Analysis of shoreline variability, seasonality and erosion/accretion trends Dec 05 - May 06 report 4 Palm Beach coastal imaging system

Author:
Turner, I. L.

Publication details:
Report No. UNSW Water Research Laboratory Technical Report No. 2006/14

Publication Date:
2006

DOI:
https://doi.org/10.4225/53/58d4a29d60005

THE UNIVERSITY OF NEW SOUTH WALES
water
research
laboratory
Manly Vale N.S.W. Australia

ANALYSIS OF SHORELINE VARIABILITY AND EROSION/ACCRETION TRENDS: DECEMBER 2005 - MAY 2006

REPORT 4
PALM BEACH COASTAL IMAGING SYSTEM

by

I L Turner

Technical Report 2006/14
June 2006

ANALYSIS OF SHORELINE VARIABILITY AND EROSION/ACCRETION TRENDS: DECEMBER 2005 – MAY 2006

REPORT 4
PALM BEACH COASTAL IMAGING SYSTEM

WRL Technical Report 2006/14 June 2006

by

I L Turner

https://doi.org/10.4225/53/58d4a29d60005

Water Research Laboratory
School of Civil and Environmental Engineering
University of New South Wales ABN 57 195 873 179
King Street
Manly Vale NSW 2093 Australia

Telephone: +61 (2) 9949 4488
Facsimile: +61 (2) 9949 4188

Technical Report No	2006/14
Report Status	FINAL
Date of Issue	June 2006
WRL Project No.	02114.02
Project Manager	Ian L Turner

Title	Analysis of Shoreline Variability and Erosion/Accretion Trends: December 2005 – May 2006 Report 4 - Palm Beach Coast Coastal Imaging System
Author(s)	Ian L Turner
Client Name	Gold Coast City Council
Client Address	135 Bundall Road SURFERS PARADISE QLD 4217
Client Contact	John McGrath/Greg Stuart
Client Reference	

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

This report was prepared by the Water Research Laboratory (WRL), of the University of New South Wales for Gold Coast City Council (GCCC). It is the fourth in a series of six-monthly reports, to describe, quantify and analyse the regional-scale coastline variability and erosion/accretion trends that occur at Palm Beach, Queensland, Australia. It is intended that this growing database of qualitative and quantitative coastal monitoring information will inform and enhance the current and future management of the Palm Beach embayment.

1.1 General

In June of 2004, an ARGUS coastal imaging system became operational at the Palm Beach site for an initial period of three years. This leading-edge technology was selected by Gold Coast City Council to provide regional-scale, continuous and long-term monitoring of this central Gold Coast coastal embayment. It is the ability to provide quantitative as well as qualitative information that distinguishes the ARGUS coastal imaging system from conventional 'webcam' or 'surfcam' technology.

The Gold Coast was the first of a growing number of coastal management sites in Australia that now utilise coastal imaging technology and associated digital image analysis techniques to monitor regional-scale coastal response to natural and engineered coastal impacts. A coastal imaging station has been operating at Surfers Paradise to the north of the Palm Beach site since 1999, and in 2002 four ARGUS coastal imaging stations were installed along the southern Gold Coast, to assist with the operation and monitoring of the Tweed River sand by-passing system.

The analysis of beach changes during the preceding six-month monitoring periods are detailed in:

- WRL Report 2004/38: June 2004 to November 2004 (Turner, 2004)
- WRL Report 2005/22: December 2004 to May 2005 (Turner, 2005)
- WRL Report 2005/36: June 2005 to November 2005 (Turner, 2006)

Electronic copies of all monitoring reports are made freely available for public viewing and download in PDF format at:

→ *www.wrl.unsw.edu.au/coastalimaging/palmqld* (link: monitoring reports)

The purpose of this fourth report is to present the results of shoreline change analysis and erosion/accretion trend analysis for the six-month monitoring period December 2005 to May 2006, and to assess the net changes that have occurred within the Palm Beach embayment since the commencement of the monitoring program 24 months ago in June 2004.

1.2 Maintenance, Upgrades and Operational Issues

In September 2005 the Body Corporate of the Royal Palm Building (atop which the Palm Beach ARGUS station is housed) requested that the cameras be temporarily removed while major roof restoration works were undertaken at the site. The ARGUS station was turned off on September 16th, and re-installed again on 12th December 2005. Unfortunately, unscheduled rectification works to correct several defects in the roof repairs necessitated the moving of the cameras again on the 19th December. Defect repairs continued through January 2006, with the ARGUS station finally re-installed and re-surveyed on 31st January 2006.

A major coastal storm struck the Gold Coast in early March 2006 (refer Section 5.2.4) and the electrical system within the host building suffered damage, causing a failure of the ARUGUS power supply. This was subsequently repaired and the system became operational again in the second half of March.

As the result of the roof defect works and power outage, images and analysis are not available for a total of approximately two months of the present six-month monitoring period.

1.3 Report Outline

Following this introduction, Section 2 of this report provides a brief description of the Palm Beach embayment, and an overview of engineering works completed at Palm Beach since commencement of the monitoring program in mid 2004.

Section 3 contains a summary description of the ARGUS coastal imaging system, including the image types that are collected on a routine basis, and an overview of the digital image processing techniques used to analyse the images. The reader requiring more detailed information is referred to Report 1 Palm Beach Coastal Imaging System entitled *System Description, Analysis of Shoreline Variability and Erosion/Accretion Trends: June 2004 - November 2005* (Turner, 2004).

The web site which is used to promote and distribute the images collected by this monitoring program is introduced in Section 4. Description includes the web-based image archive that provides unrestricted public access to all images, weekly-updated quantitative analysis of current coastline conditions, and 'time-lapse' animation files that can be generated on-demand by GCCC staff.

Section 5 introduces the beach morphodynamic classification model of Wright and Short (1983), which is then used to describe in a qualitative manner the beach changes observed using the time-series of daily images for the six month period covered by this report.

The quantitative analysis of shoreline change for the current monitoring period is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total 24 month period since monitoring commenced in mid 2004.

The application of an image analysis technique that enables patterns of beach erosion and accretion to be identified and quantified along the Palm Beach embayment on a regular (monthly) basis is presented in Section 8. Section 9 summarises the major findings of this fourth six-monthly monitoring period at Palm Beach.

2. BACKGROUND

2.1 Environmental Setting

Palm Beach is located along the central Gold Coast, south-east Queensland (Figure 2.1). The 5 km long embayment is located between Burleigh Headland to the north and Currumbin Headland to the south. As shown in Figure 2.2, the southern training wall of Tallebudgera Creek adjacent to Burleigh Headland marks the northern extent of the sandy beach. The trained entrance to Currumbin Creek and associated sand shoals, adjacent to Currumbin Headland, occur at the southern end of the Palm Beach embayment. Palm Beach is typical of the Gold Coast, with beachfront development running the length of the beach, and the beach patrolled by three surf life saving clubs along the oceanfront. In addition to the creek training walls at both the northern and southern ends of the embayment, two short rubble-mound groynes have been constructed, the northern groyne located at 21st Street, and the more southern groyne at 11th Street. A near-continuous and largely buried boulder wall runs the length of the beach from Tallebudgera Creek in the north, to the sand spit adjacent to Currumbin Creek in the south.

2.2 Nearshore Sand Nourishment

The monthly volumes of sand nourishment and the placement of this sand resource along the southern region of the Palm Beach embayment are summarised in Figure 2.3. The lower panel shows the location of the nearshore "dump boxes". The upper panel shows the volume of sand placed per month.

2.2.1 2004 Campaign

A campaign of nearshore sand nourishment commenced in April 2004 and was completed in December 2004. The first stage of sand nourishment was undertaken during April and May, and the second stage from October to December. This campaign of sand nourishment, sourced from offshore sand resources, comprised a total of **145,445 m^3**.

2.2.2 2005/2006 Campaign

From June to September 2005 a total of **22,870 m^3** of sand dredged from the entrance to the Tweed River was placed within the nearshore at Palm Beach. Commencing in October sand was sourced from the offshore region of the Palm Beach embayment, and during October 2005 – April 2006 a total of **240,217 m^3** of this sand was placed within the nearshore. Referring to Figure 2.3, since June 2004 approximately **385,668 m^3** of sand had been placed within the nearshore region of the Palm Beach embayment through to the end of April 2006.

2.3 Placement of Currumbin Creek Dredge Material

Gold Coast City Council maintains a program to dredge the lower estuaries of Currumbin and Tallebudgera Creeks every year, and to use the sand from Currumbin Creek to nourish the beachface at the southern end of Palm Beach.

2.3.1 July – September, 2004

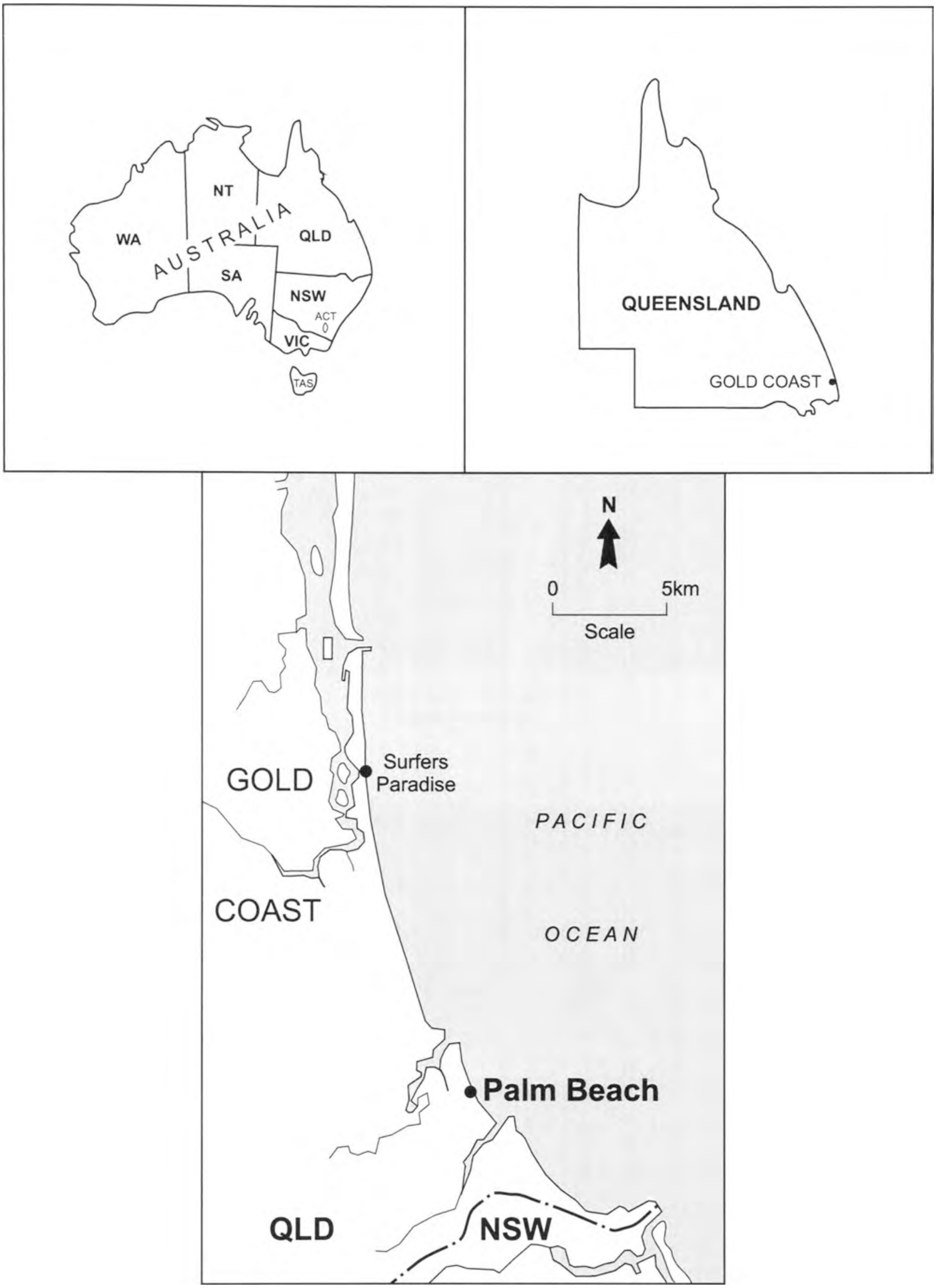
From July to September 2004 sand from Currumbin Creek was placed along the beachfront at the southern end of the Palm Beach embayment. The location of this sand placement is shown in Figure 2.4 (upper panel), along the sand spit that separates the creek from the ocean. In total, **28,946 m^3** of sand was placed during the six week period 19/7/04 to 2/9/04. Sand was placed at the rate of approximately 110 m^3 per hour generally between 6 am and 6 pm, with the outlet pipe being moved 20 m southward, every two working days.

2.3.2 April - June, 2005

From April to June 2005 an additional **26,493 m^3** of sand was placed at a single discharge point, shown in Figure 2.4 (lower panel). Daily delivery rates varied between approximately 200 m^3 and 1100 m^3 per day, with the engineering works being completed between 6 am and 6 pm.

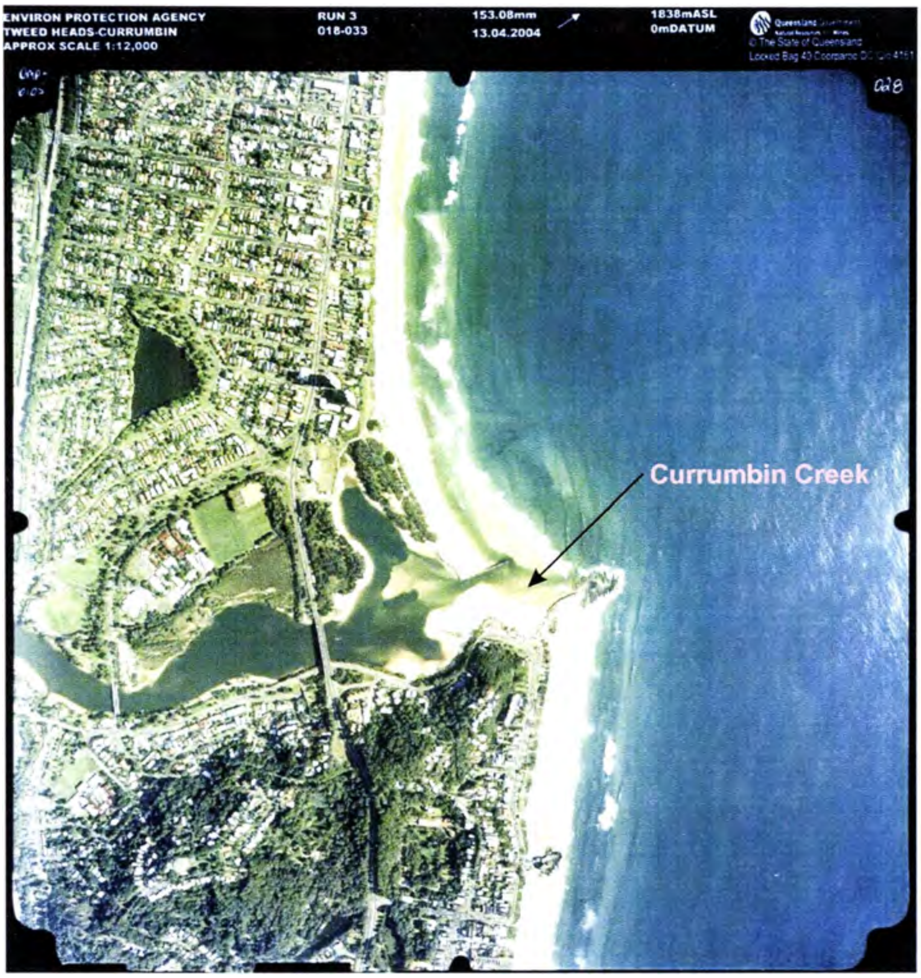
2.3.3 November – December, 2005

During the period 30th November to 14th December 2005 a further **11,593 m^3** of sand from the Currumbin Creek entrance was placed at the southern end of the Palm Beach embayment.

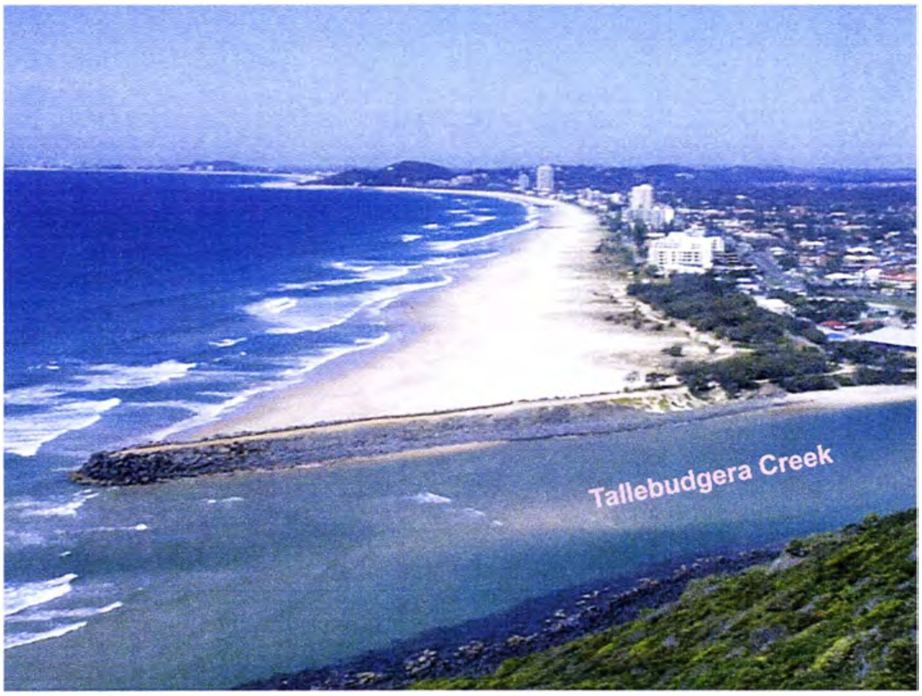


WRL Report No. 2006/14	LOCALITY	Figure 2.1

02114-2-1.cdr

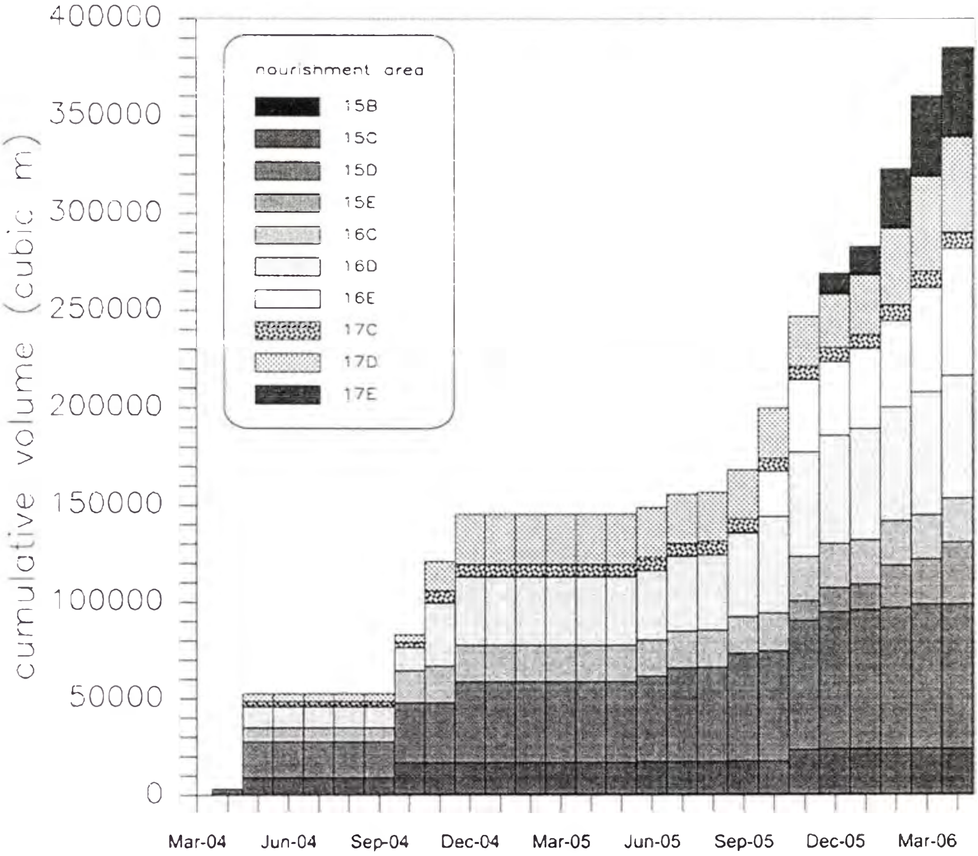


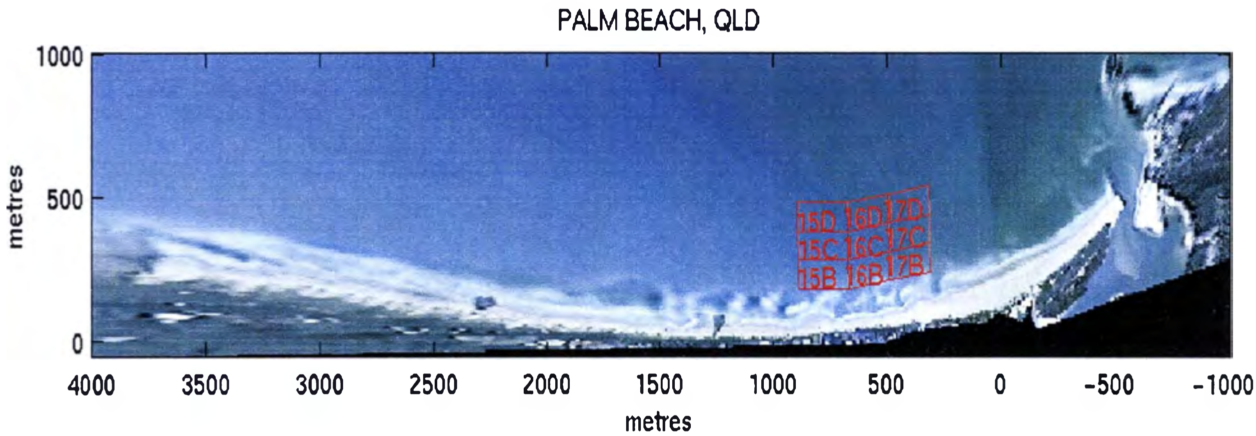
Palm Beach Embayment,
Southern Portion



Palm Beach Embayment
viewed from North

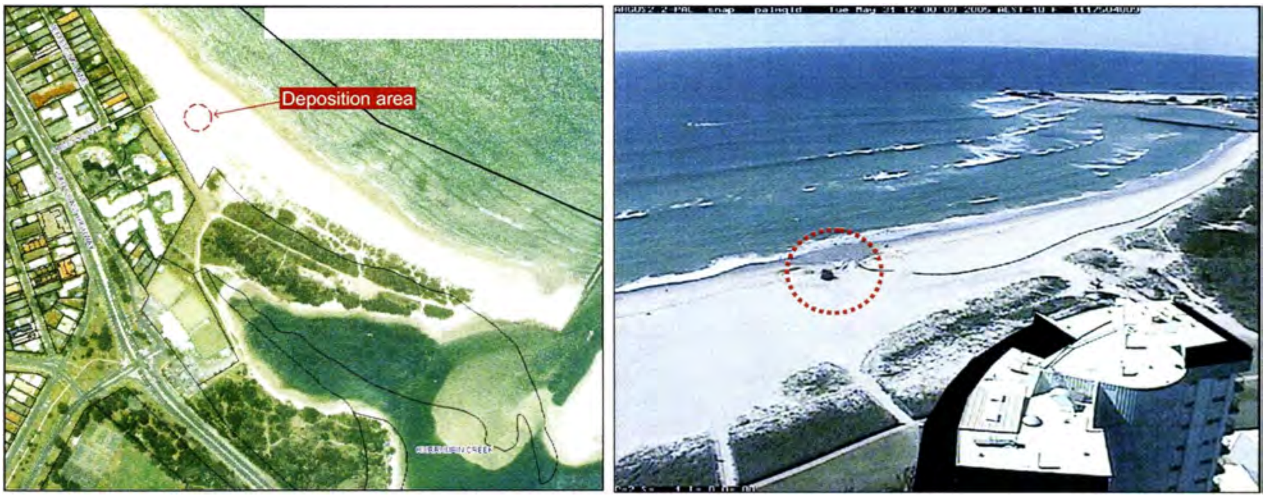
WRL Report No. 2006/14	PALM BEACH, GOLD COAST, QUEENSLAND	Figure 2.2 02114-2-2.cdr





WRL Report No. 2006/14	NEARSHORE NOURISHMENT DEPOSITION AREAS AND VOLUMES	Figure 2.3 02114-2-3.cdr

SAND PLACEMENT - 2004



SAND PLACEMENT - 2005

WRL Report No. 2006/14	PLACEMENT OF CURRUMBIN CREEK DREDGE MATERIAL	Figure 2.4

02114-2-4.cdr

3. OVERVIEW OF COASTAL IMAGING, IMAGE TYPES AND IMAGE PROCESSING METHODS

Comprehensive descriptions of the Palm Beach coastal imaging system, image types and image processing techniques were detailed in the first Palm Beach coastal imaging report *System Description, Analysis of Shoreline Variability and Erosion/Accretion Trends: June 2004 - November 2005* (Turner, 2004). For the sake of completeness, the following section provides a brief summary of the system and the image processing techniques being used to quantify beach changes.

3.1 What is Coastal Imaging?

'Coastal imaging' simply means the automated collection, analysis and storage of pictures that are then processed and analysed to observe and quantify coastline variability and change.

Aerial photography has been the tool most commonly used by coastal managers to monitor regional-scale coastal behaviour. This is expensive and as a result, coverage is often 'patchy' and incomplete. Pictures are only obtained when visibility from the airplane is satisfactory, often resulting in a limited number of suitable pictures per year (at most), with no information about the behaviour of the beach between flights.

In contrast, with the recent development of digital imaging and analysis techniques, one or more automated cameras can be installed at a remote site and, via a telephone or internet connection, be programmed to collect and transfer to the laboratory a time-series of images. These images, taken at regular intervals every hour of the day for periods of months and years, can cover several kilometres of a coastline. Not every image need be subjected to detailed analysis, but by this method the coastal manager can be confident that all 'events' will be recorded and available for more detailed analysis as required.

3.2 The Difference between Coastal Imaging and a 'Surfcam'

At the core of the coastal imaging technique is the ability to extract quantitative data from a time-series of high quality digital images. In contrast, conventional 'surfcams' are very useful to applications where a series of pictures of the coastline is sufficient, and these types of images can be used to develop a qualitative description of coastal evolution.

The extraction of quantitative information from the coastal imaging system is achieved by careful calibration of the cameras and the derivation of a set of mathematical equations that are used to convert between two-dimensional image coordinates and three-dimensional ground (or 'real world') coordinates (refer Turner, 2004). Sophisticated digital image processing techniques are then applied to extract and quantify information contained within the images.

3.3 The ARGUS Coastal Imaging System

The ARGUS coastal imaging system has developed out of fifteen years of ongoing research effort based at Oregon State University, Oregon USA (Holman et al., 1993). A schematic of a typical ARGUS station is shown in Figure 3.1. The key component of an ARGUS station is one or more cameras pointed obliquely along the coastline. The camera(s) are connected to a small image processing computer (Silicon Graphics SGI workstation), which controls the capture of images, undertakes pre-processing of images, and automatically transfers the images via the internet from the remote site to the laboratory. The cameras installed at Palm Beach are fitted with high quality lenses. A switching interface between the cameras and computer maintains synchronisation of the captured images. The SGI workstation incorporates an internal analogue I/O card that enables all images to be captured, stored and distributed in standard JPEG digital image file format.

At WRL, a dedicated host computer (dual-processor Linux workstation) stores all images as they are received from the remote site within a structured archive. This workstation is also integrated to a world-wide-web server, with the images made available to all visitors to the web site to view and download within minutes of their capture and transfer from Palm Beach to WRL. Post-processing of the images is completed using a variety of Linux and PC computer hardware and custom image processing software within the MATLAB programming environment.

3.4 Installation at Palm Beach

The ARGUS coastal imaging system was installed at Palm Beach in late May 2004. The system is located at an elevation of approximately 80m above mean sea level, within the roof services area of the Royal Palm building (Figure 3.2). The Royal Palm is located approximately 50m - 100m landward of the frontal dune, approximately 500m to the north of the Currumbin Creek entrance.

The cameras are mounted externally on a single frame that stands on the roof of the building, and are protected within weatherproof housings (Figure 3.3). The SGI workstation is housed within a pump services room, where 240 V power and a dedicated phone line connection to the internet are provided. The system is designed to run autonomously, and is self-recovering should an interruption to the mains power supply occur. Routine maintenance of the system is achieved by connection to the remote system via the internet from WRL. Occasional cleaning of the camera lenses is required.

3.5 Image Types

The ARGUS coastal imaging system installed at Palm Beach is presently configured to collect three different types of images on a routine hourly basis. A fourth image type is created by automated post-processing at the completion of each day of image collection.

Images are collected every daylight hour. The image collection procedure is fully automated and controlled by the SGI workstation at the remote site. Prior to commencing the hourly image collection routines, a test is undertaken to determine if there is sufficient daylight to proceed with image collection. If the ambient light threshold is exceeded, image collection commences. The reason for first checking for daylight conditions is to avoid unnecessary image collection at night, without excluding image collection earlier in the morning and later in the evening during extended summer daylight hours.

3.5.1 Snap-Shot 'snap' Images

The simplest image type is the snap-shot image. This is the same image obtained if a picture of the beach were taken using a conventional digital camera. Snap-shot images provide simple documentation of the general characteristics of the beach, but they are not so useful for obtaining quantitative information. An example of a snap image obtained in May 2006 is shown in Figure 3.4 (upper panel).

3.5.2 Time-Exposure 'timex' Images

A much more useful image type is the time-exposure or 'timex' image. Time-exposure images are created by the 'averaging' of 600 individual snap-shot images collected at the rate of one picture every second, for a period of 10 minutes.

A lot of quantitative information can be obtained from these images. Time exposures of the shore break and nearshore wave field have the effect of averaging out the natural variations of breaking waves, to reveal smooth areas of white, which has been shown to provide an excellent indicator of the shoreline and nearshore bars. In this manner, a quantitative 'map' of the underlying beach morphology can be obtained. An example of a timex image is shown in Figure 3.4 (middle panel).

3.5.3 Variance 'var' Images

At the same time that the timex images are being collected, an image type called a variance or 'var' image is also created. Whereas the time-exposure is an 'average' of many individual snap-shot images, the corresponding variance image displays the variance of light intensity during the same 10 minute time period.

Variance images can assist to identify regions which are changing in time, from those which may be bright, but unchanging. For example, a white sandy beach will appear bright on both snap-shot and time-exposure images, but dark in variance images. Because of this, other researchers have found that variance images are useful at some specific coastal sites for analysis techniques such as the identification of the shoreline, as the (bright) changing water surface is readily identifiable against the (dark) beach. An example of a var image is shown in Figure 3.4 (lower panel).

3.5.4 Day Time-Exposure 'daytimex' Images

The fourth image type routinely created from the coastal imaging system installed at Palm Beach is referred to as a daytimex image. It is created at the end of each day of image collection, by the averaging of all hourly timex images collected that day. This has the effect of 'smoothing' the influence of tides, and for some conditions may enhance the visibility of the shore break and bar features in the nearshore.

