)***
3	37.25	-1.325	
4	40.25	-1.385	
5	43.15	-1.465	
6	43.95	-1.66	
7	45.25	-1.755	
8	48.25	-1.995	
9	51.25	-2.145	
10	54.25	-2.33	
11	57.25	-2.455	
12	60.25	-2.67	



APPENDIX FIVE: SHORELINE MOVEMENT SUMMARY CHART

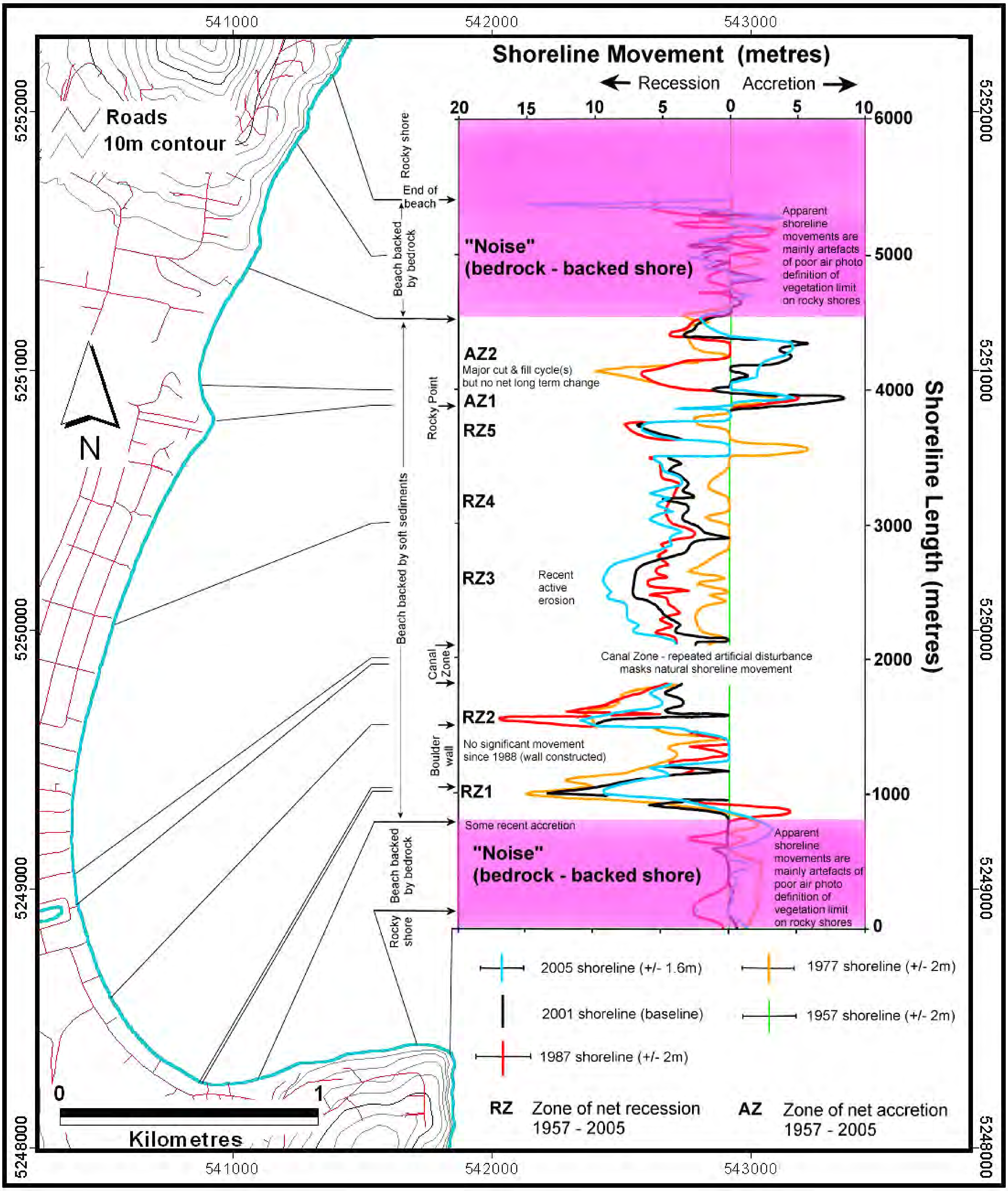


Figure 37: Shoreline Movement at Roches Beach from 1957 – 2005: Summary Chart. This chart depicts *apparent* shoreline positions along Roches Beach at 5 epochs from 1957 to 2005, which have been determined as described in report Section (4.0). For ease of comparison, the 1957 shoreline is depicted as a straight line, with later shoreline positions measured relative to the 1957 position. The coloured lines represent the *apparent* shoreline positions at each epoch; however these are not the minimum *detectable* shoreline change positions, which would be represented by the separation between shoreline position error envelopes. See also Figure 19, which depicts the minimum detectable shoreline position changes along Roches Beach between 1957 – 2005, and which is based on the separation between the error envelopes. Error envelopes for each shoreline position are represented on this figure by bars on the figure key. Nonetheless, the *apparent* shoreline positions depicted here represent the centre of the position error envelopes, and therefore represent the most *likely* shoreline positions at each epoch. The shaded portions of the shoreline movement graph are those areas in which sandy beach is backed by bedrock; in those areas shoreline position could not be reliably determined by the method used in this project due to poor definition of the vegetation limit on air photos in areas of dark-toned bedrock and bedrock-derived soil backshores. The map grid is the MGA (Zone 55) grid (GDA94 datum). Note that the scale of the "Shoreline Length" axis on the graph is not the same scale as the map. This is an enlarged version of text Figure 18.

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