Multi-Scale Morphodynamic Assessment of an Embayed Low Energy Estuarine Beach, Shoal Bay, Port Stephens, NSW

By Daniel Lee Harris

Supervisor: Dr Ana Vila-Concejo

Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science (Environmental) (Honours)

School of Geosciences, The University of Sydney, 2009
Declaration

This thesis is entirely my own work, based on my personal research and study. It is within the page and word limits specified in the Geoscience honours handbook.

Daniel Harris
Acknowledgements

First and foremost...my thanks and endless gratitude goes to Ana Vila-Concejro. This thesis would not have existed were it not for your supervision, help and suggestions throughout the year. Thank you for taking me on as your student despite the arrival of Gabriel and of course for enduring my mumbling for a year.

I would also like to thank Peter Cowell for his guidance and advice on how to improve my approach to this thesis and life in general (I have a newfound respect for the inverse square law).

To Tim Austin, none of the field work would have occurred without you and thanks for your patience in dealing with the occasional freak outs of an honours student, your advice and help throughout the year was invaluable. I owe you about 20 beers.

Javier “JAVITO” Benevente, your help in the analysis of the survey data was priceless as was your hard work in field and analysis of some Australian idiosyncrasies. I shall send you some BBQ source. Laura Del Rio, rounding off the Spanish contingent, thanks for your help in the field and with implementing the DSAS program. Hope you both enjoyed your time here.

To all the volunteers who helped with the field work a big thank you, particularly Dave Mitchell for making sure everything worked in the field and also for making sure dinner was always served. Gen Pezzimenti thanks for all your help particularly in the field where your experience (and tireless work) was invaluable. Marco Olmos you’re one in a million thanks the laughs and the pisco. Michael Kinsela, thanks for the coffee, train rides, help with this thesis and help with life in general. Kate Thornborough, thank you so much for occasionally letting me vent, for making me laugh when I needed it and taking me away to One Tree with you! Liz Abbey, for letting me cruise in and annoy you occasionally. Arjen Overduin thanks for wise words and for being a great guy to have in the building. Sam Clarke for the Douglas Adams quotes (among others!). Kel Adlam for listening to me talk about myself way too much. Amy Haughton, good luck exploring the infinite abyss. The ghosts of Hannah Power (thanks for the Matlab help), Lara Ainley and Michelle Frolich whose hard work made this thesis easier to produce.

To all my friends outside the building: The marine science crew including Sharyn Hickey and Laurence Castagnoli for all the fun over the years. The South Pacific field trippers, the world still feels warmer having met you guys. Brenton von Takach for your friendship throughout ENVI and advice over this year and Katherine Every for your comforting phone calls from Brisbane.

To the Shirefolk: Dean Schrafft, Matt Barry, Michael Wise, Jaime Pagano, Bronwyn O’Brien, Jacqui Wellington and the rest of the Caringbah and Port Hacking crew, thanks for always being there and enduring my absences with humour even though I occasionally deserve a smack around the head.

To my family, Mum for supporting and dealing with me (and my oft bad moods) this year, Ange for all you help and advice and Dad for reviewing this thesis and all the support.

Finally to the girls who got me through this year with phone calls, coffee, laughs and sage advice beyond your years. Hannah Sheppard Brennand for your constant love and support above and beyond the call of duty, without you I would not have survived this year. The same goes for Jennifer Blake whose willingness to give up her couch and be a phone call away at any hour of the day kept me going, thanks for always making me smile. I owe you both so much!

Thank you all, ill repay you one day when I figure out how I can possibly do it.

Dan Harris
Cronulla Beach - Spring 2009
Additional Acknowledgements

This research was part of the ARC project regarding flood-tide delta morphodynamics and shoreline implications in Port Stephens. More information can be found at the project website http://www.geosci.usyd.edu.au/research/re_portstephens.shtml.

This research has been funded by the Australian Research Council (ARC) in collaboration with the NSW Department of Environment, Climate Change and Water (DECCW), Great Lakes Council, Port Stephens Council and Jimmy’s Beach Restoration Society Inc. through Linkage Grant LP0668979.

The Manly Hydraulics Laboratory (MHL) is acknowledged who, on behalf of the NSW Department of Environment, Climate Change and Water, kindly provided the offshore wave data. Wind data was provided by The Australian Bureau of Meteorology (BOM) and was greatly appreciated.
Abstract

Low-energy shorelines are common coastal features, with their combined length exceeding that of high energy coastlines. Yet the morphodynamics of such systems are poorly understood with only a few process based assessments of low-energy environments. Shoal Bay is a low-energy embayed estuarine beach in the Port Stephens estuary, located on a high-energy coast. It has been undergoing erosion for the past 40 years and its cross-shore extent is associated with a well developed flood-tide delta (FTD). This study investigates the morphodynamics of Shoal Bay beach over multiple temporal scales.

Short term studies included nearshore hydrodynamic (wave and current) surveys during summer and winter. Sediment entrainment calculations were used in the nearshore current analysis and allowed for more accurate assessment of longshore sediment transport. Medium term assessment involved the analysis of morphological change from one year of beach surveys as well as an evaluation storm effects from hourly offshore wave data. Historic storm data, sediment characterisation and 43 years of aerial photography were used in the long term morphodynamic analysis.

Westward trending sediment pathways were found at all three time-scales. Short term studies indicate that under modal conditions westward transport of sediment occurs. This corresponded with accumulation of sediment in the west. Severe high-energy events triggered considerable erosion along the entire beach. Detailed analysis of beach recovery after severe events could not be made but negligible recovery is observed over one year of surveys. Significant erosion and shoreline recession was found in the medium and long term morphological analysis as was shoreline rotation. Medium term shoreline retreat was caused by high-energy stochastic events; however it seems unlikely that these events are the sole cause of long term shoreline retreat. A reduction in sediment input as well as reworking of the FTD are proposed to be the long term processes driving 43 years of chronic shoreline retreat.

The results of this study represent a scientific contribution to the morphodynamics of low-energy beaches and they are relevant for the future shoreline management of Shoal Bay and other drowned river valleys on high-energy coasts.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT .................................................................</td>
</tr>
<tr>
<td>LIST OF NOTATIONS ....................................................</td>
</tr>
<tr>
<td>LIST OF FIGURES ..........................................................</td>
</tr>
<tr>
<td><strong>1. INTRODUCTION</strong> .......................................................</td>
</tr>
<tr>
<td>1.1 Premise ...............................................................</td>
</tr>
<tr>
<td>1.2 Motivation ............................................................</td>
</tr>
<tr>
<td>1.3 Introduction to Study Site .........................................</td>
</tr>
<tr>
<td>1.4 Aims .................................................................</td>
</tr>
<tr>
<td>1.5 Significance and Scope ...............................................</td>
</tr>
<tr>
<td>1.6 Thesis Outline ......................................................</td>
</tr>
<tr>
<td><strong>2. BACKGROUND</strong> ................................................................</td>
</tr>
<tr>
<td>2.1 Morphodynamics and Scale ...........................................</td>
</tr>
<tr>
<td>2.2 Low Energy Beach Morphodynamics ................................</td>
</tr>
<tr>
<td>2.3 Low Energy Morphologies ............................................</td>
</tr>
<tr>
<td>2.4 Beach Equilibrium and Embayed Beaches .........................</td>
</tr>
<tr>
<td>2.4.1 Shoreline Equilibrium ............................................</td>
</tr>
<tr>
<td>2.4.2 Beach Rotation ....................................................</td>
</tr>
<tr>
<td>2.5 Estuarine Environments ...............................................</td>
</tr>
<tr>
<td>2.6 Multi-Scale Coastal Morphodynamic Assessment ................</td>
</tr>
<tr>
<td><strong>3. STUDY SITE</strong> ................................................................</td>
</tr>
<tr>
<td>3.1 Port Stephens ............................................................</td>
</tr>
<tr>
<td>3.2 Morphological Evolution: Flood-tide Delta and Associated Shoreline Changes</td>
</tr>
<tr>
<td>3.3 Shoal Bay ...............................................................</td>
</tr>
<tr>
<td><strong>4. METHODS</strong> ....................................................................</td>
</tr>
<tr>
<td>4.1 Introduction ..................................................................</td>
</tr>
<tr>
<td>4.1.1 Beach Sections .....................................................</td>
</tr>
<tr>
<td>4.2 Long Term ....................................................................</td>
</tr>
<tr>
<td>4.2.1 Long Term Shoreline Change: Using ArcGIS and Aerial Photographs</td>
</tr>
<tr>
<td>4.2.2 Aerial Photograph Analysis: Digital Shoreline Analysis System (DSAS)</td>
</tr>
<tr>
<td>4.2.3 Wind data ............................................................</td>
</tr>
<tr>
<td>4.2.4 Historical Wave Data .............................................</td>
</tr>
<tr>
<td>4.3 Medium Term ..............................................................</td>
</tr>
<tr>
<td>4.3.1 Topographic Surveys ..............................................</td>
</tr>
<tr>
<td>4.3.2 Morphological Analysis ..........................................</td>
</tr>
<tr>
<td>4.3.3 Hourly Offshore Wave data .....................................</td>
</tr>
<tr>
<td>4.3.4 Sediment Characterisation: Carbonate content and grain-size characteristics</td>
</tr>
<tr>
<td>4.4 Short Term ...............................................................</td>
</tr>
<tr>
<td>4.4.1 Hydrodynamic Surveys ............................................</td>
</tr>
<tr>
<td>4.4.2 Pod configurations and deployment ............................</td>
</tr>
<tr>
<td>4.4.3 Modal Conditions ..................................................</td>
</tr>
<tr>
<td>4.4.4 Hydrodynamic Analysis ...........................................</td>
</tr>
<tr>
<td>4.4.5 Sediment Entrainment .............................................</td>
</tr>
</tbody>
</table>
List of Notations

$A$ wave orbital velocity

$C$ total duration of the deployment

$C_f$ duration for which the sampled nearshore currents were above $U_{cr}$

$D_{50}$ mean grain size

$D^*$ non-dimensional sediment grain size parameter (Soulsby 1997)

d$_e$ duration of eastward current and $E$ values

d$_w$ duration of westward current and $E$ values

$E$ percentage of entrainment

$E_e$ average values of $E$ associated with eastward residual currents

$E_f$ percentage of entrainment residual scaling factor

$E_w$ average values of $E$ associated with westward residual currents

$F$ peak near bed wave orbital velocity frequency

$f_w$ wave friction factor

$g$ gravitational acceleration ($9.8 \text{ m s}^{-2}$)

$H_s$ significant wave height

$k_s$ Nikuradse roughness length

$T_z$ wave period

$U$ kinematic viscosity of water ($1.1 \times 10^{-6} \text{ m}^2 \text{s}^{-1}$)

$U_{cr}$ velocity amplitude

$U_w$ peak near bed wave orbital velocity

$v_e$ longshore velocity towards the east
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_w$</td>
<td>longshore velocity towards the west</td>
</tr>
<tr>
<td>$Rf$</td>
<td>residual current scaling factor</td>
</tr>
<tr>
<td>$r$</td>
<td>relative roughness</td>
</tr>
<tr>
<td>$s$</td>
<td>ratio of sediment to water density ($\rho_s / \rho$)</td>
</tr>
<tr>
<td>$\tan \beta$</td>
<td>beach slope</td>
</tr>
<tr>
<td>$Vi$</td>
<td>average width/shoreline displacement</td>
</tr>
<tr>
<td>$Vi(t)$</td>
<td>width/Shoreline displacement</td>
</tr>
<tr>
<td>$\sigma_i$</td>
<td>variance of width/displacement</td>
</tr>
<tr>
<td>$\vartheta_i(t)$</td>
<td>normalised width/shoreline displacement</td>
</tr>
<tr>
<td>$\rho$</td>
<td>water density (1027 kg/m³)</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>sediment density (2650 kg/m³)</td>
</tr>
<tr>
<td>$\tau_{cr}$</td>
<td>critical shear stress</td>
</tr>
</tbody>
</table>
List of Figures

Figure 2.1. Primary components of coastal morphodynamics. Modified from Cowell and Thom (1994) ................................................................. 16
Figure 2.2 Spatial and temporal scales as defined by Cowell and Thom (1994).............. 16
Figure 2.3. Profile change of cross-shore or longshore a dominated typical mesotidal estuarine beach (Nordstrom and Jackson 1992). ................................................................. 19
Figure 2.4. Sketch of typical seasonal beach rotation from changing wave direction... 22
Figure 2.5. Time series of beach width change of Narrabeen Beach (Short and Trembanis 2004). ......................................................................................... 22
Figure 2.6. Two evolutionary paths of a drowned river valley in Roy et al. (1980). ..... 25
Figure 2.7. Aliasing in time series analysis where temporal surveying of the sinusoidal curve has resulted in an increasing trend that does not accurately describe the signal... 27
Figure 3.1. Location and features of study site............................................................. 30
Figure 3.2. Figure from Frolich (2007) showing flood and ebb orientated morphology ........................................................................................................... 31
Figure 3.3. Evolution of Winda Woppa spit between 1795 and 1941......................... 32
Figure 4.1 Beach sections used in assessing shoreline change for both aerial photographs and beach surveys. ................................................................. 34
Table 4.1. Photographs used in assessing the long term shoreline change of Shoal Bay ......................................................................................... 36.
Figure 4.2. Shoreline transects and baseline used to calculate the shoreline displacement of Shoal Bay........................................................................... 37
Figure 4.3. Description of Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM) and End Point Rate (EPR) that are produced by the DSAS. ......................... 38
Figure 4.4. Position of cross-shore beach profiles from 1-23 from west to east. ............. 40
Table 4.2. Survey date, type and file name type from May 2008 to May 2009. ............. 40
Figure 4.5. Beach sections used to create surface grids .............................................. 42
Figure 4.6 Spatial distribution of sediment samples from both summer and winter on the Shoal Bay beach face. ....................................................................... 43
Figure 4.7. Underwater photo showing pod configuration ........................................ 45
Table 4.3 Sampling frequency and accuracy for the three ADV’s and PTs used for the hydrodynamic surveys. ................................................................. 45
Figure 4.8 Position of the three deployment sites where nearshore hydrodynamics was surveyed. ................................................................................ 47
Figure 4.9. Time series of zero down-crossing analysis performed from 15 minute pressure transducer data. ................................................................. 51
Figure 4.10 Wave frequency spectra from SB3 on the 16/12/08................................... 51
Figure 5.1. Time series of shoreline displacement from section 1 to section 6 (a-f respectively). ................................................................. 55

Figure 5.2. Comparison of non-dimensional normalised shoreline displacement between section 2-4 and sections 3-4 (a and b respectively). Shoreline rotation represented between sections 2-3 and section 4. ................................................................. 56

Figure 5.3. Net shoreline displacement from the 1963 shoreline in the aerial photographs for each beach section. ......................................................................................................................... 57

Figure 5.4. Average shoreline displacement from 1963-2006 for Shoal Bay.......... 58

Figure 5.5. Shoal Bay shoreline evolution with the 1963 shoreline in red and the 2006 in black. The blue rectangle indicates the 200m loss of beach in front of the seawall. ...... 58

Figure 5.6. Storm waves between 1985 and 2005. Upper panel shows total wave power. Lower panel shows wave direction. ........................................................................................................... 59

Figure 5.7. Filtered daily historic wind data for wind speeds above 10ms\(^{-1}\) between 1942 and 2009. ......................................................................................................................... 60

Figure 5.8. Time series analysis of beach statistic change for each beach section.... 63

Figure 5.9. Time series of a) beach volume (thousands of m\(^3\)); b) area; c) width; and d) slope (\(\tan{\beta}\)) between surveys from May 2008 to May 2009. .......................................................... 66

Figure 5.10. Examples of beach profile response .................................................. 68

Figure 5.11. Rate of shoreline change over a year from May 2008 to May 2009. ...... 69

Figure 5.12. Loss of volume in each beach section from 1963 to 2006. .................... 69

Figure 5.13. Example of shoreline rotation using normalised width between sections 1 and 4 from the years worth of beach surveys. ................................................................. 70

Figure 5.14. Grid comparison between 0905 and 081213 with red indicating erosion and blue accretion. ......................................................................................................................... 71

Figure 5.15. Grid comparisons between surveys .................................................... 72

Figure 5.16. Hourly wave data from Crowdy Head with significant wave height in the top panel and significant wave period at the bottom. ......................................................... 73

Table 5.2. Average statistics of the hydrodynamic forcing mechanisms, sediment entrainment and residual scaling factors over summer (a) and winter (b) hydrodynamic surveys. ................................................................. 78

Figure 5.17. Spatial distribution of sediment characteristics with a) grain size (\(\mu m\)) and b) carbonate content (%) ......................................................................................................................... 79

Table 6.1. Average statistics of the hydrodynamic forcing mechanisms, sediment entrainment and residual scaling factors over summer and winter hydrodynamic surveys. ......................................................................................................................... 83

Figure 6.1. Beach change in each section derived from one year of beach surveys...... 87

Figure 6.2. Example of profile change over 5 days during spring tidal (≈2 m) conditions ......................................................................................................................... 88.

Figure 6.3. Shoreline displacement between aerial photographs for each beach section... ......................................................................................................................... 91
1. Introduction

1.1 Premise

Low-energy shorelines are ubiquitous coastal features. Their combined length far exceeds that of oceanic shorelines, yet a comprehensive understanding of low-energy beach systems is lacking, with their morphodynamics generally assessed under existing principles that govern open ocean beaches (Nordstrom 1992; Travers 2007). These beaches are often found in environments that are densely populated, such as estuaries, bays and lagoons. They are valued ecological, recreational and economical resources but are often subject to reactive short-term shoreline management rather than long-term preventative strategies (Church et al. 2008). In order to develop a comprehensive management plan it is necessary to assess the beach morphodynamics of low-energy beaches as well as sediment pathways and magnitudes. However, these environments typically comprise complex hydrodynamic forcing and interactions between linked morphologies. Reductive assessments of such coastal systems often produce results of questionable fidelity. Assessment of the hydrodynamic forcing mechanisms and associated morphological change must occur over numerous scales in order to ascertain the holistic morphodynamics of these environments. Without such assessments both long term trends and processes driving these trends are overlooked. In spite of this, standardised methods in multi-scale analyses are not yet established.

The focus of this study is therefore twofold. Firstly, providing insights into the morphodynamics of low-energy systems and secondly, to assess the processes driving long term shoreline change, allowing for more adequate shoreline management strategies.

1.2 Motivation

The morphodynamics of low-energy beaches have been broadly overlooked in the coastal literature with few process-based assessments in such environments (Eliot et al. 2006; Hegge et al. 1996; Travers 2007). As a result, predictive and descriptive morphodynamic models and equations derived from high-energy environments often inaccurately interpret the dynamics of low-energy beaches (Nordstrom et al. 2003). While some

Most of the shoreline within the Port Stephens estuary falls within the low-energy classification set out by Jackson et al. (2002); yet process-based assessments (Ainley 2007; Pezzimenti 2008; Vila-Concejo et al. 2009a; Vila-Concejo et al. 2009b) and studies on historic evolution (Cholinski 2004; DPWS 1999; 2000 ; Frolich 2007; PWD 1985; 1987; Thom et al. 1992; Vila-Concejo et al. 2007b) have indicated a highly dynamic environment at odds with to the low-energy definition (Vila-Concejo et al. 2009a; Vila-Concejo et al. 2009b).

The majority of low-energy beaches are within protected environments such as bays, sounds, estuaries, embayments, lakes or lagoons and in lee of islands, reefs or submarine ridges (Jackson et al. 2002). As a result, the morphodynamics of such beaches are inherently connected to the evolution and fluctuations of their geological setting. Well developed flood-tide deltas commonly occur on the energetic, micro-tidal, wave-dominated coast of southeast Australia; their evolution is connected to the long term morphodynamics of the associated shorelines (Cowell et al. 1995). An integrated multi-scale approach is thus necessary to gain insight into the long term shoreline change and the processes driving such change (Ruggiero et al. 2005; Smith and Zarillo 1990).

Multi-scale analysis is a relatively new technique for assessing the morphodynamics of coastal systems. The pragmatism of this approach is the ability to separate long term trends from short term noise by extending the temporal scale of the morphodynamic assessment from short and medium term (daily/monthly) to long term (decadal). Likewise extending spatial scales to encompass associated morphologies is beneficial in determining sediment pathways and budgets. Whilst ‘best practise’ in multi-scale analysis is not yet established, the methodology presented in this study is one approach using relatively common data sets.
1.3 Introduction to Study Site

Port Stephens is a typical drowned river valley on the wave-dominated southeast Australian coast. Chronic erosion of the Port Stephens shorelines has been evident for at least the past four decades (Vila-Concejo et al. 2007a). A more comprehensive description of the study site can be found below (Section 3). Shoal Bay is an embayed estuarine beach bounded by two headlands and flanked by a well formed flood-tide delta. This environmental setting allows for an assessment of low-energy beach morphodynamics as well as an investigation into the nature of long term beach change in response to flood-tide delta evolution.

1.4 Aims

This study aims to develop insights into small scale morphodynamic behaviour of an embayed estuarine beach that may be influenced by the evolution of associated estuarine morphologies (e.g. flood-tide delta and related shoals). It will also assess the expediency of applying the multi-scale approach to coastal morphodynamics. In order to address short to long term beach change on headland controlled estuarine beaches flanking flood-tide deltas, semi-exposed to ocean swell; a number of research questions are presented that address the short and long term morphodynamics of Shoal Bay as well as the potential influence of flood-tide delta evolution on shoreline change:

1) Does shoreline rotation occur?
2) Are storms essential morphodynamic events?
3) Do changes to the flood-tide delta cause variations in Shoal Bay embayment?
4) Can short term assessment forecast long term shoreline change?
5) Is shoreline change a function of instabilities in the littoral transport, or are they more related to cross-shore changes?

1.5 Significance and Scope

This study is applicable to all lower drowned river valley estuarine environments on high-energy coastlines and is part of a larger project concerning the dynamics of the lower estuarine environment of Port Stephens. Thus methods in addressing short and long term morphodynamics have broad application in coastal studies. Past research as
part of the Port Stephens project is concerned with sediment transport and erosion on the northern shorelines (Ainley 2007; Pezzimenti 2008; Vila-Concejo et al. 2009a), sandwave dynamics (Vila-Concejo et al. 2009b) as well as evolution and morphodynamics of the flood-tide delta (Austin et al. 2009; Frolich 2007). This study will build upon previous data sets and combined with future research will result in a comprehensive process based assessment of an estuarine environment. It will also present the predictive and descriptive capabilities of morphodynamic assessment at multiple spatial and temporal scales.

1.6 Thesis Outline

Chapter 2 provides a brief background on the morphodynamic processes that may influence the evolution of Shoal Bay. It reviews current knowledge concerning low-energy beach morphodynamics, embayed beaches, estuarine environments and multi-scale morphodynamic assessments. Chapter 3 describes the environmental conditions and evolution of the study site of Shoal Bay and Port Stephens and provides details of the shoreline engineering projects conducted on Shoal Bay. Chapter 4 explains the methodologies, data analysis and field campaigns used in the morphodynamic analysis of Shoal Bay for the short, medium and long term. Chapter 5 presents the hydrodynamic, morphological and sediment characteristics of the data obtained from Chapter 4. Chapter 6 discusses the results of Chapter 5 as well as the limitations of this study and potential future research. Chapter 6 addresses the expediency of multi-scale morphodynamic assessment and the limitations of using this approach for future research.
2. Background

2.1 Morphodynamics and Scale

The concept of morphodynamics was first introduced by Wright and Thom (1977) and has since governed much of the research concerning the coastal environment, facilitating the development of models that link geomorphology to their defining physical processes. The morphodynamic approach addresses “the mutual adjustment of topography and fluid dynamics involving sediment transport” (Wright and Thom 1977). This implies that beach topography will change depending on the hydrodynamic conditions, which will in turn modify the wave and tide processes (Short 1999). This creates a “feedback loop” between fluid dynamics and topography that drives sediment transport producing morphological change (Cowell and Thom 1994) (Figure 2.1). Consequently both self organisation (positive feedback) and self regulation (negative feedback) create coastal systems that exhibit nuanced variation about a morphodynamic equilibrium until changes in the boundary conditions or a significantly extreme event produces a new morphodynamic state (Cowell and Thom 1994). These changes in equilibrium occur over varying time scales with short term fluctuations superimposed over long term evolution.

Therefore, defining the scale in which an observed coastal process is occurring is fundamental in separating the confounding “noise” from the important “signal”. Numerous definitions of both spatial and temporal scale exist but the most common terms used are instantaneous, event, engineering and geological as set out in Wright and Thom (1977) and subsequently Cowell and Thom (1994) (Figure 2.2). For the purposes of this study short, medium and long term are used to describe the instantaneous, event and engineering scales respectively.