3.6 Basic Image Processing – Merge and Rectification

As noted earlier in Section 3.2, the key feature of coastal imaging technology that distinguishes it from conventional webcam systems is the ability to extract quantitative information from the images. As described previously, this is achieved through the solution of the camera model parameters to extract 3-D real-world position from 2-D image coordinates, and the application of image processing techniques to identify, enhance and manipulate the image features of interest.

Image merging is achieved by the solution of camera model parameters for individual cameras, then the boundaries of each image are matched to produce a single composite image. Image rectification is then undertaken, whereby the dimensions of the merged image are corrected so that each pixel represents the same area on the ground, irrespective of how close to, or how far from, the camera position it may be. (In contrast, for an unrectified image the area represented by each pixel increases with increasing distance from the camera.)

Image rectification is achieved by using the calculated camera model parameters to fit an image to a regular grid that defines longshore and cross-shore distance. The rectification of merged images produces a 'plan view' of the area covered by all four cameras. This is illustrated in Figure 3.5. Also shown in this figure is a 'pan' image, which provides an alternative wide-angle (but distorted) image of the coastline. The merged and rectified plan image created from five oblique images is analogous to a montage of distortion-corrected photographs taken from an airplane flying directly overhead Palm Beach. For convenience, the longshore and cross-shore dimensions of this image are referenced (in metres) to the location of the cameras. The pixel resolution of the merged/rectified images created at Palm Beach is 5 m; that is, a single pixel represents an area 5 m × 5 m on the ground.

3.7 Shoreline Detection and Analysis

To map the position of the shoreline and its changing location through time, a rigorous image analysis methodology is required to enable the extraction of this information from the database of hourly ARGUS images.

3.7.1 Pixel Intensity Clustering

The shoreline mapping methodology used at Palm Beach utilises the full colour information available from ARGUS images. Called 'Pixel Intensity Clustering' or 'PIC', the technique aims to delineate a shoreline feature from 10 minute time exposure images, on the basis of distinctive image intensity characteristics in pixels, sampled across the sub-aqueous and sub-aerial beach. Raw image intensities in Red-Green-Blue (RGB) colour-space, sampled from a region of interest across both the dry and wet beach, are converted to Hue-Saturation-Value (HSV) colour space, to separate colour (Hue, Saturation) and grey scale (Value) information. The HSV intensities are filtered to remove outliers and scaled between 0 and 1, to improve the contrast between two clusters of dry and wet pixels. Iterative low-passing filtering of the spiky histogram of scaled intensity data yields a smooth histogram with two well-pronounced peaks P_{dry} and P_{wet}, which mark the locations of the two distinct clusters of dry and wet pixels (Figure 3.6).

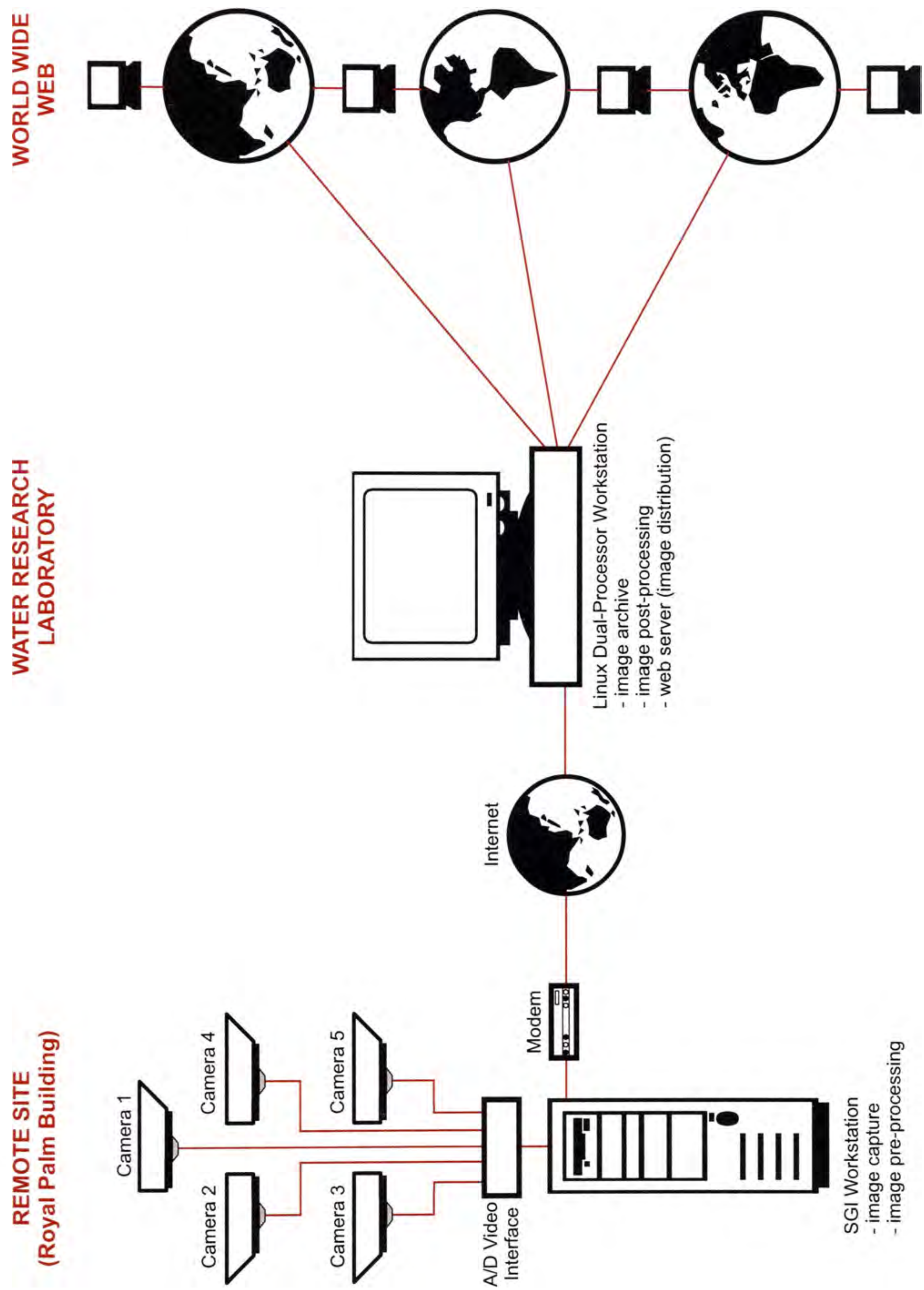
The filtered histogram is used to define a line to distinguish between Hue Saturation information used for colour discrimination (Figure 3.6a), or Value information in the case of luminance-based discrimination (Figure 3.6b). For both discriminators, the line defined in this manner crosses the saddle point of the filtered histogram, and thus provides the means to separate objectively the two clusters of dry and wet pixels within the region of interest. With the help of this line, a discriminator function Ψ is defined such that $\Psi = 0$ along this line (see Figure 3.6). The areas of dry and wet pixels are then mapped, and the boundary between the two regions defines the resulting shoreline feature of interest. Comprehensive description of the PIC shoreline identification technique is provided in Aarninkhof (2003), Aarninkhof and Roelvink (1999) and Aarninkhof et al (2003).

3.7.2 Standardised Procedure for Shoreline Mapping

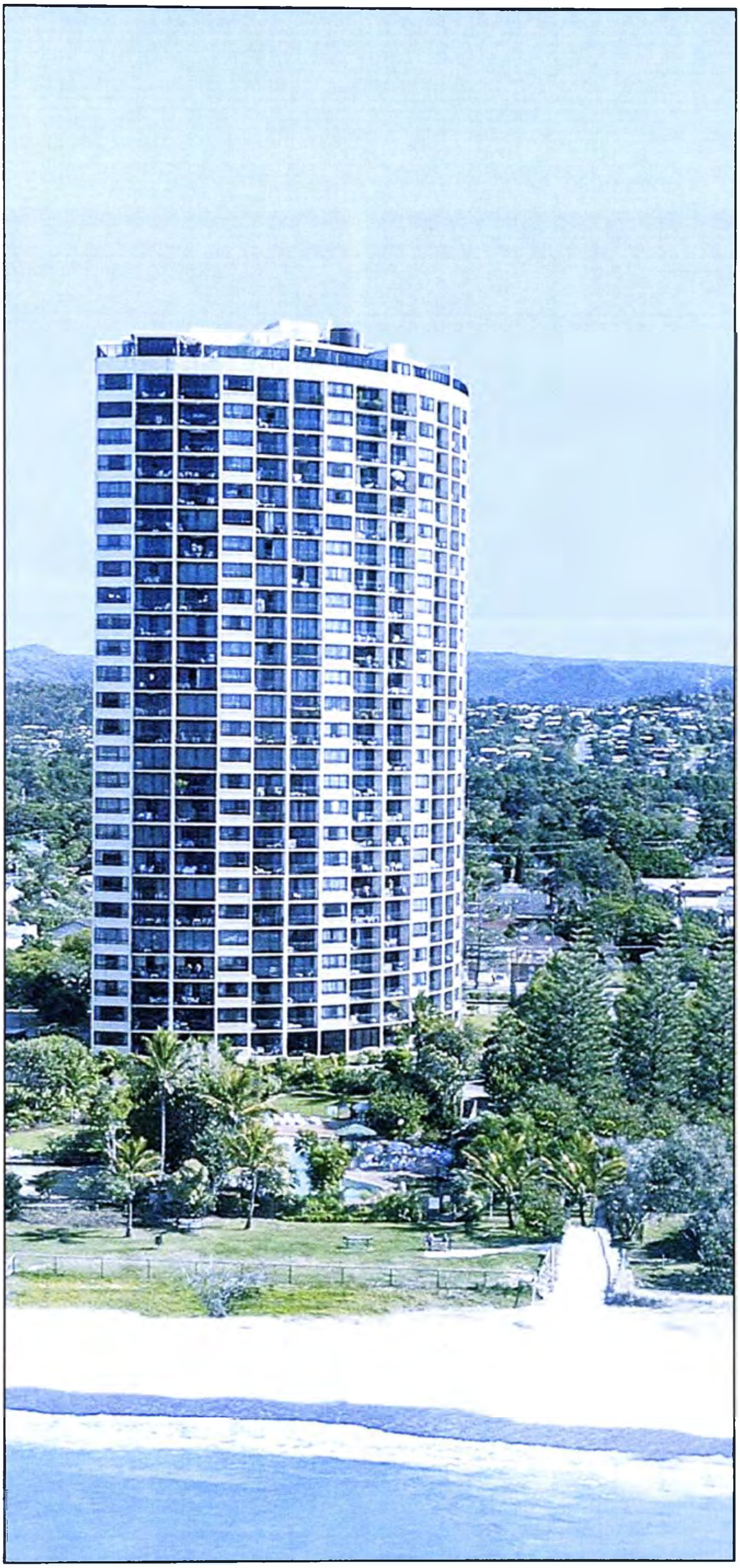
The procedure used to map the shoreline at the Palm Beach is summarised in Figure 3.7. At weekly (nominal seven day) intervals, observed tide information is used to determine the hourly timex images that correspond to mid-tide (0 m AHD). The corresponding merged-rectified 5-camera image is then created. The database of wave information is also searched to determine the rms ('root mean square') wave height (H_{rms}) and spectral peak wave period (T_p) that correspond to these daily mid-tide images.

Based on a seven day cycle, the corresponding mid-tide image is checked to confirm that the wave height satisfies the low-pass criteria $H_{rms} \leq 1.0$ m (Hs $\leq \sim 1.4$ m). This wave height criteria is used for shoreline mapping as, above this wave height, wave run-up at the beachface increases and the width of the swash zone widens, introducing a corresponding uncertainty in the cross-shore position of the waterline. If the rms wave height is less than 1.0 m, then the shoreline is mapped. If the wave height exceeds the $H_{rms} = 1.0$ m threshold, then the mid-tide image for the preceding day is checked. If this image still does not satisfy the wave height criteria, then the following day's mid-tide image is checked. This process is repeated for up to $\pm$ 3 days from the original target weekly image, to locate a mid-tide image for which the rms wave height did not exceed 1.0 m. If no mid-tide images are available in any one seven day cycle that satisfy this criteria, then no shoreline is mapped for that week.

Once the mid-tide image to be processed has been identified, the PIC method is applied and the shoreline feature is mapped. Beach width is then calculated relative to the alignment of the existing boulder wall. By repeating this procedure every seven days, a growing database is developed that contains the time-series of weekly shoreline positions at all positions along the shore. These data are then subjected to a range of analyses as described in the following Sections 6, 7 & 8.



WRL Report No. 2006/14	SCHEMATIC OF AN ARGUS COASTAL IMAGING SYSTEM	Figure 3.1 02114-3-1.cdr



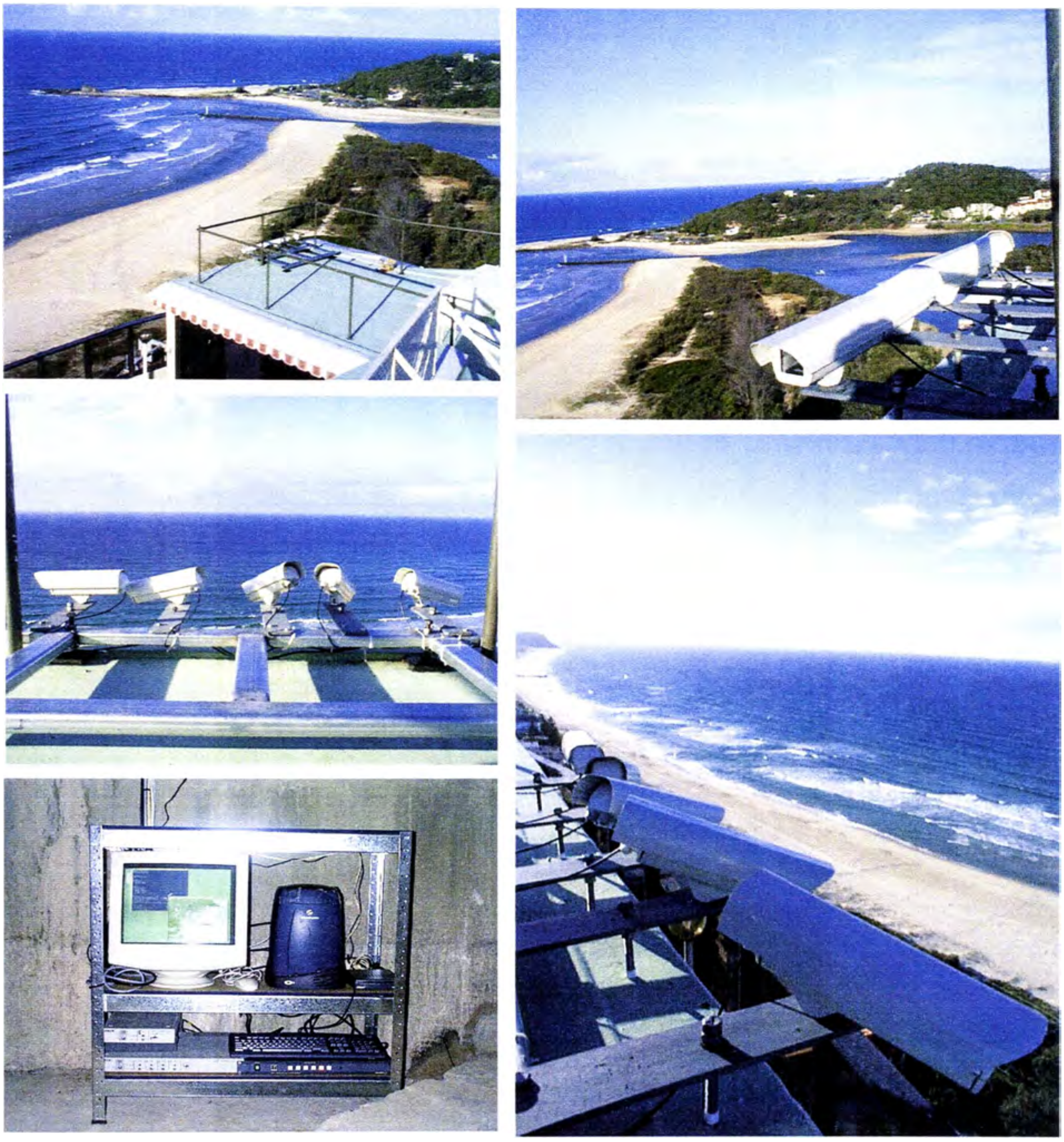
WRL

Report No. 2006/14

LOCATION OF COASTAL IMAGING SYSTEM
ROYAL PALM BUILDING

Figure 3.2

02114-3-2.cdr

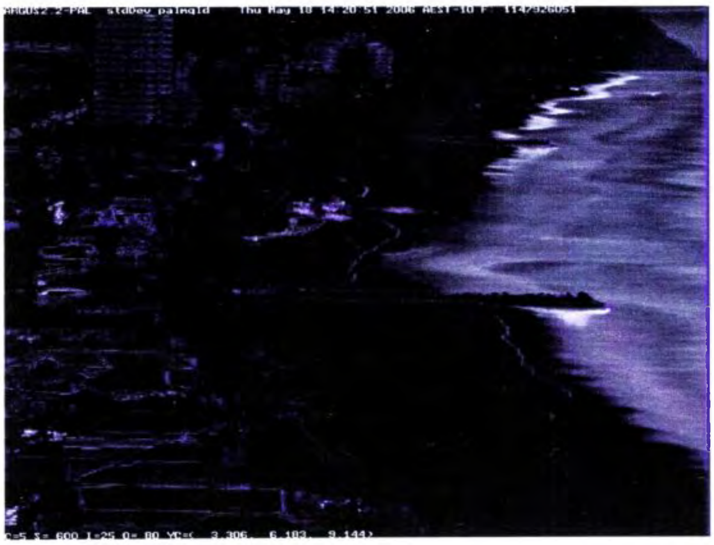


WRL Report No. 2006/14	CAMERAS MOUNTED AT AN ELEVATION OF APPROXIMATELY 80m	Figure 3.3 02114-3-3.cdr

snap

timex

var



WRL Report No. 2006/14	SNAP-SHOT, TIME-EXPOSURE AND VARIANCE IMAGE TYPES (MAY 2006)	Figure 3.4

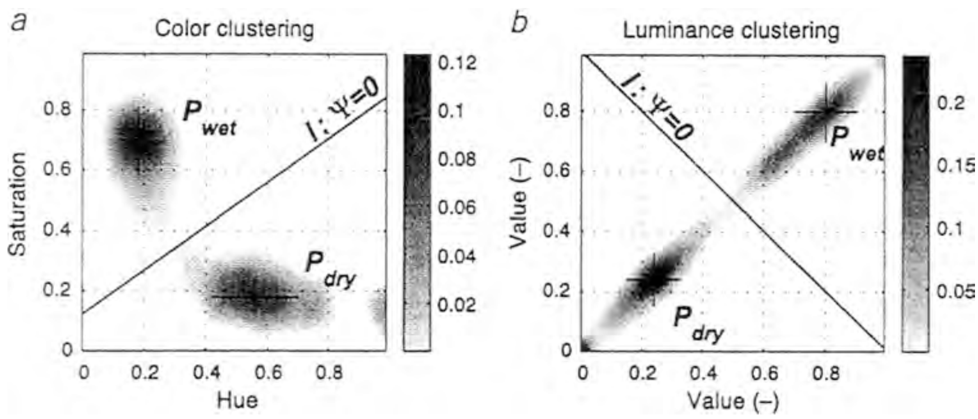
WRL

Report No. 2006/14

PAN AND PLAN VIEW IMAGES:
FIVE-CAMERA MERGE/RECTIFICATION (MAY 2006)

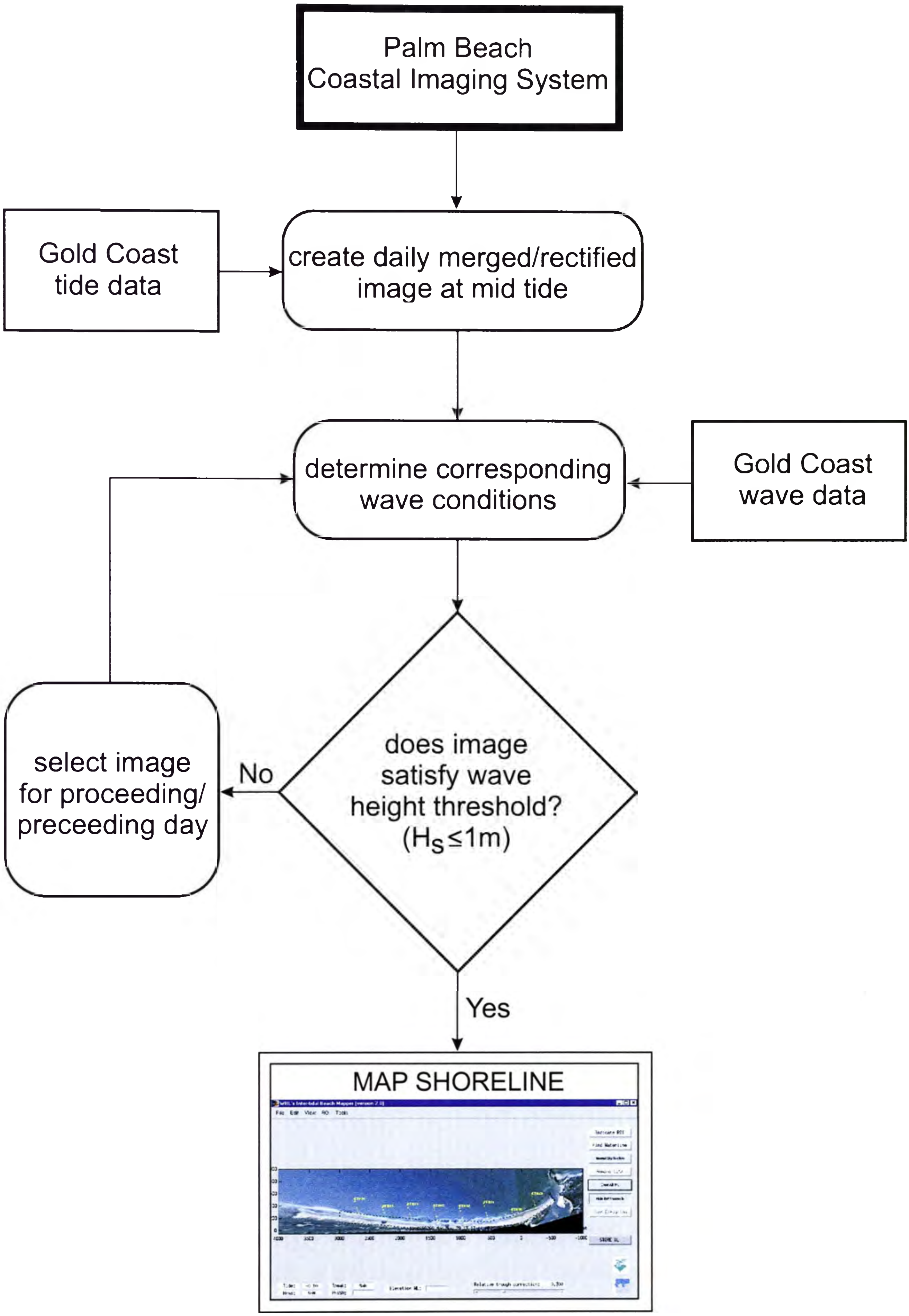
Figure
3.5

02114-3-5.cdr



Source: Aarninkhof (2003)

WRL Report No. 2006/14	IDENTIFICATION OF 'SHORELINE' FEATURE FROM COLOUR IMAGES	Figure 3.6



STANDARDISED SHORELINE MAPPING PROCEDURE

Figure
3.7

4. COASTAL IMAGING WEB SITE

4.1 Coastal Imaging Home Page

To promote the dissemination of information about the Palm Beach coastal monitoring project, to provide a convenient means to distribute images as they are collected, and to facilitate 'real-time' access to the regularly-updated results of shoreline monitoring and beach width analysis, a coastal imaging project site was established on the world-wide web at the following URL:

→ www.wrl.unsw.edu.au/coastalimaging/palmqld

The Palm Beach coastal imaging home page is shown in Figure 4.1. The most recent snap images are displayed here and updated every hour, enabling visitors to the site to observe the current beach conditions. This page also includes a number of links to a variety of background information including a description of the coastal imaging system, image types and image processing techniques. Links are also provided to the Gold Coast City Council web site, the waverider buoy site run by the Queensland Department of Environment, local weather information, and tidal predictions for the Gold Coast Seaway provided by the National Tidal Facility.

For general interest, a record is maintained of the number of visitors to the WRL coastal imaging web site and the countries they are from. At the time of writing, more than **193,000 hits** to the WRL coastal imaging web pages have been recorded to date. Visitors from Australia account for approximately half the total visitors, with the remaining visitors coming from approximately 80 countries world-wide.

4.2 Image Archive

The current snap, timex images and var images are updated and available at the project web site every hour.

All present and past images can be accessed via the on-line image archive. This provides a convenient and readily navigable structure to quickly locate the image(s) of interest. Figure 4.2 shows an example of a daily page contained within the image archive. These images are provided freely to encourage their use by students, researchers, managers and other non-commercial organisations.

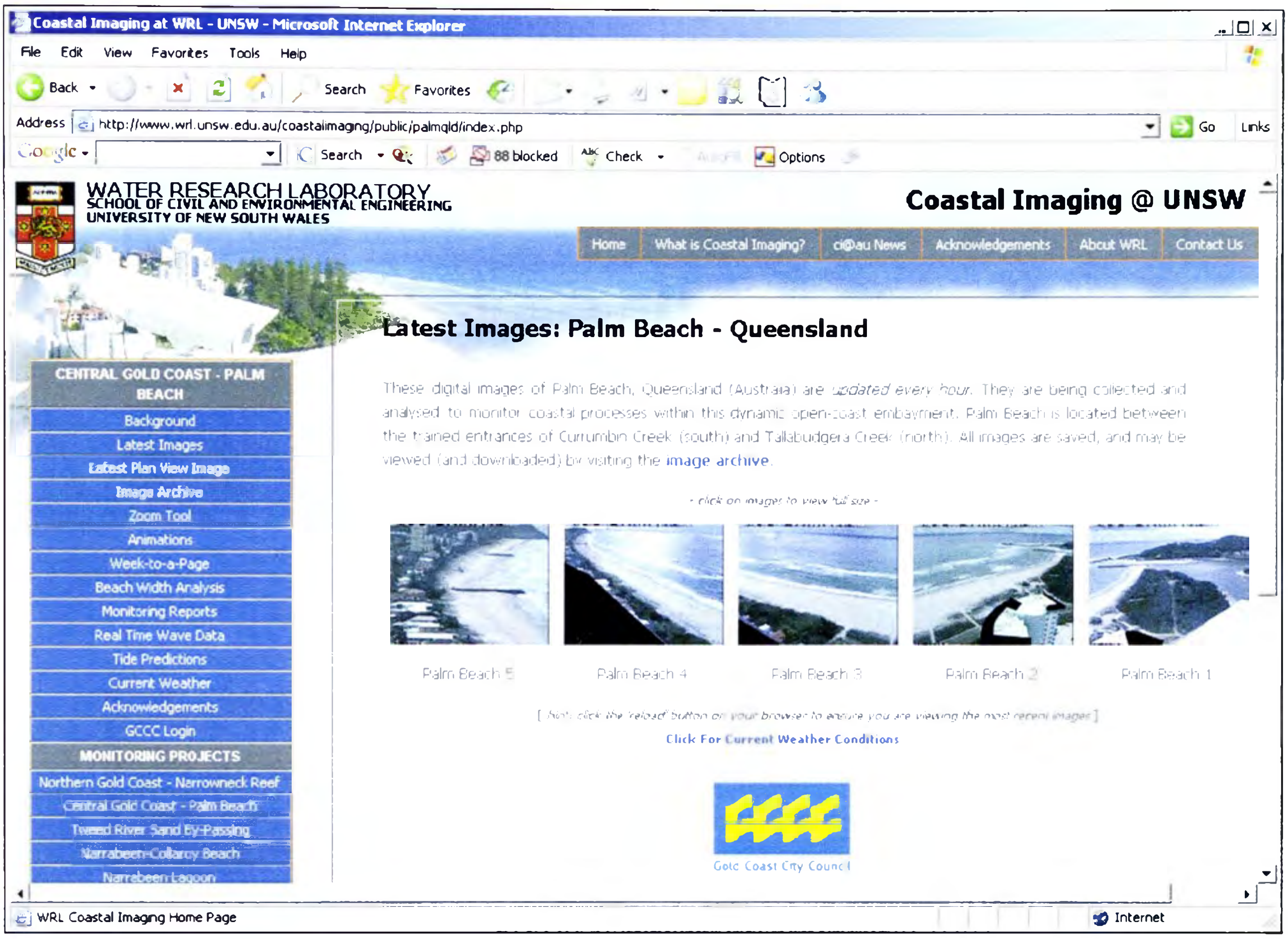
4.3 On-Line 'Beach Analysis System'

On-line access to 'real time' beach monitoring and analysis is made available at the Palm Beach coastal imaging web site. This capability results from the on-going research and development effort underway by the coastal imaging team at WRL. The purpose of this system is to provide regularly-updated results of the beach monitoring program to Gold Coast City Council and the general public on a routine basis, via the world wide web.

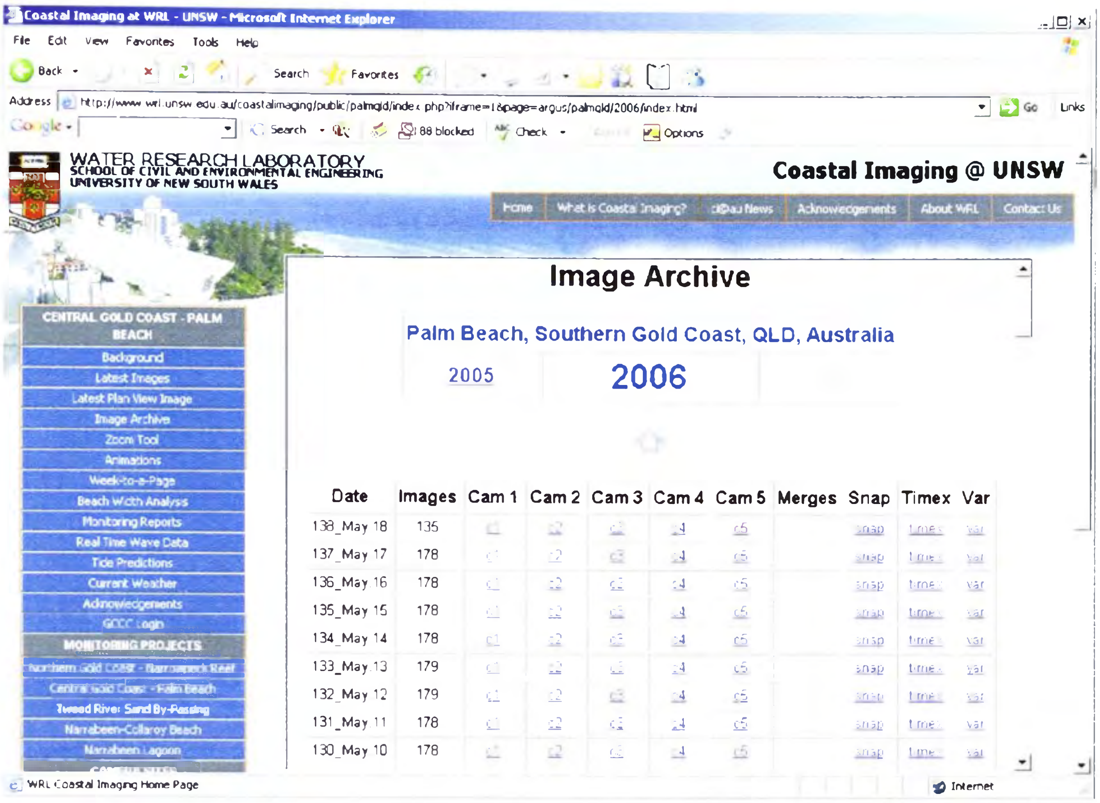
A detailed description of the capabilities of this system was detailed in Anderson et al (2003). To summarise, the features available at the project web site include the ability to view the latest mid-tide plan images; access to a zoom tool feature that enables zooming-in and panning through the current oblique and rectified images; full on-line access to all past and present monitoring reports; and two products specifically designed to assist both the qualitative and quantitative interpretation of images, shoreline data and the results of beach width analysis.