Addressing the morphodynamic changes using multiple spatial and temporal scales allows for a holistic understanding of a coastal system. That is, analysis of short term morphological variations allows for an appreciation of the hydrodynamic forcing mechanisms initiating sediment transport and subsequent morphological variation, whilst a long term morphodynamic assessment considers the trends and shifts in equilibrium that produces chronic change and shoreline evolution. Similarly, extending the spatial parameters beyond that of the immediate study site enables the assessment of significant
interactions between associated morphologies. This is specifically important in the complex sediment sharing environments of Port Stephens.

**Figure 2.1.** Primary components of coastal morphodynamics. The feedback loop between form and process is the fundamental reason for morphodynamic equilibrium and complexity in coastal evolution. Modified from Cowell and Thom (1994).

**Figure 2.2.** Spatial and temporal scales as defined by Cowell and Thom (1994).
2.2 Low Energy Beach Morphodynamics

The majority of the research concerning beach morphodynamics has been conducted in high-energy wave-dominated environments. In these beaches surf zone processes and rip currents drive the seasonal morphodynamic variations, and as a result the majority of the predictive and descriptive nomenclature developed to describe beach morphodynamics are based off such processes. When applied to environments where there are little to no surf zones many of the morphodynamic and sediment transport models developed in the high-energy environment are ineffectual (Hegge et al. 1996; Sanderson et al. 2000). Transferring these models to low-energy environments often underestimates the dynamics of such systems in which hydrodynamic forcing comes from many different sources (Nordstrom et al. 2003). Such beaches are often termed reflective, based off the Wright and Short (1984) beach model, but low-energy is a more accurate description (Jackson et al. 2002). So far attempts to develop a comprehensive low-energy morphodynamic model (e.g. Hegge et al. 1996; Travers 2007) have been of limited success.

The classification “low-energy beach” is an ambiguous term which encompasses a wide range of hydrodynamic and geological settings. In general the use of the term “low-energy” to describe a beach has been derived from the comparison between the morphodynamics of high-energy open-coast beaches and lower energy environments (Jackson et al. 2002). Hydrodynamic definitions vary from mean annual wave heights as low as <0.10 m (Tanner 1960) to mean annual significant wave heights of up to 1 m (Hegge et al. 1996) with environmental settings including bays, sounds, estuaries, embayments and in lee of islands or reefs or submarine ridges (Jackson et al. 2002). Linked with the low-energy classification are the terms ‘fetch limited’ and ‘wave attenuated’ or ‘sheltered’ environments, which imply different hydrodynamic regimes but have been used interchangeably throughout the literature (Jackson et al. 2002). The fundamental difference between ‘sheltered’ or ‘wave attenuated’ and ‘fetch limited’ is that of local or non-local wave generation. ‘Sheltered’ environments are dominated by ocean waves (swell) which have dissipated much of their energy, most commonly due to refraction. ‘Fetch-limited’ beaches often occur in estuaries or lakes where swell does not significantly interact with the shoreline, instead wave processes are controlled by locally generated wind waves. ‘Fetch limited’ or ‘sheltered’ environments are not mutually
exclusive and often interact with coastal systems simultaneously. This is particularly the case in estuarine environments which have swell dominated processes in the outer zone along with fetch limited wind waves and tidal current influences (Jackson et al. 2002).

Many factors influence the morphodynamics of low-energy beaches and defining low-energy hydrodynamic environments can often prove difficult due to the effects of geological setting such as sheltering and beach orientation which create low-energy topographies on beaches even in relatively high-energy environments. Jackson et al. (2002) suggested four criteria to define low-energy beaches: (1) minimal non-storm significant wave heights (<0.25 m); (2) significant wave heights due to strong onshore winds low (<0.50 m); (3) beach face widths narrow (<20 m); and, (4) relict morphologies occur, inherited from high-energy events. Most of the shoreline within the Port Stephens falls within the low-energy classification of Jackson et al. (2002), yet process-based assessments (Ainley 2007; Pezzimenti 2008; Vila-Concejo et al. 2009a; Vila-Concejo et al. 2009b) and studies on historic evolution (Cholinski 2004; DPWS 1999; 2000; Frolich 2007; PWD 1985; 1987; Thom et al. 1992; Vila-Concejo et al. 2007b) have indicated a highly dynamic environment antithetic to the low-energy definition (Vila-Concejo et al. 2009a; Vila-Concejo et al. 2009b).

2.3 Low Energy Morphologies

The morphodynamic nomenclature applied to open coast beaches defines low-energy beaches as reflective with a steep shoreface and often with beach step or rhythmic formations (Eliot et al. 2006; Wright and Short 1984). However, the diagnostic features attributed to reflective beaches are often absent on low-energy beaches (Eliot et al. 2006). Assumptions that lower energy beaches are subject to similar processes to higher energy beaches just on a smaller scale are misguided (Eliot et al. 2006).

In an attempt to rectify this Hegge (1996), Makaske and Augustinus (1998), Nordstrom and Jackson (1992) Sanderson (2000) and Travers (2007) among others tried to establish morphodynamic models for low-energy beach change. Whilst a comprehensive model remains elusive, a number of morphological descriptions and profile response analyses were made in these studies. Makaske and Augustinus (1998) described micro-tidal profile change in response to wave and tidal forcing. Nordstrom and Jackson (1992) assessed the parallel recession of beach profiles describing beach recession due to
longshore dominating processes which do not result in changes to profile shape (Figure 2.3).

A comprehensive low-energy morphodynamic model is not feasible for two reasons. Firstly, the influence of relict morphologies caused by low frequency, high-energy events (storms) hinders the ability to link beach morphologies to their associated hydrodynamic forcing. There is evidence that suggests storms are significant hydrodynamic forcing mechanisms in low-energy environments (Costas et al. 2005). Secondly, developing a predictable set of parameters required for a generalised model is difficult due to the hydrodynamic idiosyncrasies as a result of environmental setting. Therefore, Hegge et al. (1996) suggested that low-energy beaches cannot be defined in the conceptual realm morphodynamically, but only empirically on a site by site basis or by their morphological attributes.

An understanding of the geological and morphological linkages affecting the beach morphodynamics is particularly important in low-energy environments given that the majority of the low-energy settings are caused by other formations; be they geological (bays, estuaries, submarine ridges), biological (coral reefs) or sedimentary (tidal deltas, isthmus formations).

![Diagram showing profile change of cross-shore or longshore dominated typical mesotidal estuarine beach (Nordstrom and Jackson 1992). Modified from Jackson et al. (2002).]

**Figure 2.3.** Profile change of cross-shore or longshore dominated typical mesotidal estuarine beach (Nordstrom and Jackson 1992). Modified from Jackson et al. (2002)

### 2.4 Beach Equilibrium and Embayed Beaches

Beaches are constantly seeking a state of equilibrium. Defining such a state, however is often a topic of conjecture, since the morphodynamic approach to coastal studies includes numerous variables continually adjusting to topographical and hydrodynamic variations. Consequently the definition of equilibrium is often a matter of perspective
depending on the temporal and spatial constraints of the study (Klein 2004). Common definitions of shoreline equilibrium in embayed environments refer to the three dimensional planform of beaches.

All beaches must at some point have terminal boundaries, whether they be a sandy foreland, an inlet or in many beaches rocky headlands (Short and Masselink 1999) A shoreline bounded by headlands of rocky outcrops, whether they be manmade or otherwise, will follow a curvature of some description. These beaches have been given a variety of names but were first defined by Krumbein (1944) observing the logarithmic-spiral (hereafter abbreviated as log-spiral) planform of Halfmoon Bay, California. Subsequent derivations of the log-spiral definition include zeta curved bays, crenulated shaped bays, headland bay beaches, embayed beaches, structurally controlled beaches, bay-head beaches, pockets beaches, curved and hooked beaches and topographically bound beaches (Klein 2004). Each of these definitions generally represent a beach with an asymmetrical planform that has a curved shadow zone, a gently curved middle transitional zone, and a relatively straight tangential down coast section; each representing an increasingly energetic hydrodynamic environment (Klein and Menezes 2001).

2.4.1 Shoreline Equilibrium

Embayed beaches can be broadly associated with two forms of shoreline equilibrium, either static or dynamic (Bird 1996). Static equilibrium has a shoreline with parallel orientation to the refracted wave crest resulting in no net longshore transport of sediment (swash aligned). The observed wave pattern in such beaches shows a simultaneous breaking wave along the entire curved shoreline (Hsu et al. 1987). If a shift in the morphodynamic state occurs the temporal scale required for beach planforms to reach static equilibrium is long term with the balance between sediment supply and the ability for waves to rework the sediment occurring over years to decades (Komar 1998). Whilst beaches can be close to static equilibrium in reality some form of littoral drift occurs in swash aligned coasts through extreme stochastic events (storms, headland bypassing) or longshore currents generated by a reduction in longshore wave height (Woodroffe 2002).

The alternative to a static equilibrium state is that of dynamic equilibrium, where there is gross longshore transport of sediment; yet within the embayment input and output of
sediment is equal resulting in a balanced sediment budget for the system (Hsu et al. 1987; Klein 2004).

Dynamic equilibrium beaches are drift dominated beaches, with oblique incident waves producing longshore sediment transport with no net loss to the system (Klein 2004; Woodroffe 2002). As a result shifts in the sediment budget have profound effects on the shoreline, with a reduction in sediment input resulting in shoreline retreat. Dynamic (drift aligned) and static (swash aligned) equilibrium profiles define the end member states of beach planforms. The majority of embayed beaches fall into intermediate states coming close to the static and dynamic equilibrium planforms but rarely reaching these states, with most beaches showing some dynamic equilibrium and net sediment gain or loss (Klein 2004).

2.4.2 Beach Rotation

Beach rotation refers to the alternating accumulation of sand between the two headlands of an embayed beach. This phenomenon can occur over large spatial and temporal scales with no net loss of sediment in the coastal cell. It is usually attributed to a seasonal or periodic shift in wave direction (Figure 2.4), however longer term yearly to decadal cycles have also been observed (Ranasinghe et al. 2004; Short et al. 1995; Short and Masselink 1999; Short and Trembanis 2004) (Figure 2.5).

Rotation is common amongst headland-bay coastlines. The processes driving beach rotation are generally considered to be longshore dominated with cross-shore processes initiating sediment sharing between the sub-aerial and submerged sections of the beach face. However, Harley et al. (2009) suggested cross-shore processes can simultaneously transport submerged sediment onshore and remove sub-aerial sediment offshore; and in doing so incite beach rotation. Similarly, studies by Dail et al. (2000) and Nordstrom (1980) in protected environments observed concurrent erosion and accretion in different areas under similar wave conditions suggesting that rotation effects can be driven by cross-shore transport of sediment as well as longshore processes.

Beach rotation can theoretically incur no net sediment loss; however headland bypassing provides a mechanism through which sediment is removed from an embayment. This typically occurs when a beach experiences longshore drift and beach rotation (Short and
Masselink 1999) with extreme stochastic events transporting sediment offshore, which is subsequently lost to the system (Short and Masselink 1999).

Morphodynamic assessments of beach rotation have mostly been conducted on intermediate beaches (Harley 2009; Klein et al. 2002; Ranasinghe et al. 2004; e.g. 1995; Short and Trembanis 2004; Short et al. 2000). While short term fluctuations in beach rotation for both dissipative and reflective beaches have been observed by Klein et al. (2002), the dynamics driving rotation in lower energy environments are not well understood. Yet, protected environments containing beaches with reflective profiles have been found to exhibit the most pronounced short term rotation of shorelines (Klein et al. 2002).

Figure 2.4. Sketch of typical seasonal beach rotation from changing wave direction.

Figure 2.5. Time series of residual beach width changes for the northern (station 1) and southern (station 8) survey lines of Narrabeen Beach (Short and Trembanis 2004)
2.5 Estuarine Environments

An estuary can be defined in a variety of ways. At its most basic level an estuary can be described as an area of interaction between salt and fresh water. The most widely used definition of an estuary in geological terms was given by Dalrymple et al. (1992) as “the seaward portion of a drowned river valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth” (Dalrymple et al. 1992). Dalrymple et al. (1992) extended this definition dividing the estuary into three zones: the inner, outer and central zones. Drowned river valley (ria-like) estuaries, such as Port Stephens, are one of three types of embayment fill on the NSW coast (the remaining two being open ocean embayments and barrier estuaries) (Roy et al. 1980). In these ria-like estuaries, ocean waves influence morphology and sediment distribution around the entrance for a distance of up to 5 km landward (Roy et al. 1980). As a result, well developed flood-tide deltas (FTD) (also known as sand aprons or interior shoals) are common formations in drowned river estuaries particularly on high-energy coastlines such as NSW. These formations act as sediment ‘sinks’ for marine sediment from the open coast environment. The time frame for the most recent cycle of infilling depends on the depth of the paleovalleys but has generally occurred for approximately 7000-8000 years since the last sea level rise, with the Holocene standstill occurring for the last 6000 during which time estuaries have been slowly infilling (Roy 1984; Roy et al. 2001). Since then all estuaries have trapped sediment from both fluvial and marine sources.

The “seamless progression” of estuary infilling depends on the scale of the assessment with most analysis of estuarine environment being geological where temporal resolution of the data is in the millennial scale. However, smaller fluctuations from yearly to centennial may occur particularly in the outer estuarine environment where marine processes can significantly alter the estuarine morphologies such as the FTD (Karunaratna et al. 2008). While long term trends may show linear sedimentation, smaller scales show non-linear morphodynamics reacting to stochastic events and Markovian inheritance (Cowell and Thom 1994; Hibma et al. 2004; Roy 1984). Short term process based assessments have been the most accurate method in examining the short term morphodynamics of estuarine environments, but have limitations due to
insufficient knowledge of sediment transport processes and their linkage to hydrodynamics (Karunaratna et al. 2008).

While estuaries have been infilling for the past 6000 years; erosion trends on the NSW nearshore, beach and dune deposits have been occurring for approximately the last 3000 with effects differing from embayment to embayment (Roy et al. 1980). Cowell et al. (2001) challenges this theory by suggesting that there has been a net supply of sediment to the NSW coast from the lower shoreface. However, the alongshore component of sediment transport from south to north has caused accretion in Queensland and northern NSW sediment barriers and erosion in southern NSW which is sediment starved (Roy 2001). This suggests that supply of sediment from the shoreface is not sufficient in mitigating this process. Zeta curve (or embayed) beaches on the southern shoreline of estuarine environments are often indicative of this long term erosion trend (Roy et al. 1980). Roy et al. (1980) proposed that FTDs are expected to accrue sediment until the finite sand budget is depleted. Landward migration of the FTD then occurs with a deepening or erosion of the seaward face (Figure 2.6).
Figure 2.6. Two evolutionary paths of a drowned river valley in Roy et al. (1980). Path 3a, 3b to 3c has been proposed for the southeast Australian coast where erosion of the FTD occurs as sediment input is reduced. High fluvial input is unlikely for most estuaries on the southeast Australian coast including Port Stephens.
2.6 Multi-Scale Coastal Morphodynamic Assessment

The dynamic interaction between environmental forcing and coastal morphology occurs over a wide range of spatial and temporal scales. Temporal responses range from instantaneous effects of wave cycles to decadal climatic variations whereas spatial scales range from small bed forms (tens of cm) to hundreds of km within coastal cells. In order to present results that are relevant to coastal management and long term coastal evolution, large temporal and spatial ranges must be linked (Ruggiero et al. 2005). Research has rarely achieved a holistic understanding of the morphodynamics of a system; but with the advent of relatively cheap and powerful GIS software and survey equipment, multi-scale approaches attempting to integrate numerous scales are becoming more common with most being conducted within the last 10 to 15 years (e.g. Kaminsky et al. 1999; Morton and Speed 1998; Ruggiero et al. 2003; Ruggiero et al. 2005). Despite this standard methodology in assessing coastal environments at multiple scales has yet to be defined.

The most common form of beach assessment utilises beach surveys (Short and Trembanis 2004) which typically only exist for a few years with some rare exceptions extending into decades. As a result most assessments can only infer trends and predict shoreline change over monthly to inter-annual scales. The short term noise that is prevalent in small scale data sets ultimately limits the ability to derive a long term signal (Ruggiero et al. 2005). Long term predictions based off small scale analysis are generally inadequate or indeed impossible (Larson and Kraus 1995).

Qualitative long term data sets including aerial photographs and accurate historic charts allows for the long term trends to be extracted from the short term noise extending morphodynamic assessments beyond the yearly to the decadal (Ruggiero et al. 2005). The limitations of these data sets include their low resolution and large time steps, however this is can be beneficial in assessing long term shoreline change as small time steps between aerial photographs can often confound trends within the data set as a result of time series aliasing (Cowell 2004; Dolan et al. 1992).

Aliasing of time series data arises when sampling has occurred in which fluctuations within the sampling period are non-negligible, that is, sampled data does not occur at sufficient frequency to negate confounding effects of rapid fluctuation inherent in the
surveyed environment (Figure 2.7) (Cowell 2004; Jenkins and Watts 1968). Short term fluctuations on beaches include seasonal erosion and accretion producing summer and winter shoreface profiles and planform. Beach surveys in general attempt to assess these short term fluctuations while aerial photographs identify long term underlying trends, thereby exposing such assessments to confounding effects of aliasing. The large short-term fluctuations required to influence long term trends are less likely to occur in low-energy environments than on high-energy high-energy coastlines.

![Figure 2.7. Aliasing in time series analysis where temporal surveying of the sinusoidal curve has resulted in an increasing trend that does not accurately describe the signal. Modified from Cowell (2004).](image)

In addition to deriving long term trends in data sets a multi-scale approach has the ability to examine the mutual interaction between linked morphologies such as FTDs and their associated shorelines. This allows assessment of sediment pathways within a coastal cell where sediment sharing between multiple morphologies occurs. While analysis of this form includes some projection and extrapolation of the data sets it also offers results with greater fidelity than alternative approaches such as conceptual modelling of complex environments which are still in their infancy (Karunarathna et al. 2008).
3. Study Site

3.1 Port Stephens

Port Stephens estuary is a ria-like drowned river valley located approximately 230 km north of Sydney (Figure 2.1). It is a tidally dominated estuary on a high-energy coast, with wave processes typically a significant hydrodynamic forcing mechanism in the lower estuarine environment of such estuaries (Dalrymple et al. 1992; Roy et al. 2001). A well developed FTD is found within the lower estuary typical of a high-energy environment with ebb-tide deltas unable to form as a result of waves reworking the sediment as they propagate into the estuary (Dalrymple et al. 1992; Hayes 1980; Vila-Concejo et al. 2007a). Tides are semidiurnal with a diurnal inequality resulting in generally two high and low tides per day. Maximum tidal range is 2.0 m with mean tidal ranges of 1.6 m and 1.3 m for spring and neap tides respectively (Short 1985). Spring tidal prism at the entrance of Port Stephens is $165 \times 10^6$ m$^3$ with maximum tidal currents exceeding 1 ms$^{-1}$. The greatest potential effects on the estuarine shores occur during flooding for the northern shoreline and ebbing tides for the southern (Ainley 2007; DPWS 1999; Frolich 2007). Tidal attenuation is minimal due to the wide mouth of the estuary (1.24 km) (DPWS 1999).

The wave regime of the Southeast Australian coast is a classified as moderate with mean significant wave heights ($H_s$) of 1.5 m with an associated period ($T_z$) of 8 s (Short and Trenaman 1992). Persistent swell with significant wave heights of 1-2 m are the modal conditions (where modal conditions occur during more than 50% of the time) with rare periods of low waves (<1 m, 10%) and a substantial amount of high-energy waves (2-3 m, 21%; 3-5 m, 5%). Waves from the NE dominate during summer, with E-SE waves occurring throughout the rest of the year (Short and Trenaman 1992). Winds are strongly influenced by daily breeze patterns with strong E-SE winds (<30 km/h) occurring in the afternoon between Spring and Autumn and strong westerlies occurring throughout winter (<30km/h) (BOM 2009).
3.2 Morphological Evolution: Flood-tide delta and associated shoreline changes

According to Frolich (2007), the FTD complex appeared to be accumulating sediment over the last four decades, both in the major shoal formations as well as some of the smaller morphologies including the sand ridges and ebb shoal located close to Shoal Bay (Frolich 2007). Accretion has also occurred in two other locations, at Winda Woppa spit and Yacaaba sandwave (Cholinski 2004; Vila-Concejo et al. 2007a; 2009b). Conversely, the Port Stephens shorelines of Shoal Bay, Jimmy’s Beach, Nelson Bay have been undergoing erosion for the past 40 years (DPWS 1999; 2000; Frolich 2007; PWD 1979; 1985; 1987; Vila-Concejo et al. 2007b). A number of studies have reported eastwards trends in sediment transport as a result of wind waves generated by westerly winds. However, inconclusive hydrodynamic surveys (e.g. Vila-Concejo et al. 2009a) and westward extension of the FTD, Yacaaba sandwave and Winda Woppa spit (Cholinski 2004; Frolich 2007; Vila-Concejo et al. 2009b) suggest hydrodynamic forcing within the estuary is not that simple. Frolich (2007) determined the direction of sediment movement by observing morphological characteristics with westward sediment pathways (flood) on the northern shoreline and eastwards (ebb) in the southern as a result of the ebb channel (Figure 2.2).

Geological studies of the area suggest the FTD has been under a general trend of erosion since the mid 1800s (Thom et al. 1992). This may have been a contributing factor in the breaching of Winda Woppa spit in 1927 (Thom et al. 1992). Winda Woppa spit was initiated circa 1820 and reached its maximum length in 1910 before being catastrophically changed in 1927 (Figure 3.3). The same authors proposed an alternative evolution that suggested the spit breaching was a result of extreme storm activity in 1927. Such a process may indicate cyclic behaviour within the estuary over large time scales, with westward extension of Winda Woppa spit observed again over the last 4 decades.
Figure 3.1. (a) Location of Port Stephens, NSW, Australia; (b) Map showing the entire estuary; (c) aerial photo of the lower estuarine environment (April 2006) showing the main morphological features; (d) Study site of Shoal Bay is located on the southern shoreline immediately west of Tomaree Head, jetty in the centre of the beach and boat ramp to the west highlighted by black circles.
Figure 3.2. Figure from Frolich (2007) showing flood orientated morphology in yellow, ebb in red and blue arrows representing the ebb channel. The only flood orientated morphology on the southern section of the estuary is the ebb shoal located immediately off Tomaree Head.
3.3 Shoal Bay

Shoal Bay is the most easterly and energetic beach on the southern shoreline of Port Stephens (Figure 1d). It is a 2.5 km long embayed, swash aligned, low-energy estuarine beach most exposed to ocean swell in the western environment of the embayment (Frolich 2007; Short 2007). Existing records of sand nourishment extend back to 1986,
with almost all nourishment occurring in the areas immediately east and west of the jetty. The first major nourishment in 1986 used 25,000 m$^3$ of sand extending from the boat ramp to 500 m west of the jetty (Watson 1997). Extensive shoreline management then occurred during the 1990s with some of the erosion problems correlated with the development the boat ramp in the west and drainage outlets and associated rock wall constructed in 1991, underneath the public jetty (Figure 1d). Minor nourishment was undertaken throughout 1994 before a major nourishment of 33,000 m$^3$ of sediment was deposited on the beach from the boat ramp to 700 m west of the jetty in September 1994. By 1996 further nourishment was needed periodically until at least 1999 with approximately 50,000 m$^3$ of sand deposited between April 1994 and November 1999. The rock wall protecting the drainage outlet underneath the jetty was removed in 2000 with no major nourishment projects occurring since then$^1$. However, emergency nourishment and sand relocation from the west has occurred periodically since 2000.

---

$^1$ All information regarding shoreline management from 1991 to the present day from Geoff Dann of Port Stephens council.
4. Methods

4.1 Introduction

Field measurements of nearshore hydrodynamics and beach morphology were undertaken as both intensive field campaigns and day surveys from March 2007 to May 2009. Short term fluctuations in morphology and the associated forcing mechanisms were subsequently derived from survey data as well as offshore wave and long term climate data. These data were integrated with 43 years of aerial photographs and historical storm data to determine underlying systemic trends within the Shoal Bay system.

4.1.1 Beach Sections

To allow for ease in comparing morphological response in different areas of the beach analysis of beach change was undertaken by compartmentalising the shoreline into 6 sections. Sections 1-5 are based off previous shoreline analysis of Shoal Bay by Watson (1997) with the additional Section 6 encompassing the eastern most section of the beach (Figure 4.1). Results in beach statistics from both aerial photographs and beach surveys were compartmentalised then averaged to produce mean shoreline change values for each section. Total volume (m$^3$) within each section could then be estimated by multiplying the area (m$^3$/m) by the length of the section.

![Figure 4.1. Beach sections used in assessing shoreline change for both aerial photographs and beach surveys, with 2006 shoreline in red.](image-url)
4.2 Long Term

4.2.1 Long Term Shoreline Change: Using ArcGIS and Aerial Photographs

Aerial photographs were obtained from the Coastal Branch of the Department of Natural Resources (presently within the Department of Environment, Climate Change and Water (DECCW)) to assess long-term shoreline change. Photographs used in this study are from 1963 to 2006.

Data was georeferenced by Frolich (2007) according to the guidelines outlined in Burrough and McDonnell (2005). Photographs were georeferenced in ArcGIS using approximately 20 control points per photo, with a root mean squared (RMS) below 10 m (a maximum of 30 m for 1:30000 scale photographs). Due to lack of quality and insufficient control points, the reliable aerial photographs were reduced to 9 years of surveys that were subsequently used in assessing morphological change of Shoal Bay (Frolich 2007). The aerial photographs used in this study of Shoal Bay are from 1963, 1977, 1986, 1991, 1994, 1996, 1999, 2001 and 2006 (Table 4.1).

4.2.2 Aerial Photograph Analysis: Digital Shoreline Analysis System (DSAS)

Trends in long term shoreline change of Shoal Bay were analysed using the Digital Shoreline Analysis System (DSAS) created by the United States Geological Survey (USGS), which integrates with ArcGIS software. Cross-shore transects were created using the DSAS toolbar in ArcGIS with a total of 51 transects every 50 metres used to calculate shoreline displacement (Figure 4.2). Each transect was required to cross all shoreline alongshore profiles to be included in the ensuing shoreline displacement calculation; as a result, some transects, including transects 1 and 2, could not be used. Shoreline displacement statistics were then averaged for each beach section. Outputs from DSAS shoreline calculations were \textit{shoreline change envelope} (greatest distance between all shorelines, Figure 4.3a), \textit{net shoreline displacement} (distance between the oldest and newest shorelines, Figure 4.3b) and \textit{end point rate} (rate of change in m yr\(^{-1}\), Figure 4.3c). Negative values are indicative of shoreline recession with positive results associated with shoreline accretion. Time series assessment of shoreline change for the entire beach and for each section was conducted by calculating the net shoreline displacement from the 1963 shoreline for each aerial photograph.
Net shoreline displacement was then normalised to allow for comparison between relative shoreline change. This enabled beach rotation between different sections of the beach to be assessed. Shoreline displacement for each section \((Vi(t))\) was normalised by the average displacement for that section \((Vi)\) divided by the square root of the variance in width \((\sigma_i)\).

\[
\vartheta_i(t) = \frac{Vi(t) - Vi}{\sqrt{\sigma_i}}
\]

Eq 4.1

Error associated with the shoreline analysis was derived by using the average slope of the beach \((\tan \beta = 0.12)\), where a 1 m variation in water level results in a cross-shore shoreline displacement of 8.3m, resulting in an error of ±7 m when taking into consideration the mean amplitude of spring tides (0.8 m). A similar result was obtained by Vila-Concejo et al. (2007b).

Table 4.1. Photographs used in assessing the long term shoreline change of Shoal Bay. Modified from Frolich (2007).

<table>
<thead>
<tr>
<th>Date</th>
<th>Scale</th>
<th>Area Covered</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>19630818_5399a;</td>
<td>16,000 ASL</td>
<td>Whole estuary</td>
<td>Black and white, some areas poor quality</td>
</tr>
<tr>
<td>19771111_1998</td>
<td>1:40,000</td>
<td>Shoal Bay</td>
<td>Start of colour record Fair quality</td>
</tr>
<tr>
<td>19860419_2743;</td>
<td>1:25,000</td>
<td>Whole estuary</td>
<td>Fair quality</td>
</tr>
<tr>
<td>19910823_4152</td>
<td>1:8,000</td>
<td>Shoal Bay</td>
<td>Good quality</td>
</tr>
<tr>
<td>19940622_0225</td>
<td>1:30,000</td>
<td>Whole estuary</td>
<td>Good quality</td>
</tr>
<tr>
<td>19961206_0214</td>
<td>1:8,000</td>
<td>Shoal Bay</td>
<td>Good quality</td>
</tr>
<tr>
<td>19990919_0155</td>
<td>1:30,000</td>
<td>Whole estuary</td>
<td>Good quality</td>
</tr>
<tr>
<td>20010914_0182</td>
<td>1:8,000</td>
<td>Shoal Bay</td>
<td>Good quality</td>
</tr>
<tr>
<td>20060421_0164</td>
<td>1:30,000</td>
<td>Whole estuary</td>
<td>Good quality</td>
</tr>
</tbody>
</table>
Figure 4.2. Shoreline transects and baseline used to calculate the shoreline displacement of Shoal Bay. Profile 1 is located on the western end of the beach with profile 51 in the easternmost point. The 2006 shoreline is shown in red.
Figure 4.3. Description of Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM) and End Point Rate (EPR) that are produced by the DSAS. Modified from (Thieler et al. 2009).
4.2.3 Wind data

Over 60 years of wind data were obtained from the Bureau of Meteorology weather station at the Williamtown RAAF base located near Stockton beach just south of Port Stephens. Average wind speed throughout the day was used to assess the occurrence of wind conditions that may affect the morphology of Shoal Bay shoreline. Previous studies conducted by Frolich (2007) concluded that only winds above 10 ms\(^{-1}\) have the potential to affect the nearshore hydrodynamics of the lower estuarine environment of Port Stephens. Therefore all wind data were filtered to remove wind speeds below 10 ms\(^{-1}\).

4.2.4 Historical Wave Data

Historical wave data was obtained from Manly Hydraulics Laboratory (MHL) for the Crowdy Head waverider buoy, 115 km north of the study site. Data included date, direction, significant wave height and the duration of the storm. MATLAB scripts (Appendix A) were used for computing total wave power for each storm by assessing offshore wave power through time for the duration of the storm (Vila-Concejo et al. 2009). Offshore wave height was calculated using standard linear wave theory.

4.3 Medium Term

4.3.1 Topographic Surveys

Semi-regular topographical surveys of Shoal Bay have occurred for over two years since May 2007 to June 2009. Surveying of the beach was conducted using a Trimble R8 RTK-GNSS receiver accurate to within 5mm-10mm depending on the survey type. A total of 11 surveys were conducted approximately every two months or when significant swell events occurred, except for the surveys in December 2008 that were 5 days apart, before and after some of the largest tidal ranges experienced on the Southeast Australian coast (2.1 m), similar to the large tidal events on the coast of NSW during January 2009. For most of the surveys, 23 cross-shore profiles (transects) were taken approximately every 100 metres (Figure 4.4).

Both high water mark and cross-shore transects were undertaken during beach surveys as well as alongshore transects in the western section of the beach surveying the beach
cusps (Table 4.2). Alongshore and high water surveys were conducted using a “continuous topo” method with the RTK-GNSS. Surveys were labelled according to year then month (yymm), for example May 2008 was 0805.

![Figure 4.4. Position of cross-shore beach profiles from 1-23 from west to east.](image)

<table>
<thead>
<tr>
<th>Date</th>
<th>Survey type</th>
<th>Survey equipment</th>
<th>File</th>
<th>Tidal Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/05/2008</td>
<td>Cross-shore and high water</td>
<td>RTK-GNSS</td>
<td>0805.csv</td>
<td>Neap (1.1 m)</td>
</tr>
<tr>
<td>20/07/2008</td>
<td>Cross-shore and high water</td>
<td>RTK-GNSS</td>
<td>0807.csv</td>
<td>Neap (1.4 m)</td>
</tr>
<tr>
<td>10/10/2008</td>
<td>Cross-shore and high water</td>
<td>RTK-GNSS</td>
<td>0810.csv</td>
<td>Neap (0.8 m)</td>
</tr>
<tr>
<td>13/12/2008</td>
<td>Cross-shore and alongshore profiles</td>
<td>RTK-GNSS</td>
<td>081213.csv</td>
<td>Spring (1.6 m)</td>
</tr>
<tr>
<td>18/12/2008</td>
<td>Cross-shore and alongshore profiles</td>
<td>RTK-GNSS</td>
<td>081218.csv</td>
<td>Spring (2 m)</td>
</tr>
<tr>
<td>20/03/2009</td>
<td>Cross-shore and alongshore profiles</td>
<td>RTK-GNSS</td>
<td>0903.csv</td>
<td>Neap (0.8 m)</td>
</tr>
<tr>
<td>07/05/2009</td>
<td>Cross-shore and alongshore profiles</td>
<td>RTK-GNSS</td>
<td>0905.csv</td>
<td>Neap (1.4 m)</td>
</tr>
</tbody>
</table>

### 4.3.2 Morphological Analysis

#### 4.3.2.1 Cross-Shore Transects

Transect data were collated in ArcGIS and subsequently analysed in MATLAB (Appendix A) calculating width, linear volume and slope for each survey, enabling a time series analysis of beach change. Beach linear volume (or cross-sectional area, m$^2$ or m$^3$/m) was calculated from an arbitrary point 10 m behind the origin of the first survey (dune scarp in 0805) with the cross shore and vertical extent defined by position where
the profile crosses 0 AHD (Australian Height Datum, where AHD $\approx$ MSL). Similarly, width for each transect was determined from the dune scarp to 0 AHD. Beach slope was calculated by determining the active beach slope, usually 1m above and 1m below the 0 AHD line. Total volumetric change for the entire beach and within each section was deduced by multiplying linear volume over the alongshore extent of beach for each section.

Beach rotation was assessed using the same normalisation methods as in Section 4.2.2 using equation 4.1. Instead of normalised shoreline displacement, width was used.

4.3.2.2 Beach Grid Analysis and Alongshore Surveys

Beach surface grids (or Digital Terrain Models (DTMs)) were produced in SURFER for surveys that included longshore transects taking into account beach cusp variations from December 2008 to May 2009. Grids were created with triangulation and linear interpolation between points using weighted averages of nearest neighbours, such interpretation uses an inverse weighting function to derive the value of a specific grid cell from the nearest point elevation value. The beach was sectioned into three areas (west, centre and east) and “blanked” to reduce the grid size and remove grid cells interpolated beyond the beach face (Figure 4.5). To assess the areas of erosion and accretion between surveys, grids of the previous survey were subtracted from the subsequent survey resulting in cells below zero representing erosion (red) and those above, accretion (blue). This was performed between each survey and also between the December 2008 and May 2009 surveys. Once grid comparisons between each area were produced collation of the three gridded sections was done using SURFER which presented the DTM for the entire beach.
4.3.3 Hourly Offshore Wave data

Offshore wave data from May 2008 to June 2009 was obtained from MHL/DECCW for the Crowdy Head wave rider buoy. Data included hourly wave statistics of significant wave height and wave period ($T_s$). Storm events could then be classified into their relevant categories as high frequency ($>3$ m), moderate ($3.5<H_s<5$ m), severe ($5<H_s<6$ m) and category X ($>6$ m) (NSWG 1990; Watson et al. 2007). This wave data were compared to the associated changes in beach morphology to infer the impact of storm events or winter swell on the beach.

4.3.4 Sediment Characterisation: Carbonate content and grain-size characteristics

Sediment samples were taken along the beach to determine alongshore trends in grain-size and carbonate content. A total of 26 samples were taken in the intertidal zone below the high water mark on the beach face (Figure 4.6). 10 samples were taken during the winter field campaign on July 22nd 2008, the rest were taken during the summer field campaign on the 15th and 16th of December 2008.
Sediment was washed with de-ionised water to remove traces of salt and then oven dried at 105°C. Dried sand was weighed out in approximately 100mg sub-samples with both water then Hydrochloric acid (4.0 mol) added to the samples dissolving the carbonate. Sediment was washed, dried and reweighed with the difference in weight between the CaCO₃-free sample and the total sediment resulting in the percentage weight of carbonate.

Laser particle analysis of sediment characteristics was performed using the Malvern Mastersizer 2000 particle analyser which is most accurate when analysing homogenous sand grain-size sediment. Large shell content was minimal and considered negligible in terms of potential effects on sediment transport, therefore CaCO₃-free sediment was used in the grainulometric analysis. Mastersizer uses Mie Theory and graphic laser diffraction techniques to compute grain size characteristics, comparing scattering induced by the sample to optical models. Grain-size, sorting and skewness were all obtained with trends assessed spatially in ArcGIS. Simple geostatistical analysis was performed to create an easily observable grid using similar methods as in section 4.3.2.2.

Figure 4.6 Spatial distribution of sediment samples from both summer and winter on the Shoal Bay beach face.

4.4 Short Term

4.4.1 Hydrodynamic Surveys

Surveys of nearshore hydrodynamic conditions (waves and currents) were conducted in winter and summer of 2008 to assess the modal low-energy hydrodynamic forcing on
Shoal Bay beach. Measurement of both waves and currents was achieved by using Pressure Transducers (PTs) and Acoustic Doppler Velocimeters (ADVs) respectively. The instruments were attached and configured on “pods” for ease of deployment (Figure 4.7). Three pods were assembled with a current meter attached to each one and self logging Aquistar PT2X pressure transducer on two pods. Current meters used in the fieldwork were two hard wired current metres (SonTek ADV Ocean Probe and Nortek Acoustic Doppler Velocimeter) and one self-logging (Falmouth Scientific, Inc. (FSI) 3D ACM). The SonTek and Nortek current meters recorded current velocities with a sampling frequency of 5Hz, which is then averaged for that second, with the FSI recording current velocities at 2Hz and averaging current velocities twice a minute (Table 4.3). ADVs were configured to measure currents no greater than 20 cm above the bed to sample wave orbital velocity affecting sediment transport as well as longshore and cross-shore currents. The PTs were attached to the pods at SB1 and SB3 and measured the frequency of water depth fluctuations, allowing analysis of wave height, period and tidal cycle to occur. PTs were positioned such as the water depth above them was less than 1 m to ensure pressure variations were accurately recorded, with deep water confounding pressure results of localised wind waves due to attenuation of energy.
Figure 4.7. Underwater photo showing pod configuration of the SonTek ADV, with the ADVOcean Probe in the blue circle and the Aquistar PT2X pressure transducer in the red circle (photo Austin, T.P. 2008).

Table 4.3. Sampling frequency and accuracy for the three ADV’s and PTs used for the hydrodynamic surveys. FSO refers to the Full Scale Output of the PT signal. That is, under 100 PSI the accuracy is within 0.06 PSI.

<table>
<thead>
<tr>
<th>ADV</th>
<th>Sampling Frequency</th>
<th>Velocity Accuracy</th>
<th>PT</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SonTek</td>
<td>5Hz</td>
<td>+/- 1% or 0.1cm/s</td>
<td>PT2X</td>
<td>0.06% FSO</td>
</tr>
<tr>
<td>Nortek</td>
<td>5Hz</td>
<td>+/- 0.5% or 0.1cm/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FSI</td>
<td>2Hz</td>
<td>+/- 2% or 1cm/s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pods were positioned in the Shoal Bay beach nearshore zone after the characteristically small to absent surf zone and steep shoreface of a reflective beach. ADV sensors were aligned parallel to the shore to enable cross-shore and longshore to be measured along the Cartesian xyz planes. Machined notches on the ADVs are located on the positive alongshore direction (x), which was always directed west during deployment. Movement of the pods was required periodically throughout deployment to accommodate for the tide cycles and resultant shifting breaker zone, ensuring accurate measurement of the nearshore hydrodynamics. Pod locations throughout the deployments were taken by a Trimble RTK-GNSS.

Three sites (SB1, SB2 and SB3) were selected to sample the varying hydrodynamic conditions along the embayment, with SB3 in the western section of the beach, SB1 sampling in the east and SB2 located between these two locations (Figure 4.8). The data obtained from SB1 and SB3 positions was deemed the most valuable in determining the varying nearshore current processes of Shoal Bay. Therefore, the hard wired Nortek and SonTek current meters were situated at SB1 and SB3 for both summer and winter field campaigns to ensure accurate and consistent hydrodynamic measurement with constant supervision during deployment. Current velocities could be observed in real time as well as correlation of the sampled data (100% correlation indicates unobstructed water flow). Correlation below 50% is indicative of inaccurate sampling, with the current meters checked for obstructions (e.g. seaweed) if this occurred. Current data for the Nortek and SonTek ADV’s was recorded in 15 minute intervals on every half hour to gain representative current velocities during a tidal cycle. Station notebooks for the SonTek and Nortek pods as well as personal field notebooks were utilised during deployment to record field observations (such as periods of poor correlation in the current data) as well as climate and hydrodynamic conditions.
4.4.2 Pod configurations and deployment

Pod deployments would ideally survey the hydrodynamic conditions for the full tide cycle to account for wind, wave and tidal forcing in different tidal stages. However, during the winter field campaign limited daylight hours reduced surveys to approximately 9-10 hours, which while not surveying the entire cycle is still adequate in assessing the dominant hydrodynamic forcing mechanisms.

The winter field campaign was conducted over three days from 22/07/08-24/07/08 during a neap tidal range of approximately 1m. Nortek and SonTek pods were deployed at SB1 and SB3 respectively. Pods were recording usually between 7:00 am to 4:30pm. You need to say where was deployed each and the file structure.

Deployments during summer occurred over 4 days 13/12/08-14/12/08 and 16/12/08-17/12/08 during 2m spring tidal ranges. Extended daylight hours allowed for hydrodynamics to be sampled for 13 hours over the full tide cycle from 6:30am to 7:30pm on most days. Additional deployment of the self logging FSI pod at SB2 occurred on three of the 4 days of surveying (13th, 14th and 16th of December); however some of the data was unusable due to occasional poor position within the nearshore zone as a result of irregular supervision.
4.4.3 Modal Conditions

Offshore wave heights during the survey period were compared to two years of offshore wave heights (from March 2007 to June 2009) to determine if the hydrodynamic surveys were conducted under the modal conditions $H_s$ ranges that occur at or above 50% are considered modal. Other considerations included wind and tidal data, the most significant of which were the extremely large 2 metre tides during the summer deployment.

4.4.4 Hydrodynamic Analysis

Correlation values for the SonTek and Nortek current data were used to remove erroneous measurements, replacing them with averaged values from data points adjacent to the removed sections. Data was removed if correlation fell below 50%, however during deployments correlation was relatively good with only minimal removal of current data required. The FSI ADV does not record correlation; as a result identification of poor quality data was attributed to large uncharacteristic fluctuations in current, which were subsequently removed.

4.4.5 Sediment Entrainment

To determine the ability of the surveyed currents to entrain sediment wave orbital velocity as well as Shields’ parameter equations were used. Currents were measured at less than 20 cm from the bed and they were carefully oriented such as one axis was perpendicular to the incoming waves; thus it can be assumed that the oscillatory measurements that were taken in the across-shore direction correspond to the waves orbital velocities that cause sediment entrainment. Peak near bed orbital velocity ($U_w$, ms$^{-1}$) and its associated frequency ($F$) ($H_s$) were used in Equations 4.2, 4.3 and 4.4 to determine the orbital velocity ($A$) (ms$^{-1}$, Eq. 4.2), relative roughness ($r$, Eq. 4.3) and wave friction factor ($f_w$, Eq. 4.4);

\[
A = \frac{U_w F}{2\pi} \quad \text{Eq. 4.2}
\]

\[
r = \frac{A}{k_s} \quad \text{Eq. 4.3}
\]

\[
f_w = 0.237r^{-0.52} \quad \text{Eq. 4.4}
\]
where, \( k_s \) is Nikuradse roughness length (2.5×\( D_{50} \)) and \( D_{50} \) is the mean grain size.

Critical shear stress (\( \tau_{cr} \), Eq. 4.7) and velocity amplitude (\( U_{cr} \), Eq. 4.8) (ms\(^{-1}\)) were then determined using Equations 4.5, 4.6, 4.7 and 4.8:

\[
D_* = D_{50} \left[ \frac{g(s-1)}{(u^2)^{3}} \right] \quad \text{Eq. 4.5}
\]

\[
\theta_{cr} = \left[ \frac{0.30}{1+1.2D_*} \right] + 0.055[1 - \exp(-0.02D_*)] \quad \text{Eq. 4.6}
\]

\[
\tau_{cr} = \theta_{cr} g(\rho - \rho_s)D_{50} \quad \text{Eq. 4.7}
\]

\[
U_{cr} = \frac{2\tau_{cr}}{\rho_{fw}} \quad \text{Eq. 4.8}
\]

where \( \rho \) is water density (1027 kg/m\(^3\)), \( \rho_s \) is the sediment density (2650 kg/m\(^3\)), \( s \) is ratio of sediment to water density (\( \rho_s / \rho \)), \( g \) is the gravitational acceleration (9.8 ms\(^{-2}\)) and \( u \) is the kinematic viscosity of water (1.1×10\(^{-6}\) m\(^2\) s\(^{-1}\)).

Currents exceeding the velocity amplitude were deemed capable of entraining sediment. The percentage of entrainment \( (E) \) was computed using Eq. 4.9 and represents how often the surveyed nearshore currents have the theoretical capability to entrain sediment from the bed.

\[
E = \left( \frac{C_f}{C} \right) \times 100 \quad \text{Eq. 4.9}
\]

where, \( C_f \) is the duration for which the sampled nearshore currents were above \( U_{cr} \); and \( C \) is the total duration of the deployment.

### 4.4.6 Residuals: Current and Percentage of Entrainment

Residual current velocities were averaged over the 15 minute runs to determine the dominant direction of the longshore current velocity. Direction of net residual flow in the alongshore direction was determined by a non-dimensional residual scaling factor \( R_f \) (Eq. 4.10) modified from Austin et al. (2009)

\[
R_f = (d_w \times v_w) - (d_e \times v_e) \quad \text{Eq. 4.10}
\]
where, \( d_w \) and \( d_e \) are the duration of currents in the west and east directions respectively and \( v_w \) and \( v_e \) the longshore velocity towards the west and east.

A similar approach was taken in determining the direction of current flow producing the most entrainment. \( E_f \) (Eq. 4.11) was derived by using the nearshore current residuals towards the east and the west and their associated values of \( E \) where

\[
E_f = (d_w \times E_w) - (d_e \times E_e) \quad \text{Eq. 4.11}
\]

\( E_w \) corresponds to the average values of \( E \) associated with westward residual currents and \( E_e \) with eastwards. Values obtained from residual scaling factors only suggest dominant direction of current and entrainment and are therefore useful as a comparative tool but with no real value attached to the subsequent results. Larger values do not necessarily suggest stronger hydrodynamic forcing but dominance in either the east or west direction.

### 4.4.7 Pressure Data

MATLAB scripts developed by Power (2007) were used to process the pressure data (Appendix A) deriving wave height, period and water depth throughout the deployment. Pressure data was split into 15 minute intervals to correlate with the associated 15 minute surveyed current. Tidal stationarity was assumed during these 15 minute runs allowing for a zero down-crossing analysis to be performed (Figure 4.9). Pressure sensor data was filtered in two-stages. The data was firstly low-pass impulse response filtered to remove instrument noise. The second step included a high-pass moving average filter to isolate short waves (gravity and wind). The frequency spectrum for the wave data was calculated to allow for a cut-off frequency chosen at the location of the spectral valley between long and short waves. If differentiation between long and short waves could not be easily discerned a frequency of 0.075Hz was selected (Figure 4.10). The length \( f_L \) of the high-pass filter was defined by:

\[
f_L = f_c^{-1} f_s \quad \text{Eq. 4.12}
\]

where, \( f_c \) is the cut-off frequency and \( f_s \) is the sampling frequency.

Wave statistics \( (H_s \text{ and } T_z) \) as well as water depth \( (h) \) were calculated off the filtered wave record. Depth of PT in relation to the bed was recorded, however with each pod
movement recalibration of the water depth using RTK-GNSS survey points was necessary to accurately record the tidal cycle.

Figure 4.9. Time series of zero down-crossing analysis performed from 15 minute pressure transducer data, with tidal stationarity assumed. Time on the x-axis and surface elevation on the y-axis.

Figure 4.10 Wave frequency spectra from SB3 on the 16/12/08. Cut off frequency shown in red. Frequency (Hz) on the x-axis and spectral density (m²s) on the y-axis. Smoothed frequency of figure b) is used to accent spectral valley where it is not obvious in figure a).
4.5 Summary

A total of 174 hours of ADV and PT data, over 161 cross-shore transects from one year of beach surveys, 9 beach grids, 9 aerial photos over four decades, 26 sediment samples, 60 years of wind data, one year of hourly offshore wave heights and 20 years of historical storm data were collected and used to assess the long term change of Shoal Bay. The breadth of spatial and temporal data used in the long term morphodynamic assessment of Shoal Bay exceeds the majority of quantitative process based studies of beach change. For estuarine beaches such an assessment is relatively novel. This collection of data allows for future research into small scale hydrodynamic forcing of Shoal Bay beyond the large scale holistic nature of this study.
5. Results

5.1 Introduction

The results presented herein are obtained from the multi-scale analysis of the Shoal Bay data sets outlined in Chapter 4. Resolution of the data varies spatially and temporally and is at its most coarse in the long term and finest in the short to medium. As a result, data sets at higher resolutions are used to describe the processes driving morphological change and larger scales to derive long term trends.