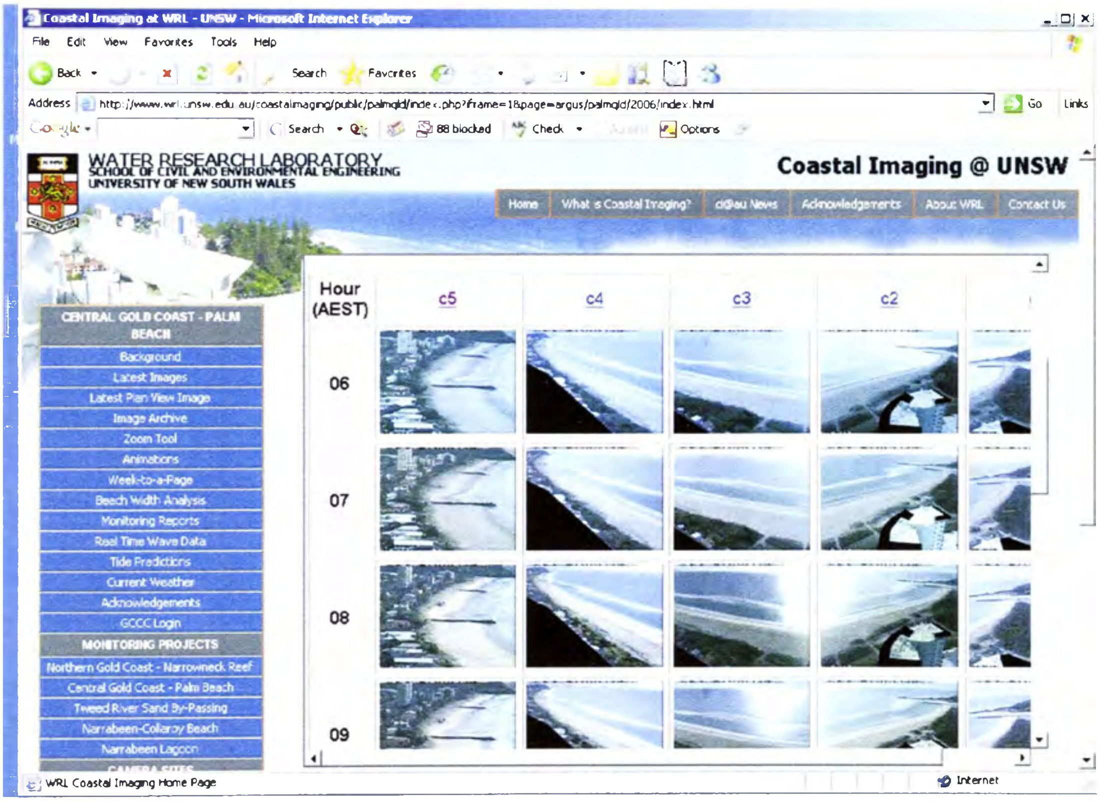
An example of the first of these products called 'week-to-a-page' is illustrated in Figure 4.3. Every Monday morning, this figure is generated and made available for viewing (and download, if required) via the project web site. The figure is pre-formatted to fit on a standard A4 page, to assist reporting. This figure compiles daily mean sea level plan view images of the entire northern Gold Coast study site for that week, into a compact one-page summary. This product provides coastal managers a means of quickly and efficiently interpreting the daily changes in beach morphology and shoreline position, without continual recourse to the hourly images. An archive of these weekly figures is also maintained and available on-line.

The second product that is also updated each Monday morning and made available via the project web site is 'Beach-Width-Analysis' (Figure 4.4). This figure in graphical format summarises quantitative information of the mean shoreline position for that week; shoreline variability by comparing the current shoreline position with previous weeks and months; beach width along pre-defined monitoring transects; and beach width trends throughout the history of the monitoring project.

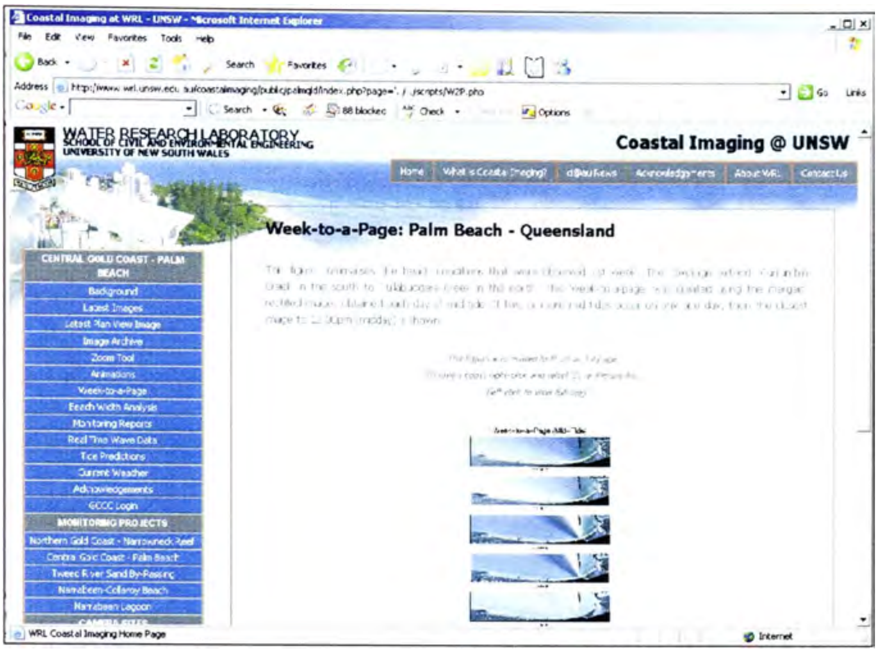


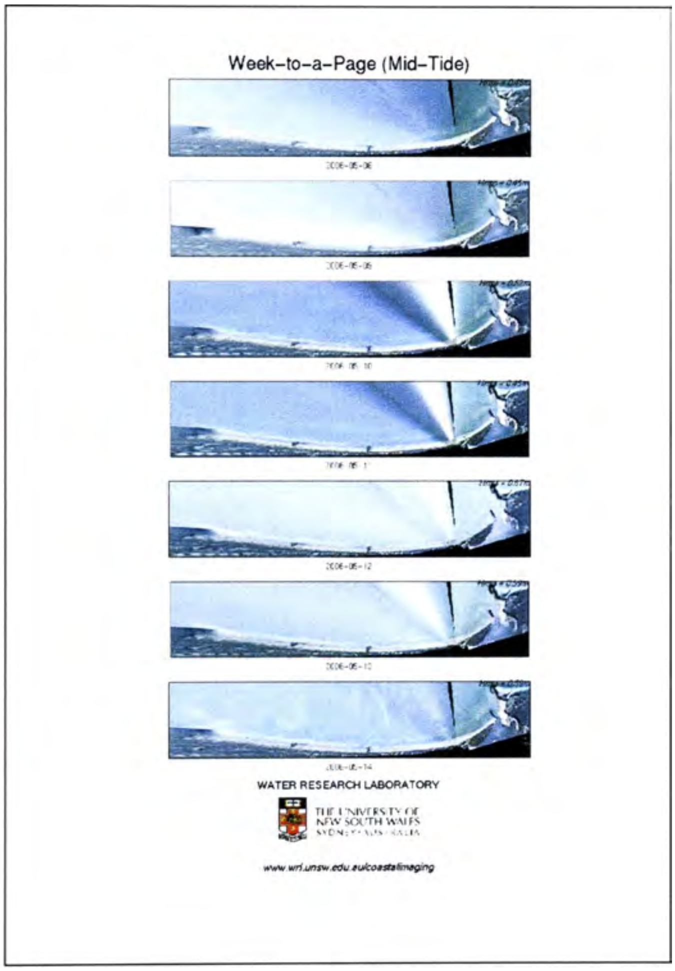
WRL Report No. 2006/14	COASTAL IMAGING WEB SITE - HOME PAGE	Figure 4.1 02114-4-1.cdr





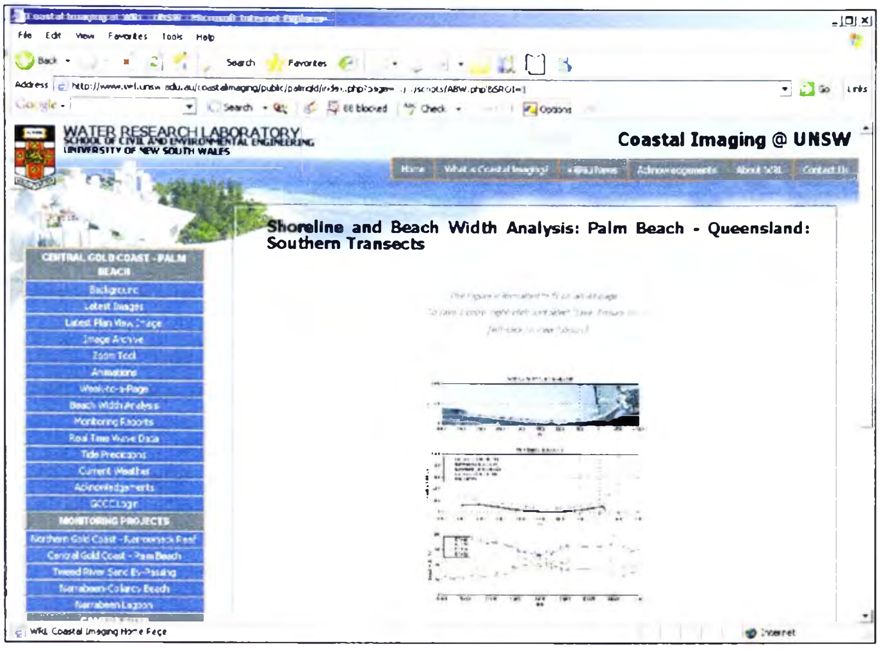
WRL Report No. 2006/14	COASTAL IMAGING SYSTEM WEB SITE - IMAGE ARCHIVE	Figure 4.2

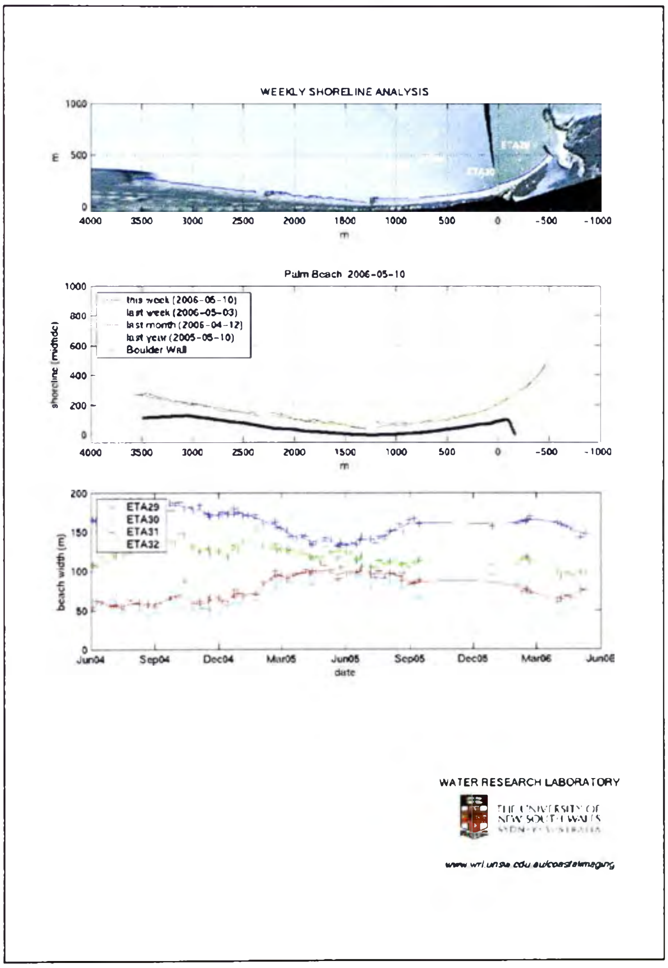




WRL Report No. 2006/14	ON-LINE BEACH ANALYSIS SYSTEM 'WEEK -TO-A-PAGE'	Figure 4.3

02114-4-3.cdr





WRL Report No. 2006/14	ON-LINE BEACH ANALYSIS SYSTEM 'BEACH WIDTH ANALYSIS'	Figure 4.4

02114-4-4.cdr

5. MORPHODYNAMIC DESCRIPTION OF PALM BEACH: DECEMBER 2005 – MAY 2006

From the daily images obtained by the ARGUS coastal imaging station atop of the Royal Palm building, it is self-evident that Palm Beach is dynamic and continually changing. Bars move onshore and offshore and vary in shape from straight to crescentic, rips emerge and disappear, and the shoreline changes shape and translates landward and seaward in response to varying wave conditions. This section is included to provide a qualitative description of the observed beach changes during the present monitoring period December 2005 to May 2006. The 'week-to-a-page' summary figures that are updated every week and made publicly available for inspection and download via the project web site are used in this section to illustrate the observed beach changes. The objective is not to describe every characteristic of Palm Beach during this period, but rather provide an overview of general trends and predominant features that were observed during this time.

To summarise beach changes in some structured manner, it is useful to first outline a systematic beach classification scheme with which to undertake this qualitative analysis. For consistency, this same classification scheme is also used at the Surfers Paradise site, and will continue to be used in future reports to enable inter-comparison as the monitoring programs continue.

5.1 A Morphodynamic Classification of Beaches

Despite the seemingly endless range of changes observed at any sandy coastline, in fact it has been shown that beaches tend to exhibit certain characteristics that vary in a systematic and predictable way. One such scheme for describing these changes is the 'Morphodynamic Beach State Model' first outlined by Wright and Short (1983). This beach classification scheme was developed in Australia, and is now the most widely-used descriptive beach model internationally. The term 'morphodynamics' derives from the combination of the words 'morphology' and 'hydrodynamics', emphasising the strong linkage between the shape of a beach and the associated wave and current conditions.

Beaches can be classified as being in one of six beach 'states' at any given point in time. The generalised cross-section and plan-form characteristics of these six beach states are summarised in Figure 5.1. A brief description of each of these states is provided below.

At one extreme is the *dissipative* beach state (Figure 5.1a), which is characterised by a very low profile slope and wide surfzone. Dissipative beaches are generally composed of fine sand and occur along coastlines exposed to high wave energy. Nearshore bathymetry is usually characterised by one or more straight and shore-parallel bars. The term 'dissipative' is used to describe beaches that exhibit these characteristics because wave energy is essentially dissipated by extensive wave breaking across the surf zone, before it can reach the shoreline.

At the other end of the beach state spectrum, *reflective* beaches (Figure 5.1f) are invariably steep, with no nearshore bars. Waves tend to break close to or right at the shoreline, and hence very little wave energy is dissipated; instead it is reflected by the beachface and propagates offshore. These beaches tend to be composed of coarse sediments and/or are generally located in protected or low wave energy coastal regions.

Between the dissipative and reflective extremes, four *intermediate* beach states can be identified. These incorporate elements of both the reflective and dissipative domains. The four intermediate beach types are referred to as *longshore bar-trough* LBT (Figure 5.1b), *rhythmic bar and beach* RBB (Figure 5.1c), *transverse bar and rip* TBR (Figure 5.1d) and *low tide terrace* LTT (Figure 5.1e). Together, these intermediate beach types form a sequence of characteristic beach states related to the movement of sand onshore (decreasing wave steepness) and offshore (increasing wave steepness). The onshore-offshore movement of sand is most easily recognised by the movement and changing shape of bars within the nearshore zone.

Following the characteristic offshore movement (*ie.,* erosion) of sediment during a major storm, typical post-storm beach recovery includes the gradual onshore migration of nearshore bars and the development of weak and then stronger rips (LBT → RBB → TBR). If low wave conditions persist, bars ultimately disappear as the bar becomes welded to the beach to form a terrace (LTT). Beaches of the moderately high energy east Australian open coast are typically observed to transfer between these four intermediate morphodynamic beach states, in response to lower wave conditions interspersed by episodic storm events.

5.2 Morphodynamic Interpretation of Daily Images

All of the available week-to-a-page figures for the period December 2005 to May 2006 are presented in Appendix A. Each of these figures shows a week (seven days) of sequential mid-tide plan images, with the date of each indicated. All images are obtained at the same stage of the tide (mean sea level), to enable the direct comparison between different days and weeks. The region shown in these figures extends 5000 m alongshore, from the southern training wall at the Tallebudgera Creek entrance to the Currumbin Headland.

To assist the interpretation of these images, Appendix B contains monthly summaries of wave height and period, obtained from the Gold Coast Waverider buoy and supplied to WRL by the Queensland Department of Environment.

5.2.1 December 2005

Due to unscheduled roof defect repairs at the Royal Palm building, the ARGUS coastal imaging station at Palm Beach operated for five days only during December 2005. However, the images obtained during this brief operational period can be used to identify the main features of the beach during this period.

The wave climate remained mild throughout December, with significant wave height declining from 1.5 m to less than 1 m in the first few days of the month, and remaining at or below 1 m for the remainder of the month. Peak wave period varied in the range of 5 sec to 12 sec in response to the prevalence of local sea breezes during this time. The central and northern beach exhibited a series of rip channel systems spaced at quasi-regular intervals alongshore, characteristic of lower energy TBR morphology. In the southern beach milder conditions prevailed, characterised by the absence of rip channels and only limited wave breaking in this region.

5.2.2 January 2006

No images are available during January 2006, due to the completion of roof defect repairs at this time. Operation of the Palm Beach ARGUS coastal Imaging station re-commenced 31 January 2006.

5.2.3 February 2006

For the first week of February significant wave height was in the range of 1 – 1. 5 m, then rose during the 7th to 2 m, before declining to around 1 m again on the 9th. Offshore significant waves remained at or below 1 m for the following 12 day period through to the 21st, at which time it increased again to 1.5 m, rising slowing to 2 m late on the 24th. A malfunction of the Gold Coast wave-rider buoy during a period a very high waves (refer next section) resulted in no wave measurements after the 26th February.

Complex and rather unusual beach morphology persisted through to the commencement of the major storm event at the end of February. In the central and northern beach, complex rip channels persisted, characteristic of the intermediate TBR beach state. However, in the more southern region of the Palm Beach embayment the effects of the nearshore nourishment program were evident. In this region the bar was observed to remain disconnected from the beach, resulting in the presence of a longshore channel separating the bar from the shore. Interestingly, this LBT morphology is characteristic of previous observations at the more northern monitoring site at Narrowneck, where the surfeit of sand placed in the nearshore region at that location during a nourishment campaign in 1999 – 2000 was observed to result in the 'forcing' of the beach toward a lower gradient and more dissipative beach state. Throughout February 2006 at Palm Beach this same behaviour was monitored. Unusual alongshore bar features emerging within the main nearshore channel system were also present, again indicative of the large nearshore sand reserve at this time. As the wave energy began to increase on the 21st February, the bar along the central and northern regions of the embayment moved offshore and the rip channels disappeared, as the beach transitioned to the higher energy RBB-LBT beach states at all locations within the Palm Beach embayment.

5.2.4 March 2006

The month of March was dominated by the occurrence of a major coastal storm, peaking on Saturday 4th. Significant waves up to 7.2 m were recorded by the Brisbane wave-rider buoy, with individual waves up to 15.0 m. QLD EPA reported that these were the second highest wave conditions measured by a wave rider buoy near the Gold Coast in nearly 30 years. During this period many beaches in the Gold Coast region experienced significant scarping. At Palm Beach scarping was reported to be about 0.5 m at Lacey's Lane, increasing to about a metre by 4th Avenue. At the far northern end of the beach scarping of over 1.5 m in height was reported adjacent to the Tallebudgera Creek training wall.

As noted previously in Section 1.2, the major coastal storm that struck the Gold Coast in early March 2006 damaged the electrical system within the Royal Palm building, causing a failure of the ARGUS power supply. This was subsequently repaired and the system became operational again on 23rd March. From the week-to-a-page images obtained for the reminder of the month the embayment-scale impacts of the storm are readily apparent. Along the entire embayment the bar had moved well offshore, to form high-energy and dissipative LBT morphology. A wide and continuous nearshore channel separated the bar from the beach. Significant wave heights peaked again at around 2 – 3 m on the 26th and maximum offshore waves of between 5 m and 6 m were recorded, during which wave breaking in the vicinity of the sand nourishment dump boxes was observed, located seaward of the LBT bar. As wave energy then declined to a significant wave height of below 1 m by the end of the month, limited wave breaking only was observed along the entire Palm Beach embayment.

5.2.5 April 2006

The wave climate in April remained moderate, with the result that relatively rapid changes in post-storm beach recovery were observed. Throughout the month the offshore significant wave height varied in the general range of 1 – 2 m, with maximum offshore waves exceeding 3 m for a number of days throughout the month. Generally long period waves prevailed, with peak periods up to 18 seconds recorded by the Gold Coast wave-rider buoy. More typically, peak wave period through the month of April was in the range of 10 – 15 seconds, only dipping below 10 seconds for a period of four days around the 13th - 17th.

The relatively energetic wave conditions combined with generally long period swells caused the rapid transition of the beach from LBT to RBB, and by the end of the month, TBR morphology except again, for the more southern region of the beach in the vicinity of the sand nourishment area and the entrance to Currumbin creek. Along the northern and central regions of the Palm Beach embayment the offshore bar developed crescentic features and rip channels progressively formed inshore. In contrast, to the south of the 11th Street groyne the bar remained linear and separated from the shore by a channel, extending to Currumbin Rock. The distinctive morphology in this region appears to be the combined result of the nearshore nourishment campaign plus the natural bypassing of sand northward around Currumbin Rock at the southern end of Palm Beach, both providing the principal sources of sand to the entire embayment.

5.2.6 May 2006

Generally mild wave conditions through May resulted in little further changes to beach and nearshore conditions within the Palm Beach embayment. Offshore significant wave height was generally at or below 1 m, rising up to 1.5 m for 1-2 days in the middle and towards the end of the month. Peak wave period was generally in the range of 8 – 10 seconds. When wave breaking was sufficient to reveal the underlying nearshore morphology it was observed that a TBR beach state continued along the central and northern regions of the beach, while in the south the bar remained essentially linear and separated from the shore by a channel, extending to Currumbin Rock. Again, the distinctive morphology in this region appears to be the combined result of the nearshore nourishment campaign plus the natural bypassing of sand northward around Currumbin Rock at the southern end of the Palm Beach embayment.

5.3 Visual Assessment of Beach Width Changes (December 2005 – May 2006)

Beach and nearshore conditions during the period December 2005 to May 2006 were dominated by high wave energy conditions in early March, and the subsequent recovery of the beach in April and May. A qualitative visual assessment of the net trends in beach adjustment during this period can be seen by contrasting images of the beach obtained at the start and end of this period.

Figure 5.2 shows the snap images obtained at mid-tide from Camera 2 (south) in December 2005 and May 2006 respectively. The corresponding snap images of the northern beaches obtained from Camera 4 are shown in Figure 5.3. Along the southern beach (Figure 5.2) in the region of the Currumbin Spit a distinctive trend of beach narrowing is apparent at the far southern end of the Palm Beach embayment, while in the region in the immediate vicinity of the Royal Palm building a slight decrease in beach width is discernable. Looking north along the Palm Beach embayment (Figure 5.3), from December 2005 to May 2006 the region immediately south of the 11th Street groyne increased in width, while the region between the 11th and 21st Street groynes appears to have narrowed, especially just north of the of the 11th Street groyne. To the north of the 21st Street groyne a general trend of beach retreat during this present six month period is discernable.

5.4 Visual Assessment of Total Beach Width Changes (June 2004 – May 2006)

The net beach changes to date since the commencement of monitoring at Palm Beach two years ago in early June 2004 are seen in Figure 5.4. In this figure, mid-tide timex images of the beach to the south and north of the Palm Beach embayment are shown at six-monthly intervals for the entire monitoring period June 2004 – May 2006.

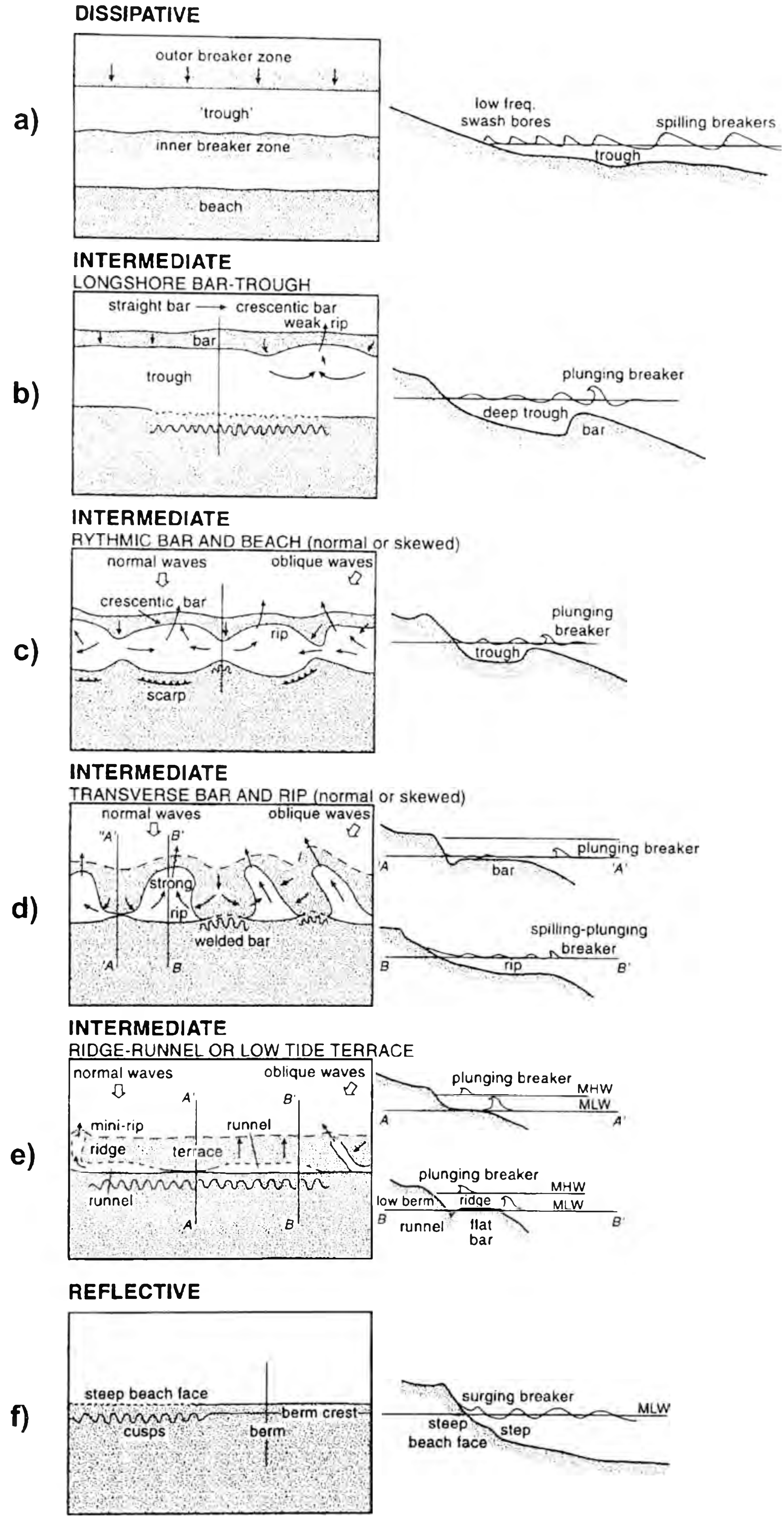
During the first six months June to November 2004, along the southern beach the surfeit of sand that was observed within the intertidal and nearshore in June, appeared to have moved onshore by November, resulting in modest beach widening and a general straightening of the beach alignment in this southern region. Toward the north, from June to November the southern end of this region appeared to have generally widened. In contrast, toward the middle and northern end of the embayment, the shoreline appeared much more irregular and scalloped, with a discernable trend of a generally narrower beach.

From December 2004 to May 2005 the southern beach receded again, and from visual assessment was clearly narrower than the initial beach conditions observed twelve months earlier in June 2004. In contrast, toward the north a general trend of beach widening was observed, with the beach reverting to a more uniform alignment than was observed to develop during the preceding six month period.

From June to December 2005 a general trend of beach widening was apparent at the far southern end of the Palm Beach embayment, while in the region in the immediate vicinity of the Royal Palm building little net change in beach width is discernable. The region immediately south of the 11th Street groyne decreased in width, while the region between the 11th and 21st Street groynes increased in beach width. By December 2005 the southern beach was similar to the conditions that prevailed at the commencement of the monitoring program in June 2004, while along the central and northern regions of embayment the impacts of the nearshore nourishment campaign were clearly discernable, with the beach especially to the south and between the 11th and 21st Street groynes exhibiting a substantially wider beach and more uniform alignment alongshore.