5.2 Long Term: Shoreline Evolution of Shoal Bay

Shoreline analysis from 43 years of aerial photography (Appendix B) was successful in determining the long term shoreline trends of Shoal Bay. However, the evolution of the shoreline has not been comparable in every section of the beach. Analysis of long term shoreline change is conducted for each section with the most significant results then summarised.

5.2.1 Beach Section Analysis

Section 1

Section 1, the western most section of the beach, receded 22 m between 1963 to 2006, at a rate of 0.52 myr\(^{-1}\). It followed the average trend of three periods of extensive shoreline recession between 1963-77, 1994-96 and 1999-2006 (Figure 5.1a). Trends of shoreline accretion occurred during 1977-91 and 1996-1999 however they are not sufficient to mitigate the overall trend of recession.

Section 2

Section 2 undergoes the largest recession over 4 decades, with the shoreline receding approximately 32 m behind the 1963 position at a rate of 0.76 myr\(^{-1}\) (Figure 5.1b). It followed the same erosion and accretion periods observed in Section 1. However, shoreline retreat between 1963-77 and the 1999-2006 were larger than the accretion periods and thus, the overall trend for Section 2 was shoreline recession.
**Section 3**

The overall shoreline evolution in Section 3 is dominated by the recession that occurred in 1963-77 which caused 24 m of erosion at 1.7 myr^{-1} (Figure 5.1c). The 1977 shoreline remained static until 1986, and since then some smaller episodes of accretion and erosion have occurred (Figure 5.1c) that have resulted in approximately 20 of recession (0.48 myr^{-1}).

**Section 4**

Unlike other sections of the beach, Section 4 underwent accretion between 1963 and 1986, which resulted in approximately 5 m of shoreline progradation (Figure 5.1d). Erosion occurred twice between 1986-91 and 1994-99 and accretion occurred in all other periods. Resultant net shoreline displacement was -9 m from 1963 at -0.22 myr^{-1}. The opposite trends obtained in sectors 2, 3 and 4 shows that beach rotation processes are important in Shoal Bay (Figure 5.2)

**Section 5**

Total recession in Section 5 was 26 metres (0.61 myr^{-1}). The maximum recession was reached in 2001, 30 metres behind the 1963 shoreline (Figure 5.1e). Periods of stability occurred in this section between 1986-94 and 1996-2001.

**Section 6**

Continuous recession occurred from 1963-1991 in Section 6 without the periods of accretion found in the western sections of the beach (Figure 5.1f). This resulted in 25 m of recession at just under 1 myr^{-1}. After a period of accretion between 1991 and 1994, the 1994-96 period incurred 14 m of erosion at 4.6 myr^{-1} resulting in a shoreline almost 35 m behind the 1963 shoreline. Since then, accretion occurred to the 2006 position approximately 24 m behind the 1963 shoreline.
Figure 5.1. Time series of shoreline displacement from section 1 to section 6 (a-f respectively).
Figure 5.2. Comparison of non-dimensional normalised shoreline displacement between section 2-4 and sections 3-4 (a and b respectively). Shoreline rotation represented between sections 2-3 and section 4.
5.2.2 Summary of Shoreline Recession

Analysis of shoreline change from four decades of aerial photography showed an erosive trend along the entire length of Shoal Bay. Each section of the beach receded from the initial shoreline of 1963, however the extent of shoreline recession varies within the embayment (Figure 5.3). The most extensive recession occurred in Sections 1-2 and 5-6, with smaller amounts of shoreline recession observed in the centre sections of the beach (3-4).

Shoreline displacement occurred at a rate of \(-0.52 \text{ myr}^{-1}\) for the last 43 years causing approximately 22 m of shoreline recession (Figure 5.4). A section of the beach 200 m long disappeared with the seawall maintaining the location of the shoreline since at least 1986 (Figure 5.5). Maximum average shoreline displacement was 24 m behind the 1963 shoreline in 1996, the majority of this occurring between 1963 and 1977, the rest taking place during 1994-96 and 2001-06 after a period of stability with small amounts of accretion between 1977-94 (Figure 5.4). The largest rates of recession are found between 1994 and 1996 with rate of shoreline change approximately \(-3.8 \text{ myr}^{-1}\). During this period the shoreline receded on average 9.3 m in 2.5 years (Figure 5.4).

![Figure 5.3. Net shoreline displacement from the 1963 shoreline in the aerial photographs for each beach section. The red plot is the 2006 shoreline.](image)
Figure 5.4. Average shoreline displacement from 1963-2006 for Shoal Bay.

Figure 5.5. Shoal Bay shoreline evolution with the 1963 shoreline in red and the 2006 in black. The blue rectangle indicates the 200m loss of beach in front of the seawall.
5.2.3 Forcing mechanisms: Decadal Evolution

The historic storm data from Crowdy Head show clustering of storms between 1985 and 1991 are found in the historic storm data followed by a period of little storm activity that extends to the mid 1990s. Storm events increase again in 1995, 1999 and 2002 however when compared to the late 1980’s the period from 1991 to 2006 was relatively calm (Figure 5.6).

The strongest winds are from the southeast during summer and west during winter, with westerly winds incurring the highest speeds (Figure B.1, Appendix B). Filtered wind data indicates a period of strong wind activity between 1950-60 and again between the mid 1980s to the mid 1990s (Figure 5.7). Some grouping of high wind speeds occurs in the late 1960s and 1970s as well, but mostly lower energy conditions have occurred for the remainder of the time. Wind speeds above 10 ms$^{-1}$ only occur approximately 2% of the time during 60 years of daily records.

![Figure 5.6. Storm waves between 1985 and 2005. Upper panel shows total wave power. Lower panel shows wave direction. Vertical lines correspond to dates of aerial photos used in this study (modified from Vila-Concejo et al. (2009b)).](image)
5.4 Medium Term: Morphological Change of Shoal Bay

Short term morphological change was observed in the beach surveys undertaken between May 2008 to May 2009. As was expected medium term morphological surveys showed much larger beach fluctuations then in the long term shoreline analysis. Analysis of beach change between each section is conducted with the most significant beach change then summarised.

5.4.1 Beach Section Analysis

Section 1

Significant erosion and shoreline recession occurred between May and July 2008 (-4500 m$^3$) followed by accretion between July 2008 and March 2009 (+ 3500 m$^3$) (Figure 5.8a). Recession of the shoreline was not observed between March/May 2009; overall,
the shoreline prograded approximately 1.5 metres over a year from May 2008 to May 2009 (Figure 5.8a).

**Section 2**

Section 2 behaved similarly to Section 1 increasing its width but decreasing its volume. The beach underwent a general trend of increasing width over the year with only one period of recession between December 18th 2008 and March 2009. Volumetric changes on the beach face were slightly different to Section 1 with accretion from July 2008 to the 13th of December after a period of little change between May and July 2008 (Figure 5.8b). Erosion occurred from December 18th to May 2009 with 1500m³ lost between May 2008 and May 2009.

**Section 3**

Section 3 responds differently to the western sections of the beach with accretion occurring during winter (May 2008-Oct 2008 and 13th December 2008-May 2009) and erosion during summer (Oct 2008 – 13th December 2008) (Figure 5.8c). The changes occurred over 5 days between the 13th and 18th of December 2008, which seem to be related to the large tidal ranges experienced between these surveys (section 5.5.2).

**Section 4**

Unlike the western sections, width and volume are closely correlated in Section 4. It reduces its volume and width with only minor slope variations over the survey period. After a period of little change between May to October 2008 significant erosion occurred between October and December 13th 2008 as well as December 18th to May 2009 (Figure 5.8d). The annual loss of sediment was 2600m³ with shoreline recession of 4.8 m.

**Section 5**

Similarly to Section 4, width and area are correlated in Section 5. A trend of accretion between May to October 2008 was found and erosion observed for the rest of the surveys, with the exception of the surveys from December 13th to 18th which showed
accretion (Figure 5.8e). A total loss of around 700m$^3$ of sediment occurred between May 2008 and May 2009.

Section 6

Section 6 changed almost antithetically to the rest of the beach accreting slightly between May 2008 and May 2009 (Figure 5.8f). Two events of accretion and subsequent erosion occurred over the survey period with May-July 2008 showing accretion and July/Oct 2008 subsequently eroding a portion of this sediment (Figure 5.8f). Similarly from December 2008 to March 2009 accretion occurred with March-May 2009 showing some erosion. Fluctuations in this section were only minor when compared to the rest of the beach with change in profile area within 1 m$^2$. 
Figure 5.8. Time series analysis of beach statistic change for each beach section. From top left to bottom right, volume, area, width, slope. a) represents section 1 and b) section 2
c) 

![Graphs showing c) section 3 and d) section 5.](image)

Figure 5.8. continued with c) section 3 and d) section 5.
Figure 5.8. continued with e) section 5 and f) section 6.
5.4.2 Summary of Morphological Change

Shoal Bay underwent substantial erosion between May 2008 and May 2009 with approximately 10000 m$^3$ of sediment lost from the beach (Figure 5.9a). This erosive trend is correlated with an average shoreline recession of almost 1 m and a loss of linear volume (area) of 4.3 m$^3$/m; however beach slope remained relatively similar (Figure 5.9b-d). There are three significant periods of beach change over the study period. Between July and Oct 2008 accretion occurred along the beach which was subsequently eroded back to the previous shoreline between Oct and Dec 2008. The most significant erosion occurred between March and May 2009 with the majority of the 10,000 m$^3$ erosion occurring between these surveys.

Figure 5.9. Time series of a) beach volume (thousands of m$^3$); b) area; c) width; and d) slope ($\tan \beta$) between surveys from May 2008 to May 2009.

Typical summer and winter profiles were found in the western areas of the beach with flatter beaches and pronounced erosion scarps during winter events and steep profiles during summer (Figure 5.10a). Parallel recession was observed in the centre of the beach without much change to the profile shape (Figure 5.10b) and little change to the steep beach face and low tide terrace in the east (Figure 5.10c).
Shoreline recession was most pronounced in the centre of the beach (Sections 3-5) with the west prograding (Sections 1 and 2) and the east (Section 6) undergoing little change (Figure 5.11). Average shoreline rate of change was -1 myr⁻¹ with the largest recession in Section 4 at almost -5 myr⁻¹ and the maximum progradation in Section 2 at 2 myr⁻¹. Similarly, the most significant section of erosion was Section 4 losing over 13m² in cross sectional area or approximately 4500m³ in volume. The rest of the beach lost between 2-4 m³/m of area over the survey period, except for Section 6 which exhibited small accretion of almost 1 m³/m (Figure 5.12).

Rotation between Sections 1-2 and 3-5 occurred with the east receding and the west accumulating sediment (Figure 5.13). This is particularly evident between Oct 2008 and 13th Dec 2008 (Figure 5.13). The converse occurred between May and July 2008 with Sections 1-2 eroding and Sections 3-5 accreting (3-5).

However, severe storms between March-May 2009 incited a analogous morphological response in all beach sections with approximately 4500m³ of erosion Section 1 alone (Figure 5.13a). A total of 23m³/m was lost in linear volume across the entire beach, resulting in over 10,000 m³ of sediment eroded (Figures 5.8a and b). Only Section 3 showed a small amount of accretion during this time.

During surveys in December 2008 the entire beach became flatter and wider with Sections 1-3 losing approximately 2000m³ of sediment with the rest of the beach accruing 1100m³ (Figure 5.13). This shoreline change occurred over five days.
Figure 5.10. Examples of beach profile response with a) (profile 7) in the western sections (section 2) of the beach with flatter beaches and erosion scarps during winter and steep profiles during summer; b) Parallel recession in beach profile response (profile 15) in the centre of the beach; c) Example profile from section 1 in the east exhibiting steep beach profile and low tide terrace, with little profile change over time.
Figure 5.11. Rate of shoreline change over a year from May 2008 to May 2009.

Figure 5.12. Loss of volume in each beach section from 1963 to 2006.
Digital Terrain Models

Comparisons of the DTMs between December 13th 2008 to May 2009 showed erosion in the central/eastern areas of the beach with the only areas of accretion in the west (Figure 5.14). Between the December surveys, erosion on the lower beach face and accretion on the upper beach face occurred in the west and minor erosion for the rest of the beach (Figure 5.15a). Erosion in the east and accretion in the west occurred in the period between December 2008 and March 2009 (Figure 5.15b), with erosion along the entire beach observed in the last grid comparison of March and May 2009 (Figure 5.15c).

**Figure 5.13.** Example of shoreline rotation using normalised width between sections 1 and 4 from the years worth of beach surveys.

5.4.3 Digital Terrain Models
Figure 5.14. DTM comparison between 0905 and 081213 with red indicating erosion and blue accretion. Scale indicates elevation change in metres.
Figure 5.15. DTM comparisons between surveys a) 081213-081218, b) 0903-081218 and c) 0905-0903.
5.4.4 Forcing Mechanisms: Monthly Evolution

Analysis of the of hourly wave data from the Crowdy Head wave rider buoy indicates that a number of storm events occurred during the study period. One severe storm as well as a category X storm (extreme storm) occurred between March to May 2009 (Figure 5.16)(NSWG 1990; Watson et al. 2007). Moderate storms occurred between May and October 2008 with high-frequency low-energy storms dispersed throughout the rest of the wave record.

![Figure 5.16. Hourly wave data from Crowdy Head with significant wave height in the top panel and significant wave period at the bottom. Red lines indicate beach surveys.](image)

5.5 Short Term: Hydrodynamic Forcing

5.5.1 Wind and Wave data

Wave heights were characteristically small for the low-energy setting of Shoal Bay. However, differences in wave height were observed between summer and winter deployments. Much larger significant wave heights with longer wave periods occurred throughout the winter deployment when compared to summer wave conditions (Table 5.2). Swell waves were most obvious at SB3 with much higher significant wave heights that SB1. However, wave periods were generally larger at SB1 when compared to SB3.
Both summer and winter surveys were performed under calm wind conditions with the exception of the afternoon of the 14th December survey where $Rf$ and $Ef$ values towards the east at SB3 were observed (Appendix B).

5.5.2 Winter Deployments

5.5.2.1 July 22nd

Tidal range on 22/07/08 was 1.4 m which is 0.2m below average. Westerly winds between 5-7 ms$^{-1}$ occurred throughout the day with $Rf$ values trending eastwards at both stations (Table 5.2a). Significant wave height and period increased in the afternoon at SB3 from approximately 0.3 to 0.7 m and 10 to 13 s respectively (Figure B.2, Appendix B). SB1 incurs relatively constant wave conditions with $H_s$ about 0.25 m and $T_z$ 11 s.

Only high tide slack water, flood and ebb tides were surveyed with high tide producing the large residuals towards the east. $Rf$ results may be somewhat skewed towards the east without surveying low tide slack water which typically incurred westward trending residuals during winter. $Ef$ results showed eastwards directed sediment transport at SB3 with no strong trend at SB1 (Table 5.2a).

5.5.2.2 July 23rd

Wind speeds at around 5ms$^{-1}$ from W-SW occur throughout the deployment. Average $H_s$ remained similar to the conditions at the end of July 22, at around 0.6 m with a $T_z$ of 10 s at SB3 and at SB1 a significant wave height of 0.4 m and wave period of 12 s (Figure B.2, Appendix B). Tidal range was 1.3 metres with only high, flood and ebb tide stages surveyed. In spite of this, strong westward trending $Rf$ values were found throughout the day, dissimilar to the previous days deployment (Table 5.2a). Entrainment residuals follow the trends observed in the $Rf$ results, exhibiting westward sediment transport.

5.5.2.3 July 24th

All tidal stages were surveyed for at least half of their period (approximately 1.5 hours) during the July 24th deployment. Tidal range was 1.1 m and wind conditions were calm (<5ms$^{-1}$). $H_s$ at SB3 was 0.6 m with a $T_z$ of 9 s, SB1 incurred significant wave heights of 0.3 m and $T_z$ of approximately 10 s (Figure B.2, Appendix B). $Rf$ values towards the west
were observed at SB3 and east for SB1. Entrainment values showed westward directed transport at both SB1 and SB3. While the SB1 $Ef$ values suggested an opposing direction of sediment transport to the dominant longshore current, this trend is relatively minor (Table 5.2a).

5.5.3 Summer Deployments

5.5.3.1 December 13th

Calm conditions occurred at the start of the day with winds increasing in speed in the afternoon reaching over 10ms$^{-1}$ from the west. Significant wave heights were relatively consistent during deployment, with an average $H_s$ of 0.2 m and wave periods of 8 s at SB1 and average significant wave heights of 0.55 m at wave periods of 7.5 s at SB3 (Figure B.2, Appendix B).

Residual longshore currents trend towards the west at both stations with a spring tidal range close to meso-tidal conditions at 2 m. $Ef$ values indicated minor eastwards sediment transport at SB1 and towards the west at SB3 (Table 5.2b).

FSI ADV current data from SB2 were obtained between 7:45 to 12:30, with the residual current data indicating trends towards the west (Figure B.3a, Appendix B).

5.5.3.2 December 14th

$Rf$ results during the 14th trend differently to the rest of the summer deployments with trends towards the east at SB3 and towards the west at SB1. Such trends are associated with strong winds that occurred throughout the day with westerlies between 10-15ms$^{-1}$. Tides are meso-tidal conditions with a 2.1 m tidal range, which is larger than the theoretical maximum for the micro-tidal southeast Australian coast. Wave conditions were slightly less energetic then the previous with significant wave heights of 0.13 m and an average wave period of 8.7 s found at SB1 and significant wave heights of 0.24 m with a $T_z$ of 8.8 s at SB3.

SB3 were a result of the strong easterly trends during high tide slack water (Figure B.2e, Appendix B). $Ef$ values showed opposite trends to the residual current results with minor westward trends at SB3 and to the east at SB1 (Table 5.2b).
Westward currents were recorded on SB2 from 7:45 to 14:00 and 19:15 to 19:45 (Figure B.3b, Appendix B).

5.5.3.3 December 16\textsuperscript{th}

Winds returned to calm conditions below 5ms\textsuperscript{-1} and remained for the rest of the summer deployments. Significant wave heights were on average 0.4 m and wave period was 8.3 s at SB3 and 0.15 m and 9.2 s at SB1 (Figure B.2, Appendix B). Tidal range was 1.8 m and incurred $R_f$ values towards the west at SB3 and east in SB1. Entrainment residuals showed similar trends with only minor transport towards the east at SB1 (Table 5.2b).

Westward currents occurred on SB2 from 6:45 to 19:30; the intensity of the currents and in strength during the ebbing tide (Figure B.3c, Appendix B).

5.5.3.4 December 17\textsuperscript{th}

Tide range during the 17\textsuperscript{th} was 1.8 m with wind conditions calm around 5ms\textsuperscript{-1} changing from W in the morning to N-NE in the afternoon. Nearshore wave climate incurred $H_s$ of 0.13 m and $T_c$ of 9 s at SB1 and 0.3 m and 8.2 s at SB3 similar to the 16\textsuperscript{th}. SB3 $R_f$ results showed a westerly trend with SB1 indicating no net longshore current over the tide cycle. Entrainment residuals incurred a similar result with strong westward trends at SB3 and no discernable trend at SB1 (Table 5.2b).

5.5.4 Summary of Hydrodynamic Deployments

Modal conditions were generally observed throughout the surveys however offshore wave heights indicate low-energy storm conditions during winter surveys and the 2 m meso-tidal ranges during summer surveys generated stronger tidal velocities than what would be sampled under average tidal ranges.

The average longshore residual currents during deployment were generally from east to west at both stations during summer and winter conditions, this trend was driven by strong ebb-tide flows particularly in meso-tidal summer conditions. However, some deployments showed eastward residual currents at both SB1 (22/07/08, 24/07/08, 16/12/08) and SB3 (22/07/08, 12/14/08) (Table 5.2). Summer deployments incurred stronger currents then winter surveys in both east and west sections of the embayment.
However, direction of current flow at different stages throughout deployment changed between summer and winter. Flood tides showed westward trends at both stations during winter but only SB3 showed westward residuals during winter with SB1 showing eastward trending currents (Figure B.2, Appendix B). Similarly, ebb tides incurred large residual currents towards the west at both stations during summer, however during winter westward trends are only observed at SB3 with SB1 incurring eastwards residuals. High tides often surveyed strong currents towards the east at SB3 and westward at SB1 and low tides westward trends at SB3 and eastwards at SB1 (Figure B.2, Appendix B).

Reduced deployments (9-10 hours) during winter only surveyed three of the tidal stages in most instances (ebb, flood, low and high), resulting in residual flows that can potentially misrepresent the average current direction. Particularly if the deployments are skewed towards sections of the tidal cycle that often trend in a longshore direction, for example, high tide which trends eastwards.

Modal conditions were generally observed throughout the surveys however offshore wave heights indicate low-energy storm conditions during winter surveys and the 2m metre “king tides” during summer surveys generated stronger tidal velocities than what would be sampled under average tidal ranges.
Table 5.2. Average statistics of the hydrodynamic forcing mechanisms, sediment entrainment and residual scaling factors over summer (a) and winter (b) hydrodynamic surveys. Positive values in the $Rf$ and $Ef$ results indicate a westward trending residual and negative eastwards.

### a)

<table>
<thead>
<tr>
<th>Date</th>
<th>Pod</th>
<th>Wave Hs (m)</th>
<th>Tz (sec)</th>
<th>Wave Average Speed (m/s)</th>
<th>Wind Max Wind Speed Dir (°/WSNE)</th>
<th>Tide Range (m)</th>
<th>Ucr (%)</th>
<th>Rf</th>
<th>Ef</th>
</tr>
</thead>
<tbody>
<tr>
<td>22/07/2008</td>
<td>SB1</td>
<td>0.24</td>
<td>11.30</td>
<td>5.33</td>
<td>203/SW</td>
<td>1.4</td>
<td>0.93</td>
<td>-1.42</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.44</td>
<td>10.66</td>
<td></td>
<td></td>
<td>67.39</td>
<td></td>
<td>-2.76</td>
<td>-2.95</td>
</tr>
<tr>
<td>23/07/2008</td>
<td>SB1</td>
<td>0.40</td>
<td>12.10</td>
<td>3.44</td>
<td>190/S</td>
<td>1.3</td>
<td>8.74</td>
<td>1.49</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.62</td>
<td>10.40</td>
<td></td>
<td></td>
<td>66.38</td>
<td></td>
<td>5.75</td>
<td>6.05</td>
</tr>
<tr>
<td>24/07/2008</td>
<td>SB1</td>
<td>0.29</td>
<td>9.82</td>
<td>3.84</td>
<td>141/SE</td>
<td>1.1</td>
<td>4.21</td>
<td>-0.35</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.60</td>
<td>8.96</td>
<td></td>
<td></td>
<td>75.20</td>
<td></td>
<td>3.54</td>
<td>3.98</td>
</tr>
</tbody>
</table>

### b)

<table>
<thead>
<tr>
<th>Date</th>
<th>Pod</th>
<th>Wave Hs (m)</th>
<th>Tz (sec)</th>
<th>Wave Average Speed (m/s)</th>
<th>Wind Max Wind Speed Dir (°/WSNE)</th>
<th>Tide Range (m)</th>
<th>Ucr (%)</th>
<th>Rf</th>
<th>Ef</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/12/2008</td>
<td>SB1</td>
<td>0.20</td>
<td>7.86</td>
<td>6.6815</td>
<td>307/WNW</td>
<td>2</td>
<td>25.90</td>
<td>2.10</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.57</td>
<td>7.52</td>
<td></td>
<td></td>
<td>71.40</td>
<td></td>
<td>4.02</td>
<td>2.40</td>
</tr>
<tr>
<td>14/12/2008</td>
<td>SB1</td>
<td>0.13</td>
<td>8.71</td>
<td>10.241</td>
<td>287/WNW</td>
<td>2.1</td>
<td>8.48</td>
<td>2.48</td>
<td>-1.50</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.24</td>
<td>8.84</td>
<td></td>
<td></td>
<td>42.42</td>
<td></td>
<td>-3.59</td>
<td>0.14</td>
</tr>
<tr>
<td>16/12/2008</td>
<td>SB1</td>
<td>0.15</td>
<td>9.22</td>
<td>2.6635</td>
<td>317/WNW</td>
<td>1.8</td>
<td>2.38</td>
<td>-0.06</td>
<td>-0.16</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.39</td>
<td>8.28</td>
<td></td>
<td></td>
<td>75.40</td>
<td></td>
<td>3.00</td>
<td>6.15</td>
</tr>
<tr>
<td>17/12/2008</td>
<td>SB1</td>
<td>0.13</td>
<td>8.95</td>
<td>3.8395</td>
<td>108/SE</td>
<td>1.7</td>
<td>0.97</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.29</td>
<td>8.21</td>
<td></td>
<td></td>
<td>59.05</td>
<td></td>
<td>5.51</td>
<td>5.20</td>
</tr>
</tbody>
</table>

5.6 Sediment Characterisation

Geo-statistical analysis of the sediment spatially orientated trends within the two sampled data sets. It showed conspicuous concentrations in sediment characteristics on the beach face of Shoal Bay. Grain-size distribution varied along Shoal Bay with fine sediment found in lee of Tomaree Head, coarsening towards the west with the largest grain-sizes found in the eastern extremities of the beach near Nelson Head (Figure 5.17a). Sediment was well sorted with near symmetrical skewness. Variations in these values were minimal and any discerning trend was not apparent. Carbonate content from both summer and winter collections was at its most concentrated in the easternmost region of the beach and diminishing towards the west (Figure 5.17b).
Figure 5.17. Spatial distribution of sediment characteristics with a) grain size (μm) and b) carbonate content (%)
6. Discussion

6.1 Introduction

This study integrates three distinct scales. The aims within this thesis were to assess the holistic morphodynamics of a low-energy embayed beach in a complex sediment sharing environment. Sections 6.2 and 6.3 discuss the forcing mechanisms of shoreline change with Sections 6.4 and 6.5, relating these processes to long term shoreline evolution. Section 6.6 links together the most significant outcomes of all three scales. The limitations of this study and for future research are presented in Section 6.7.