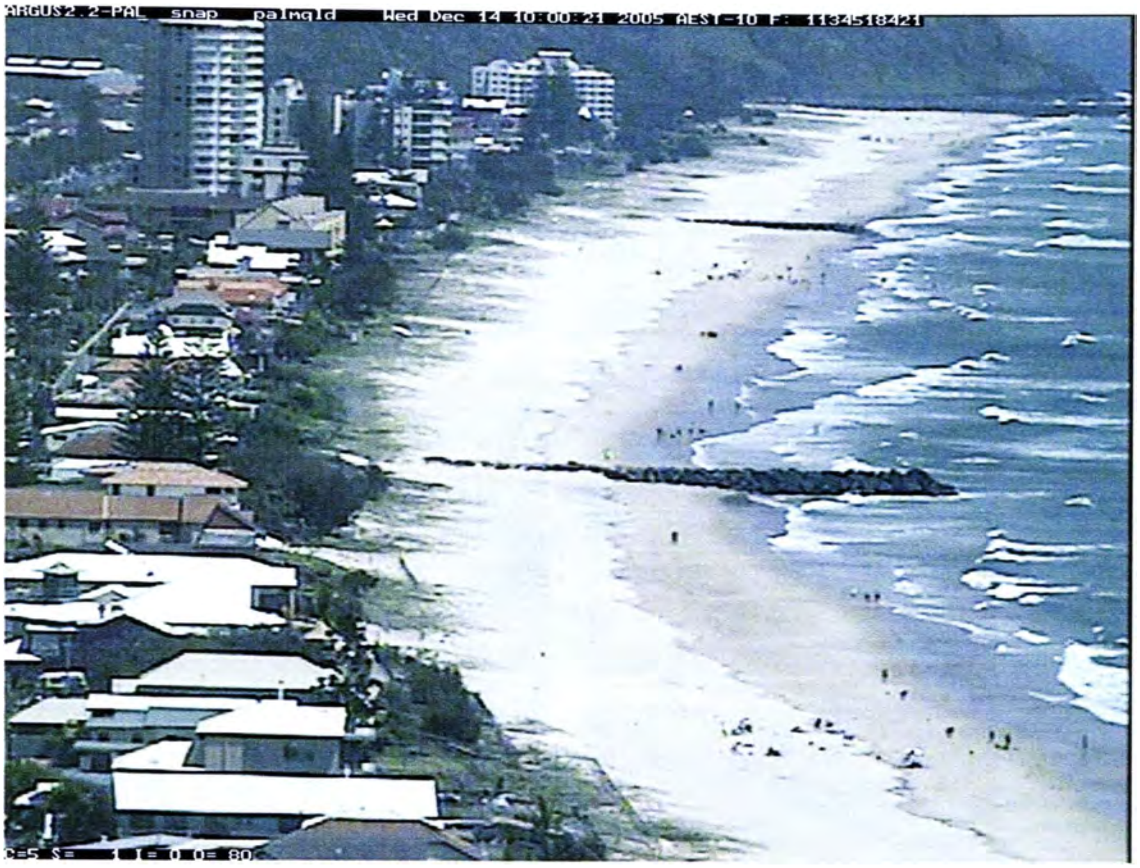
Through the present six-month monitoring period to May 2006 a distinctive trend of beach narrowing was apparent at the far southern end of the Palm Beach embayment in the region of the Currumbin Spit. Immediately south of the 11th Street groyne the beach had increased in width, while the region between the 11th and 21st Street groynes and to the north exhibited a general trend of beach retreat. The beach conditions that prevailed at the end of May 2006 along the southern Palm Beach embayment were similar to the eroded conditions observed 12 months earlier in May 2005. Along the northern beach the conditions in May 2006 were intermediate to the accreted beach that was observed in May 2005, and the eroded beach observed six months prior to that time in December 2004.

A more quantitative assessment of the response of Palm Beach for the period December 2005 to May 2006 is detailed in the following Section 6.



WRL Report No. 2006/14	MORPHODYNAMIC BEACH STATE MODEL (after WRIGHT and SHORT, 1983)	Figure 5.1

WRL Report No. 2006/14	SNAP IMAGES FROM CAMERA 1 (SOUTH): DECEMBER 2005 AND MAY 2006	Figure 5.2 02114-5-2.cdr



WRL Report No. 2006/14	SNAP IMAGES FROM CAMERA 4 (NORTH): DECEMBER 2005 AND MAY 2006	Figure 5.3 02114-5-3.cdr

June 2004

June 2004

December 2004

December 2004

May 2005

May 2005

December 2005

December 2005

May 2006

May 2006

WRL Report No. 2006/14	SIX-MONTHLY BEACH CHANGES CAMERA 2 (SOUTH) AND CAMERA 4 (NORTH): JUNE 2004 - MAY 2006	Figure 5.4 02114-5-4.cdr

6. QUANTITATIVE ANALYSIS OF SHORELINE CHANGES: DECEMBER 2005 – MAY 2006

The primary function of the coastal imaging system installed at Palm Beach is to quantify shoreline changes and beach variability along this partially engineered coastline, to document and better understand the behaviour of this coastal embayment. In addition, the impacts of current (and possible future) beach improvement works will be assessed. Quantitative analysis of shoreline position and beach width provide an objective measure to assess both beach amenity and the extent of the storm buffer seawards of the existing boulder wall alignment.

6.1 Weekly Shorelines

All available weekly shorelines for the period 01/12/05 to 31/05/06 are shown in Figure 6.1. A total of 18 mid-tide shorelines were mapped during this period (for shoreline mapping method and procedure refer Section 3.7). For reference, these measured shorelines are overlaid on to a representative merged/rectified timex image (image date: 23rd May 2006). The image represents a 5000m length of the southern Gold Coast coastline, extending from the southern training wall at Tallebudgera Creek in the north, to Currumbin Headland in the south. The ARGUS station is located at coordinate [0,0], just north of the sand spit that separates the lower Currumbin Estuary from the oceanfront. For reference, the alignment of the back-beach boulder wall (used to calculate beach width) is also indicated (landward red line).

To see more clearly the range of shoreline positions mapped during this six month period, Figure 6.2 shows a plot of the position of the weekly shorelines relative to the boulder wall alignment. The distance of these shorelines from the wall alignment is plotted in the upper panel, and for convenience the alongshore position in this figure is relative to the location of the ARGUS station (0m). In the lower panel of this figure the same mid-tide timex image used in the previous figure is shown for reference.

During the monitoring period 01/12/05–31/05/06 it can be seen from Figure 6.2 that the beach along the Palm Beach oceanfront varied in width from a minimum of approximately 40 m (relative to the alignment of the back-beach boulder wall) in the vicinity of the 11th Street groyne, to around 180 m at the extreme northern end of the embayment adjacent to Tallebudgera Creek. At the southern end of the boulder wall, adjacent to Currumbin Creek, the wall alignment dips landward, resulting in over 250 m of beach between the wall and shoreline. The envelope of beach width changes along the entire embayment was in the range of 20 - 70 m during this period.

6.2 Shoreline Variability – Mean, Maximum, Minimum, Standard Deviation

The alongshore variability of the measured shoreline positions during the monitoring period 01/12/05 – 31/05/06 is further quantified in Figure 6.3. The upper panel of this figure shows a plot of the mean, maximum and minimum shoreline position at 5 m increments alongshore. For reference, in the lower panel the mean shoreline position during this period is overlaid on to a merged/rectified timex image of the northern Gold Coast (image date: 23rd May, 2006).

Referring to Figure 6.3, the median beach width at mid-tide (relative to the alignment of the back-beach boulder wall) was of the order of 60 – 70 m along the Palm Beach embayment. With the alignment of the boulder wall changing orientation and dipping landward at the southern sand spit, the measured beach width is observed to increase accordingly, reaching 100 m in front of the site of the cameras (ie., distance = 0 m alongshore in Figure 6.3).

The analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals a relatively uniform trend alongshore, with the beach width varying by of the order of ±30 m from the mean shoreline position.

The middle panel of Figure 6.3 shows the standard deviation (s.d.) of weekly shorelines from the mean shoreline position during the same period 01/12/05 - 31/05/06. The relatively high standard deviation of weekly shorelines was in the range of 10 – 20 m, which is greater than was observed during the previous monitoring period (Turner, 2005). The areas of greatest shoreline variability and change were located in the vicinity of the 11th Street groyne and in the region extending to the 21st Street groyne and northward.

6.3 Time-Series of Beach Widths at Transects ETA29 - ETA36

The variations in shoreline position measured at Gold Coast City Council's ETA transects 29 - 36 for the monitoring period December 2005 to May 2006 are shown in Figures 6.4 and 6.5. Due to the shut-down of the system through the latter part of December and throughout January while roof defect repairs were completed, and then the failure of the power system in early March, gaps in these data are present. Figure 6.4 plots the weekly shoreline position at the southern transects ETA29 - ETA 32, and Figure 6.5 plots the weekly shoreline position at the more northern transects ETA33 - ETA36. The alongshore position of each of these beach transects is shown in the accompanying merged/rectified image (image date: 15/09/2005).

6.3.1 Southern Transects (ETA29 – ETA32)

At the southern-most transects ETA29 and ETA30 (Figure 6.4), the dominance of the large storm waves in early March are apparent. At ETA29 and ETA30 the beach was observed to accrete by around 10 m from December to the end of February, then in early March erosion of 5 m (ETA29) and 20 m (ETA30) was observed. During April – May at the southern-most transect ETA29 the beach continued to decline in beach width from 5 m to around 20 m narrower than the conditions that prevailed prior to the onset of the storm in early March. At the more northern Transect ETA30 the 20 m of erosion that occurred in early March was maintained.

At monitoring transects ETA31 and ETA32 the beach was observed to decline in width by 10 – 20 m during the period December to February, then with the onset of the storm in March a further period of erosion was observed, followed by recovery. At ETA31 the storm caused the beach to narrow by around 10 m, then through April May return to the conditions that were observed at the end of February, prior to the onset of the storm. At the more northern ETA32 a greater degree of erosion and recovery were observed, with the beach decreasing in width by some 40 – 50 m immediately after the storm, then recovering though April-May of the order of 30 m beach width.

At the end of the present six month monitoring period, the beach width along the southern monitoring transects had eroded of the order of 15 – 20 m.

6.3.2 Central and Northern Transects (ETA33 – ETA36)

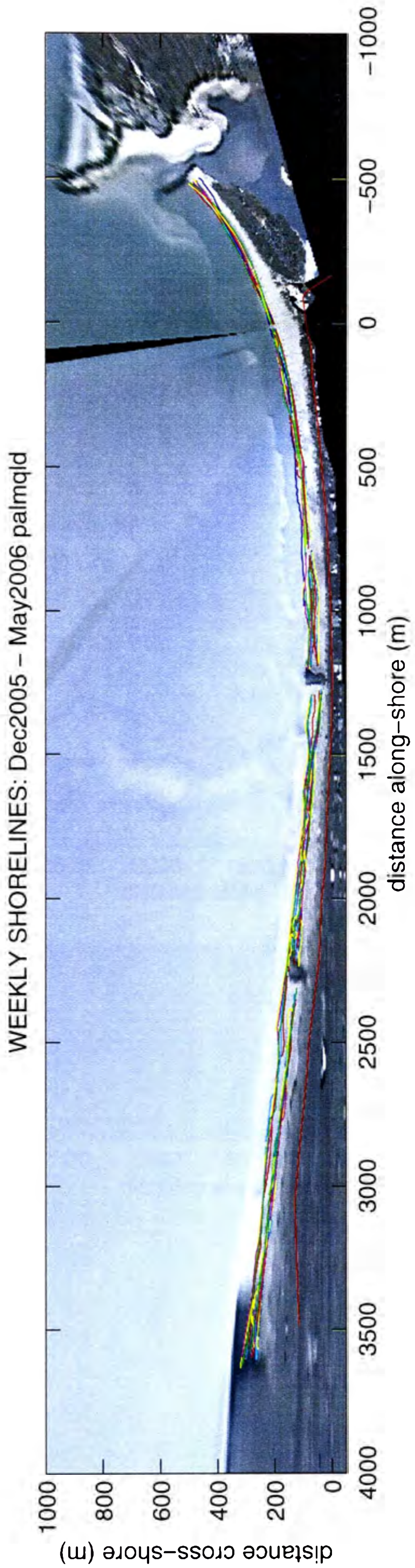
The weekly analysis of shoreline position at the central and northern transects ETA33 to ETA36 are shown in Figure 6.5. At all northern transects the impacts of the storm in early March are pronounced. From February to March beach retreat of the order of 50 m was measured at ETA33, ETA35 and ETA36, with around 40 m erosion observed mid-way between the 11th Street and 21st Street groynes in the vicinity of ETA34. At the northern ETA36 and southern ETA33 only minimal recovery of beach width was measured during April – May, while at ETA34 and ETA35 by the end of May the beach had recovered to within 10 m of the conditions that prevailed prior to the onset of the storm.

In summary, the dominant observation during the present monitoring period was the rapid erosion of the Palm Beach embayment following the onset of the storm in early March, followed by variable recovery of beach width through April and May. By the end of May 2006 the beach was 10 – 50 m narrower than the conditions that prevailed at the end of February 2006, immediately prior to the onset of the storm.

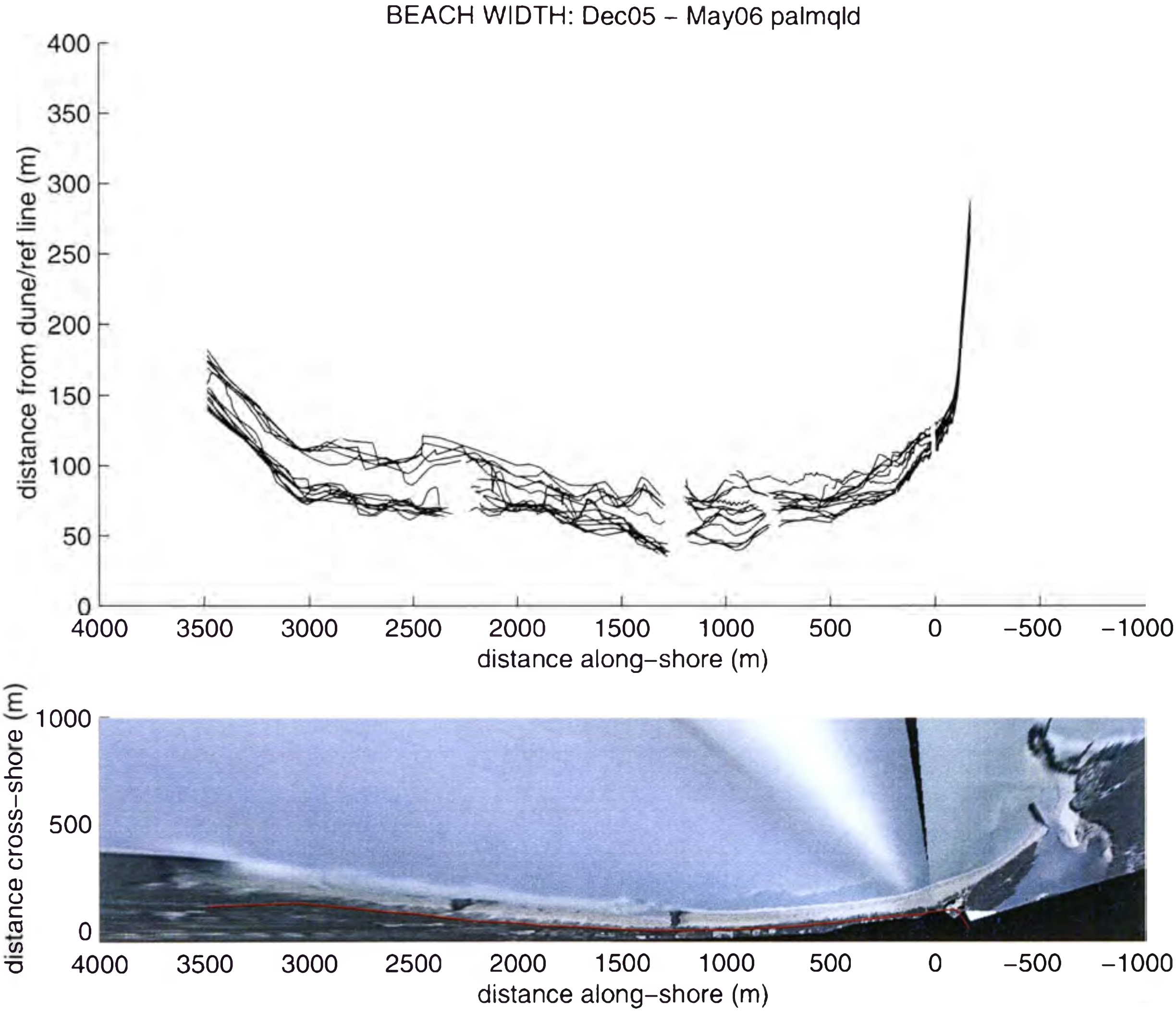
6.4 Weekly Shorelines (December 2005 - May 2006) Relative to Mean Shoreline Position of Previous Monitoring Period (June - November 2005)

The beach changes observed during the present six-month monitoring period contrasted to those reported for the prior six months. To summarise, Figure 6.6 presents the analysis of all available weekly beach widths for the period December 2005 to May 2006, relative to the mean shoreline alignment calculated for the prior six month period June 2005 to November 2005. In the upper panel the deviation of weekly shorelines from this prior mean shoreline alignment is plotted. In the lower panel this mean shoreline position for the previous monitoring period June - November 2005 is shown, along with the mean shoreline calculated for the present monitoring period.

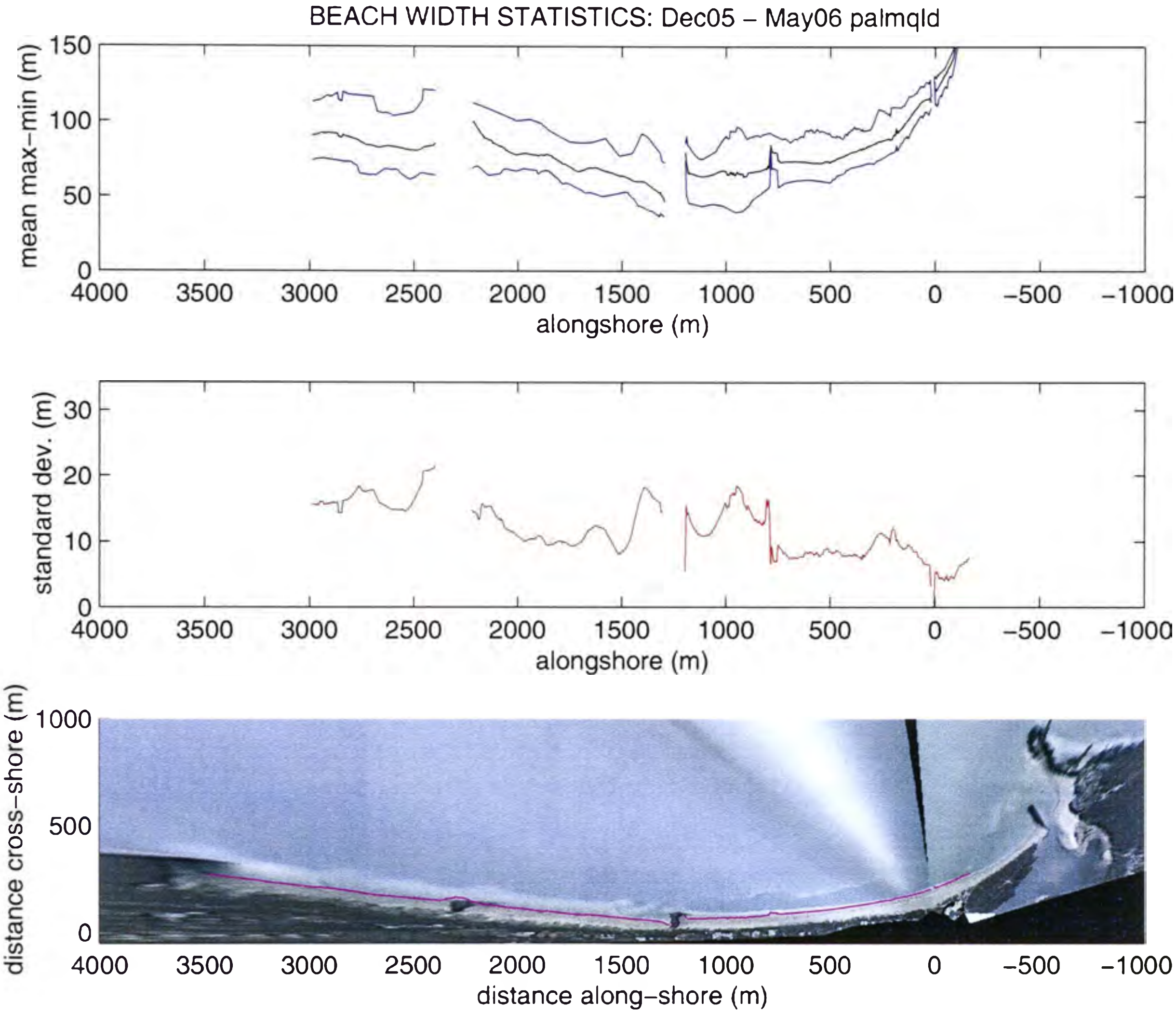
This analysis shows that, relative to the mean shoreline position for the preceding six month period, the entire Palm Beach embayment experienced pronounced and relatively uniform-alongshore erosion, with the exception of Currumbin Spit. Prior to March the region north of the 21st Street groyne exhibited an accretionary trend prior to the major erosion event, while along the remainder of the embayment, erosion (relative to conditions six months prior) generally predominated throughout the present six-month period.



WRL Report No. 2006/14	WEEKLY SHORELINES: DECEMBER 2005 - MAY 2006	Figure 6.1 02114-6-1.cdr

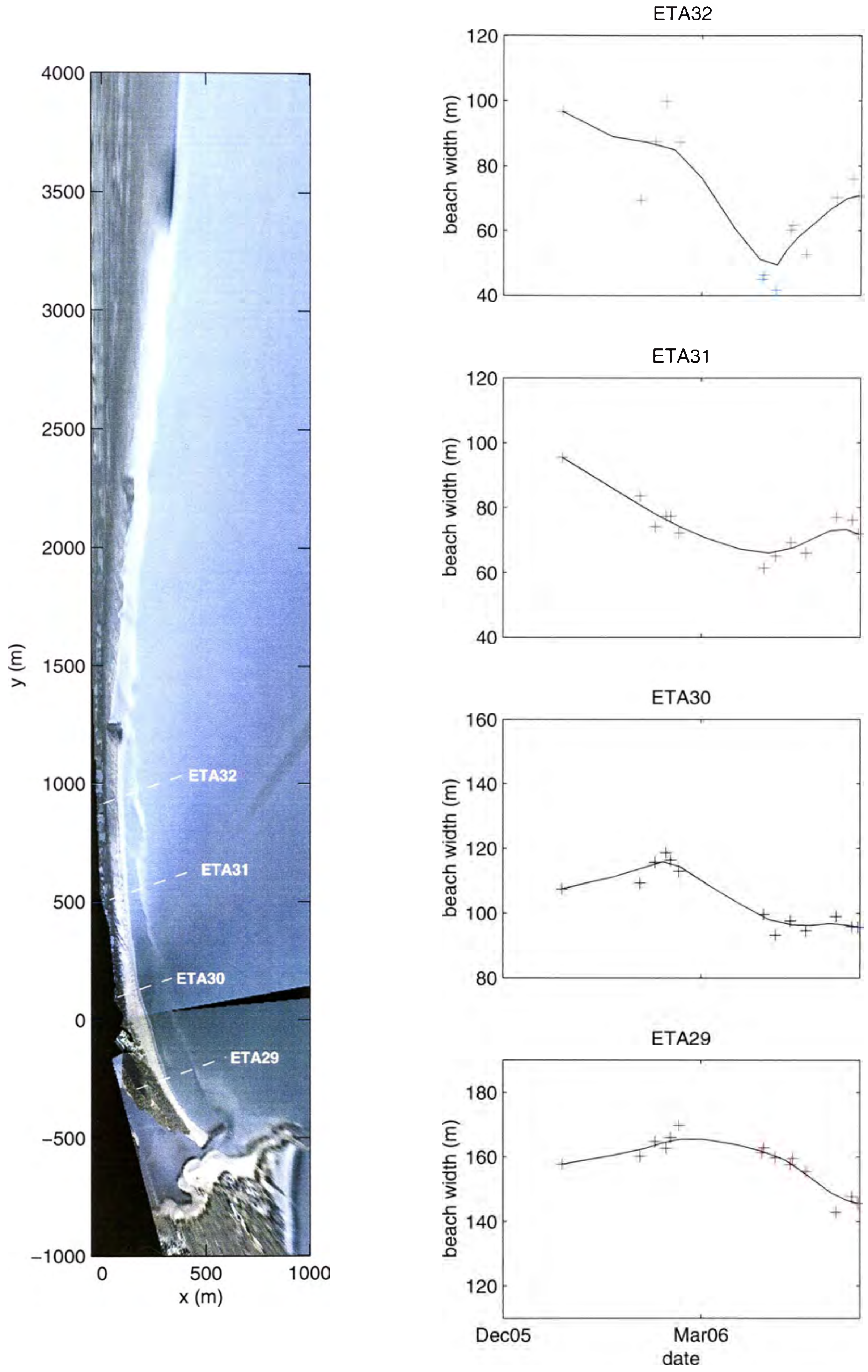


WRL Report No. 2006/14	WEEKLY BEACH WIDTH: DECEMBER 2005 - MAY 2006	Figure 6.2 02114-6-2.cdr



WRL Report No. 2006/14	STATISTICAL SUMMARY OF BEACH WIDTH CHANGES: DECEMBER 2005 - MAY 2006	Figure 6.3

02114-6-3.cdr



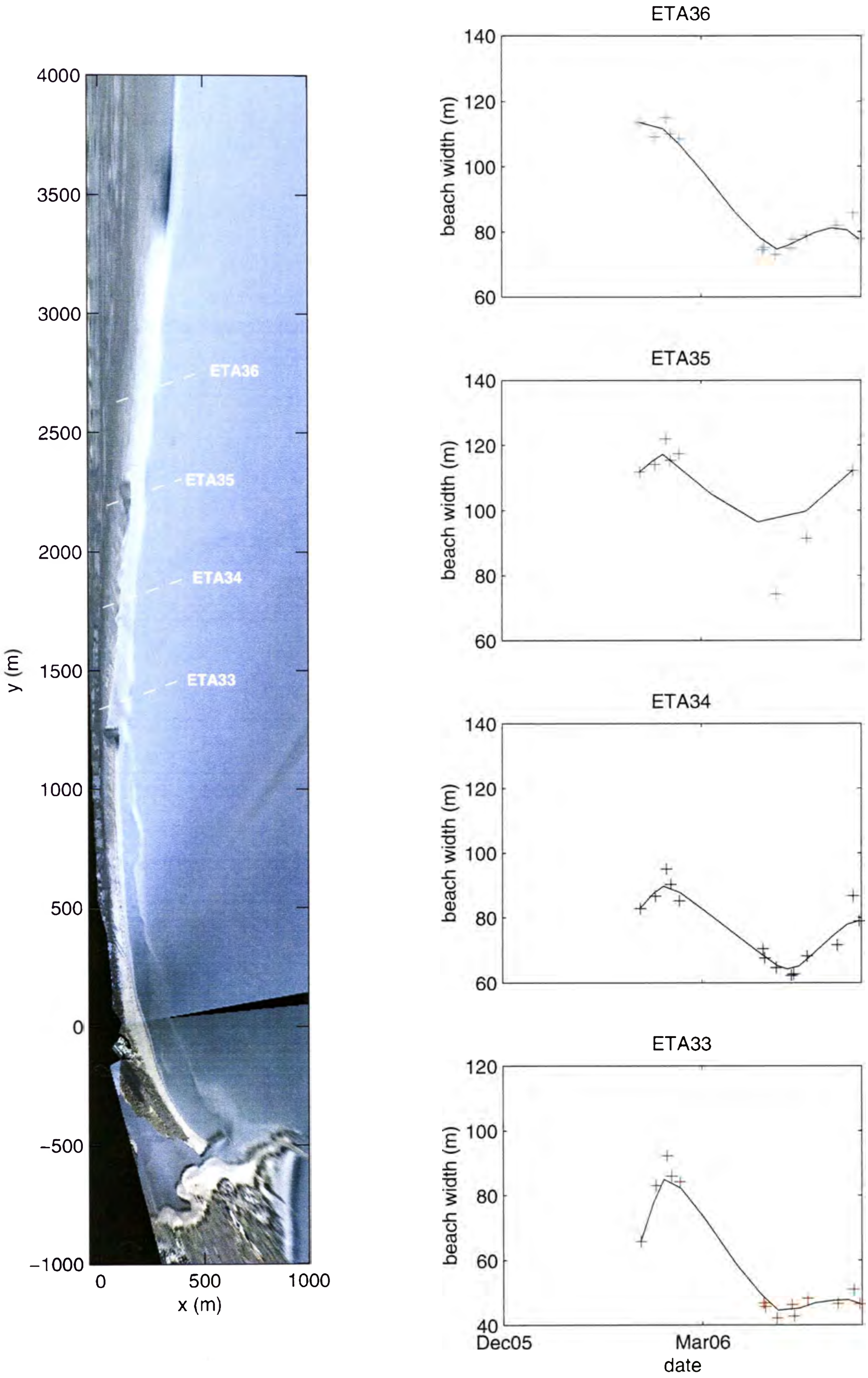
WRL

Report No. 2006/14

TIME-SERIES OF BEACH WIDTH (SOUTH):
DECEMBER 2005 - MAY 2006

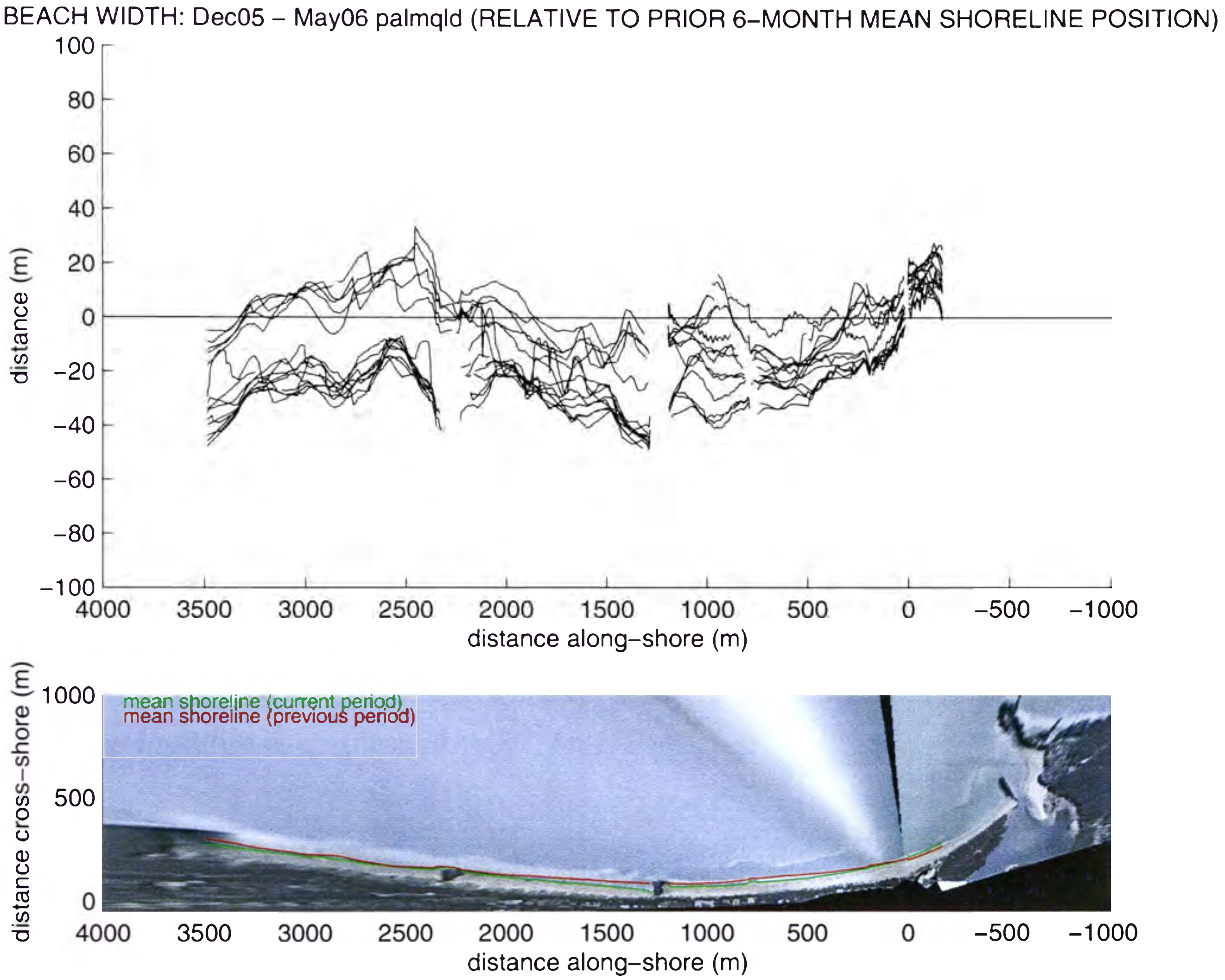
Figure
6.4

02114-6-4.cdr



WRL Report No. 2006/14	TIME-SERIES OF BEACH WIDTH (NORTH): DECEMBER 2005 - MAY 2006	Figure 6.5

02114-6-5.cdr



WRL Report No. 2006/14	WEEKLY BEACH WIDTH DECEMBER 2005 - MAY 2006 RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION	Figure 6.6 02114-6-6.cdr

7. QUANTITATIVE ANALYSIS OF TOTAL SHORELINE CHANGES: JUNE 2004 – MAY 2006

The completion of a total of 2 years (24 months) of monitoring at Palm Beach provides the opportunity to summarise and analyse longer-term shoreline changes observed to date. As the monitoring program continues in the future, this analysis will extend accordingly, providing potential insight to possible seasonal and/or longer-term trends that may emerge.

7.1 Weekly Shorelines and Shoreline Variability: June 2004 – May 2006

All weekly beach widths (relative to the alignment of the back-beach boulder wall) for the 104 week period June 2004 to May 2006 are shown in Figure 7.1. As per previous figures, a merged/rectified image is shown in the lower panel for reference (image date: 23rd May 2006). Since June 2004 the mid-tide beach width along the entire Palm Beach embayment generally varied in the order of 50 - 60 m, with up to 80 m beach change recorded in the vicinity of the nearshore nourishment works located to the south of the 11th Street groyne.

The variations in shoreline position measured at the eight ETA survey transects for the entire period June 2004 to May 2006 are shown in Figures 7.2 and 7.3. Figure 7.2 plots the weekly shoreline position for the southern transects ETA29 to ETA32, and Figure 7.3 shows the same for the central and northern transects ETA33 to ETA36. The alongshore position of each of these representative transects is shown in the accompanying merged/rectified image (image date: 23rd May 2006).

7.1.1 Southern Sand Spit

At transect ETA29 (Figure 7.2) the beach changes during the initial 12 month period June 2004 to May 2005 were dominated by an initial accretionary response to the beachfront placement of sand, then subsequent readjustment as this sand redistributed alongshore and cross-shore. From mid July 2004 to early September 2004 the beach width grew rapidly from around 160 m to 190 m in width, then from September 2004 through to the end of the May 2005 a steady decline in beach was observed, with the final width of the beach in this region at that time around 130 m. From June to November 2005 the erosion trend reversed in response to the placement at the beachface of additional sand from Currumbin Creek, with the beach width regaining around 30 m to 160 m in December. This beach width was maintained through to the end of February 2006, at which time beach erosion by some 20 m was recorded, following the onset of the major storm in early March. Minimal beach recovery was observed in this region up to the end of May 2006. By the end of May the beach in this region was of the order of 20 m narrower than the conditions that prevailed 2 years earlier in June 2004.

Fluctuations of the beach width at ETA30 (Figure 7.2) were similarly dominated by the beachface sand placement in 2004 and a second phase in April-May 2005. From June 2004 to September 2004 the beach width in this region increased by around 40 m to be 110 m - 150 m in response to the direct placement of sand in this area. A second increase then decline in beach width occurred during December 2004 to April 2005, as the 'slug' of sand placed in previous months along the central sand spit area moved northward through this region. In April – May 2005 the beach width again increased to 130 m, in response to the second phase of beachface placement, coinciding with the location of this transect.

From June to August 2005 the beach width then declined again by around 20 m, but in September accretion by approximately 10 m was observed. At this time the beach width had returned to within 5 – 10 m of the conditions that prevailed at the commencement of monitoring in June 2004. Similar conditions were observed in February 2006, but then storm erosion in early March resulted in the retreat of the beach by around 30 m, with again minimal recovery observed through to the end of May. Two years since the commencement of monitoring the beach was observed to be around 10 m narrower than was observed in June 2004.

7.1.2 Nearshore Nourishment Area

During the 12 month period June 2004 to May 2005 beach width changes at transects ETA31 and ETA32 (Figure 7.2) were dominated by the nearshore nourishment campaign completed in December 2004. Commencing November – December 2004 the beach at ETA31 & ETA32 began to increase, and by May 2005 this region of the Palm Beach beachfront increased in width by the order of 40 - 50 m. Commencing June 2005 and continuing through to mid September 2005, the beach at both ETA31 and ETA32 decreased by 20 – 30 m as a portion of the nourishment volume moved northward and the beach in this vicinity of the embayment adjusted toward a new equilibrium alignment.

By December 2005 the beach had recovered again, and at both ETA31 and ETA 32 was of the order of 40 m wider than the conditions that prevailed at the commencement of monitoring in June 2004. Storm erosion in early March 2006 resulted in the temporary loss of this additional beach width, but by the end of May 2006 recovery in the range of 20 – 40 m was observed. At the end of May 2006 the beach in this region was 20 m wider than it was two years prior in June 2004.

7.1.3 Central – Northern Embayment

From June 2004 to March 2005 the more northern transects ETA33, ETA34, ETA35 and ETA36 (Figure 7.3) located between and to the immediate north of the 11th and 21st Street groynes all exhibited fluctuations in beach width in response to the varying wave energy during this time, with no clearly identifiable trends emerging. At ETA33 and ETA34, located between the 11th and 21st Street groynes, a marginal trend of decreasing beach width was recorded, with the beach width decreasing to around 50 – 60 m. Commencing in March at the more southern ETA33 and ETA34 transects and a month later at the more northern ETA35, a distinct trend of beach widening was observed, with the beach by mid September 2005 increased by 30 – 40 m. This widening was attributed to the continued northward movement of sand placed within the nearshore of more southern transects some six months previously. At the most northern transect ETA36 located to the north of the 21st street groyne, the beach width through the period June 2004 to September 2005 continued to react in response to the varying incident wave energy, with no net accretion or erosion trend in evidence.

A general trend of net erosion was observed from September 2005 to February 2006 at the more southern transects ETA33 and ETA34, and then distinctive and rapid storm erosion in early March 2006. Varying degrees of beach recovery were monitored through to the end of May 2006. At the most northern ETA 36 the beach remained in an eroded state, with the beach around 20 m narrower than the conditions that prevailed 2 years earlier in June 2004. More pronounced post-storm recovery was observed at ETA35 and ETA34 located at the 21st Street groyne and midway between the two groyne structures, resulting in a 5 – 10 m wider beach relative to the commencement of the monitoring program in mid 2004. At ETA33 just north of the 11th Street groyne, minimal recovery was observed, so that by the end of May 2006 the beach in this region was of the order of 20 m narrower than 2 years prior in June 2004.

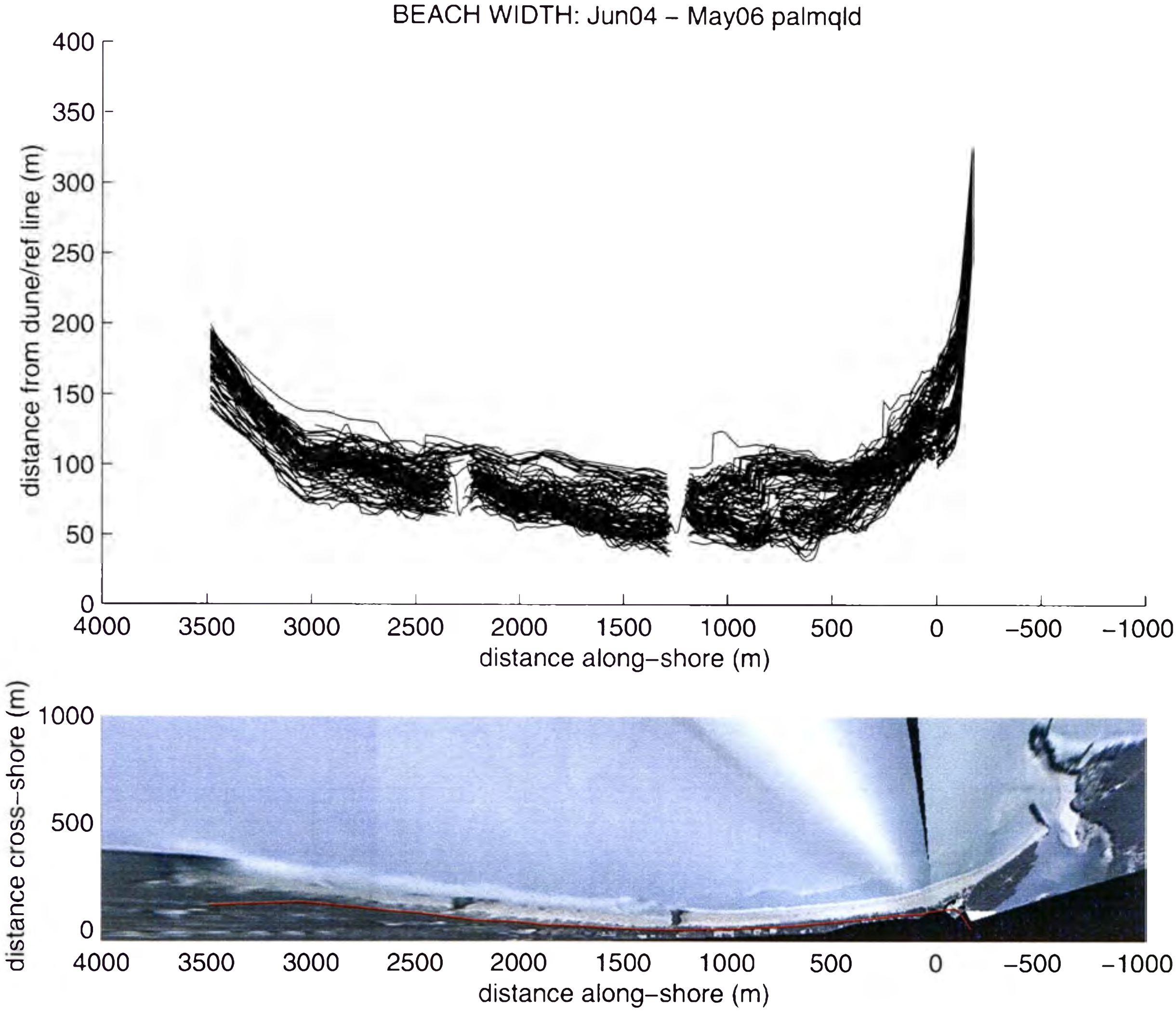
7.2 On-Line Beach Width Analysis

For the sake of completeness, Figures 7.4 and 7.5 are included here that show the same data presented in Figures 7.2 & 7.3, but in the on-line graphical format ('Beach Width Analysis') that are updated each week, and are available for public viewing (and download) via the monitoring project web site (refer Section 4). The top and bottom panels in these figures are equivalent to the two panels in Figures 7.2 and 7.3, with the additional feature that a selection of shorelines are also shown. As well as the same trends identified and discussed above, an interesting additional feature that is more clear in this alternative representation of the data is the convergence toward a more uniform width alongshore along much of the Palm Beach embayment. At the commencement of the monitoring program in June 2004 the width of the storm buffer seaward of the boulder wall varied by up to 150 m. As shown in Figures 7.3 and 7.4, by June 2005 the beach width at ETA transect lines had converged toward a more uniform range of around 100 ± 20 m at all of the eight ETA transects. However, following the most recent storm of March 2006, divergence of beach width alongshore was again apparent.

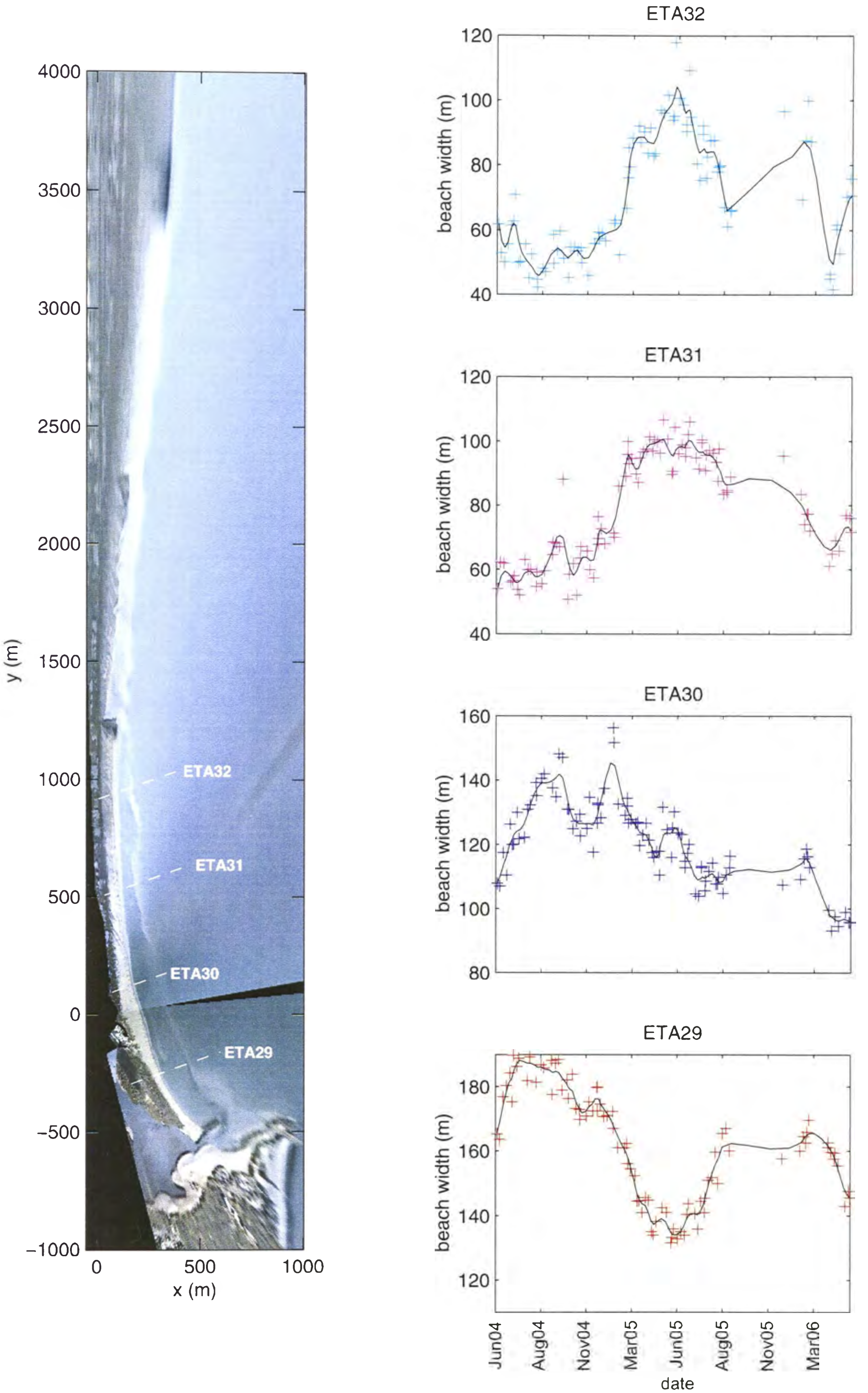
7.3 Summary

Prior to March 2006, the dominant beach changes observed within the Palm Beach embayment were directly attributable to the nearshore nourishment and beachface sand placement campaigns completed in 2004 and 2005. At the southern sand spit area (ETA 29) the beach had receded due to the alongshore and cross-shore re-distribution of sand originally placed along the beachface. In contrast, in the southern-central region (ETA31 to ETA32) the landward movement of sand placed within the nearshore had resulted in a net widening and straightening of the beach. Between the 11th and 21st Street groynes (ETA 33 – ETA35) the delayed widening of the beach has been observed, as a portion of the nearshore nourishment volume moved northward along the Palm Beach embayment. Only in the northern region of the Palm Beach embayment (ETA36) are the impacts of the nourishment campaign not observed to date.

The major storm event that occurred in March 2006 caused significant retreat of the beach along much of the Palm Beach embayment. The results of the next six-month monitoring period should provide useful new insight to the rate and degree of recovery of the recently nourished Palm Beach embayment.

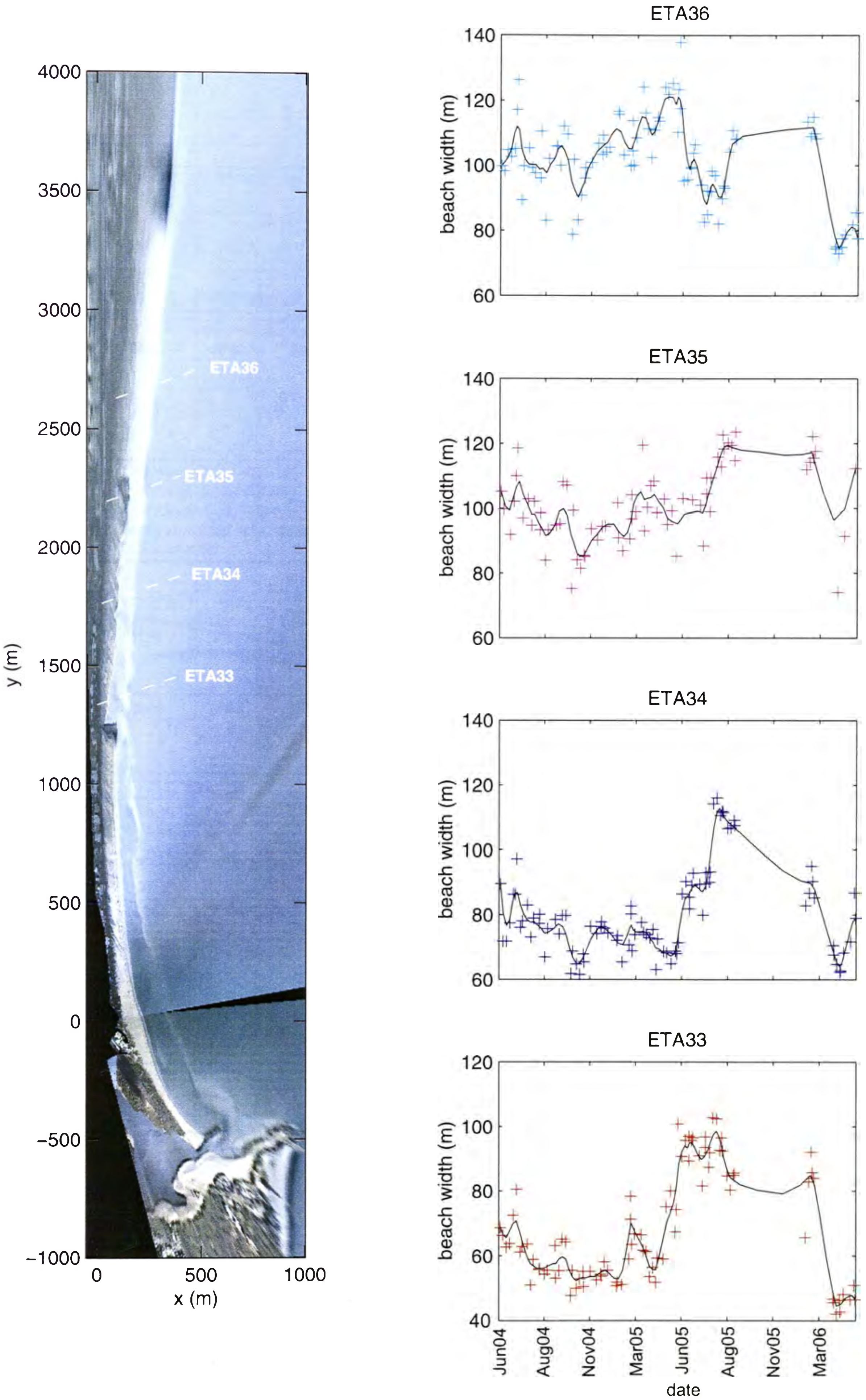


WRL Report No. 2006/14	WEEKLY BEACH WIDTH: JUNE 2004 - MAY 2006	Figure 7.1 02114-7-1.cdr



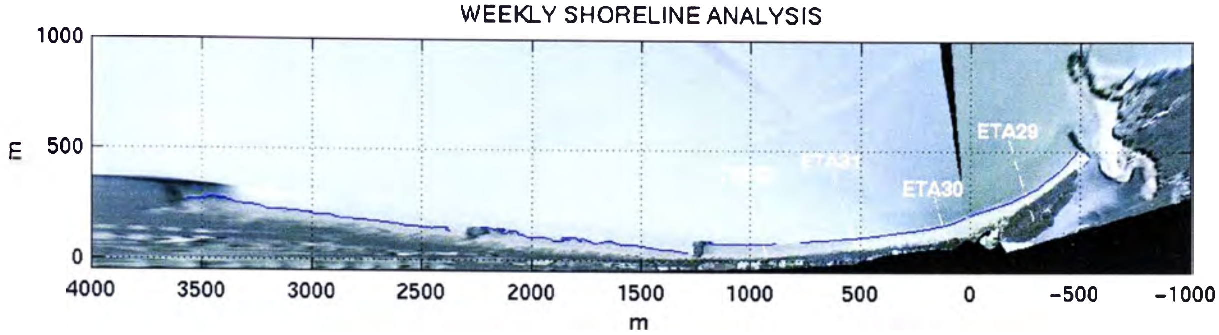
WRL Report No. 2006/14	TIME-SERIES OF BEACH WIDTH (SOUTH): JUNE 2004 - MAY 2006	Figure 7.2

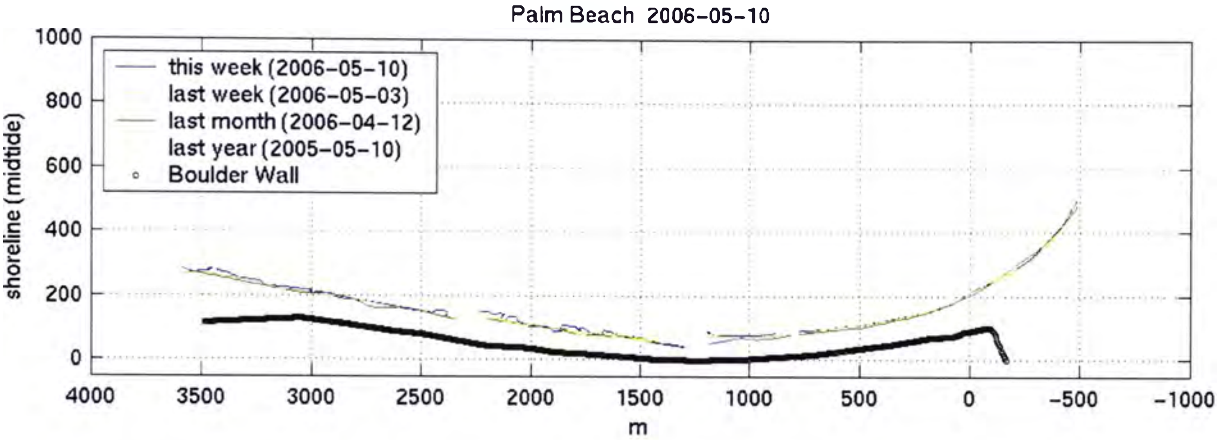
02114-7-2.cdr

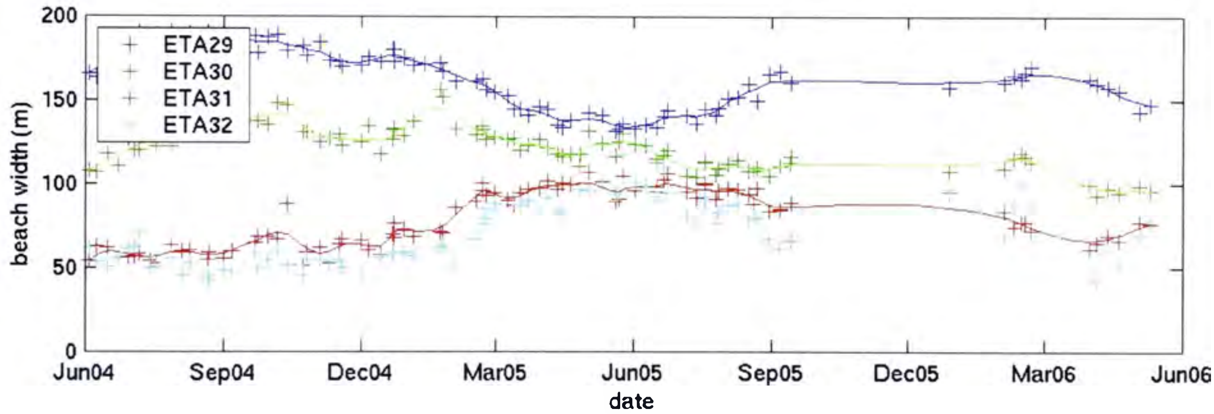


WRL Report No. 2006/14	TIME-SERIES OF BEACH WIDTH (NORTH): JUNE 2004 - MAY 2006	Figure 7.3

02114-7-3 cdr







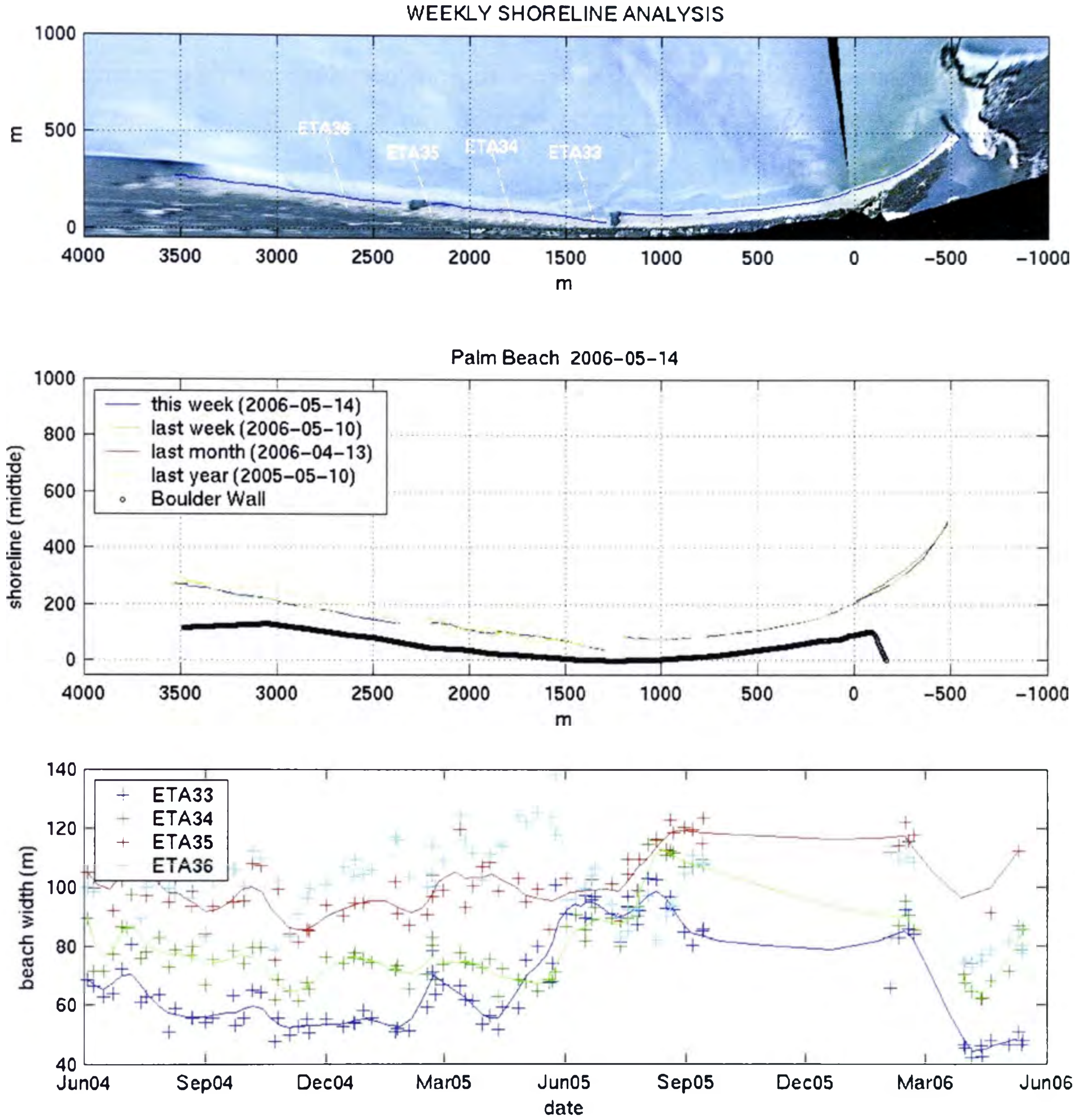
WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	ON-LINE BEACH WIDTH ANALYSIS TO MAY 2006 (SOUTH)	Figure 7.4

02114-7-4.cdr



WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	ON-LINE BEACH WIDTH ANALYSIS TO MAY 2006 (NORTH)	Figure 7.5

8. ANALYSIS OF EROSION-ACCRETION TRENDS

Coinciding with the implementation of the ARGUS-based beach monitoring program at Palm Beach in mid 2004, a new routine image analysis technique was implemented enabling patterns of beach erosion and accretion to be identified and quantified. On a monthly basis, hourly images throughout a single spring tide are analysed and a 3-D bathymetry of the beachface extending from the low tide waterline to the high tide waterline is derived. These data are further analysed to assess regions of beachface erosion and deposition within the Palm Beach embayment.

8.1 Methodology

A detailed description of the analysis techniques used to derive three-dimensional beachface bathymetry from two-dimensional image analysis was provided in Turner (2004). In summary, throughout a single spring tide cycle, the shoreline mapping technique is applied to locate the waterline in successive hourly images. The elevation corresponding to the detected waterlines is calculated on the basis of concurrent tide and wave information, which is incorporated in a model that combines the effects of wave setup and swash, at both incident and infragravity frequencies. As illustrated in Figure 8.1, if this process is repeated at all points alongshore throughout a complete spring-tide cycle, a three-dimensional bathymetry of the beachface - between the high tide and low tide waterlines - is derived. The beachface is the most dynamic region of sediment movement within the coastal system, and sand changes observed in this area are indicative of the total profile.

8.2 Monthly Beachface Bathymetric Mapping

Beachface bathymetries derived at approximately monthly intervals along the Palm Beach embayment are shown in Figure 8.2 (14 February 2006 and 30 March 2006) and Figure 8.3 (13 April 2006 and 13 May 2006). Bathymetries for the two months of December 2005 and January 2006 are not available, due to the temporary shutdown of the ARGUS system during roof repairs (refer Section 1.2).