6.2 Short Term Forcing Mechanisms

Hydrodynamic conditions during summer and winter deployments show a number of differences. Tidal ranges during winter deployments were between 1 to 1.5 m (neap tides). The maximum tidal range for the NSW coast was surveyed during summer with 1.8 to 2 m spring tide ranges. December 14th was outside this range with 2.1 m tides, larger than the theoretical maximum for the NSW coast. Wave conditions were much more energetic during winter and also in the western areas of the beach, with SB3 surveying much larger wave heights than SB1. Smaller longshore currents during winter are associated with neap tides and more energetic wave conditions (Appendix B; Section 5.5). This appears to be a result of smaller tidal forcing during neap tides as well as incident waves being more shore normal with larger wave periods allowing for greater refraction of swell waves around Tomaree Head. Similarly, the stronger longshore currents surveyed during summer are possibly a result of a larger tidal ranges and larger angle of wave crest incidence associated with smaller wave periods and decreased refraction (Komar 1998).

Both summer and winter hydrodynamic conditions show dominant westward trending residual currents (Table 6.1, Section 5.5). However, during flood and ebb tides longshore currents of Shoal Bay flow in opposite directions to what is experienced at the entrance: while ebb tides flow from east to west at the estuarine entrance, the nearshore currents of Shoal Bay flow west to east. This seems to be due to the shape and geological position of Shoal Bay that creates eddies within the nearshore zone. These eddies were observed
during deployment and have been reproduced in the numerical modelling undertaken by Jiang et al. (2009). The eddies occurred in winter and in summer, but were much more pronounced during the spring tides of the summer field campaign (meso-tidal conditions).

Winds of $10 \text{ m s}^{-1}$ rarely occur in Port Stephens with only $2\%$ of average daily wind speeds greater than $10 \text{ m s}^{-1}$ over the last 60 years which is not regular enough to significantly affect the morphodynamics of Shoal Bay. Similar results have been found in studies within the estuary, with eastward transport of sediment under westerly wind conditions (DPWS 1999; 2000; PWD 1985; 1987; Watson 1997; 2000) that are unlikely to counteract SE swell (Vila-Concejo et al. 2009a). In spite of this, strong westerly winds above $10 \text{ m s}^{-1}$ influenced the nearshore residual current direction on December 14th with easterly trending residuals dominating throughout the day at SB3. However, entrainment results show that highly energetic winds do not affect values of $E$ (Table 5.2b; Table 6.1, Appendix B), with sediment entrainment related to significant wave height. This is observed at SB3 with $E$ and $H_s$ values much larger than that of SB1; similarly entrainment at SB3 during winter is larger than during summer.

However, the relationship between $E$ and $H_s$ is not entirely clear with $H_s$ of $0.36 \text{ m}$ associated with $60\%$ entrainment percentages at SB3 during summer and a $H_s$ of $0.31 \text{ m}$ incurring an $E$ value of only $5\%$ at SB1 during winter (Table 6.1, Eq. 4.9). An explanation to these inconsistencies might be related to the inclusion of wind waves generated by local winds in the $H_s$ and $T_z$ calculations. Wind waves were observed at SB3 during the field campaign; computed values of $H_s$ and $T_z$ at SB3 showed shorter wave periods with larger wave heights when compared to SB1, which contradicts what it would be expected according to standard linear wave theory. It appears that the small wave periods of wind waves may have reduced the $T_z$ calculations.

$Ef$ and $Rf$ results demonstrate opposing residual directions at SB1 during summer (Table 6.1), suggesting that nearshore currents are not adequate as a proxy for sediment transport. The eastward trending $Ef$ values at SB1 during summer are significantly influenced by high $E$ values at low tide slack water (particularly during 13/12/08 and 14/12/08, Table 5.2b) which typically observe eastward trending residual currents (Appendix B). The large tidal ranges during the 13th and 14th of December ($>2 \text{ m}$) may allow for greater wave interaction with the low tide terrace at low tide (Masselink and
Short 1993). As a result, $Ef$ values are influenced by eastward directed entrainment at low tide during large tidal ranges. Higher $E$ values at low tide are not observed during the neap tidal ranges of winter and more regular spring tides during 17th of December, suggesting that this phenomenon only occurs during tidal ranges greater than 1.8 m, which only occasionally occur in NSW.

The most active area of longshore sediment transport is in the central/western area of the beach indicated by large entrainment values at SB3 (Appendix B, Section 5.5, Table 6.1), strong currents at SB2 and SB3 (Appendix B) and large amounts of erosion in Sections 3-4 over the year of surveys (Appendix B, Figure 6.1). Parallel recession of the cross-shore profiles occurs in these sections which is indicative of longshore dominating processes (Nordstrom and Jackson 1992). Sediment build up on the east of the boat ramp indicates longshore transport to the west from Sections 5 and 6 over long time scales. Sediment grain-size (Section 5.6) also supports this process with coarsening trends in the direction of transport previously found in tidal inlets (Nordstrom 1989). Frolich (2007) assumed the driving hydrodynamic force inciting westward transport of sediment was swell waves; however conflicting or inconclusive studies over the governing morphodynamic processes in other shorelines within the estuary (e.g. PWD 1985; 1987; Vila-Concejo et al. 2009a; Vila-Concejo et al. 2009b; Watson 2000) suggest that it is not necessarily this simple.

In summary, dominant hydrodynamic forcing mechanisms in Shoal Bay are waves that work in conjunction with tidal forces, producing longshore westward sediment transport under modal conditions. No other forces occur with the strength or frequency required to incite change of the beach morphology in the long term. Similarly, waves are the only force that is capable of entraining sediment that is subsequently transported alongshore. Previous studies that suggest winds significantly affect the morphodynamics of Shoal Bay (Watson 1997) were based off previous work done on Jimmy’s Beach (northern margin of Port Stephens). According to our data, while waves are the most important forcing mechanism entraining sediment, longshore sediment transport is also affected by tidal flows. Such hydrodynamics are unique to estuarine environments and this study is an attempt to infer the significance of each forcing mechanism.
8.3 Medium Term Morphological Change

Westward modal sediment transport is supported by beach survey results with general trends of accretion in the west and erosion in the east occurring during lower energy summer conditions (Figure 6.1, Section 5.4). The most significant periods of westward transport of sediment were between October 2008 and March 2009. During this period beach rotation between Sections 3-5 and Sections 1-2 occurred. In some instances during winter, specifically between Sections 2 and 3, these trends are reversed with accretion in the central/eastern areas of the beach and erosion in the west (Figure 6.1, Section 5.4). Beach rotation is usually the result of changing seasonal swell wave direction (Figure 2.4, Short and Masselink 1999); however this process cannot occur in estuarine beaches, since swell is always propagated through the entrance and thus arrives from the same direction. It is unlikely that westerly winds incite such rotation, since they rarely reach speeds required to influence nearshore hydrodynamics. Rotation in Shoal Bay seems to be a function of differences in cross-shore processes. Accretion in the east as a result of attenuated waves and erosion in the west as a result of less attenuated waves are associated with high-energy winter swell. As a result, similar wave conditions produce onshore hydrodynamic forcing in the protected environment in lee of Tomaree Head and scouring in the west. Indeed, significant wave heights at SB1 during winter are similar to the wave heights found at SB3 during summer, which are associated with accretion (Table 6.1). Harley (2009) observed similar results where cross-shore forcing was a likely mechanism inciting rotation on an embayed beach. Similarly, Dail et al. (2000) and Nordstrom (1980) observed wave conditions causing erosion and accretion concurrently in different areas of the beach. This has already been observed within the Port Stephens estuary with extreme events (category X storms (Watson et al. 2007),

<table>
<thead>
<tr>
<th>Field Campaign</th>
<th>Station</th>
<th>Wave</th>
<th>Residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hs (m)</td>
<td>Tz (sec)</td>
</tr>
<tr>
<td>Summer</td>
<td>SB1</td>
<td>0.16</td>
<td>8.62</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.36</td>
<td>8.26</td>
</tr>
<tr>
<td>Winter</td>
<td>SB1</td>
<td>0.31</td>
<td>11.07</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>0.56</td>
<td>9.98</td>
</tr>
</tbody>
</table>
Section 3.3.3) causing both erosion and accretion in different areas on the northern shoreline (Vila-Concejo et al. 2009a). In Shoal Bay such extreme events associated with this morphological change in the northern shoreline cause erosion in all areas of the beach.

During high-energy events offshore forcing mechanisms dominate the entire embayment. The severe storms between March and May 2009 resulted in erosion and a reduction in slope in almost all sections of the beach with a net loss of 10,000 m$^3$ of sediment (Section 5.4). Recovery of sediment by onshore processes under modal conditions has previously been observed to be inadequate in low-energy environments (e.g. Costas et al. 2005; Hegge et al. 1996; Sanderson et al. 2000; Travers 2007). Thus complete beach recovery after severe events is only possible with an extended period of fair weather conditions, if at all (Costas et al. 2005; Nordstrom 1980; Owens 1977). The western sections (1 and 2) are most exposed to ocean swell and therefore are most affected by storm events with over half of the erosion occurring between March and May 2009 lost from these sections. The location of sediment that has been lost during severe events is undetermined; while some replenishment may occur, the hypothesised transport pathways of Frolich (2007) suggest potential reworking of sediment towards the east as a result of ebb channel tidal forcing (Figure 3.2).

Shoreline recession was most pronounced in centre of the beach (Sections 3 and 4); with profiles in these areas undergoing parallel retreat that has been associated with beach change dominated by longshore transport (Nordstrom and Jackson 1992). The recession measured from beach surveys does not correlate with rates of shoreline displacement obtained from the aerial photography, with Sections 3 to 4 showing the smallest amount of recession over 43 years. Such a result can be attributed to the effects of beach nourishment and shoreline management which were most intense in these areas of the beach since at least 1986. In spite of this, average rates of recession are 1 myr$^{-1}$ from the beach surveys, twice that of the aerial photograph analysis (0.5 myr$^{-1}$). Short term assessment often results in much larger trends when compared to longer term analysis, with small scale fluctuations (such as storms) affecting the results derived from short term analysis (Cowell 2004; Larson and Kraus 1995; Ruggiero et al. 2005; Smith and Zarillo 1990). Therefore, the veracity of long term trends inferred from short to medium term assessments are subject to much conjecture (Larson and Kraus 1995). Only beach surveys which exist on decadal scales are capable of deriving long term trends, yet there
are few beaches with such data sets available. Most are contained to the southeast Australian coast (i.e. southeast Australian beaches of Narrabeen (e.g. Harley 2009; Short 1985; Short and Trembanis 2004; Short et al. 2000) and Moruya (e.g. Thom and Hall 1991)). The use of aerial photography in deriving long term trends is crucially important when extending the analysis of coastal systems to the long term or decadal scale (Ruggiero et al. 2005; Smith and Zarillo 1990).

### 6.3.1 Beach Response to Meso-Tidal Conditions

Meso-tidal environments are defined as having tidal ranges on average between 2 and 4 m (Davies 1964). The coast of NSW, with an average spring tidal range of 1.6m, falls within the micro-tidal definition; however the tidal range of the largest spring tides verges on meso-tidal conditions. On December 14th 2008 tidal range was above this maximum at 2.1 m, which produced hydrodynamic conditions that rarely occur on the southeast Australian coast and within Shoal Bay. As a result the extended swash zone allowed for greater reworking of the profile shape particularly on a steep beach face (Makaske and Augustinus 1998).

Volumetric evolution shows a loss of 2000m$^3$ in Sections 1-3 and a gain of 1100m$^3$ in Sections 4-6. Such loss to the beach face is unlikely to have occurred in the low-energy conditions experienced during the summer hydrodynamic deployments. This apparent change in the beach face can be explained by the methods applied to assess morphological variations, measuring width, area, and volume above the 0 AHD level. Accumulation of sediment below this level was not used in the analysis of the beach face. Consequently, results obtained from such calculations can be misleading, specifically during meso-tidal conditions over the summer deployments. The extended swash zone allowed for the reworking of sediment from the berm or cusp scarp to below 0 AHD. An increase of sediment above the 0 AHD line occurred in the lower energy sections (4-6) with sediment deposited on the beach face above the berm as well as on the lower beach face. A small amount of erosion occurred in the central/eastern area of the beach face (Figure 6.2a). The loss of sediment in the west involved the removal of sand in the swash zone depositing it below the 0 AHD line, with only minor accretion in the upper beach face (Figure 5.15a, Figure 6.2b). Makaske and Augustinus (1998) describe this as the translation of the beach face along the profile – it maintains profile shape but alters its position. Both profile responses in the eastern and western sections adhere to the
Makaske and Augustinus (1998) model, with a combination of erosion in the central area of the beach and accretion in the upper and lower areas of the shoreface. However, removal of sediment in the swash zone and subsequent deposition below 0 AHD is more substantial in the west, resulting in an overall erosion trend while in the east deposition on the upper beach face resulted in accretion.

Morphologies inherent to the beach are overlooked in any analysis using 0 AHD as a base level. Taking surveys during similar tidal ranges would avoid the distorting effects of tidal conditions. The tidal conditions preceding the rest of the beach surveys generally exhibited average tidal ranges (Table 4.2).
Figure 6.1. Beach change in each section derived from one year of beach surveys with summer conditions in blue and winter in black with the with red the last survey in May 2009 after a severe storm event. Graphs represent: a) normalised width indicating rotation between summer and winter surveys; b) total beach width; c) normalised volume; d) total volume.
Figure 6.2. Example of profile change over 5 days during spring tidal (≈2 m) conditions with accretion observed in the centre of the beach (a) and erosion in the west (b) above the 0 AHD line. Translation of sediment from the upper beach face to the lower is most substantial in b).
6.4 Long Term Shoreline Retreat

Long term recession trends in Shoal Bay suggest the shoreline is attempting to return to equilibrium in response to changes in the morphodynamic boundary conditions. It is difficult to ascertain the effects of historic storms on the beach with only a slight correlation between erosion occurring during 1994-1996 and storms during 1995. However, comparing long term storm data to aerial photography will usually produce inconclusive results unless the photographs were taken immediately after a storm event (Smith and Zarillo 1990). The large time steps between the aerial photography therefore limit the ability to infer the effects of historic storms on the long term shoreline evolution. The most significant recession periods occurred between 1963-77, 1994-96 and 1999-2006 with a trend of accretion between 1996 and 1999 (Section 5.2). For most sections of the beach the erosion between 1963-77 has caused the majority of the shoreline displacement between 1963 and 2006. While storm events observed in the Crowdy Head record do not appear to affect the beach in the aerial photos, the severe storms of the 1970s have been well documented to cause major erosion along the entire NSW coastline (e.g. Thom and Hall 1991). The inability of the shoreline to recover back to the 1963 shoreline after the erosion of 1963-77 is indicative of an extreme event significantly changing the morphodynamic equilibrium of the system (Cowell and Thom 1994). Shoreline recession caused by these storms may not have been recovered, as is the case for numerous beaches on the southeast Australian coast (Chapman et al. 1982; Hanslow and Gissing 2008; Hanslow and Howard 2006; Thom 1974; Thom and Hall 1991).

Research by Thom et al. (1992) has shown that such fundamental changes to the morphodynamics of the lower Port Stephens shorelines has occurred previously (Winda Woppa spit breaching). In spite of this, stochastic events are often considered fluctuations superimposed over underlying long term trends (Cowell and Thom 1994). However, extreme stochastic events may be a fundamental forcing mechanism in shoreline retreat; particularly in low-energy environments where sediment loss during severe storms is unlikely to be recovered (Costas et al. 2005; Hegge et al. 1996; Sanderson et al. 2000; Travers 2007). The majority of the 10,000 m$^3$ of sediment that was eroded between May 2008 and May 2009 was during a period of severe storms. It is difficult to determine the affects of severe storms in the long term record, yet it does not
discount the prospect that removal of sediment from Shoal Bay beach is a function of severe storm events.

The extensive erosion that occurred throughout the 1990s was possibly exacerbated by shoreline engineering with the rock wall and drainage line under the jetty being constructed in 1991 (Section 3.3). Subsequent nourishment in Sections 3-5 seem to have been ultimately transported and accumulated in the western sections (1-3), yet when major nourishment projects ceased in the 2000s erosion occurred in these sections (1-3) from 2001-06. During this time, accretion occurs in the west (2001-06) while accretion occurred in the east (Sections 4 and 5). This was potentially associated with the removal of the rock wall and groin underneath the public jetty in 2000 as well as small emergency nourishment that has been undertaken periodically.

Beach rotation usually only occurs over seasonal to yearly time scale (Short and Masselink 1999), yet rotation over decadal scales was observed in Shoal Bay. This indicates significant anthropogenic influence through sand nourishment. However, rotation has also been observed in relation to other climate anomalies (e.g. El Nino/La Nina cycles or Southern Oscillation Index) suggesting that longer term rotation also occurs (Ranasinghe et al. 2004). Whilst it is possible the shoreline engineering of 1991 affected the sediment budgets of Shoal Bay - highlighted by the erosion in Section 4 immediately west of the jetty during 86-91 and 96-99 (Figure 6.3) – this has been associated with long term trends of recession, and while it has exacerbated erosion, it is unlikely to be the sole cause of shoreline recession.

Chronic erosion observed throughout the entire aerial photo record indicates that while the severe storms of the 1970s may have influenced the morphodynamics of the system, it is not extreme stochastic events solely driving long term morphological change. It is more likely that stochastic events work in concert with underlying processes (such as reduction in sediment input) that operate at larger scales.
6.5 Long Term Evolution

The tidal forces within Shoal Bay continually provide longshore currents even if longshore radiation stresses from waves are minimal under a sheltered swash aligned environment. Therefore the theoretical equilibrium planform for Shoal Bay will most likely be dynamic with littoral drift comprising an implicit component. Indeed, in many coastal environments waves entrain the sediment with longshore currents as the mechanisms of transport (Aagaard and Masselink 1999). Beaches in dynamic equilibrium incur significant recession if net sediment input is reduced without an associated reduction in output (Bird 1996; Hsu et al. 2000; Klein 2004; Silvester and Hsu 1997). This has most likely caused the observed recession in Shoal Bay, however, the cause of reduced sediment supply remains undetermined.

Two hypotheses are possible. Firstly, sediment input from the marine environment has reduced and subsequently caused the observed shoreline erosion. Roy et al. (1980) suggested that the erosion trends on the NSW coast over the last 3000 years indicate that there is a finite marine sediment budget that fills drowned river valleys. The embayed planform of Shoal Bay is a typical example of erosion caused by a reduction in sediment supply from marine sources (Roy et al. 1980). The increased carbonate concentrations in the eastern section of the beach suggest there is still sediment supply from the marine

![Figure 6.3. Shoreline displacement between aerial photographs for each beach section.](image-url)
environmen (Figure 5.17, Section 5.6), however the increased faunal assemblages associated with the seagrass habitat in this area may also contribute to this result (Orth et al. 1984). Yet this does not discount the possibility that sediment input has been reduced.

The second hypothesis suggests that the westward migration of the FTD and other associated morphologies is a result of sediment reworking within the estuary, with erosion of the seaward face of the FTD and the adjacent shorelines supplying the sediment for the westward extension of the FTD (Section 2.5, Frolich 2007). This hypothesis is supported by Thom et al. (1992) who observed erosion of the FTD since 1851; as well as Bryant (1980), Roy et al. (1984) and Roy (1984) who note coastal erosion and deepening of sandy bodies occurring over geological time scales.

Erosion of the FTD has the capability of lowering the shoreface of Shoal Bay, changing the cross-shore equilibrium of the beach. A lowering of the shoreface in open coast environments generally results in shoreline recession as the beach attempts to revert to an equilibrium profile (Hughes and Turner 1999). Applying this theory to Shoal Bay would suggest that erosion of the seaward face of the FTD causes the beach to recede. However, conferring this theory to such a complex sediment sharing environment is not necessarily this simple, since the spatial aggregation techniques utilised in the open coast are not always applicable to estuarine environments (Cowell et al. 1995; Karunarathna et al. 2008). Similarly, accretion found in the ebb shoal immediately off Tomaree head (Figure 3.1) suggests that the greater FTD complex does not evolve linearly – erosion of the seaward face of the FTD does not necessarily occur in all environments. Accretion in the ebb shoal may have affected the morphodynamics of Shoal Bay, indeed sediment lost from the beach may be reworked into the ebb shoal as well as other the formations within the embayment. Whilst this is unlikely to affect the long term imbalance in the sediment budget it does suggest FTD evolution is inextricably linked to shoreline change.

### 6.6 Synthesis

Westward transport of sediment occurs at all three scales. Modal conditions are shown to transport sediment towards the west, driven predominantly by wave and tidal forcing; which is in turn observed in the morphological analysis with erosion in the east and accretion in the west. Evolution over short and long term also exhibits rotation. Long term rotation is influenced by beach nourishment projects, however yearly to decadal
climate fluctuations (e.g. EL Nino/La Nina cycles) may also be involved. Short term rotation in winter is associated with cross-shore accretion due to transport from the FTD in the east and erosion in the west. The converse occurs during summer due to longshore transport under modal conditions. As a result, shoreline stability of Shoal Bay is connected to the transport of sediment from the FTD to the shoreline. In spite of this, overall erosion has occurred for the last 4 decades. The long term recession trends suggest the shoreline is attempting to return to equilibrium in response to changes in the morphodynamic boundary conditions. This suggests that the FTD does not supply sufficient sediment to the shoreline; with high-energy events eroding the beach most significantly in the west, without adequate replenishment. Previous research suggests the deficiency in the littoral sediment budget is linked to the evolution of the Port Stephens estuary and long term sediment transport of the NSW coast (Roy 1984; Roy et al. 1980).

It is debatable whether short term results can be used to predict long term shoreline change (Larson and Kraus 1995; Ruggiero et al. 2005). While short term studies showed trends of erosion, these were more pronounced than what was found in the longer term assessment, particularly in the central sections of the beach. However, long term rates of recession were heavily influenced by beach nourishment making it difficult to ascertain shoreline recession driven by natural processes. GIS analysis of aerial photography is thus an essential component in assessing long term trends that may be confounded by short term fluctuations.