As was observed in previous monitoring reports (e.g. Turner, 2006), these data reveal a persistent feature of the Palm Beach embayment that was not discernable from the raw images or shoreline analysis, namely that there is a distinct flattening of the beach gradient northward along the beachfront. This observation is consistent with the increasing exposure of the beach to predominantly south-easterly waves. The flattening of the beach gradient with increasing distance north of Currumbin is attributed to the modal beach state transitioning from more reflective (steeper), lower-intermediate morphology in the south, to increasingly dissipative (flatter), higher energy intermediate beach states towards the north. The post-storm cutting back of the beach in the region centred around 1300 m alongshore and located immediately north of the 11th Street groyne, is also readily apparent in these figures. This observation is discussed further in the following section.

8.3 Monthly Erosion-Accretion Trends

By further processing of the monthly bathymetries shown in Figures 8.2 - 8.3, a quantitative measure of the net change in sand volumes across the beachface (between the elevations of -0.5 and +0.7 m AHD) throughout the Palm Beach embayment can be obtained. Figure 8.4 shows the results of these calculations to determine the net change in bed elevation between February - March 2006, March - April 2006, and April - May 2006. Due to the absence of bathymetry data for the months of December 2005 and January 2006, these calculations for the two periods December – January and January - February are not available.

The top panel of Figure 8.5 confirms that from February to March 2006 Palm Beach experienced pronounced erosion in response to the passage of the major storm event in early March 2006. Averaged along the entire embayment, a total of **-102,890 m^3** of sand was eroded from the beachface, equating to an average of **–31.1 m^3 per m of shoreline** (between -0.5 and +0.7 m AHD). The extent of this erosion increased towards the northern end of the embayment, with greater than 1 m vertical erosion measured along the entire embayment north of Currumbin Spit.

From March to April (Figure 8.4, middle panel) a modest net trend of beach accretion was observed. Net beachface accretion of **+16,899 m^3** of sand (or around 15% of the sand volume that was eroded the previous month) was measured within the Palm Beach embayment, equating to **+5.1 m^3 per m shoreline**. The area of greatest recovery was observed immediately inshore of the nearshore nourishment area at around 500 – 1000 m alongshore, indicating that a portion of the nourished volume had moved shoreward during following the storm. Northward of the 11th Street groyne a quasi-regular erosion-accretion pattern was discernable alongshore, indicative of the accretion of the beach state from dissipative and two-dimensional LBT, to lower energy and more complex three-dimensional RBB morphology (refer Section 5.2).

April to May 2006 (Figure 8.4, lower panel) saw the modest continued accretion along much of the Palm Beach embayment. During this period just **+4,034 m^3** of additional sediment was measured to accrete between -0.5 and +0.7 m AHD, equating to **1.2 m^3 per m shoreline**.

8.4 Net Erosion-Accretion Trends

The net change in beachface bathymetry calculated for the previous and present monitoring periods are summarised in Figure 8.5a-b. The upper panel of Figure 8.5a is for the six month period June –November 2004, while the lower panel of Figure 8.5a is for the six month period December 2004 – May 2005. Figure 8.5b shows the net change in beachface bathymetry for the prior period of June 2005 – September 2005 (at which time the cameras were first removed for roof repairs), and for the present monitoring period of February to May 2006.

During June to November 2004 (Figure 8.5a, upper panel) the region of beach that extends southward from midway between 11th Street groyne and Currumbin Spit experienced a period of distinct beach accretion, centred around two areas: the first in the lee of the southern offshore sand dump boxes area, and the second where sand was placed from the dredging of the lower Currumbin Estuary during July – September 2004. Northward of this region a general trend of net beach erosion was observed. Lowering of the beachface profile by 0.2 m to 0.6 m was measured along the majority of the embayment.

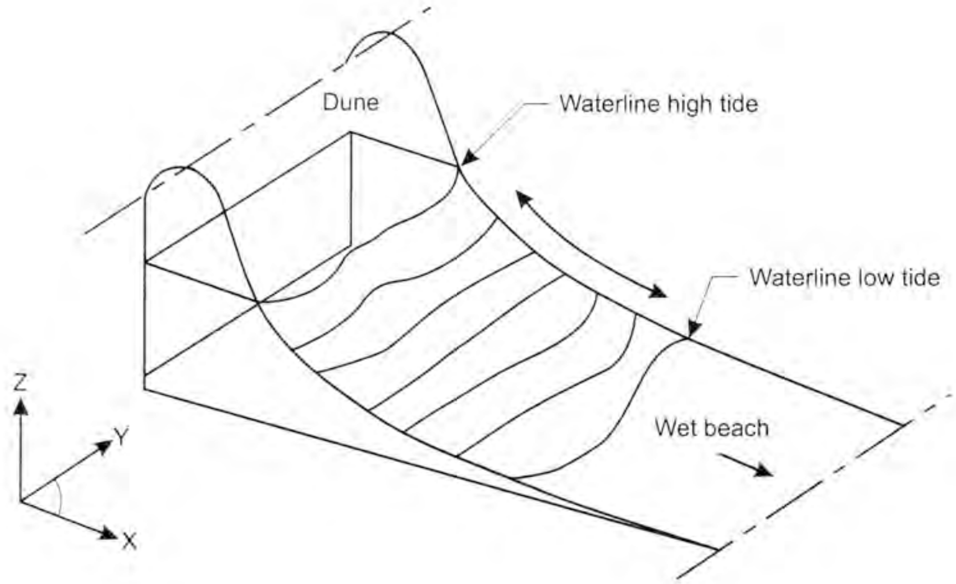
In contrast, during December 2004 to May 2005 the southern sand spit eroded, whereas the region of beach extending from in front of the Royal Palm building (0 m alongshore) to around the 11th Street groyne exhibited a period of major beachface accretion. During this time the positive benefits of the 2004 nearshore nourishment campaign had emerged and were very clearly evident during this monitoring period.

The monitoring period June – September 2005 was dominated by the re-distribution along the Palm Beach embayment of the nearshore nourishment placed in the latter part of 2004. The northward movement of the surfeit of sand away from the region immediately inshore of the nourishment area (500 – 1000 m alongshore) resulted in the retreat of the southern half of the embayment, countered by accretion along the northern half as sand moved alongshore. At the extreme southern end along the sand spit adjacent to the Currumbin estuary, the beach accreted, in response to the beachface placement of sand dredged from the estuary entrance. During this four month period the Palm Beach embayment experienced an embayment-scale rotation, as a new equilibrium shoreline alignment developed to accommodate the approximately 250,000 cubic metres of sand had been placed within the nearshore at that time.

The present monitoring period was dominated by the storm erosion event that occurred in early March 2006, with substantial erosion of the beach resulting, and only modest recovery to date. By May 2006 around 20% of the total sand volume that had been removed from the beachface during the storm three months earlier had returned to the beach. Net vertical erosion of the beachface by 1 m or more was characteristic of the entire embayment through to May 2006. Only in one very localised area immediately up-drift of the 11^{th} Street groyne had this net erosion trend reversed by the end of May. It will be of particular interest to monitor the continued rate of beachface recovery during the next six-month monitoring period.

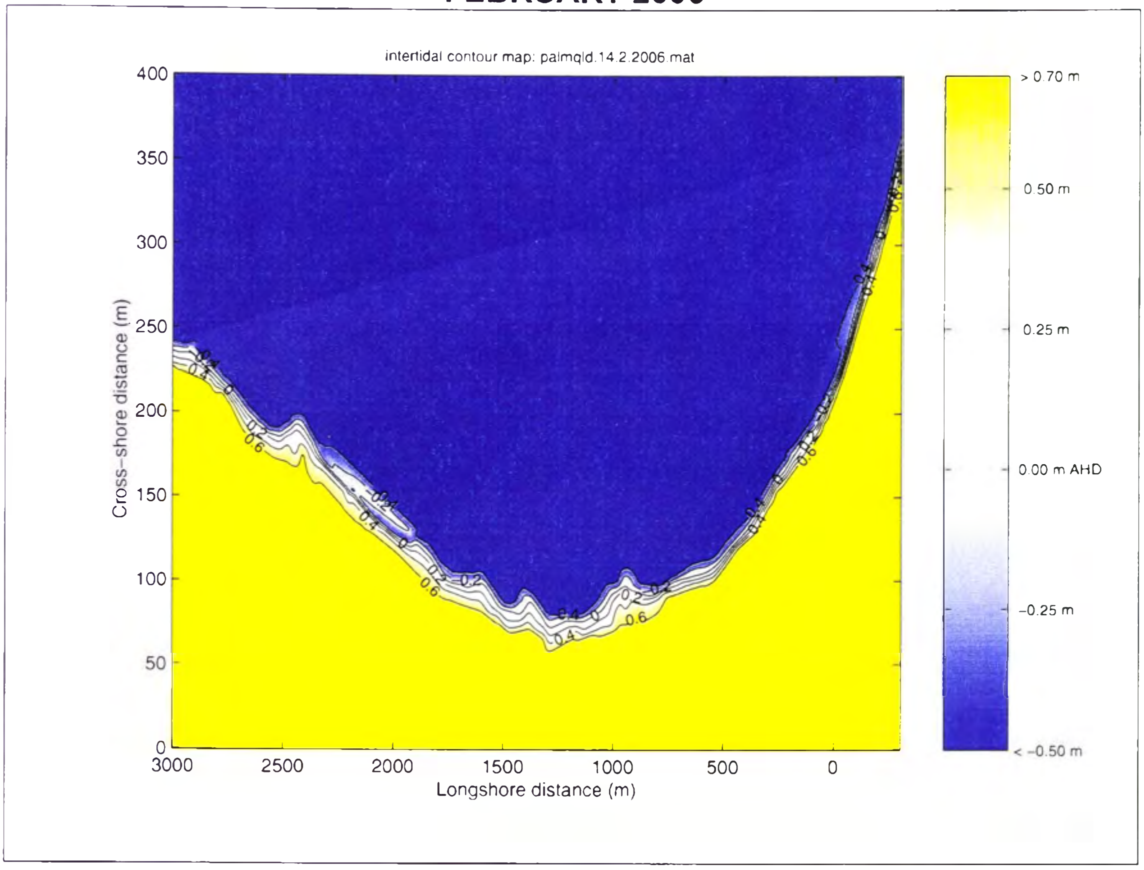
8.5 Total Erosion-Accretion Trends: June 2004 - May 2006

The final Figure 8.6 shows the total net change in beachface bathymetry for the entire monitoring period June 2004 to May 2006. The dominance of the March 2006 storm is evident, super-imposed by the 2004 and 2005/2006 nearshore nourishment campaigns along the more southern portion of the Palm Beach embayment. Within the intertidal beach (-0.5 and +0.7 m AHD) a total net volume of approximately **-14,772 m^3** of sand was lost along the ~3.5 km of beachfront included in this monitoring program, equating to an alongshore-averaged loss of around **-4.5 m^3** within the intertidal profile, for every 1 m alongshore. However, inshore of the nearshore nourishment area a distinctive net trend of beachface accretion to date is observed, revealing the positive effects of the nearshore nourishment campaign to this region of the beach. Despite the occurrence of a major storm erosion event during the total two year monitoring period, an area of around 1000 m of beach (a third of the total Palm Beach embayment) has exhibited a net gain in beach width that is directly attributable to the nourishment campaigns to date.

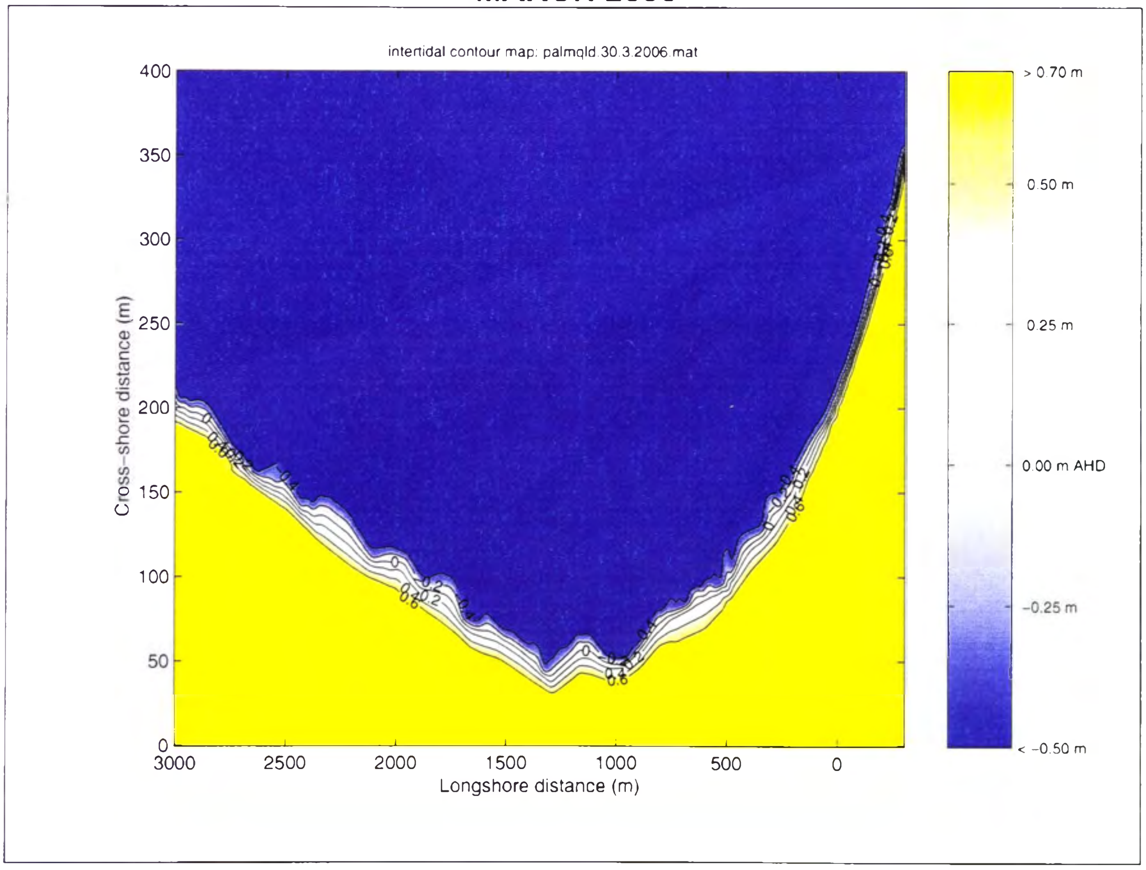


WRL Report No. 2006/14	DEFINITION SKETCH INTERTIDAL BATHYMETRY FROM HOURLY WATERLINES	Figure 8.1

FEBRUARY 2006



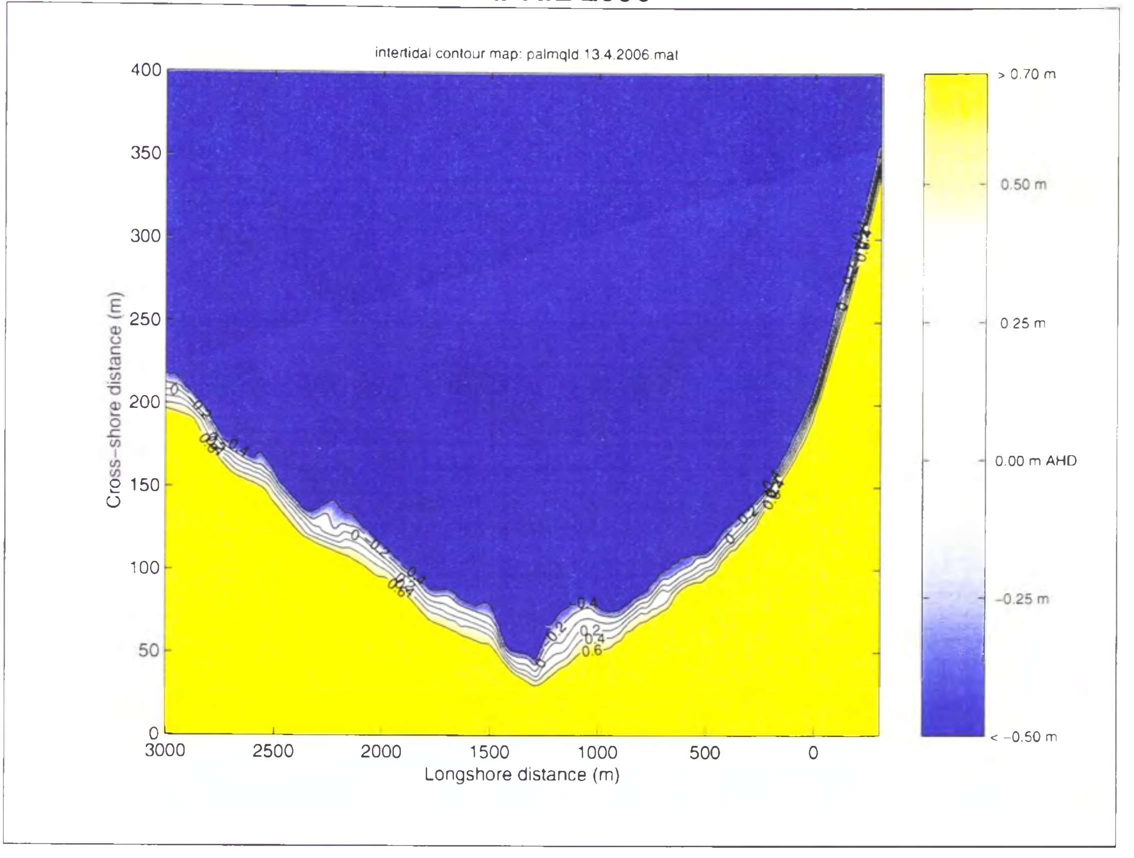
MARCH 2006



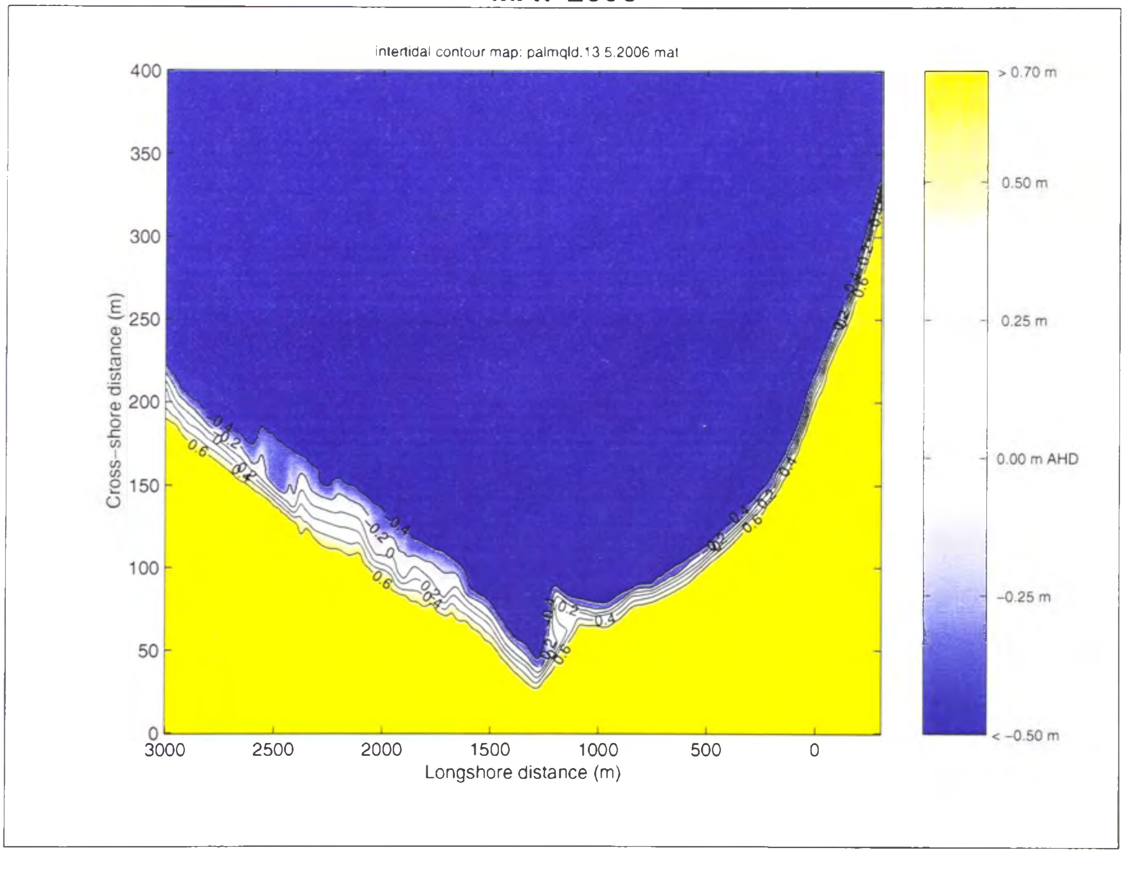
WRL Report No. 2006/14	BEACHFACE MAPPING - FEBRUARY, MARCH 2006	Figure 8.2

02114-8-2.cdr

APRIL 2006

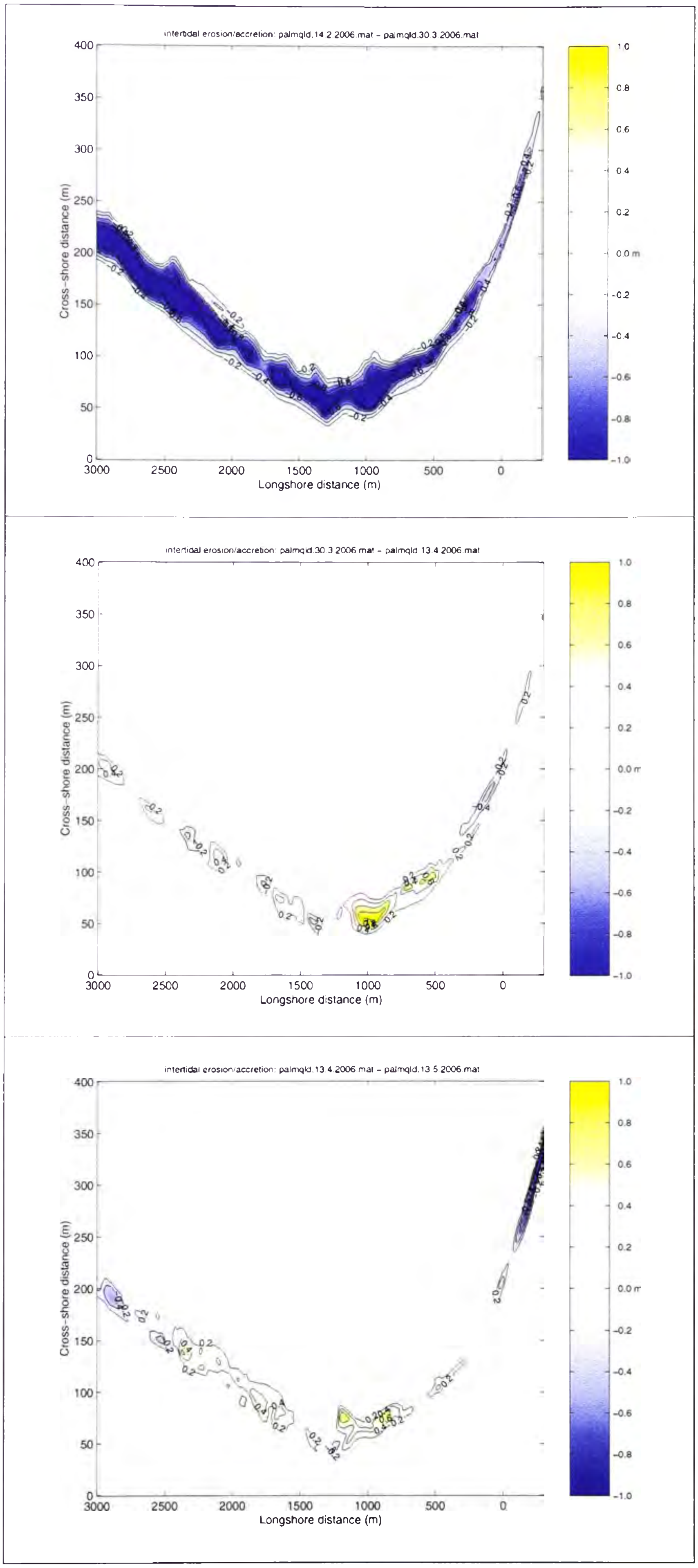


MAY 2006



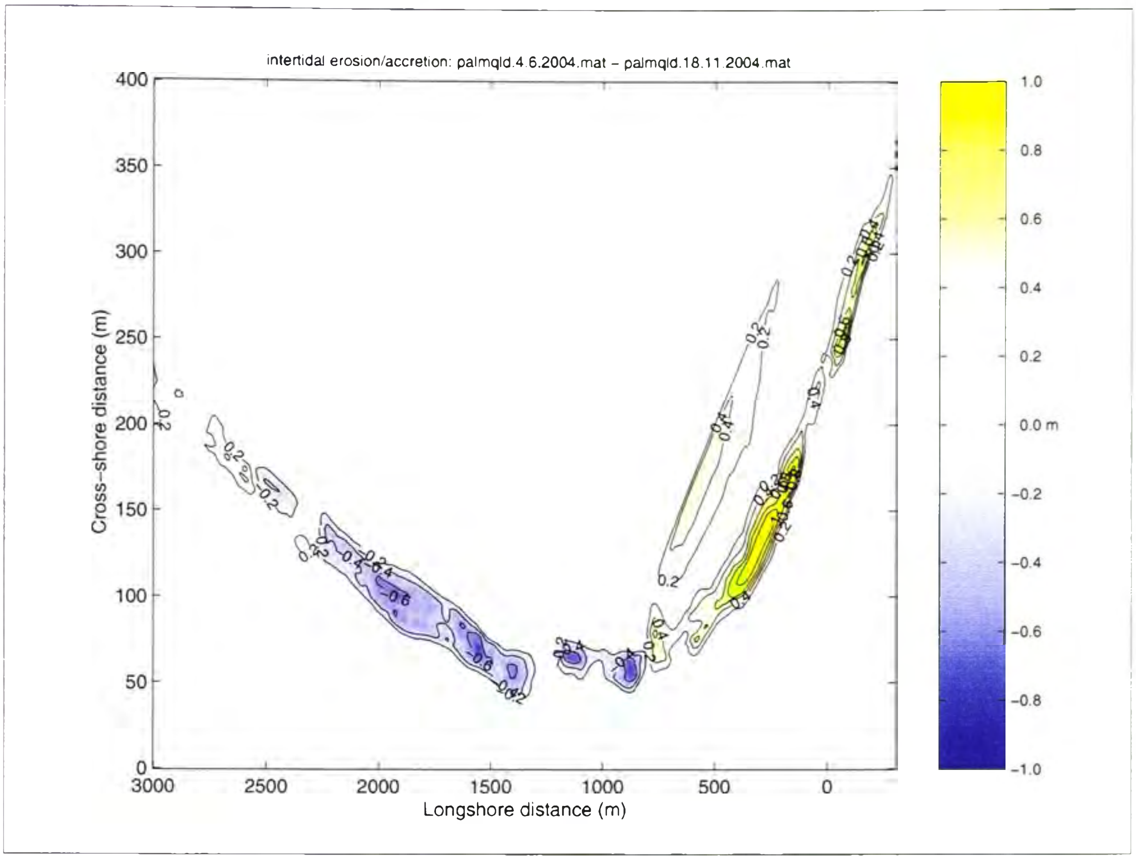
WRL Report No. 2006/14	BEACHFACE MAPPING - APRIL, MAY 2006	Figure 8.3

02114-8-3.cdr

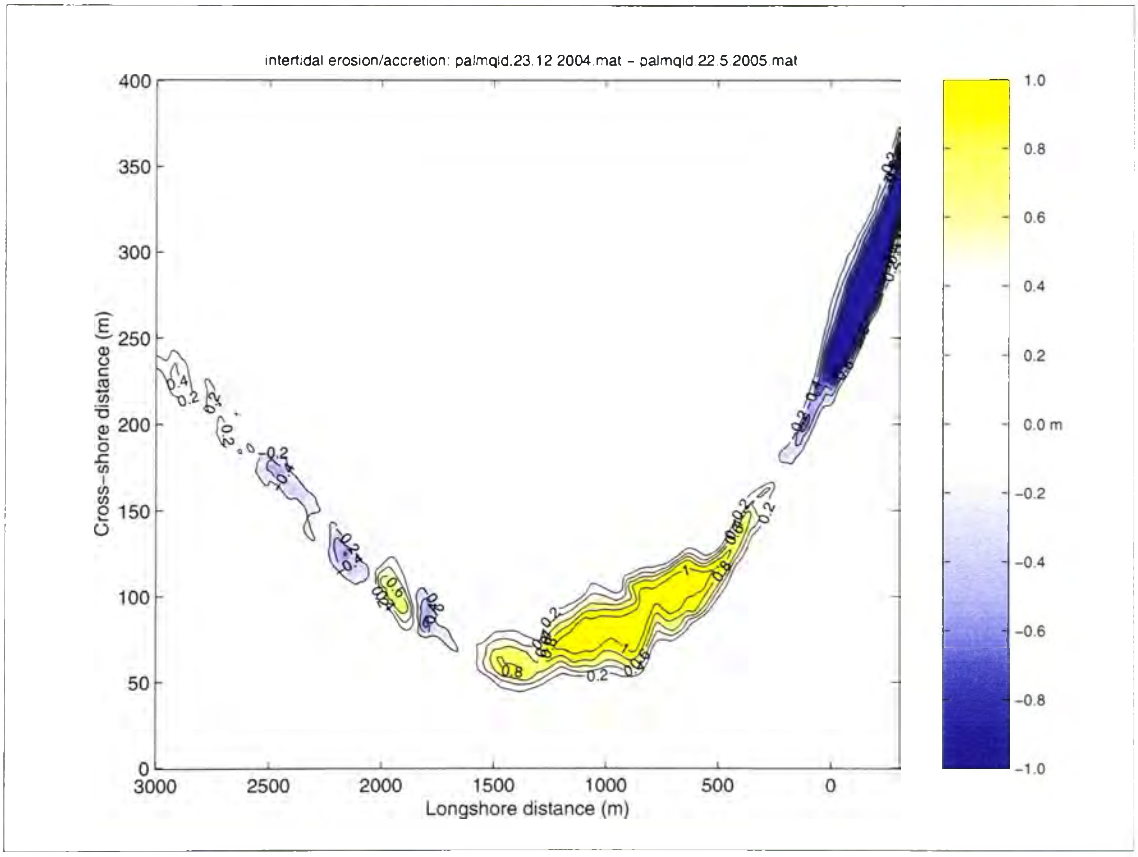


WRL Report No. 2006/14	MONTHLY EROSION/ACCRETION: FEBRUARY - MAY 2006	Figure 8.4 02114-8-4.cdr

NET CHANGE: JUNE - NOVEMBER 2004

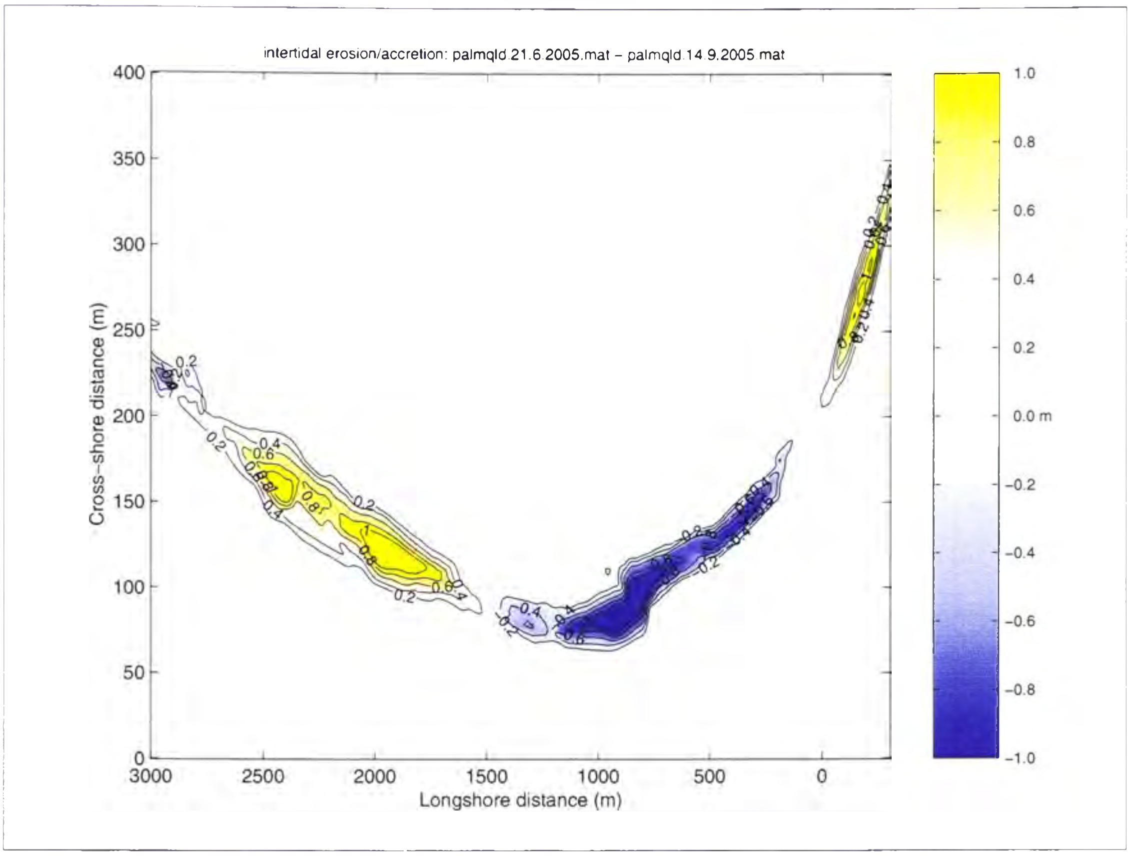


NET CHANGE: DECEMBER 2004 - MAY 2005

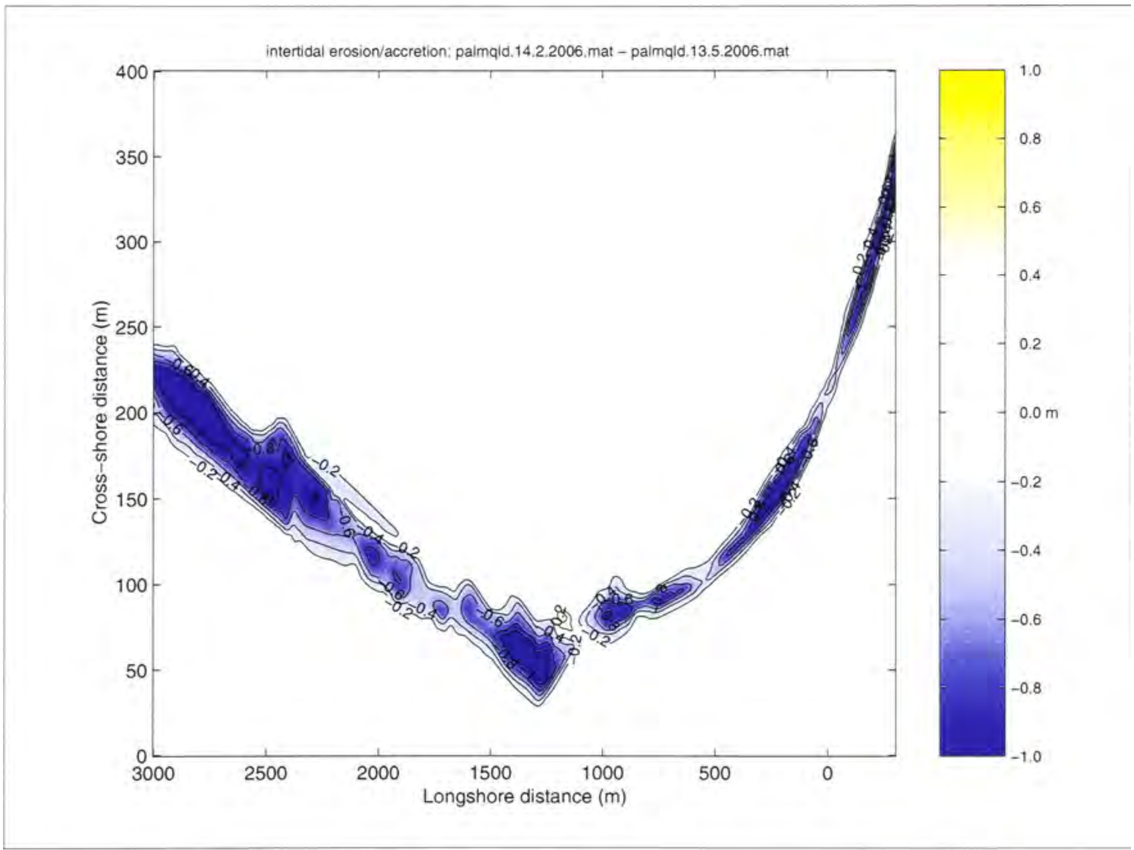


WRL Report No. 2006/14	EROSION/ACCRETION PER MONITORING PERIOD	Figure 8.5a 02114-8-5a.cdr

NET CHANGE: JUNE - SEPTEMBER 2005

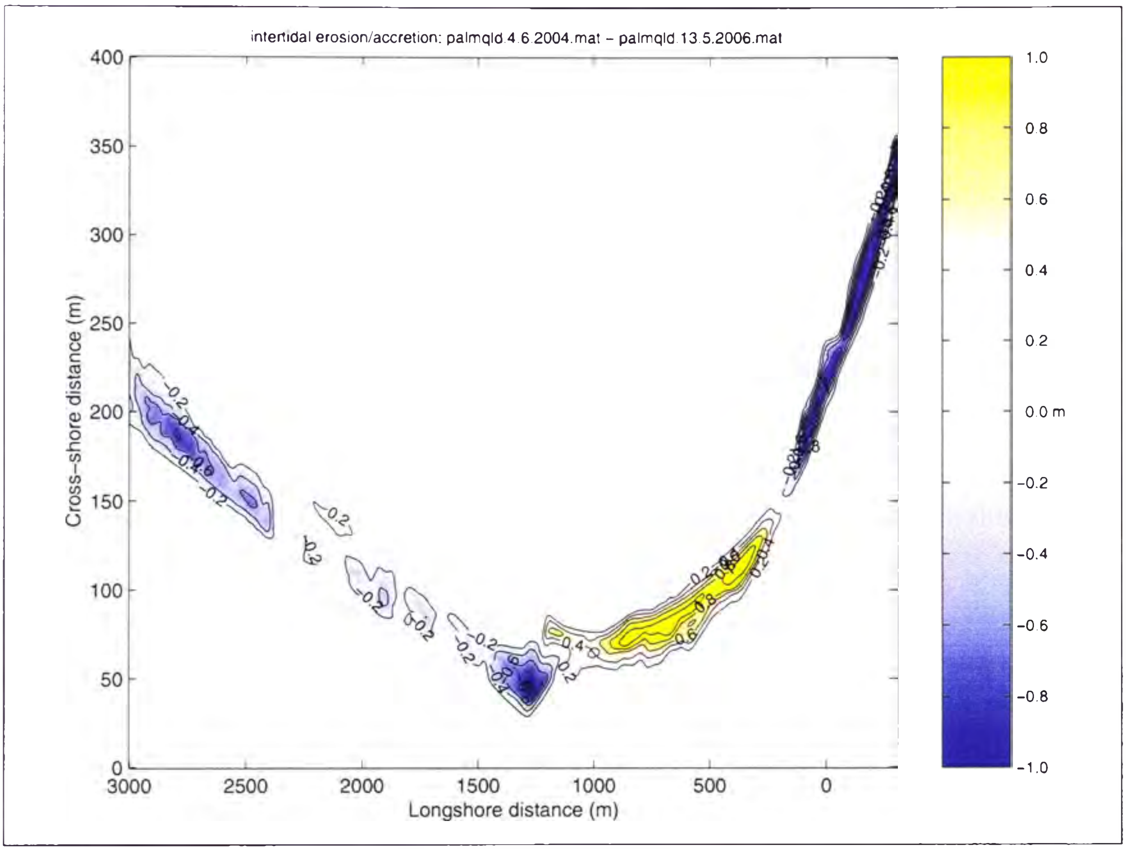


NET CHANGE: FEBRUARY 2006 - MAY 2006



WRL Report No. 2006/14	EROSION/ACCRETION PER MONITORING PERIOD	Figure 8.5b

TOTAL NET CHANGE: JUNE 2004 - MAY 2006



WRL Report No. 2006/14	TOTAL NET EROSION/ACCRETION TO MAY 2006	Figure 8.6 02114-8-6.cdr

9. SUMMARY AND CONCLUSIONS

The present monitoring period June 2005 to November 2005 is the fourth in the series of regular six-month monitoring reports to be produced for Palm Beach. During this six month period, approximately 138,600 cubic metres of nearshore nourishment was completed (Figure 2.3), bringing the total volume to-date to approximately 385,600 m^3.

In September 2005 the Body Corporate of the Royal Palm Building (atop which the Palm Beach ARGUS station is housed) requested that the cameras be temporarily removed while major roof restoration works were undertaken at the site. The ARGUS station was turned off on September 16th, and re-installed again on 12th December 2005. Unfortunately, unscheduled rectification works to correct several defects in the roof repairs necessitated the moving of the cameras again on the 19th December. Defect repairs continued through January 2006, with the ARGUS station finally re-installed and re-surveyed on 31st January 2006.

A major coastal storm struck the Gold Coast in early March 2006 and the electrical system within the host building suffered damage, causing a failure of the ARGUS power supply. This was subsequently repaired and the system became operational again in the second half of March.

As the result of the roof defect works and power outage, images and analysis are not available for a total of approximately two months of the present six-month monitoring period.

9.1 Qualitative Visual Assessment

An alongshore wave energy gradient generally exists at Palm Beach, due to the increased exposure at the northern end of the embayment to the predominately south-easterly swells.

Beach and nearshore conditions during the period December 2005 to May 2006 were dominated by high wave enegy conditions in early March, and the subsequent recovery of the beach in April and May. A visual assessment of resulting beach changes during December 2005 to May 2006 (Figure 5.2 and Figure 5.3) shows that along the southern beach in the region of the Currumbin Spit a distinctive trend of beach narrowing was apparent at the far southern end of the Palm Beach embayment, while in the region in the immediate vicinity of the Royal Palm building a slight decrease in beach width is discernable. Looking north along the Palm Beach embayment, from December 2005 to

May 2006 the region immediately south of the 11th Street groyne increased in width, while the region between the 11th and 21st Street groynes retreated, especially just north of the of the 11th Street groyne. To the north of the 21st Street groyne a general trend of beach retreat during this present six month period was discernable.

Extending this qualitative visual assessment of images to include the entire 2 year monitoring period, (Figure 5.4) from June to November 2004, along the southern beach the surfeit of sand that was observed within the intertidal and nearshore in June, appeared to have moved onshore by November, resulting in modest beach widening and a general straightening of the beach alignment in this southern region. Toward the north, from June to November 2004 the southern end of this region appeared to have generally widened. In contrast, toward the middle and northern end of the embayment, the shoreline appeared much more irregular and scalloped, with a discernable trend of a generally narrower beach.

From December 2004 to May 2005 the southern beach receded again, and from visual assessment was clearly narrower than the initial beach conditions observed 12 months earlier in June 2004. In contrast, toward the north a general trend of beach widening was observed, with the beach reverting to a more uniform alignment than was observed to develop during the preceding six month period.

During June to December 2005 a general trend of beach widening was apparent at the far southern end of the Palm Beach embayment, while in the region in the immediate vicinity of the Royal Palm building little net change in beach width is discernable. The region immediately south of the 11th Street groyne decreased in width, while the region between the 11th and 21st Street groynes increased in beach width. By December 2005 the southern beach was similar to the conditions that prevailed at the commencement of the monitoring program in June 2004, while along the central and northern regions of embayment the impacts of the nearshore nourishment campaign were clearly discernable, with the beach especially to the south and between the 11th and 21st Street groynes exhibiting a substantially wider beach and more uniform alignment alongshore.

As noted above, through the present six-month monitoring period to May 2006 a distinctive trend of beach narrowing was apparent at the far southern end of the Palm Beach embayment in the region of the Currumbin Spit. Immediately south of the 11th Street groyne the beach had increased in width, while the region between the 11th and 21st Street groynes and to the north exhibited a general trend of beach retreat. The beach conditions that prevailed at the end of May 2006 along the southern Palm Beach embayment were similar to the eroded conditions observed 12 months earlier in May 2005. Along the northern beach the conditions in May 2006 were intermediate to the accreted beach that was observed in May 2005, and the eroded beach observed six months prior to that time in December 2004.

9.2 Shoreline Variability and Weekly Beach Width Analysis at GCCC Survey Lines ETA29 – ETA36

Based upon the quantitative analysis of the available weekly shoreline positions during the present monitoring period 01/12/05 to 31/05/06, the beach along the Palm Beach oceanfront varied in width from a minimum of approximately 40 m (relative to the alignment of the back-beach boulder wall) in the vicinity of the 11th Street groyne, to around 180 m at the extreme northern end of the embayment adjacent to Tallebudgera Creek. At the southern end of the boulder wall, adjacent to Currumbin Creek, the wall alignment dips landward, resulting in over 250 m of beach between the wall and shoreline. The envelope of beach width changes along the entire embayment was in the range of 20 - 70 m during this period.

The median beach width at mid-tide (relative to the alignment of the back-beach boulder wall) was of the order of 60 – 70 m along the Palm Beach embayment (Figure 6.3). With the alignment of the boulder wall changing orientation and dipping landward just north of the sand spit, the measured beach width is observed to increase accordingly, reaching 100 m in front of the site of the cameras (ie., distance = 0 m alongshore). Analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals a relatively uniform trend alongshore, with the beach width varying by of the order of ± 30 m from the mean shoreline position. The standard deviation (s.d.) of weekly shorelines from the mean shoreline position during the period 01/12/05 - 31/05/06 was in the range of 10 – 20 m, which is greater than was observed during the previous monitoring period. The greatest areas of shoreline variability and change were located in the vicinity of the 11th Street groyne and in the region extending to the 21st Street groyne and northward. These trends are attributed to continued onshore and northward movement of sand, following the major phase of nearshore nourishment completed at the end of 2004 and continuing in late 2005.

The variation in shoreline position measured at Gold Coast City Council's ETA transects 29 to 36 for the monitoring period December 2005 to May 2006 reveals different behaviour between the southern, central and northern regions of the Palm Beach embayment. Due to the shut-down of the system through the latter part of December and throughout January while roof defect repairs were completed, and then the failure of the power system in early March, gaps in these data are present. At the southern-most transects ETA29 and ETA30 (Figure 6.4), the dominance of the large storm waves in early March are apparent. At the southern transects ETA29 and ETA30 the beach was observed to accrete by around 10 m from December to the end of February, then in early March beach retreat of 5 m (ETA29) and 20 m (ETA30) was observed. During April – May at the southern-most transect ETA29 the beach continued to decline in beach width from 5 m to around 20 m narrower than the conditions that prevailed prior to the onset of the storm in early March. At the more northern Transect ETA30 the 20 m of erosion that occurred in early March was maintained.

At monitoring transects ETA31 and ETA32 the beach was observed to decline in width by 10 – 20 m during the period December to February, then with the onset of the storm in March a further period of erosion was monitored, followed by recovery. At ETA31 the storm caused the beach to retreat by around 10 m, then through April-May return to the conditions that were observed at the end of February, prior to the onset of the storm. At the more northern ETA32 a greater degree of erosion and recovery were observed, with the beach decreasing in width by some 40 – 50 m immediately after the storm, then recovering though April-May of the order of 30 m beach width. At the end of the present six month monitoring period, the beach width along the southern monitoring transects had eroded of the order of 15 – 20 m.

At all northern transects ETA33 to ETA 36 (Figure 6.5) the impacts of the storm in early March are pronounced. From February to March beach retreat of the order of 50 m was measured at ETA33, ETA35 and ETA36, with around 40 m erosion observed mid-way between the 11th Street and 21st Street groynes in the vicinity of ETA34. At the northern ETA36 and southern ETA33 only minimal recovery of beach width was measured during April – May, while at ETA34 and ETA35 by the end of May the beach had recovered to within 10 m of the conditions that prevailed prior to the onset of the storm.

When the weekly shorelines data for the period December 2005 to May 2006 were re-analysed to assess beach width changes relative to the mean shoreline position for the preceding six month period (Figure 6.6), this analysis shows that, relative to the mean shoreline position for the preceding six month period, the entire Palm Beach embayment experienced pronounced and relatively uniform-alongshore erosion, with the exception of Currumbin Spit. Prior to March 2006 the region north of the 21st Street groyne exhibited an accretionary trend up to onset of the major erosion event, while along the remainder of the embayment, erosion (relative to conditions six months prior) generally predominated throughout the present six-month period.

In summary, the dominant observation during the present monitoring period was the rapid and marked erosion of the Palm Beach embayment following the onset of the storm in early March 2006, followed by variable recovery of beach width through April and May. By the end of May 2006 the beach was 10 – 50 m narrower than the conditions that prevailed at the end of February 2006, immediately prior to the onset of the storm.

9.3 Erosion/Accretion Trends

Due to the absence of bathymetry data for the months of December 2005 and January 2006, beachface bathymetries for the two periods December – January and January - February are not available. Beachface bathymetries derived at monthly intervals for the remaining months along the Palm Beach embayment (Figures 8.2 - 8.3) continue to show a persistent feature of the Palm Beach embayment that was not discernable from the raw images or shoreline analysis, namely that there is a distinct flattening of the beach gradient northward along the beachfront. This observation is consistent with the increasing exposure of the beach to predominantly south-easterly waves. The flattening of the beach gradient with increasing distance north of Currumbin is attributed to the modal beach state transitioning from more reflective (steeper), lower-intermediate morphology in the south, to increasingly dissipative (flatter), higher energy intermediate beach states towards the north.

From February to March 2006 (Figure 8.5, top panel) Palm Beach experienced pronounced erosion in response to the passage of the major storm event in early March 2006. Averaged along the entire embayment, a total of **-102,890 m^3** of sand was eroded from the beachface, equating to an average of **–31.1 m^3 per m of shoreline** (between -0.5 and +0.7 m AHD). The extent of this erosion increased towards the northern end of the embayment, with greater than 1 m vertical erosion measured along the entire embayment north of Currumbin Spit.

From March to April (Figure 8.4, middle panel) a modest net trend of beach accretion was observed. Net beachface accretion of **+16,899 m^3** of sand (or around 15% of the sand volume that was eroded the previous month) was measured within the Palm Beach embayment, equating to **+5.1 m^3 per m shoreline**. The area of greatest recovery was observed immediately inshore of the nearshore nourishment area at around 500 – 1000 m alongshore, indicating that a portion of the nourished volume had moved shoreward during following the storm. Northward of the 11th Street groyne a quasi-regular erosion-accretion pattern was discernable alongshore, indicative of the accretion of the beach state from dissipative and two-dimensional LBT, to lower energy and more complex three-dimensional RBB morphology (refer Section 5.2).

April to May 2006 (Figure 8.4, lower panel) saw the modest continued accretion along much of the Palm Beach embayment. During this period just **+4,034 m^3** of additional sediment was measured to accrete between -0.5 and +0.7 m AHD, equating to **1.2 m^3 per m shoreline**.

The present monitoring period December 2005 to May 2006 (Figure 8.5, lower panel) was dominated by the storm erosion event that occurred in early March 2006, with substantial erosion of the beach resulting, and only modest recovery to date. By May 2006 around 20% of the total sand volume that had been removed from the beachface during the storm three months earlier had returned to the beach. Net vertical erosion of the beachface by 1 m or more was characteristic of the entire embayment through to May 2006. Only in one very localised area immediately up-drift of the 11th Street groyne had this net erosion trend reversed by the end of May. It will be of particular interest to monitor the continued rate of beachface recovery during the next six-month monitoring period.

The final analysis of total net change in beachface bathymetry for the entire monitoring period June 2004 to May 2006 (Figure 8.6) reveals the dominance of the March 2006 storm event, super-imposed by the 2004 and 2005/2006 nearshore nourishment campaigns along the more southern portion of the Palm Beach embayment. Within the intertidal beach (-0.5 and +0.7 m AHD) a total net volume of approximately **-14,772 m^3** of sand was lost along the ~3.5 km of beachfront included in this monitoring program, equating to an alongshore-averaged loss of around **-4.5 m^3** within the intertidal profile, for every 1 m alongshore. However, inshore of the nearshore nourishment area a distinctive net trend of beachface accretion to date is observed, revealing the positive effects of the nearshore nourishment campaign to this region of the beach. Despite the occurrence of a major storm erosion event during the total two year monitoring period, an area of around 1000 m of beach (a third of the total Palm Beach embayment) has exhibited a net gain in beach width that is directly attributable to the nourishment campaigns to date.

10. ACKNOWLEDGEMENTS

This project was commissioned and funded by the Gold Coast City Council.

The Body Corporate of Royal Palm are thanked for permitting the ARGUS system to reside on the roof of the building. Also, we thank the building managers for their support during installation and routine maintenance visits to the site.

The Queensland Department of Environment is acknowledged for the ongoing provision of deepwater wave data from the Gold Coast Waverider buoy.

Doug Anderson of WRL continues to assist with wave and tide data processing, computer operations for remote communications, image storage, off-line image archiving and web serving at WRL. Ian Cunningham of WRL was responsible for the weekly analysis and updating of monitoring program information via the project web site.

Finally, Professor Rob Holman of Oregon State University and the growing world-wide team of ARGUS users are acknowledged for continuing system development. These research efforts are providing practical tools for coastal monitoring and management.

11. REFERENCES

Aarninkhof, S G J (2003). "Nearshore bathymetry derived from video imagery". Unpublished PhD thesis, Technical University Delft, 175p.

Aarninkhof, S G J and Roelvink, J A, (1999). "ARGUS-based monitoring of intertidal beach morphodynamics". *Proceedings, Coastal Sediments Conference*, Long Island (NY), USA, 2429-2444.

Aarninkhof, S G J, Turner I L, Dronkers T D T, Caljouw, M and Nipius, L, (2003), "A video-based technique for mapping intertidal bathymetry", *Coastal Engineering*, 49, 275-289.

Anderson, D J, Turner, I L, Dyson, A, Lawson, S and Victory, S, (2003), "Tweed River Entrance Sandy Bypassing Project: 'real-time' beach monitoring and analysis system via the world-wide-web", *Proceedings, 16th Australasian Coastal and Ocean Engineering Conference*, IEA,, Auckland, New Zealand, Paper #002 (CD Conference Volume), 9p.

Holman R A, Sallenger Jr A H, Lippmann T C D and Haines J W, (1993), "The Application of Video Image Processing to the Study of Nearshore Processes", *Oceanography*, Vol.6, No.3.

Turner I L, (2004), System Description, Analysis of Shoreline Variability and Erosion/Accretion Trends: June 2004 – November 2004, *WRL Technical Report 2004/38.*

Turner I L, (2005), Analysis of Shoreline Variability and Erosion/Accretion Trends: December 2004 – May 2005, *WRL Technical Report 2005/22.*

Turner I L, (2006), Analysis of Shoreline Variability and Erosion/Accretion Trends: June 2005 – November 2005, *WRL Technical Report 2005/36.*

Wright L D and Short A D, (1983), Morphodynamics of Beaches and Surfzones In Australia, In Komar, P.D., (ed), *Handbook of Coastal Processes and Erosion*, CRC Press, Boca Raton, 34-64.

Appendix A

Week-to-a-Page: December 2005 - May 2006

image not available

2006-01-30

2006-01-31

2006-02-01

2006-02-02

2006-02-03

2006-02-04

2006-02-05

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 30/01/2006 - 05/02/2006	Figure A1

02114-A01.cdr

Week-to-a-Page (Mid-Tide)

2006-02-06

2006-02-07

2006-02-08

2006-02-09

2006-02-10

2006-02-11

2006-02-12

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 06/02/2006 - 12/02/2006	Figure A2

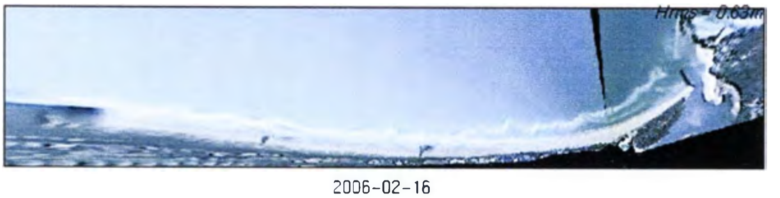
02114-A02.cdr

Week-to-a-Page (Mid-Tide)

2006-02-13

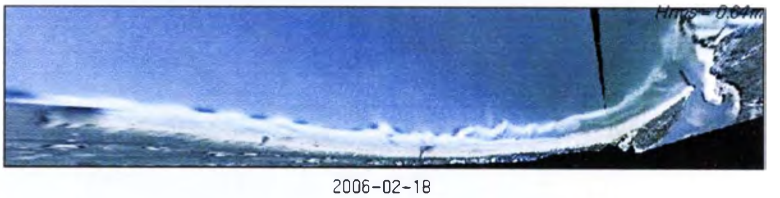
2006-02-14

2006-02-15



2006-02-16

2006-02-17



2006-02-18

2006-02-19

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 13/02/2006 - 19/02/2006	Figure A3

02114-A03.cdr

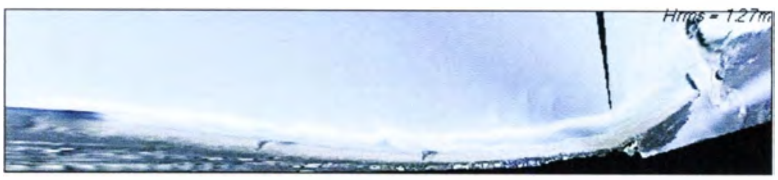
Week-to-a-Page (Mid-Tide)

2006-02-20

2006-02-21

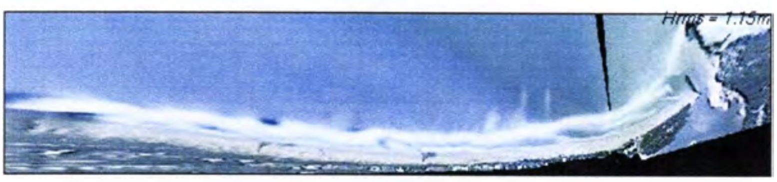
2006-02-22

2006-02-23



2006-02-24

2006-02-25



2006-02-26

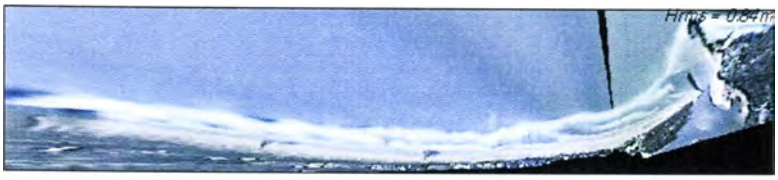
WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

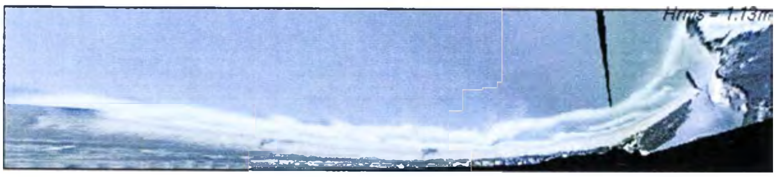
WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 20/02/2006 - 26/02/2006	Figure A4

Week-to-a-Page (Mid-Tide)



2006-02-27

2006-02-28



2006-03-01

2006-03-02

2006-03-03

image not available

2006-03-04

image not available

2006-03-05

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 27/02/2006 - 05/03/2006	Figure A5

02114-A05.cdr

image not available
2006-03-06

image not available
2006-03-07

image not available
2006-03-08

image not available
2006-03-09

image not available
2006-03-10

image not available
2006-03-11

image not available
2006-03-12

WATER RESEARCH LABORATORY

THE UNIVERSITY OF
NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 06/03/2006 - 12/03/2006	Figure A6 02114-A06.cdr

image not available
2006-03-13

image not available
2006-03-14

image not available
2006-03-15

2006-03-16

image not available
2006-03-17

image not available
2006-03-18

image not available
2006-03-19

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

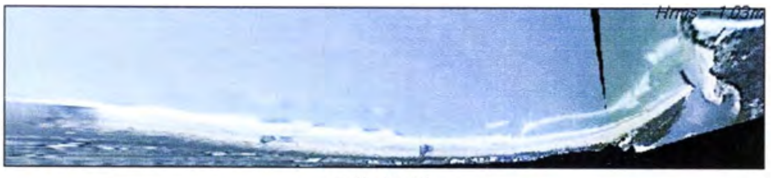
www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 13/03/2006 - 19/03/2006	Figure A7 02114-A07.cdr

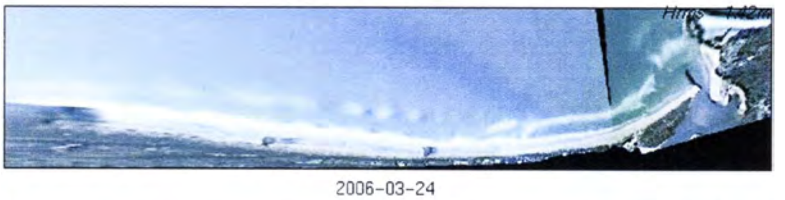
image not available
2006-03-20

image not available
2006-03-21

image not available
2006-03-22

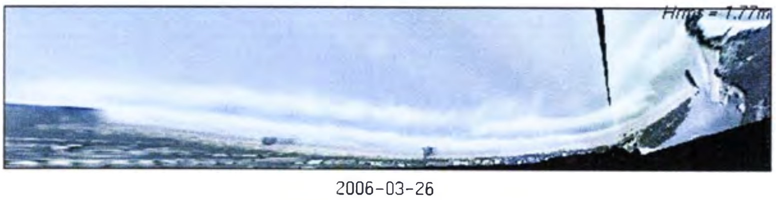


2006-03-23



2006-03-24

2006-03-25



2006-03-26

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 20/03/2006 - 26/03/2006	Figure A8 02114-A08.cdr

Week-to-a-Page (Mid-Tide)

2006-03-27

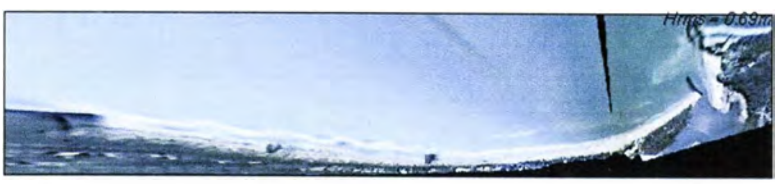
2006-03-28

2006-03-29

2006-03-30

2006-03-31

2006-04-01



2006-04-02

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 27/03/2006 - 02/04/2006	Figure A9 02114-A09.cdr