6.7 Limitations and Future Research

This study has achieved the aims set out in Section 1.3, however it has certain limitations, both in method and approach. Short to medium term morphodynamic assessment within this study involved few assumptions regarding forcing mechanisms and resultant beach change. Yet inferring the direction of sediment transport using nearshore currents may not necessarily be an accurate method. The differentials between entrainment and current results indicate that it is not always adequate to use nearshore currents to predict sediment transport, with an important part of the littoral sediment transport occurring in the swash zone (Elfrink and Baldock 2002). To gain a comprehensive morphodynamic assessment of the Port Stephens estuary, research into swash zone transport has already been proposed.
Thieler and Danforth (1994) concluded that there were five types of errors inherent to shoreline mapping that affect the accuracy of shoreline positions obtained from maps and photos: (1) inaccurate source data, (2) careless mistakes or blunders, (3) constant errors (e.g. measuring instrument), (4) systematic errors (e.g., lens distortion), and (5) random errors (e.g., operator). Some errors are easily avoidable, such as careless mistakes. The rest are implicit in any analysis. Constant and systematic errors could be reduced in future research by using image pre-processing software; however the errors associated in this data set are most likely minimal as photographs deemed poor in quality are not used in the shoreline assessment. Random errors generally result in a normal distribution around zero without any effects on the shoreline digitization. However, time series assessment of shorelines will always encounter errors regarding aliasing. Short term fluctuations are capable of disrupting the long term trends within data sets even if aerial photographs are in ideal time intervals. The fluctuations between accretion and erosion trends in the 1990s are potentially a result of both shoreline engineering and time series aliasing (Section 2.6; Section 6.4).

Beyond errors associated with methodology, there are limits to knowledge that are implicit in multi-scale analyses of shoreline change. Cowell (2002) identified two basic limits in a morphodynamic assessment: intrinsic and temporal. Intrinsic limits are unavoidable and are a result of nonlinear dynamics of coastal systems driven by stochastic input, that is, they are associated with the difficulties in deriving the long term signal out of short term noise (Cowell and Thom 1994; Phillips 1992). Collecting more data and implementing further analysis on coastal systems is often the avenue taken to reduce the intrinsic limits that can inhibit the ability to derive a desired result (Cowell 2002). It is also a common method employed when attempting to extend the temporal scale of a morphodynamic study. Yet process based assessments are at their weakest when attempting to derive sediment sharing and transport pathways (Karunarathna et al. 2008). The extrapolation of sediment pathways beyond Shoal Bay beach were the more tenuous components within this study. Heuristic extrapolation from known morphodynamics is often the only possible method of assessment once it is accepted that some results are inaccessible, saving both time and limited resources (Cowell 2002). Such deductive assessment along with integration of results from different scales (both spatial and temporal) can reduce both the intrinsic and temporal limitations.

In spite of this, the analysis presented within this data set could be enhanced by:
1. greater temporal span of beach surveys limiting confounding effects of stochastic events and

2. time series bathymetric data allowing for quantitative analysis between fluctuations in the FTD and associated shorelines.

Including sensitivity analysis, complex statistical analysis, (Larson et al. 2003; Southgate et al. 2003) inverse problem theory (Tarantola 1987), stochastic simulation (Banks and Carson 1984) and fuzzy-set modelling (Zeng et al. 2001) would enhance the methodology of this study. Employing these assessments was well beyond the scope of this thesis, as they can only begin once field work is completed and data sets finalised.

The expediency of this study is due to the relatively quick assessment of the short to long term morphodynamics of a complex sediment sharing environment. Whilst some of the long term predictions and assessment were enhanced by previous research within the estuary; hydrodynamic assessments on other shorelines lend credibility to the short term results presented within this study.

Future research within Port Stephens regarding hydrodynamic modelling and analysis of FTD morphodynamics will provide more data sets, allowing for greater resolution when assessing long term shoreline changes and associated variations in the FTD. In addition to this study, integrating data sets already in existence for Port Stephens with current research on the FTD morphodynamics offers a rare opportunity to push the limits of what multi-scale morphodynamic assessments can accurately predict and explain.
Conclusion

This study represents a contribution to the limited knowledge base of low-energy beach morphodynamics. It does so by assessing the hydrodynamics, morphological changes and sediment budgets and pathways of Shoal Bay/Port Stephens at three temporal scales. At the short to medium term scales, hydrodynamic and morphological surveys were used to successfully derive the significant hydrodynamic processes driving change in the beach morphology. It was found that the direction of residual nearshore currents did not adequately predict the direction of sediment transport; sediment entrainment calculations were implemented and allowed for greater accuracy in the hydrodynamic results.

Modal conditions were shown to transport sediment towards the west with an associated accumulation of sediment in the western sections of the beach. Severe storm events would then cause erosion across the entire beach. Detailed studies of beach recovery after severe storms could not be made but during the one year of beach surveys negligible recovery was observed. Rotation occurred in the study area and it was driven by both cross- and long-shore processes: (1) Longshore transport from east to west was observed during summer, causing clockwise rotation; and (2) high energy conditions during winter caused cross-shore sediment transport with accretion in the east and erosion in the west resulting in anti-clockwise rotation. As a result, the morphological change in Shoal Bay is driven by longshore littoral transport under modal conditions and cross-shore sediment sharing between the submerged and sub-aerial sections of the beach during high-energy swell.

Long-term shoreline retreat was observed in the four decades of aerial photography. Rates of recession found in medium term studies were larger than what was found in the aerial photographs; short to medium term assessments are rarely capable of accurately deriving long term trends. Shoreline rotation was also observed in the long term analysis and it was found to be related to shoreline management interventions where sand nourishment in the east eventually erodes and accrues in the west. However, long term beach rotation driven by natural processes cannot be discounted. This also indicates that westward transport of sediment found in the short and medium term acts at a long term scale.
Storm events play an important role in removing sediment from the beach and contribute to the erosion rate (i.e. most storms will cause faster erosion rates in the long term) but most likely do not drive chronic shoreline retreat. Shoreline recession is proposed to be a function of net imbalance in the littoral sediment flux as well as reworking of sediment in the FTD. It is hypothesised that the cause of the reduction in sediment input could be related to the long term coastal erosion observed on the southeast Australian coast. Moreover, the morphodynamics of Shoal Bay are inherently connected to the evolution of the FTD. Future assessment of estuarine beaches may be benefitted by considering them as simply a component of the FTD or greater sand complexes within the estuary. Therefore, morphodynamic assessments on multiple scales are necessary in complex sediment sharing environments in order to derive sediment pathways and the processes driving coastal change.

Aside from the purely scientific contribution to the morphodynamics of low-energy beaches, the findings of this thesis will be used to improve shoreline management of Port Stephens estuary; the findings might also be applicable to other similar environments (e.g. Port Hacking).
References


Appendix A.

Matlab Scripts

This section contains Matlab scripts that were used for the data analysis of this study. Section A.1 includes Matlab scripts that were used to calculate wave statistics. Section A.2 includes the assessment of the ADV current data and Section A.3 contains the scripts used to analyse the beach profiles.
A.1

Matlab scripts used in the nearshore wave data analysis. Scripts were developed to assess numerous wave characteristics by Power (2007), some function scripts are not relevant to this study but included as they are components of the wave analysis master script. The master script was used to run the nine function scripts. The first two function scripts plot the frequency spectrum to allow a cutoff frequency to be chosen and, using this cut off frequency, filter the data. The function scripts calculating Ursell, Gamma, area and shape parameters were not used in this study. The remaining scripts were sued to calculate wave height and run statistics.
%MASTER SCRIPT FOR PRESSURE TRANSDUCER DATA PROCESSING
%RUNS ALL WAVE ANALYSIS USING NINE FUNCTION SCRIPTS
%COURTESY OF HANNAH POWER

clear all;clc;close all

% Sampling frequency
Fs=6;

jj=0;
kk=0;
ff=0;

for i=4:2:17 % CHANGE RUN NUMBERS
    if i<10
        ZZ=['split_pt14run0' num2str(i) '.txt']; % CHANGE PT NUMBER
    elseif i>9 & i<99
        ZZ=['split_pt14run' num2str(i) '.txt']; % CHANGE PT NUMBER
    end
    ZZ=char(ZZ);
    orig_data=load(ZZ); % loads current file
    stat_no=str2double(ZZ(1,9:10));

    n=orig_data(:,1)+0.91; % ADJUST FOR HEIGHT OF PT

% Noise filter
    bnoise=fir1(20,0.5/(0.5*Fs),'low',hanning(21));
    n=filtfilt(bnoise,1,n);

% Calculate spectrum & plot
    [P1 f1 P2 f2]=f_specplot(n,Fs);

% Create arrays of frequency data
    result_P1(:,ff+1)=P1;
    result_P2(:,ff+1)=P2;
    result_f1(:,ff+1)=f1;
    result_f2(:,ff+1)=f2;
    ff=length(result_P1(1,:));

% Normalised cutoff freq
    [x,y]=ginput(1);
    Fc=x;

% High pass filtering & water surface elevation plots
    [filt_data]=f_highfilt(n,Fs,Fc,ZZ);
    pause

% Wave dimensions
% Calculate crossings

[dcrossings ucrossings]=f_crossings(filt_data);
% Determine wave dimensions between downcrossings

[peaks peak_time peak_depths troughs heights period gamma] = f_waveheights(filt_data, dcrossings, n, Fs);

% Determine area under the wave above the zero crossing

[wave_area] = f_wavearea(dcrossings, ucrossings,filt_data,Fs);

% Calculate wave asymmetry and deformation

[wave_asym wave_def] = f_asymdef(dcrossings, ucrossings, peaks, heights, peak_time);

% Calculate record skewness and asymmetry

[total_skew total_asym] = f_totalskewsym(filt_data,Fs);

% Calculate Ursell Number

[ur_num wlength c] = f_ursell(heights, peaks, period, n);

% Create array with all wave dimensions

% Col 1: Run number
% Col 2: Station number
% Col 3: Wave heights (H)
% Col 4: Wave periods (T)
% Col 5: Water depth under wave peaks
% Col 6: Wave area
% Col 7: Wave asymmetry
% Col 8: Wave deformation
% Col 9: Gamma (=H/h) where h=depth under trough
% Col 10: Ursell number
% Col 11: Wavelength
% Col 12: Wavespeed
% Col 13: Height of crest above mean water surface elevation

wave_dim=[repmat(i,length(heights),1),repmat(stat_no,length(heights),1),heights,period,peak_depths,wave_area,wave_asym,wave_def,gamma,ur_num,wlength,c,peaks];

% Calculate wave statistics

[wave_dim wave_stats] = f_wavestats(wave_dim, n);

% Create wave stats array - for waves with T>4

% Col 1: Run number
% Col 2: Station number
% Col 3: Hrms
% Col 4: Hs
% Col 5: Mean of wave period
% Col 6: Mean original water surface elevation elevation of water above

wave_dim=[repmat(i,length(heights),1),repmat(stat_no,length(heights),1),heights,period,peak_depths,wave_area,wave_asym,wave_def,gamma,ur_num,wlength,c,peaks];
% Col 7: Mean of trough depth
% Col 8: Mean of wave area
% Col 9: Mean wave asymmetry
% Col 10: StDev wave asymmetry
% Col 11: Mean wave deformation
% Col 12: StDev wave deformation
% Col 13: Gamma calculated using Hrms and mean water surface elevation
% Col 14: Gamma calculated using Hrms and mean of trough depths
% Col 15: Mean wave-by-wave gamma
% Col 16: StDev wave-by-wave gamma
% Col 17: Total skewness
% Col 18: Total asymmetry
% Col 19: Mean of Ursell Number
% Col 20: Filter cutoff frequency

wave_stats=[i,stat_no,wave_stats,total_skew,total_asym,mean(wave_dim(:,10)),Fc];
wave_stats=[wave_stats wave_stats(:,6)-0.09]; %replace ahd with elevation of PT i.e -1m

% Col 21: Mean original water surface elevation (AHD)

% Build Result Arrays

% Array with all waves
result_wave_dim(jj+1:jj+length(wave_dim(:,1)),:)=wave_dim;
jj=length(result_wave_dim(:,1));

% Array with wave stats
result_wave_stats(kk+1:kk+length(wave_stats(:,1)),:)=wave_stats;
kk=length(result_wave_stats(:,1));

clear mean* H* L* P* S ZZ b20 bnoise dcrossings def_* std* gamma* ur_num wlength

close all
end
dlmwrite('wavedim.txt',result_wave_dim, '\t');
dlmwrite('wavestat.txt',result_wave_stats, '\t');
% f_specplot.m

% This function calculates the frequency spectrum of the water surface elevation both unsmoothed and smoothed and displays them in a figure

% Input values:
% n = original water surface elevation record with noise removed if necessary
% Fs = sampling frequency (Hz)

% Output values:
% No output arrays
% Displays figure of frequency spectrum of data - both smoothed and unsmoothed

function [P1 f1 P2 f2]=f_specplot(n,Fs)

L=length(n);

[P1 f1]=psd(n,L,Fs,L,0,'linear');
[P2 f2]=psd(n,L,Fs,round(L/4),round(L/8),'linear');
figure
subplot(2,1,1);
plot(f1,P1);
v=axis;
v(1,1:2)=[0 0.5];
axis(v);
title('Frequency spectrum - unsmoothed');
ylabel('Spectral density (m^2s)');
clear v
subplot(2,1,2);
plot(f2,P2);
v=axis;
v(1,1:2)=[0 0.5];
axis(v);
title('Frequency spectrum - smoothed (Segment length 1/4, 50% overlap)');
ylabel('Spectral density (m^2s)');
xlabel('Frequency (Hz)');
clear v
% f_highfilt.m

% This function high pass filters the data and demeans it and then plots
% the water surface elevation of the original data and the filtered data

% Input values:
% n = water surface elevation record with noise removed if necessary
% Fs = sampling frequency (Hz)
% Fc = cutoff frequency

% Output values:
% filt_data = demeaned and high pass filtered water surface elevation record
% Also displays figure with water surface elevation of original record and
% filt_data record

function [filt_data]=f_highfilt(n,Fs,Fc,ZZ)

% Define length of filter
filt_length=Fc^-1*Fs;

% Apply filter
filt_data=filtfilt(ones(round(filt_length),1),round(filt_length),n);
filt_data=n-filt_data;

% Create time array at sampling frequency
L=length(n);
S=1/Fs;
orig_time=(0:S:((L-1)*S));

% Plot original and filtered surface elevation
figure
subplot(2,1,1);
plot(orig_time,n);
title(ZZ);
ylabel('Surface elevation (m)');
axis tight
subplot(2,1,2);
plot(orig_time,filt_data);
title('Filtered data');
ylabel('Surface elevation (m)');
xlabel('Time (s)');
hold on
% Plot zero water surface elevation line
plot(0:(L/Fs),0,'r');
hold off
axis tight
% f_crossings.m

% This function calculates the upcrossings and downcrossings of a time series of water surface elevations and creates two arrays with the row numbers where the upcrossings and downcrossings occur

% Input values:
% filt_data = water surface elevation record that has been high pass filtered, noise filtered and demeaned

% Output values:
% dcrossings = row numbers in filt_data array where downcrossings occur
% ucrossings = row numbers in filt_data array where upcrossings occur

function [dcrossings ucrossings]=f_crossings(filt_data)

% Determine row numbers of downcrossings
for j=1:length(filt_data)-1
    if filt_data(j,1)>0 & filt_data(j+1,1)<0
        dcrossings(j,1)=j;
    else dcrossings(j,1)=NaN;
    end
end

dcrossings(isnan(dcrossings))=[]; % Removes NaNs from crossings array

% Determine row numbers of upcrossings
kk=dcrossings(1,1);
for k=kk:length(filt_data)-1
    if filt_data(k,1)<0 & filt_data(k+1,1)>0
        ucrossings(k-kk+1,1)=k;
    else ucrossings(k-kk+1,1)=NaN;
    end
end

ucrossings(isnan(ucrossings))=[]; % Removes NaNs from crossings array

clear j k kk
% f_waveheights

% This function calculates the values of the peaks, their row numbers
% and the original water surface elevation under the wave peak, the values
% of the troughs, their periods and the heights of each wave in the water
% surface elevation
% record

% Input values:
% filt_data = water surface elevation record that has been high pass
% filtered, noise filtered and demeaned
% dcrossings = array with row numbers where downcrossings occur in the
% filt_data array
% n = original water surface elevation record with noise removed if
% necessary
% Fs = sampling frequency (Hz)

% Output values:
% peaks = magnitude of wave peaks relative to mean water surface
elevation
% peak_time = row numbers where wave peaks occur
% peak_depths = water depth under wave peaks
% troughs = magnitude of wave troughs relative to mean water surface
elevation
% heights = wave heights = peaks + abs(troughs)
% period = wave period in seconds
% gamma = gamma value for each wave where depth is depth under wave
% trough

function [peaks peak_time peak_depths troughs heights period
gamma]=f_waveheights(filt_data,dcrossings,n,Fs)

for j=1:length(dcrossings(:,1))
    peaks(j,1)=max(filt_data(dcrossings(j,1)+1:dcrossings(j+1,1),1));
    peak_time(j,1)=find(filt_data(dcrossings(j,1):dcrossings(j+1,1),1)==peaks(j,1))+dcrossings(j,1)
    troughs(j,1)=min(filt_data(dcrossings(j,1):dcrossings(j+1,1),1));
    heights(j,1)=peaks(j,1)+abs(troughs(j,1));
end

clear j

for j=1:length(peak_time);
    peak_depths(j,1)=n(peak_time(j,1),1);
end

clear j

for j=2:length(dcrossings);
    period(j-1,1)=(dcrossings(j,1)-dcrossings(j-1,1))/(Fs);
end

clear j

gamma=heights./((peak_depths-heights));
% f_wavearea.m

% This function calculates the area under the wave shape above the zero
crossing line for all the waves in the water surface elevation record

% Input values:
% dcrossings = row numbers in filt_data array where downcrossings occur
% ucrossings = row numbers in filt_data array where upcrossings occur
% filt_data = water surface elevation record that has been high pass
% filtered, noise filtered and demeaned
% Fs = sampling frequency (Hz)

% Output values:
% wave_area = area under the waveform for each wave in the record

function [wave_area]=f_wavearea(dcrossings,ucrossings,filt_data,Fs);
for j=1:(length(dcrossings(:,1))-1);
    wave_area(j,1)=sum(filt_data(ucrossings(j,1):dcrossings(j+1,1),1))/Fs;
end

clear j
% f_asymdef

% This function calculates the wave asymmetry and deformation for all the
% waves in the water surface elevation record

% Asymmetry = 2n/H
% Deformation = a/b

% Input values:
% dcrossings = row numbers in filt_data array where downcrossings occur
% ucrossings = row numbers in filt_data array where upcrossings occur
% peaks = magnitude of wave peaks relative to mean water surface elevation
% heights = wave heights
% peak_time = row numbers where wave peaks occur

% Output values:
% wave_asym = wave asymmetry for each wave in the record
% wave_def = wave deformation for each wave in the record

function [wave_asym, wave_def] = f_asymdef(dcrossings, ucrossings, peaks, heights, peak_time);

% Calculate wave asymmetry

wave_asym = 2 * peaks / heights;

% Calculate wave deformation

for j = 1:(length(dcrossings(:,1)) - 1);
    def_a(j,1) = peak_time(j,1) - ucrossings(j,1);
    def_b(j,1) = dcrossings(j+1,1) - peak_time(j,1);
    wave_def = def_a ./ def_b;
end

junk = find(wave_def == inf);
if length(junk) > 0
    wave_def(junk(:,1)) = NaN;
end

clear junk
clear j
% f_totalskewasym

% This function calculates the skewness and asymmetry of the whole record
% of water surface elevation

% Input values:
% filt_data = demeaned and high pass filtered water surface elevation record
% Fs = sampling frequency (Hz)

% Output values:
% total_skew = skewness for total water surface elevation record
% total_asym = asymmetry for total water surface elevation record

function [total_skew total_asym]=f_totalskewasym(filt_data,Fs);

% Calculate skewness for total wave record

    total_skew=(mean(filt_data.^3))/((mean(filt_data.^2))^(3/2));

% Calculate asymmetry for total wave record

    for j=1:length(filt_data)-1;
        asym(j,1)=(filt_data(j+1,1)-filt_data(j,1))/(1/Fs);
    end

    total_asym=-{mean(asym.^3)}/({mean(asym.^2)}^(3/2));

    clear j
function [ur_num wlength c]=f_ursell(heights,peaks,period,n);

% Calculates wave speed based on solitary wave theory where h = mean water
% depth over the whole time series
c=sqrt((peaks+mean(n))./9.81);

% Calculates wavelength
wlength=c.*period;

% Calculates ursell number
ur_num=(heights.*(wlength.^2))./(mean(n)^3);
This function calculates the wave statistics for the entire wave run including Hrms, mean water surface elevation, and mean and standard deviation of both asymmetry and deformation, gamma calculated using Hrms and both mean water surface elevation and the mean of the depths under the wave troughs, and the mean and standard deviation of gamma calculated wave by wave.

It only calculates these values on waves with periods > 4secs

Input values:
- `wave_dim` = array containing wave heights, periods, depth under peaks, asymmetry, deformation and gamma
- `n` = original water surface elevation record with noise removed if necessary

Output values:
- `wave_dim` = wave dimensions array now only with waves with T > 4secs
- `Hrms` = root mean squared wave height
- `Hs` = significant wave height
- `mean_T` = mean wave period
- `mean_n` = mean of the original water surface elevation record
- `mean_area` = mean of the area under each wave
- `mean_asym` = mean of wave asymmetry
- `std_asym` = standard deviation of wave asymmetry
- `mean_def` = mean of wave deformation
- `std_def` = standard deviation of wave deformation
- `gammarmsn` = gamma calculated using Hrms and h=mean_n
- `gammarmarmst` = gamma calculated using Hrms and the mean of the depths under the wave troughs
- `mean_gamma` = mean of gamma for each individual wave
- `std_gamma` = standard deviation of gamma for each individual wave

function [wave_dim wave_stats]=f_wavestats(wave_dim,n);

Remove waves with period < 4secs
for j=1:length(wave_dim(:,1))
    if wave_dim(j,4)<4
        wave_dim(j,:)=NaN;
    end
end
wave_dim(any(isnan(wave_dim))',:)=[];

function [wave_dim wave_stats]=f_wavestats(wave_dim,n);

Remove waves with period < 4secs
for j=1:length(wave_dim(:,1))
    if wave_dim(j,4)<4
        wave_dim(j,:)=NaN;
    end
end
wave_dim(any(isnan(wave_dim))',:)=[];

clear j

Sort final heights into ascending order
H=wave_dim(:,3);
H=sort(H);

Hrms
Hrms=sqrt(mean(H.^2));

Hs
Hs=mean(H(length(H)-round(length(H)/3):length(H),1));
% Mean period
mean_T=mean(wave_dim(:,4));

% Mean original water surface elevation
mean_n=mean(n);

% Mean trough depth
mean_tr=mean(wave_dim(:,5)-wave_dim(:,3));

% Mean of wave area
mean_area=mean(wave_dim(:,6));

% Mean & stdev of wave asymmetry
mean_asym=mean(wave_dim(:,7));
std_asym=std(wave_dim(:,7));

% Mean & stdev of wave deformation
mean_def=nanmean(wave_dim(:,8));
std_def=nanstd(wave_dim(:,8));

% Gamma using Hrms and mean_n
gamma_rmsn=Hrms/mean_n;

% Gamma using Hrms and mean of wave troughs
gamma_rmst=Hrms/(mean(wave_dim(:,5)-wave_dim(:,3)));

% Mean & stdev of gamma
mean_gamma=mean(wave_dim(:,9));
std_gamma=std(wave_dim(:,9));

wave_stats=[Hrms,Hs,mean_T,mean_n,mean_tr,mean_area,mean_asym,std_asym,mean_def,std_def,gamma_rmsn,gamma_rmst,mean_gamma,std_gamma];
A.2

This section contains scripts that were used to assess current data and entrainment percentages. The first script is the master script that processes the ADV data with the second function script calculating the critical velocity ($U_{cr}$) and the percentage of entrainment ($E$). The final script was used to plot wave and current data into a single figure.
%ADVcorvel

% Processing ADV data.
% Sampling frequency 5Hz
% Correlation Analysis
% Assignment of variables
% Created by Ana Vila-Concej0 15/09/09
% Modified 15 September 2009

% This script processes ADV data and calculates entrainment percentages
% using f_ucrit. Figures for alongshore, cross-shore and vertical
currents % for each run are then plotted

clear all
close all

disp('Please remember to alter paths in ADVcorvel and sediment characteristics in f_ucrit')

% Load the data
% Load correlation data
data_path='C:\Honours\SBW\data4dan\0807ShoalBay\ADV_Data\GEN724\';
[fname,pname]=uigetfile([data_path '*.cor'],...
'Get CORRELATION data');
data_cor=load([fname pname]);
disp(['Filename : ' fname])

% User input start time:
ts=input('Enter start time [yyyy mm dd HH MM SS]');
t_ini=datenum(ts);

% Assign correlation variables
t=(data_cor(:,1));
t_real=t_ini+t;
xcor=(data_cor(:,6)); % Sontek
ycor=(data_cor(:,4)); % Sontek
zcor=(data_cor(:,5)); % Sontek
% create constant
a=50;

% Load VELOCITY data
[fname,pname]=uigetfile([data_path '*.vel'],...
'Get VELOCITY data');
data_vel=load([fname pname]);

% Clean the data
% Assign velocity variables
xvel=data_vel(:,6)/100;
yvel=(data_vel(:,4)/100);
zvel=data_vel(:,5)/100;
% fs=sampling frequency=5 Hz
fs=5;
% Create three new data arrays that contain the filtered data
xmaf=filtfilt(ones(1,fs),fs,xvel);
ymaf=filtfilt(ones(1,fs),fs,yvel);
zmaf=filtfilt(ones(1,fs),fs,zvel);

% create two new data arrays where poorly correlated data points (<50% correlation) are substituted
%with data points from the moving
for i=1:length(xvel);
    if xcor(i,1)>50;
        xvel_fil(i,1)=xvel(i,1);
    else xvel_fil(i,1)=xmaf(i,1);
    end
if ycor(i,1)>50;
    yvel_fil(i,1)=yvel(i,1);
else yvel_fil(i,1)=ymaf(i,1);
    end
if zcor(i,1)>50;
    zvel_fil(i,1)=zvel(i,1);
else zvel_fil(i,1)=zmaf(i,1);
end
end

U=yvel_fil; %For March24
V=xvel_fil; %For March24

%Average current velocities and directions
Xm=mean(xvel_fil);
Ym=mean(yvel_fil);
Zm=mean(zvel_fil);

%Maximum;Minimum values
Xmx=max(xvel_fil);
Xmn=min(xvel_fil);

Ymx=max(yvel_fil);
Ymn=min(yvel_fil);

%Significant currents?

% Calculate critical values of entrainment
[Uc, exceed]=f ucrit(U,V);

% Xst=sort(xvel_fil);
% Xmx_sig=mean(Xst(3001:length(Xst)));
% Xmn_sig=mean(Xst(1:1500));
%
% Yst=sort(yvel_fil);
% Ymx_sig=mean(Yst(3001:length(Yst)));
% Ymn_sig=mean(Yst(1:1500));

format long g
out=[t_real xvel_fil yvel_fil zvel_fil];
opname='C:\Honours\Current_data\SBW3-0724\';
disp(opname);
ofname=fname;
save([opname ofname],'out','-ascii');
ofname='Results.txt';
fid=fopen([opname ofname],'a');
fprintf(fid,'%04.3f %04.3f %04.3f %04.3f %04.3f %04.3f %04.3f %04.3f
%04.3f %04.3f\r',...
[t_ini Xm Ym Zm Xmx Xmn Ymx Ymn Uc exceed]);
fclose(fid);
%Plot filtered velocities vs. time
figure
subplot(3,1,1)
plot(t,xvel_fil)
xlabel('Time(s)')
ylabel('Velocity(m/s)')
title('Across-shore Current Velocity') %For March 25 2007
axis([-inf inf -inf inf])

subplot(3,1,2)
plot(t,yvel_fil)
xlabel('Time(s)')
ylabel('Velocity(m/s)')
title('Alongshore Current Velocity') %For March 25 2007
axis([-inf inf -inf inf])

subplot(3,1,3)
plot(t,zvel_fil)
xlabel('Time(s)')
ylabel('Velocity(m/s)')
title('Vertical Current Velocity') %For March and June 2007
axis([-inf inf -inf inf])
function [Uc, exceed]=f_ucrit(U,V)

%Created by Michael Hughes
%Edited by Ana Vila-Concejo and Dan Harris

%This function calculates how often the shore normal current exceeds the %critical entrainment value U_cr.

% Start edits
--------------------------------------

D50=input(["Enter D50 in metres"]);
D50=412.25e-6; % Enter D50 in metres
Fs=5; % Enter sampling frequency (Hz)
U=yvel_fil; % Shore-normal velocity component
V=xvel_fil; % Shore-parallel velocity component

% End edits
--------------------------------------

% Start constants
---------------------

g=9.8; % Gravitational acceleration
kin_vis=1.1e-6; % Kinematic viscosity
rho=1027; % Water density
rho_s=2650; % Sediment density
s=rho_s/rho; % Ratio of sediment to fluid densities

% End constants
---------------------

% Start some preliminary calculations
------------------------------------

S=sqrt(U.^2+V.^2); % Velocity magnitude (speed)
Uw=4*std(S); % Significant speed
U_1=detrend(U);

% Calculate U autospectrum
[P,F]=pwelch(U,boxcar(length(U_1)),0,length(U_1),Fs);
P_smooth=filtfilt(ones(11,1),11,P); % Smooth spectrum
plot(F,P_smooth) % Plot spectrum to check
axis([0 1 0 max(P_smooth)]) %to avoid zero frequencies associated to red spectra

%I am excluding all frequencies smaller than 0.05 as they are not the orbital velocities that I am searching.
ii=find(F>0.05);
[dum,mi]=max(P_smooth(ii));
Fmax=F(ii(mi));

T=1/Fmax; % Peak wave period

A=(Uw*T)/(2*pi); % "Run-average" orbital excursion
ks=2.5*D50; % Nikuradse roughness length
r=A/ks; % Relative roughness
fw=0.237*(r^-0.52); % "Run-avaergae" wave friction factor

% End some preliminary calculations
------------------------------------

% Start calcs for critical values for entrainment
------------------------------------
\[ D_{\text{star}} = \left( \frac{g(s-1)}{\text{kinvis}^2} \right)^{1/3} \times D_{50}; \]  
\[ \text{% Dstar (Soulby Eq. 75)} \]

\% Critical Shields (Soulby Eq. 74)
\[ \theta_{cr} = \left( 0.3 / (1 + (1.2 \times D_{\text{star}})) \right) + \left( 0.055 \times (1 - \exp(-0.02 \times D_{\text{star}})) \right); \]
\[ \text{tao}_{cr} = \theta_{cr} \times g \times (\rho_s - \rho) \times D_{50}; \]  
\[ \text{% Critical shear stress} \]
\[ U_{\text{cr}} = \sqrt{\left( 2 \times \text{tao}_{cr} / \rho \times \text{fw} \right)}; \]  
\[ \text{% Critical velocity amplitude} \]
\% End calcs for critical values for entrainment  

\[ S_{\text{smooth}} = \text{filtfilt(ones(1,5),5,S)}; \]
\[ \text{delta}_{S} = \text{diff}(S_{\text{smooth}}); \]
\[ j = 1; \]
\[ \text{for } i = 1: \text{length(delta}_S) - 1 \]
\[ \text{if } \text{delta}_S(i,1) > 0 \text{ & delta}_S(i+1,1) < 0 \]
\[ \text{temp3}(j,1) = i; \]
\[ j = j + 1; \]
\[ \text{end} \]
\[ S_{\text{peaks}} = S(\text{temp3} + 1,1); \]
\[ \text{CF}(1,1:2) = \begin{bmatrix} 0 & 0 \end{bmatrix}; \]
\[ j = 2; \]
\[ \text{for } i = \text{min}(S_{\text{peaks})} : (\text{max}(S_{\text{peaks}}) - \text{min}(S_{\text{peaks}})) / 100 : \text{max}(S_{\text{peaks}}) \]
\[ \text{CF}(j,1:2) = \begin{bmatrix} i & \text{length(find(S_{\text{peaks}} <= i))} \end{bmatrix}; \]
\[ j = j + 1; \]
\[ \text{end} \]
\[ \text{CF}(:,2) = \text{CF}(:,2) / \text{length}(S_{\text{peaks}}); \]
\[ \text{temp4} = \text{find(CF(:,1) < U_{\text{cr}},1,'last')} ; \]
\[ \text{figure(2)} \]
\[ \text{plot(CF(:,1),CF(:,2))} \]
\[ \text{hold on} \]
\[ \text{plot([U_{\text{cr}};U_{\text{cr}}],[0;\text{CF(temp4,2)}],'r')} \]
\[ \text{plot([0;U_{\text{cr}}],[\text{CF(temp4,2);CF(temp4,2)}],'r')} \]

\[ \text{exceed} = 100 - \text{CF(temp4,2)} \times 100; \]
\[ \text{Uc = U_{\text{cr}};} \]
\[ \text{disp(exceed)}; \]
%This script plots wave, depth, current and entrainment data in a single figure.

clear all
close all

data_path='C:\Honours\Current_data\SBW\';

[fname,pname]=uigetfile([data_path '* .csv']);

cur_data=load([pname fname]);

time=cur_data(:,1);
u=cur_data(:,2);
v=cur_data(:,3);
depth=cur_data(:,4);
Hs=cur_data(:,5);
Tz=cur_data(:,6);

data_path='C:\Honours\Current_data\SBW3-0724\';

[fname1,pname]=uigetfile([data_path '* .txt'],...
'Get data');
data=load([pname fname1]);

t_ini=data(:,1);
Ucrit=data(:,9);
Perc=data(:,10);

title('fname')

figure1=figure(1);

subplot(4,1,1)
plot(t_ini,depth,'k-*')
grid on
datetick('x')
title(fname,'fontsize',12)
ylabel ('Water Elevation (m)','fontsize',12)
axis([-inf inf -1.5 3.5])

subplot(4,1,2)
hold('all')
plot(t_ini,u,'k-o')
plot(t_ini,v,'k-*')
grid on
datetick('x')
ylabel ('Current Velocity (m/s)','fontsize',12)
legend('Longshore, +west -east','Cross-shore, +Offshore - Onshore','Orientation','horizontal','Location','SouthEast');
axis([-inf inf -0.2 0.2])

%Critical Velocity
This section contains scripts used to analyse the beach profiles. The first script runs the 8 other function scripts. The first four scripts are preliminary processing of the profile data identifying the origin of the survey and where the profile crosses 0 AHD with the fifth script plotting these profiles. The sixth and seventh function scripts calculate the area of the profile above 0 AHD and the eighth assessing beach slope.
clear all
close all
clc

data_path='C:\Honours\surveys\Profiles\P12\';

% Load data
Load the data- it refers to the profile data obtained with profile_maker

Prof_num=input('Enter profile number: ');

[d0705 d0805 d0807 d0810 d081213 d081218 d0903 d0905]=load_profile_SB(Prof_num);

% Determine origines.
% Determine 1st and 2nd point of May profile (determines line along May profile)
% and first point for each of the rest of the profiles to compare the distance relative to the first point of May as if the profiles were exactly along the same line.

[orig]=identify_origin_SB(d0705, d0805, d0807, d0810, d081213, d081218, d0903, d0905);

% Calculate distances along the line of the May 2007 profile
[corr_dist]=calc_dist_along09_SB(orig);

% Correct profiles!
% we need to add the value of corr_dist to each distance along the profiles so we obtain new corrected profiles

[profs]=correct_profiles_SB(d0705, d0805, d0807, d0810, d081213, d081218, d0903, d0905, corr_dist);

% Plot all profiles in one graph
plot_profiles_SB(profs, Prof_num)

% AHD analyses
% Analyse across-shore location of AHD and area above AHD (to obtain lineal volumes)

[AHD_data]=AHD_analyser_SB(profs, Prof_num);
%% TanB analyses
%Calculate tanB for each profile's beach face.

%pause
[tanB]=tanB_analyser_SB(profs, Prof_num);

%% Export data
%Need to export the data. The columns in OUT1 are 6: 'Year' 'Month'
'Distance to AHD' 'AHD' (to
%double check) 'Area above AHD' 'TanB'

format long g
out1=[AHD_data tanB];
[ofname,opname]=uiputfile([data_path '*.dat']);
save([opname ofname],'out1','-ascii');

figure
axes('XTickLabel',{'0705','0805','0807','0810','081213','081218','0903'
,'0905'});
box('on');
grid('on');
hold('all');
plot(out1(:,2),out1(:,5), 'k-x')
plot(out1(:,2),(out1(:,6)*1000), 'ko--')
legend('Area above AHD (m2)', 'TanB * 1000')
function [d0705 d0805 d0807 d0810 d0812 d0903 d0905]=load_profile_SB(Prof_num)

%Function created to load SB profile data
%
%works with profile_analyserSB

%Created by Ana Vila Concejo
%Sunday 21 October 2007
%Last modified Monday 10 March 2008
%Modified by Dan Harris 24 June 2009

data_path='C:\Honours\surveys\Profiles\P12\';

%May 2007 data

[fname0705,pname]=uigetfile([data_path 'P*0705*.csv'],...
'Get MAY data');

data_in0705=load([pname fname0705]);
d0705.x=data_in0705(:,1);
d0705.y=data_in0705(:,2);
d0705.d=data_in0705(:,3);
d0705.z=data_in0705(:,4);

%Nov 2007 data

% [fname0711,pname]=uigetfile([data_path 'P*0711*.csv'],...
% 'Get Nov data');
% 
%data_in0711=load([pname fname0711]);
%d0711.x=data_in0711(:,1);
d0711.y=data_in0711(:,2);
d0711.d=data_in0711(:,3);
d0711.z=data_in0711(:,4);

%May 2008 data

[fname0805,pname]=uigetfile([data_path 'P*0805*.csv'],...
'Get May data');

data_in0805=load([pname fname0805]);
d0805.x=data_in0805(:,1);
d0805.y=data_in0805(:,2);
d0805.d=data_in0805(:,3);
d0805.z=data_in0805(:,4);

%July 2008 data

[fname0807,pname]=uigetfile([data_path 'P*0807*.csv'],...
'Get JULY data');

data_in0807=load([pname fname0807]);
d0807.x=data_in0807(:,1);
d0807.y=data_in0807(:,2);
d0807.d=data_in0807(:,3);
d0807.z=data_in0807(:,4);

%Oct 2008 data
[fname0810,pname]=uigetfile([data_path 'P*0810*.csv'],...
'Get Oct data');
data_in0810=load([pname fname0810]);
d0810.x=data_in0810(:,1);
d0810.y=data_in0810(:,2);
d0810.d=data_in0810(:,3);
d0810.z=data_in0810(:,4);

%Dec 2008 data
[fname081213,pname]=uigetfile([data_path 'P*081213*.csv'],...
'Get Dec081213 data');
data_in081213=load([pname fname081213]);
d081213.x=data_in081213(:,1);
d081213.y=data_in081213(:,2);
d081213.d=data_in081213(:,3);
d081213.z=data_in081213(:,4);

%Dec 2008 data
[fname081218,pname]=uigetfile([data_path 'P*081218*.csv'],...
'Get Dec081218 data');
data_in081218=load([pname fname081218]);
d081218.x=data_in081218(:,1);
d081218.y=data_in081218(:,2);
d081218.d=data_in081218(:,3);
d081218.z=data_in081218(:,4);

%March 2009 data
[fname0903,pname]=uigetfile([data_path 'P*0903*.csv'],...
'Get May data');
data_in0903=load([pname fname0903]);
d0903.x=data_in0903(:,1);
d0903.y=data_in0903(:,2);
d0903.d=data_in0903(:,3);
d0903.z=data_in0903(:,4);

%May 2009 data
[fname0905,pname]=uigetfile([data_path 'P*0905*.csv'],...
'Get May data');
data_in0905=load([pname fname0905]);
d0905.x=data_in0905(:,1);
d0905.y=data_in0905(:,2);
d0905.d=data_in0905(:,3);
d0905.z=data_in0905(:,4);
function [orig]=identify_origin_SB(d0705, d0805, d0807, d0810, d081213, d081218, d0903, d0905)

% Determine origins.
% Determine 1st and 2nd point of March profile (determines line along March profile)
% and first point for each of the rest of the profiles to compare the %distance relative to the first point of March as if the profiles were %exactly along the same line.
% works with profile_analyser

%Created by Ana Vila Concejo
%Tuesday 23 October 2007
%Last modified Tuesday 4 February 2008
%Modified by Dan Harris Wednesday 24 June 2009

%0705- first point
orig.x07051=d0705.x(1,1);
orig.y07051=d0705.y(1,1);

%0705- second point
orig.x07052=d0705.x(2,1);
orig.y07052=d0705.y(2,1);

%0707- first point
%orig.x07071=d0707.x(1,1);
%orig.y07071=d0707.y(1,1);

%0710- first point
%orig.x07101=d0710.x(1,1);
%orig.y07101=d0710.y(1,1);

%0711- first point
%orig.x07111=d0711.x(1,1);
%orig.y07111=d0711.y(1,1);

%0805- first point
orig.x08051=d0805.x(1,1);
orig.y08051=d0805.y(1,1);

%0807- first point
orig.x08071=d0807.x(1,1);
orig.y08071=d0807.y(1,1);

%0810- first point
orig.x08101=d0810.x(1,1);
orig.y08101=d0810.y(1,1);

%081213- first point
orig.x0812131=d081213.x(1,1);
orig.y0812131=d081213.y(1,1);

%081213- first point
orig.x0812181=d081218.x(1,1);
orig.y0812181=d081218.y(1,1);

%0903- first point
orig.x09031=d0903.x(1,1);
orig.y09031=d0903.y(1,1);
%0905 - first point
orig.x09051=d0905.x(1,1);
orig.y09051=d0905.y(1,1);
function [corr_dist]=calc_dist_along09_SB(orig)

.%Calculates the distances that need to be corrected to all the points in
.%the profiles so they are calculated in relation to the first point in
.%May 2007 (our first campaign in Shoal Bay) and along the line defined
.%by the first
.%two points of May 2007.
.%It works with profile_analyser

.%Created by Ana Vila Concejo
.%Tuesday 23 October 2007
.%Last modified Thursday 13 March 2008
.%Modified by Dan Harris Wednesday 24 June 2009

.%Distance between the first two points of May
%d07101_07102=sqrt((orig.x07101-orig.x07102)^2 + (orig.y07101-
.orig.y07102)^2);
d07051_07052=sqrt((orig.x07051-orig.x07052)^2 + (orig.y07051-
.orig.y07052)^2);

.%Distance between the FIRST point in May and the first point of the
%remaining months
%d07051_07071=sqrt((orig.x07051-orig.x07071)^2 + (orig.y07051-
.orig.y07071)^2);
%d07051_07101=sqrt((orig.x07051-orig.x07101)^2 + (orig.y07051-
.orig.y07101)^2);
%d07051_07111=sqrt((orig.x07051-orig.x07111)^2 + (orig.y07051-
.orig.y07111)^2);
d07051_08051=sqrt((orig.x07051-orig.x08051)^2 + (orig.y07051-
.orig.y08051)^2);
d07051_08071=sqrt((orig.x07051-orig.x08071)^2 + (orig.y07051-
.orig.y08071)^2);
d07051_08101=sqrt((orig.x07051-orig.x08101)^2 + (orig.y07051-
.orig.y08101)^2);
d07051_0812131=sqrt((orig.x07051-orig.x0812131)^2 + (orig.y07051-
.orig.y0812131)^2);
%d07052_07071=sqrt((orig.x07052-orig.x07071)^2 + (orig.y07052-
.orig.y07071)^2);
%d07052_07101=sqrt((orig.x07052-orig.x07101)^2 + (orig.y07052-
.orig.y07101)^2);
%d07052_07111=sqrt((orig.x07052-orig.x07111)^2 + (orig.y07052-
.orig.y07111)^2);
d07052_08051=sqrt((orig.x07052-orig.x08051)^2 + (orig.y07052-
.orig.y08051)^2);
d07052_08071=sqrt((orig.x07052-orig.x08071)^2 + (orig.y07052-
.orig.y08071)^2);
d07052_08101=sqrt((orig.x07052-orig.x08101)^2 + (orig.y07052-
.orig.y08101)^2);
d07052_0812131=sqrt((orig.x07052-orig.x0812131)^2 + (orig.y07052-
.orig.y0812131)^2);
\[d_{07052_081218} = \sqrt{(\text{orig.x}_{07052} - \text{orig.x}_{081218})^2 + (\text{orig.y}_{07052} - \text{orig.y}_{081218})^2};\]

\[d_{07052_09031} = \sqrt{(\text{orig.x}_{07052} - \text{orig.x}_{09031})^2 + (\text{orig.y}_{07052} - \text{orig.y}_{09031})^2};\]

\[d_{07052_09051} = \sqrt{(\text{orig.x}_{07052} - \text{orig.x}_{09051})^2 + (\text{orig.y}_{07052} - \text{orig.y}_{09051})^2};\]

%Distance to correct July profile (relative to March)
\[
corr\_dist.july07 = \frac{(d_{07051_07052}^2 + d_{07051_07071}^2 - d_{07052_07071}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct OCT profile (relative to March)
\[
corr\_dist.oct07 = \frac{(d_{07051_07052}^2 + d_{07051_07101}^2 - d_{07052_07101}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct NOVEMBER profile (relative to March)
\[
corr\_dist.nov07 = \frac{(d_{07051_07052}^2 + d_{07051_07111}^2 - d_{07052_07111}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct MAY 2008 profile (relative to March)
\[
corr\_dist.may08 = \frac{(d_{07051_07052}^2 + d_{07051_08051}^2 - d_{07052_08051}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct JULY 2008 profile (relative to March)
\[
corr\_dist.july08 = \frac{(d_{07051_07052}^2 + d_{07051_08071}^2 - d_{07052_08071}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct OCTOBER 2008 profile (relative to March)
\[
corr\_dist.oct08 = \frac{(d_{07051_07052}^2 + d_{07051_08101}^2 - d_{07052_08101}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct DECEMBER 13 2008 profile (relative to March)
\[
corr\_dist.dec1308 = \frac{(d_{07051_07052}^2 + d_{07051_0812131}^2 - d_{07052_0812131}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct DECEMBER 13 2008 profile (relative to March)
\[
corr\_dist.dec1808 = \frac{(d_{07051_07052}^2 + d_{07051_0812181}^2 - d_{07052_0812181}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct MARCH 2009 profile (relative to March)
\[
corr\_dist.march09 = \frac{(d_{07051_07052}^2 + d_{07051_09031}^2 - d_{07052_09031}^2)}{2 \times \text{d}_{07051_07052}};
\]

%Distance to correct MAY 2009 profile (relative to March)
\[
corr\_dist.may09 = \frac{(d_{07051_07052}^2 + d_{07051_09051}^2 - d_{07052_09051}^2)}{2 \times \text{d}_{07051_07052}};
\]
function [profs]=correct_profiles_SB(d0705, d0805, d0807, d0810, d081213, d081218, d0903, d0905, corr_dist)
% Function created to work with profile analyser, it gets all the profile
% data and corrects the distances using the results from "%calc_dist_along05_SB.m. It creates an structure array that includes all data
% from the analysed profile.

% Created by Ana Vila Concejo
% Wednesday 24 October 2007
% Last modified Thursday 13 March 2008
% Modified by Dan Harris Wednesday 24 June 2009

% Corrects distance along profile
% d0707corr=d0707.d+corr_dist.july07;
% d0710corr=d0710.d+corr_dist.oct07;
% d0711corr=d0711.d+corr_dist.nov07;
% d0805corr=d0805.d+corr_dist.may08;
% d0807corr=d0807.d+corr_dist.july08;
% d0810corr=d0810.d+corr_dist.oct08;
% d081213corr=d081213.d+corr_dist.dec1308;
% d081218corr=d081218.d+corr_dist.dec1808;
% d0903corr=d0903.d+corr_dist.march09;
% d0905corr=d0905.d+corr_dist.may09;

% Creates new data arrays for each survey date
prof0705=[d0705.x d0705.y d0705.d d0705.z];
prof0707=[d0707.x d0707.y d0707corr d0707.z];
prof0710=[d0710.x d0710.y d0710corr d0710.z];
prof0711=[d0711.x d0711.y d0711corr d0711.z];
prof0805=[d0805.x d0805.y d0805corr d0805.z];
prof0807=[d0807.x d0807.y d0807corr d0807.z];
prof0810=[d0810.x d0810.y d0810corr d0810.z];
prof081213=[d081213.x d081213.y d081213corr d081213.z];
prof081218=[d081218.x d081218.y d081218corr d081218.z];
prof0903=[d0903.x d0903.y d0903corr d0903.z];
prof0905=[d0905.x d0905.y d0905corr d0905.z];

% Creates structure array with all data for the profile being analysed.
profs=struct('p0705', prof0705, 'p0805', prof0805, 'p0807', prof0807, ...
    'p0810', prof0810, 'p081213', prof081213, 'p081218', prof081218, ...
    'p0903', prof0903, 'p0905', prof0905);
function plot_profiles_SB(profs, Prof_num)

%Created by Ana Vila Concejo
%Wednesday 24 October 2007
%Last modified Thursday 13 March 2008
%Modified by Dan Harris Wednesday 24 June 2009

plot(profs.p0705(:,3), profs.p0705(:,4), '^ - k')
hold
plot(profs.p0707(:,3), profs.p0707(:,4), 'o - k')
plot(profs.p0710(:,3), profs.p0710(:,4), 'd - k')
plot(profs.p0711(:,3), profs.p0711(:,4), 'x - k')
plot(profs.p0805(:,3), profs.p0805(:,4), '< - k')
plot(profs.p0807(:,3), profs.p0807(:,4), '* - k')
plot(profs.p0810(:,3), profs.p0810(:,4), '> - k')
plot(profs.p081213(:,3), profs.p081213(:,4), 'v - k')
plot(profs.p081218(:,3), profs.p081218(:,4), 'x - k')
plot(profs.p0903(:,3), profs.p0903(:,4), 'p - k')
plot(profs.p0905(:,3), profs.p0905(:,4), 'h - k')

%pretty labels...
ylabel('Elevation (m)')
xlabel('Distance (m)')
grid
title(['Profile' num2str(Prof_num)])
legend('0705', '0805', '0807', '0810', '081213', '081218', '0903', '0905')

%to double check profile location on the beach
figure
plot(profs.p0705(:,1),profs.p0705(:,2), '^ - k')
hold
plot(profs.p0707(:,1),profs.p0707(:,2), 'o - k')
plot(profs.p0710(:,1),profs.p0710(:,2), 'd - k')
plot(profs.p0711(:,1),profs.p0711(:,2), 'x - k')
plot(profs.p0805(:,1),profs.p0805(:,2), '< - k')
plot(profs.p0807(:,1),profs.p0807(:,2), '* - k')
plot(profs.p0810(:,1),profs.p0810(:,2), '> - k')
plot(profs.p081213(:,1),profs.p081213(:,2), 'v - k')
plot(profs.p081218(:,1),profs.p081218(:,2), 'x - k')
plot(profs.p0903(:,1),profs.p0903(:,2), 'p - k')
plot(profs.p0905(:,1),profs.p0905(:,2), 'h - k')

% Pretty labelling stuff
set(gca,'dataaspectratio',[1 1 1])
set(gca,'yticklabel',num2str(get(gca,'ytick'))) 
set(gca,'xticklabel',num2str(get(gca,'xtick'))) 
xlabel('Eastings (m)')
ylabel('Northings (m)')
title(['Location for Profile ' num2str(Prof_num)])
legend('0705', '0805', '0807', '0810', '081213', '081218', '0903', '0905')
function [AHD_data]=AHD_analyser_SB(profs, Prof_num)
%To calculate area above AHD and cross-shore location of AHD in beach
%profiles. It works with profile_analyser and needs AHD_picker.

%Created by Ana Vila Concejo
%Wednesday 24 Oct 2007
%Last modified Thursday 13 March 2008

%% MAY DATA
    d=profs.p0705(:,3);
    z=profs.p0705(:,4);

    figure
    plot(d,z)

    [dd,zz]=AHD_picker(d,z);

    %Need to calculate area above AHD using polyarea
    %for that we need to define the polygon

    %NOTE: -10 is an arbitrary point located behind May 2007 so all the
    %profiles
    %start at the same point... will need to change if retreat is
    %larger than
    %10m behind march profile.
    dd4=[-10; dd];
    zz4=[zz(1); zz];

    poly_dd=[dd4; -10; -10];
    poly_zz=[zz4;0;zz4(1)];

    plot(poly_dd, poly_zz, 'r o')
    hold on
    area(poly_dd, poly_zz)
    a=polyarea(poly_dd, poly_zz);

    dAHD_0705=dd(length(dd));
    zAHD_0705=zz(length(zz));
    aAHD_0705=a;
    AHDo705=[2007 1 dAHD_0705 zAHD_0705 aAHD_0705];

%% NOVEMBER DATA
    %d=profs.p0711(:,3);
    %z=profs.p0711(:,4);

    %figure
    %plot(d,z)

    %[dd,zz]=AHD_picker(d,z);

    %Need to calculate area above AHD using polyarea
%for that we need to define the polygon

%NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
%start at the same point... will need to change if retreat is larger than
%10m behind march profile.

%dd4=[-10; dd];
%zz4=[zz(1); zz];

%poly_dd=[dd4; -10; -10];
%poly_zz=[zz4; 0; zz4(1)];

%plot(poly_dd, poly_zz, 'r o')
%hold on
%area(poly_dd, poly_zz)

%a=polyarea(poly_dd, poly_zz);

%dAHD_0711=dd(length(dd));
%zAHD_0711=zz(length(zz));
%aAHD_0711=a;
%AHD0711=[2007 4 dAHD_0711 zAHD_0711 aAHD_0711];

% May 2008 DATA
d=profs.p0805(:,3);
z=profs.p0805(:,4);

figure
plot(d,z)

[dd,zz]=AHD_picker(d,z);

% Need to calculate area above AHD using polyarea
% for that we need to define the polygon

%NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
%start at the same point... will need to change if retreat is larger than
%10m behind march profile.

dd4=[-10; dd];
zz4=[zz(1); zz];

poly_dd=[dd4; -10; -10];
poly_zz=[zz4; 0; zz4(1)];

plot(poly_dd, poly_zz, 'r o')
hold on
area(poly_dd, poly_zz)
a=polyarea(poly_dd, poly_zz);

dAHD_0805=dd(length(dd));
zAHD_0805=zz(length(zz));
aAHD_0805=a;
AHD0805=[2008 2 dAHD_0805 zAHD_0805 aAHD_0805];

%% July 2008 DATA
    d=profs.p0807(:,3);
    z=profs.p0807(:,4);
    figure
    plot(d,z)
    [dd,zz]=AHD_picker(d,z);
    %Need to calculate area above AHD using polyarea
    %for taht we need to define the ploygon
    %NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
    %start at the same point... will need to change if retreat is larger than
    %10m behind march profile.
    dd4=[-10; dd];
    zz4=[zz(1); zz];
    poly_dd=[dd4; -10; -10];
    poly_zz=[zz4;0;zz4(1)];
    plot(poly_dd, poly_zz, 'r o')
    hold on
    area(poly_dd, poly_zz)
    a=polyarea(poly_dd, poly_zz);
    dAHD_0807=dd(length(dd));
    zAHD_0807=zz(length(zz));
    aAHD_0807=a;
    AHD0807=[2008 3 dAHD_0807 zAHD_0807 aAHD_0807];

%% Oct 2008 DATA
    d=profs.p0810(:,3);
    z=profs.p0810(:,4);
    figure
    plot(d,z)
    [dd,zz]=AHD_picker(d,z);
    %Need to calculate area above AHD using polyarea
    %for taht we need to define the ploygon
    %NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
    %start at the same point... will need to change if retreat is larger than
    %10m behind march profile.
    dd4=[-10; dd];
zz4=[zz(1); zz];

poly_dd=[dd4; -10; -10];
poly_zz=[zz4;0;zz4(1)];

plot(poly_dd, poly_zz, 'r o')
hold on
area(poly_dd, poly_zz)

a=polyarea(poly_dd, poly_zz);

dAHD_0810=dd(length(dd));
zAHD_0810=zz(length(zz));
aAHD_0810=a;
AHD0810=[2008 4 dAHD_0810 zAHD_0810 aAHD_0810];

%% Dec 2008 DATA

d=profs.p081213(:,3);
z=profs.p081213(:,4);

figure
plot(d,z)

[dd,zz]=AHD_picker(d,z);

%Need to calculate area above AHD using polyarea
%for that we need to define the ploygon

%NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
%start at the same point... will need to change if retreat is larger than
%10m behind march profile.

dd4=[-10; dd];
zz4=[zz(1); zz];

poly_dd=[dd4; -10; -10];
poly_zz=[zz4;0;zz4(1)];

plot(poly_dd, poly_zz, 'r o')
hold on
area(poly_dd, poly_zz)

a=polyarea(poly_dd, poly_zz);

dAHD_081213=dd(length(dd));
zAHD_081213=zz(length(zz));
aAHD_081213=a;
AHD081213=[2008 5 dAHD_081213 zAHD_081213 aAHD_081213];

%% Dec 2008 DATA

d=profs.p081218(:,3);
z=profs.p081218(:,4);

figure
plot(d,z)
[dd,zz]=AHD_picker(d,z);

% Need to calculate area above AHD using polyarea
% for that we need to define the polygon

% NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
% start at the same point... will need to change if retreat is larger than
% 10m behind march profile.

dd4=[-10; dd];
zz4=[zz(1); zz];

poly_dd=[dd4; -10; -10];
poly_zz=[zz4; 0; zz4(1)];

plot(poly_dd, poly_zz, 'r o')
hold on
area(poly_dd, poly_zz)

a=polyarea(poly_dd, poly_zz);

dAHD_081218=dd(length(dd));
zAHD_081218=zz(length(zz));
aAHD_081218=a;
AHD081218=[2008 6 dAHD_081218 zAHD_081218 aAHD_081218];

% March 2009 DATA

d=profs.p0903(:,3);
z=profs.p0903(:,4);

figure
plot(d,z)

[dd,zz]=AHD_picker(d,z);

% Need to calculate area above AHD using polyarea
% for that we need to define the polygon

% NOTE: -10 is an arbitrary point located behind May 2007 so all the profiles
% start at the same point... will need to change if retreat is larger than
% 10m behind march profile.

dd4=[-10; dd];
zz4=[zz(1); zz];

poly_dd=[dd4; -10; -10];
poly_zz=[zz4; 0; zz4(1)];

plot(poly_dd, poly_zz, 'r o')
hold on
area(poly_dd, poly_zz)

a=polyarea(poly_dd, poly_zz);
dAHD_0903 = dd(length(dd));
zAHD_0903 = zz(length(zz));
aAHD_0903 = a;
AHD0903 = [2009 7 dAHD_0903 zAHD_0903 aAHD_0903];

%% May 2009 DATA
  d = profs.p0905(:,3);
  z = profs.p0905(:,4);

  figure
  plot(d, z)

  [dd, zz] = AHD_picker(d, z);

  % Need to calculate area above AHD using polyarea
  % for that we need to define the polygon

  % NOTE: -10 is an arbitrary point located behind May 2007 so all the
  % profiles
  % start at the same point... will need to change if retreat is
  % larger than
  % 10m behind march profile.

  dd4 = [-10; dd];
  zz4 = [zz(1); zz];

  poly_dd = [dd4; -10; -10];
  poly_zz = [zz4; 0; zz4(1)];

  plot(poly_dd, poly_zz, 'r o')
  hold on
  area(poly_dd, poly_zz)
  a = polyarea(poly_dd, poly_zz);

  dAHD_0905 = dd(length(dd));
  zAHD_0905 = zz(length(zz));
  aAHD_0905 = a;
  AHD0905 = [2009 8 dAHD_0905 zAHD_0905 aAHD_0905];

  % Close all figures
  display('Press any key to continue')
  pause

  close
  close
  close
  close

  % COMPILe ALL RESULTS
  [AHD_data] = [AHD0705; AHD0805; AHD0807; AHD0810; AHD081213; AHD081218; AHD0903; AHD0905];
function [dd, zz] = AHD_picker(d, z)  
% [dd, zz] = AHD_picker(d, z)  
% Created by Ana Vila Concejo  
% Sometime in October 2004  
% Last modified Sunday 7 October 2007  

[zm, mi] = min(z);  
lz = length(z);  

da = d(1:mi);  
za = z(1:mi);  
di1 = interp1(za(max(find(za > 0)):min(find(za < 0))),...  
    da(max(find(za > 0)):min(find(za < 0))), 0);  

% db = d(mi: lz);  
% zb = z(mi: lz);  
% di2 = interp1(zb(max(find(zb < 0)):min(find(zb > 0))),...  
%     db(max(find(zb < 0)):min(find(zb > 0))), 0);  

ii = find(z > 0);  

dd = [d(ii); di1];  
zz = [z(ii); 0];
function [tanB]=tanB_analyser_SB(profs, Prof_num)

%To calculate tanB (slope or gradient) for beach profiles. It works in
%combination with profile_analyser_SB

%Created by Ana Vila Concejo
%Wednesday 24 Oct 2007
%Last modified Thursday 13 March 2008

d=profs.p0705(:,3);
z=profs.p0705(:,4);

figure
plot(d,z, '- x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given
%the tidal range in the study area (microtidal), we would expect this
%limit to be approximately +-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));

tanB=dif_elevation/dif_distance;
tanB0705=tanB;
close

%% NOVEMBER 2007

d=profs.p0711(:,3);
z=profs.p0711(:,4);

figure
plot(d,z, '- x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given
%the tidal range in the study area (microtidal), we would expect this
%limit to be approximately +-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));
	%tanB=dif_elevation/dif_distance;
%tanB0711=tanB;
%close

%% May 2008

d=profs.p0805(:,3);
z=profs.p0805(:,4);

figure
plot(d,z ,' - x')
hold
plot(d, z , 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given
%the tidal range in the study area (microtidal), we would expect this
%limit to be approximately +/-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));

tanB=dif_elevation/dif_distance;
tanB0805=tanB;

close

%% July 2008

d=profs.p0807(:,3);
z=profs.p0807(:,4);

figure
plot(d,z ,' - x')
hold
plot(d, z , 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given
%the tidal range in the study area (microtidal), we would expect this
%limit to be approximately +/-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));

tanB=dif_elevation/dif_distance;
tanB0807=tanB;
close

%% Oct 2008

d=profs.p0810(:,3);
z=profs.p0810(:,4);

figure
plot(d,z, '- x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given %the tidal range in the study area (microtidal), we would expect this %limit to be approximately +-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));
tanB=dif_elevation/dif_distance;
tanB0810=tanB;

close

%% Dec 2008

d=profs.p081213(:,3);
z=profs.p081213(:,4);

figure
plot(d,z, '- x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given %the tidal range in the study area (microtidal), we would expect this %limit to be approximately +-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));
tanB=dif_elevation/dif_distance;
tanB081213=tanB;

close
%% Dec 2008

d=profs.p081218(:,3);
z=profs.p081218(:,4);

figure
plot(d,z, ' -x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given %the tidal range in the study area (microtidal), we would expect this %limit to be approximately +/-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));

tanB=dif_elevation/dif_distance;
tanB081218=tanB;
close

%% March 2009

d=profs.p0903(:,3);
z=profs.p0903(:,4);

figure
plot(d,z, ' -x')
hold
plot(d, z, 'o r')
grid

%Need to identify the upper and lower limit of the beach face; given %the tidal range in the study area (microtidal), we would expect this %limit to be approximately +/-1m around AHD

upper=input('Upper beachface limit: point number = ');
lower=input('Lower beachface limit: point number = ');

dif_elevation=abs((z(upper)-z(lower)));
dif_distance=abs((d(lower)-d(upper)));

tanB=dif_elevation/dif_distance;
tanB0903=tanB;
close

%% May 2009

d=profs.p0905(:,3);
z = profs.p0905(:,4);

figure
plot(d, z, '- x')
hold
plot(d, z, 'o r')
grid

% Need to identify the upper and lower limit of the beach face; given
% the tidal range in the study area (microtidal), we would expect this
% limit to be approximately ±1m around AHD

upper = input('Upper beachface limit: point number = ');
lower = input('Lower beachface limit: point number = ');

dif_elevation = abs((z(upper) - z(lower)));
dif_distance = abs((d(lower) - d(upper)));

tanB = dif_elevation / dif_distance;
tanB0905 = tanB;

close

% Gathering all data to export

[tanB] = [tanB0705; tanB0805; tanB0807; tanB0810; tanB081213; tanB081218; tanB0903; tanB0905];
A.4

Analysis of the historic storm data from Crowdy Head was done using the same script as Vila-Concejo et al. (2009b). Wavepower was analysed using standard linear wave theory and wave direction during storms was also assessed.
%PS_Storms
%CREADO PARA PROCESAR LOS DATOS DE TORRENTAS
%FACILITADOS POR MANLY HYDRAULICS LABORATORY
%CREADO POR ANA VILA CONCEJO
%THURSDAY 18 JANUARY 2007
%LAST MODIFIED THURSDAY 08 FEBRUARY 2007

clear

ana_data_path='C:\Documents and Settings\Ana\Mis documentos\Alterados\DATA\PortStephens\StudyArea_DATA\Wave_data'';

[fname,pname]=uigetfile([ana_data_path '*.dat'],...
 'Get data');
data_in=load([pname fname]);

%PARA CARGAR UN VECTOR POR COLUMNA
%PRIMERA COLUMNA, ASIGNE -1 PARA AQUELLAS TORRENTAS QUE NO FUERON
REGISTRADAS POR ENTERO
%EL RESTO DE LAS TORRENTAS TIENEN VALOR 0
complete=data_in(:,1);

%LAS COLUMNAS 2, 3 Y 4 ES LA FECHA (DD MM AA) DE INICIO DE LA TORRENTEA
%ASIGNO UN NOMBRE A CADA COLUMNA
yr_ini=data_in(:,4);
mth_ini=data_in(:,3);
day_ini=data_in(:,2);

%DEFINO FECHA DE INICIO EN FORMA VECTORIAL
date_ini=[yr_ini mth_ini day_ini];
%CONVIERTO A TIEMPO NUMERICO
date_ini_num=datenum(date_ini);

%REPITO EL MISMO PROCESO PARA LA FECHA EN LA QUE LA TORRENTE TERMINA;
%COLUMNAS
%5, 6 Y 7 (DD MM AA)
yr_nd=data_in(:,7);
mth_nd=data_in(:,6);
day_nd=data_in(:,5);
date_nd=[yr_nd mth_nd day_nd];
date_nd_num=datenum(date_nd);

%LAS SIGUIENTES COLUMNAS CORRESPONDEN AL NUMERO DE HORAS EN LAS QUE LA
ALTURA DE OLA
%SIGNIFICANTE EXCEDE UN DETERMINADO VALOR: POR EJEMPLO H>3M ES EL
NUMERO DE HORAS CON
%OLAS MAYORES DE 3M. LO EXPRESO EN CENTIMETROS PARA NO TENER QUE
ESCRIBIR DECIMALES
hrs_300cm=data_in(:,8);
hrs_350cm=data_in(:,9);
hrs_400cm=data_in(:,10);
hrs_450cm=data_in(:,11);
hrs_500cm=data_in(:,12);
hrs_550cm=data_in(:,13);
hrs_600cm=data_in(:,14);
hrs_650cm=data_in(:,15);
hrs_700cm=data_in(:,16);
hrs_750cm=data_in(:,17);
hrs_800cm=data_in(:,18);

%con estas columnas puedo calcular la duracion total EN HORAS de cada tormenta
storm_dur= hrs_300cm + hrs_350cm + hrs_400cm + hrs_450cm +
hrs_500cm + hrs_550cm + ...
+ hrs_600cm + hrs_650cm + hrs_700cm + hrs_750cm + hrs_800cm;

%puedo tambien calcular la Hs media ponderada para cada tormenta --
me he dado cuenta de que
%esta es la manera que MHL usa para calcular Pmean! al representar
ambos el resultado es casi
%igual
Hs_mn_wt= ((hrs_300cm*3) + (hrs_350cm*3.5) + (hrs_400cm*4) +
(hrs_450cm*4.5) + ... +
(hrs_500cm*5) + (hrs_550cm*5.5) + (hrs_600cm*6) +
(hrs_650cm*6.5) + ... +
(hrs_700cm*5) + (hrs_750cm*7.5) + (hrs_800cm*8))/storm_dur;

%continuo asignando las variables a cada columna

%Altura de ola significante de pico Hs_pk, media Hs_mn y maxima de pico Hmx_pk
Hs_pk=data_in(:,19);
Hs_mn=data_in(:,20);
Hmx_pk=data_in(:,21);

%Periodo medio significante y periodo medio de pico
Ts_mn=data_in(:,22);
Tpk_mn=data_in(:,23);

%Wave power de pico y medio
Ppk=data_in(:,24);
Pmn=data_in(:,25);

%Direccion del temporal
Dir=data_in(:,26);

%Utilizando Pmn y la duracion total de la tormenta podemos CALCULAR
wave power asociado
%a toda la tormenta
Ptot=Pmn.*storm_dur*60;

%Y hacer unos graficos. La funcion datetick lo que hace es colocar
la fecha en formato
%reconocible en lugar de la fechanumerica con la que trabaja
matlab. axis tight le dice
%que establezca los limites de acuerdo con los limites d elos
data. para el de direcciones
%establezco YO los limites de Y (0 y 360) y le digo donde colocar
las divisiones.
%debería ser capaz de introducir lineas con las fotos que estoy utilizando...
%introducir las fechas de las fotos AQUI:
stm51= datenum('26-oct-1951');
stm63= datenum('18-aug-1963');
stm72= datenum('09-sep-1972');
stm77= datenum('19-aug-1977');
stm86= datenum('19-apr-1986');
stm91= datenum('23-aug-1991');
stm93= datenum('02-mar-1993');
stm94= datenum('22-jun-1994');
stm96= datenum('06-dec-1996');
stm99= datenum('16-sep-1999');
stm01= datenum('22-sep-2001');
stm06= datenum('06-mar-2006');

subplot(2,1,1); plot(date_ini_num, Ptot); datetick('x'); grid on;
axis tight;
axis([-inf, inf, 0, 2800000]); set(gca,'fontsize',12);
ylabel('Wave power (J·m^-1·s^-1) per storm','fontsize',12);
title(fname);
%line([stm51 stm51],get(gca,'ylim'),'color','k')
%line([stm63 stm63],get(gca,'ylim'),'color','k')
%line([stm72 stm72],get(gca,'ylim'),'color','k')
%line([stm86 stm86],get(gca,'ylim'),'color','r')
%line([stm77 stm77],get(gca,'ylim'),'color','r')
%line([stm91 stm91],get(gca,'ylim'),'color','r')
%line([stm93 stm93],get(gca,'ylim'),'color','r')
%line([stm94 stm94],get(gca,'ylim'),'color','r')
%line([stm96 stm96],get(gca,'ylim'),'color','r')
%line([stm99 stm99],get(gca,'ylim'),'color','r')
%line([stm01 stm01],get(gca,'ylim'),'color','r')
%line([stm06 stm06],get(gca,'ylim'),'color','r')
%
%retire este grafico porque es practicamente igual que el de Ptot
%subplot(3,1,2); plot(date_ini_num, Hs_mn_wt); datetick('x',24);
grid on; axis tight;
subplot(2,1,2); plot(date_ini_num, Dir, '.'); datetick('x'); grid on; axis tight;
axis([-inf, inf, 0, 360]); set(gca,'ytick',[90 180 270 360],'fontsize',12)
xlabel('Dates of storm occurrences','fontsize',12);
ylabel('Wave direction (°N)','fontsize',12);
%line([stm51 stm51],get(gca,'ylim'),'color','k')
%line([stm63 stm63],get(gca,'ylim'),'color','k')
%line([stm72 stm72],get(gca,'ylim'),'color','k')
%line([stm86 stm86],get(gca,'ylim'),'color','r')
%line([stm77 stm77],get(gca,'ylim'),'color','r')
%line([stm91 stm91],get(gca,'ylim'),'color','r')
%line([stm93 stm93],get(gca,'ylim'),'color','r')
%line([stm94 stm94],get(gca,'ylim'),'color','r')
%line([stm96 stm96],get(gca,'ylim'),'color','r')
%line([stm99 stm99],get(gca,'ylim'),'color','r')
%line([stm01 stm01],get(gca,'ylim'),'color','r')
%line([stm06 stm06],get(gca,'ylim'),'color','r')
Appendix B

Climate and Morphological Figures

Appendix B includes figures that were not crucial to the results in Section 4 but are part of the subsequent discussion and analysis of beach change. Wind data over the survey period is contained in the first figure (Figure B.1) with hydrodynamic data for each deployment in Figures B.2 and B.3.
Figure B.1 Wind speed and occurrence in each quadrant with wind data at 09:00am in the top figure and data from 15:00pm in the lower. NW winds dominate in the morning with SE dominating in the afternoon in summer and WNW in winter. Strongest winds are observed in the NW quadrant.
Figure B.2 Hydrodynamic data for each deployment including, water elevation (tidal cycle), current data (cross- and long-shore), wave data (H<sub>s</sub> and T<sub>z</sub>) and entrainment results.

a) represents deployment at SB1 on 22/07/08 and b) 23/07/08
Figure B.2 cont with c) SB1 on 24/07/08 and d) SB3 on 22/07/08
Figure B.2 cont e) SB3 on 23/07/08 and f) SB3 on 24/07/08
Figure B.2 cont g) SB1 on 13/12/08 and h) SB1 on 14/12/08
Figure B.2 cont i) SB1 on 16/12/08 and j) SB1 on 17/12/08
Figure B.2 cont k) SB3 on 13/12/08 and j) SB3 on 14/12/08
m)  

Figure B.2 cont m) SB3 on 16/12/08 and n) SB3 on 17/12/08
Figure B.3 Current data from SB2 with long shore and cross-shore currents on the 13/12/08 in a) and 14/12/08 b)
Figure B.3 SB2 current data continued with c) 16/12/08.
Aerial photographs of Shoal Bay

18/08/63

11/11/77