Week-to-a-Page (Mid-Tide)

2006-04-03

2006-04-04

2006-04-05

2006-04-06

2006-04-07

2006-04-08

2006-04-09

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 03/04/2006 - 09/04/2006	Figure A10

02114-A10.cdr

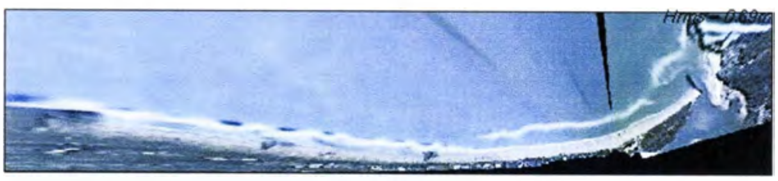
Week-to-a-Page (Mid-Tide)

2006-04-10

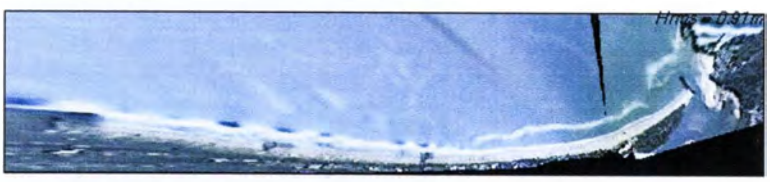
2006-04-11

2006-04-12

2006-04-13



2006-04-14



2006-04-15

2006-04-16

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 10/04/2006 - 16/04/2006	Figure A11

02114-A11.cdr

Week-to-a-Page (Mid-Tide)

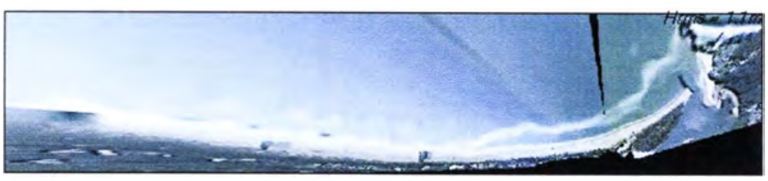
2006-04-17

2006-04-18

2006-04-19

2006-04-20

2006-04-21



2006-04-22

2006-04-23

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 17/04/2006 - 23/04/2006	Figure A12 02114-A12.cdr

Week-to-a-Page (Mid-Tide)

2006-04-24

2006-04-25

2006-04-26

2006-04-27

2006-04-28

2006-04-29

2006-04-30

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 24/04/2006 - 30/04/2006	Figure A13

02114-A13.cdr

Week-to-a-Page (Mid-Tide)

2006-05-01

2006-05-02

2006-05-03

2006-05-04

2006-05-05

2006-05-06

2006-05-07

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 01/05/2006 - 07/05/2006	Figure A14

Week-to-a-Page (Mid-Tide)

2006-05-08

2006-05-09

2006-05-10

2006-05-11

2006-05-12

2006-05-13

2006-05-14

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 08/05/2006 - 14/05/2006	Figure A15 02114-A15.cdr

Week-to-a-Page (Mid-Tide)

2006-05-15

2006-05-16

2006-05-17

2006-05-18

2006-05-19

2006-05-20

2006-05-21

WATER RESEARCH LABORATORY

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 15/05/2006 - 21/05/2006	Figure A16

02114-A16.cdr

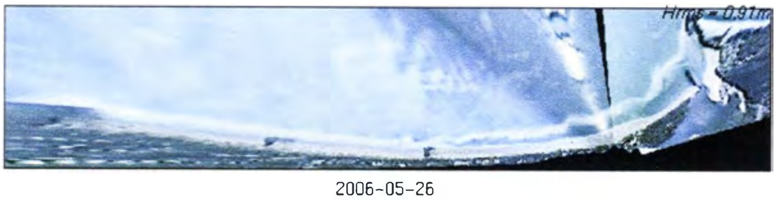
Week-to-a-Page (Mid-Tide)

2006-05-22

2006-05-23

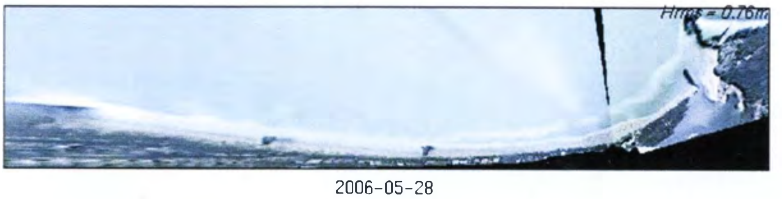
2006-05-24

2006-05-25



2006-05-26

2006-05-27



2006-05-28

WATER RESEARCH LABORATORY

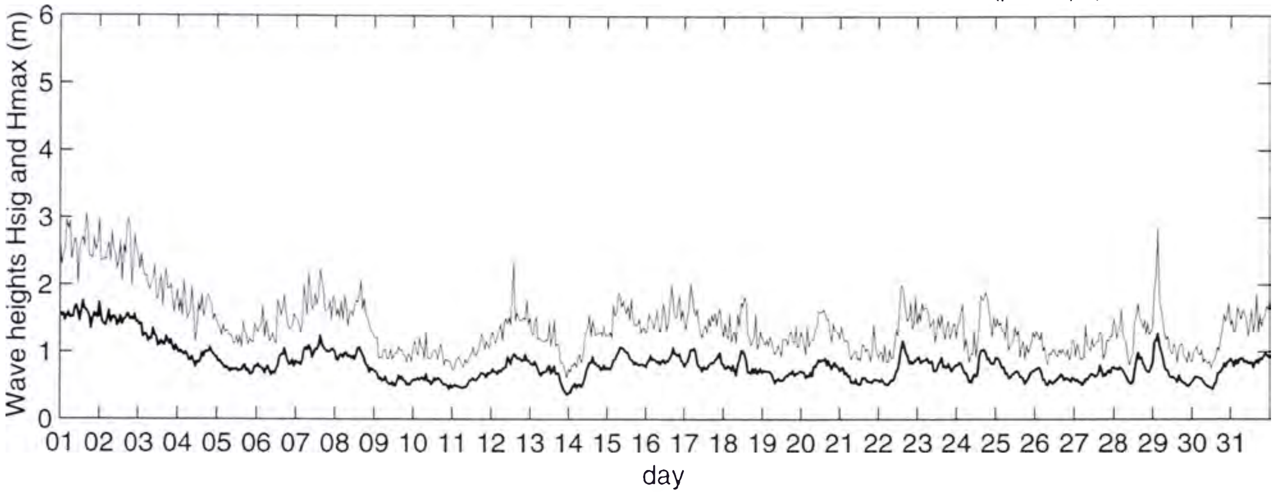
THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

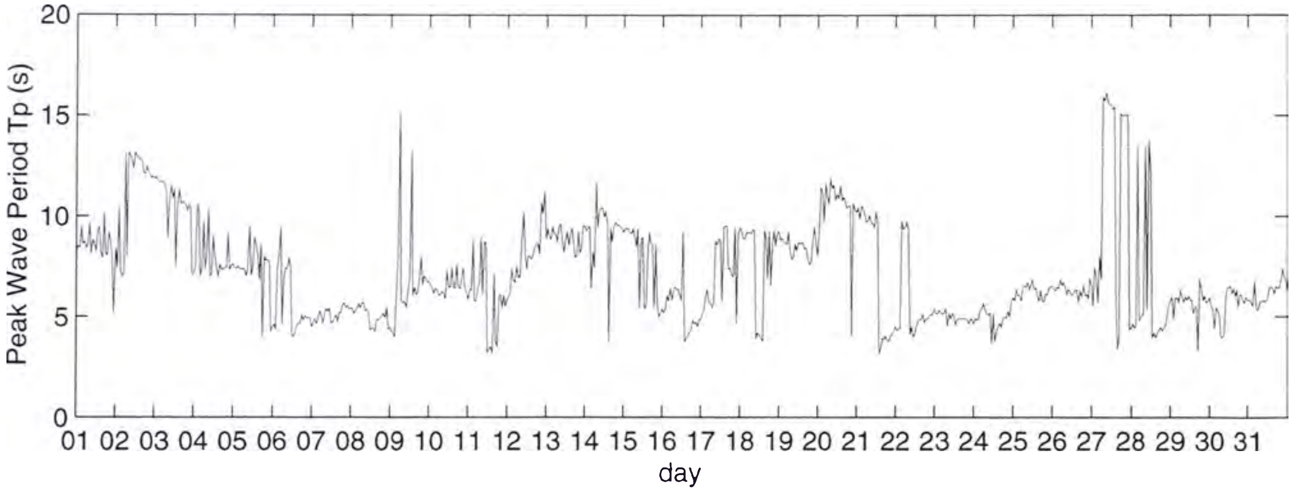
www.wrl.unsw.edu.au/coastalimaging

WRL Report No. 2006/14	DAILY MID-TIDE IMAGES 22/05/2006 - 28/05/2006	Figure A17

02114-A17.cdr

OFFSHORE WAVE CLIMATE: 01-Dec-2005 to 31-Dec-2005 (palmqld)

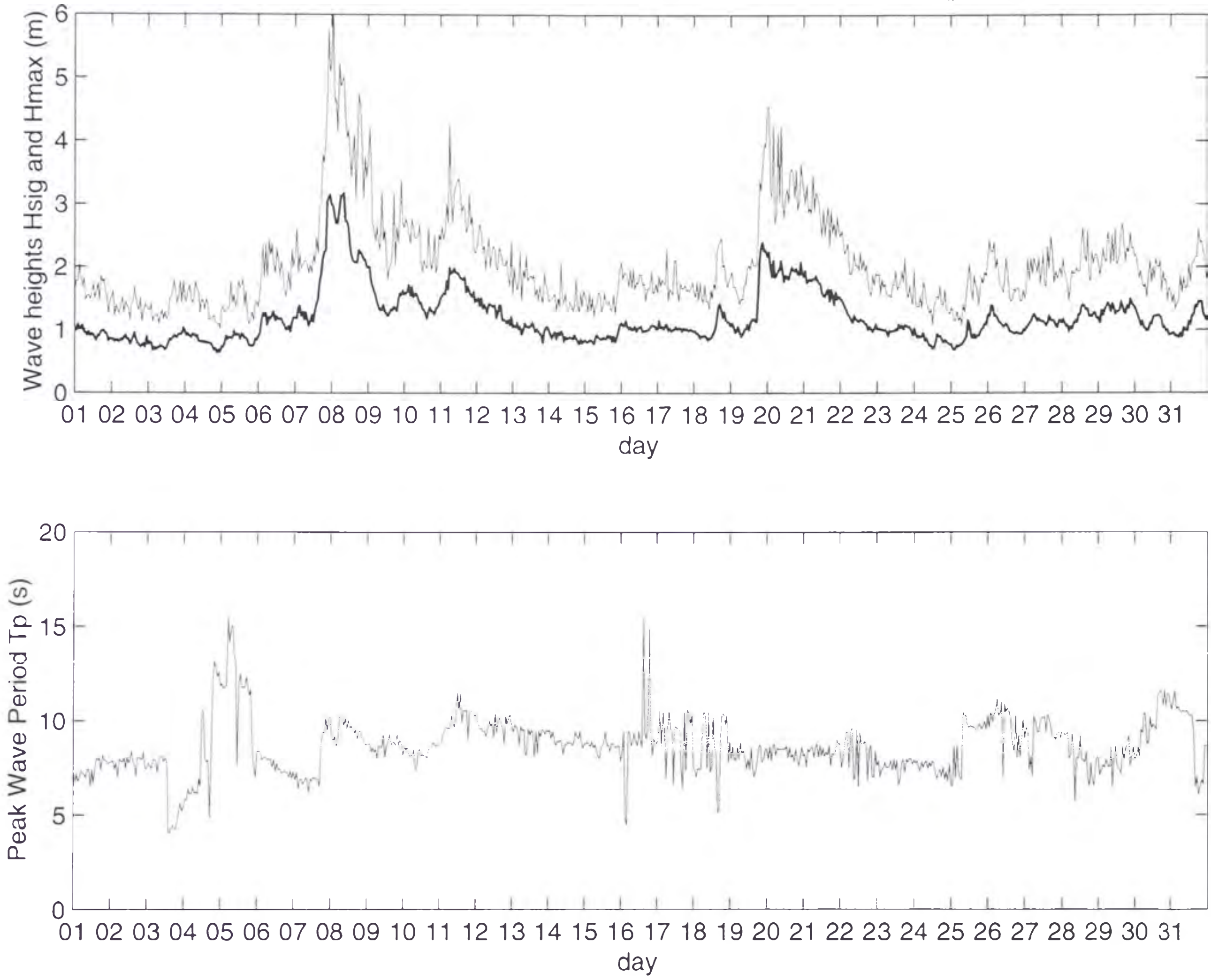




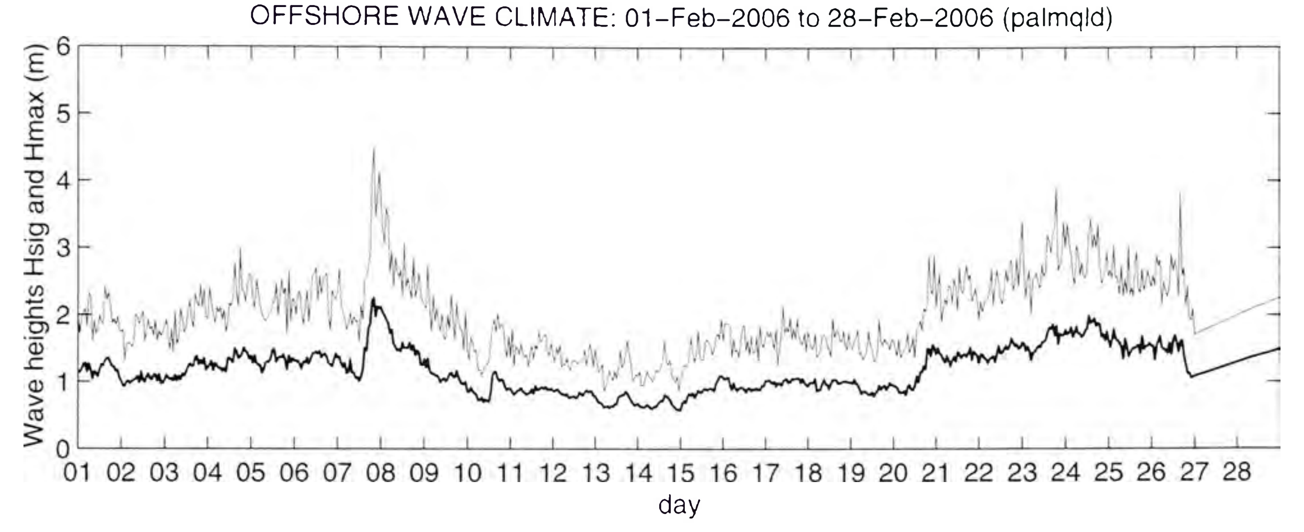
WRL Report No. 2006/14	MONTHLY WAVE SUMMARY DECEMBER 2005	Figure B1

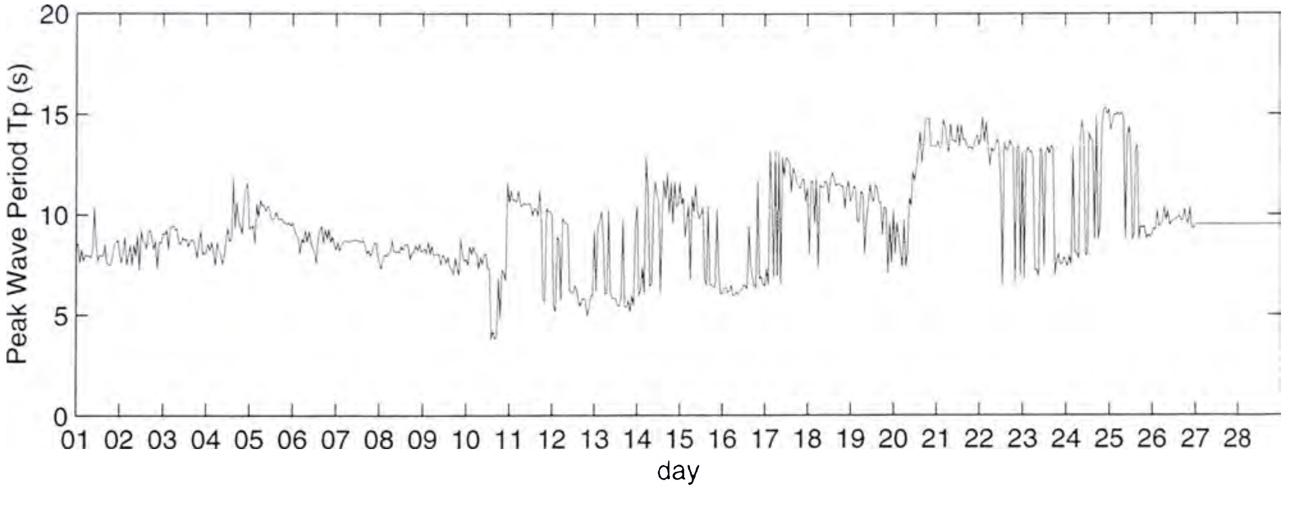
02114-B01.cdr

OFFSHORE WAVE CLIMATE: 01-Jan-2006 to 31-Jan-2006 (palmqld)



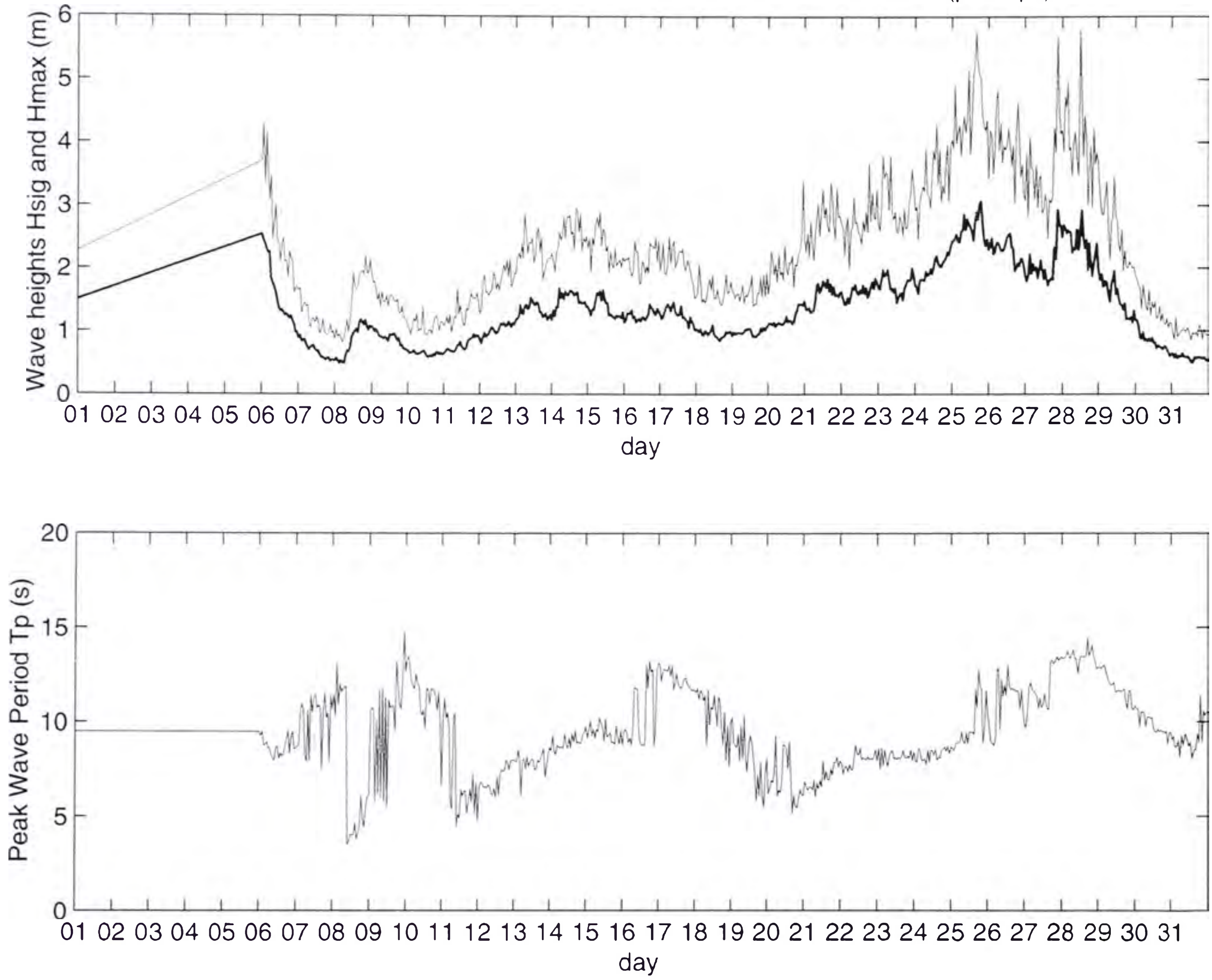
WRL Report No. 2006/14	MONTHLY WAVE SUMMARY JANUARY 2006	Figure B2 02114-B02.cdr





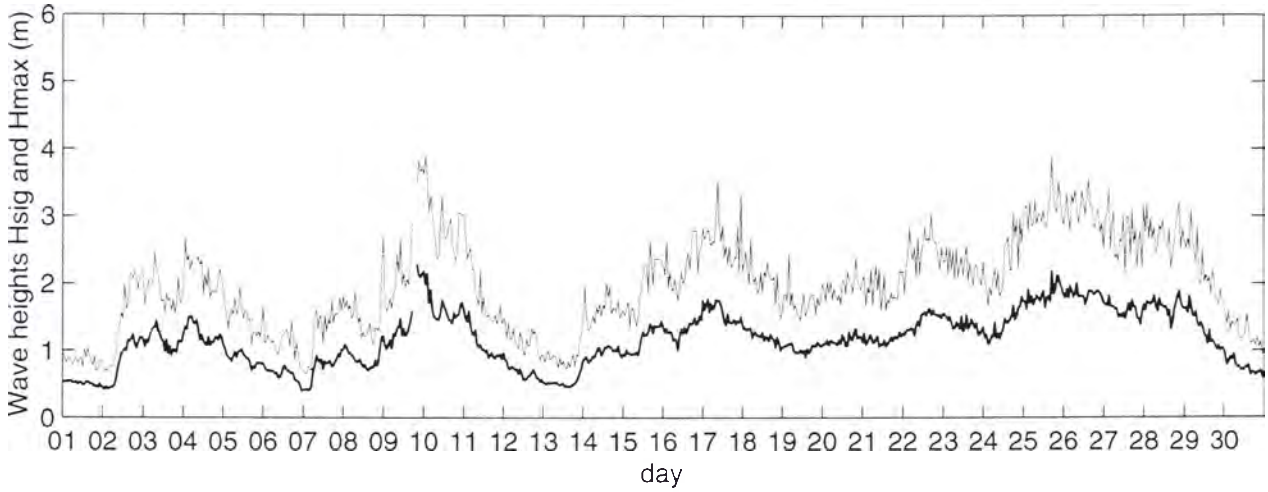
WRL Report No. 2006/14	MONTHLY WAVE SUMMARY FEBRUARY 2006	Figure B3 02114-B03.cdr

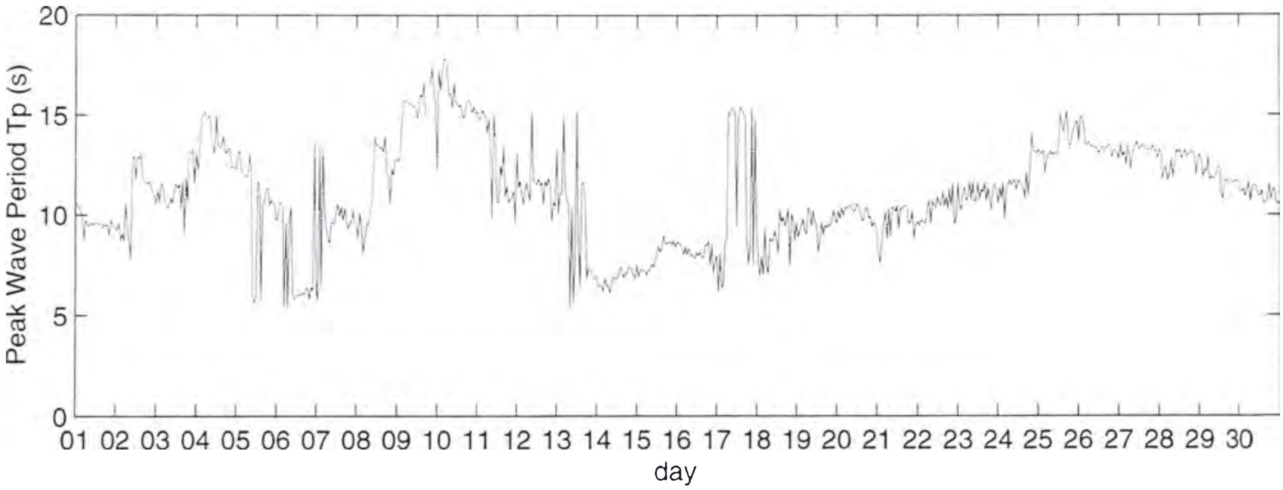
OFFSHORE WAVE CLIMATE: 01-Mar-2006 to 31-Mar-2006 (palmqld)



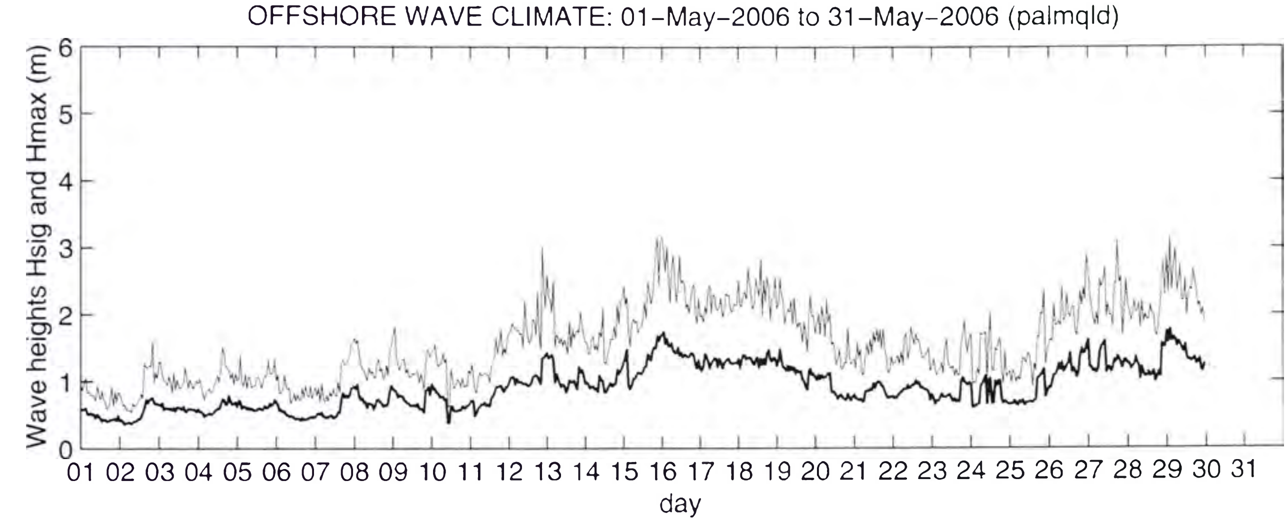
WRL Report No. 2006/14	MONTHLY WAVE SUMMARY MARCH 2006	Figure B4 02114-B04.cdr

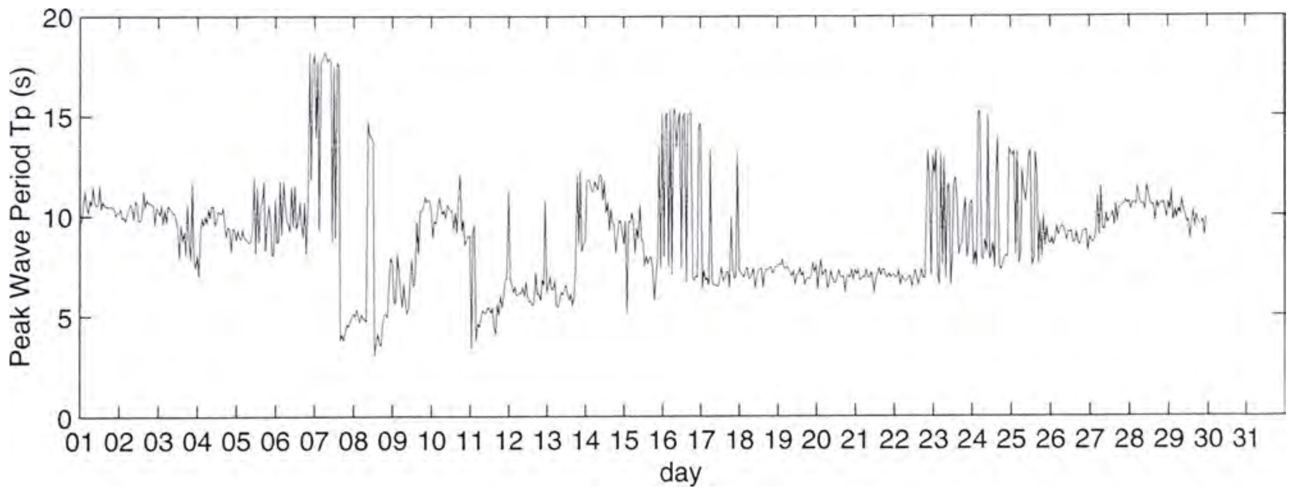
OFFSHORE WAVE CLIMATE: 01-Apr-2006 to 30-Apr-2006 (palmqld)





WRL Report No. 2006/14	MONTHLY WAVE SUMMARY APRIL 2006	Figure B5 02114-B05.cdr





WRL Report No. 2006/14	MONTHLY WAVE SUMMARY MAY 2006	Figure B6 02114-B06.cdr

Appendix C

'ARGUS Coastal Imaging Applications and Research in Australia'
(Journal of Coastal Research, January 2006)

Journal of Coastal Research	22	1	37–48	West Palm Beach, Florida	January 2006

Coastal Imaging Applications and Research in Australia

Ian L. Turner[†], **Stefan G.J. Aarninkhof**[‡], **Rob A. Holman**[§]

[†]Water Research Laboratory
School of Civil and
Environmental Engineering
University of New South
Wales
King Street, Manly Vale
Sydney, NSW 2093, Australia
ian.turner@unsw.edu.au

[‡]Marine and Coastal
Management
WL | Delft Hydraulics
Delft, The Netherlands

[§]College of Ocean and
Atmospheric Sciences
Oregon State University
Corvallis, OR U.S.A.

ABSTRACT

TURNER, I.L.; AARNINKHOF, S.G.J., and HOLMAN, R.A., 2006. Coastal imaging applications and research in Australia. *Journal of Coastal Research*, 22(1), 37–48. West Palm Beach (Florida), ISSN 0749-0208.

Remote sensing methods are increasingly being deployed to measure and investigate morphology and hydrodynamics in the littoral zone, across spatial scales ranging from centimetres to kilometres, and at time-scales ranging from seconds to years. In the past 5 years in Australia, the deployment of video-based coastal imaging systems has grown rapidly, and by 2004, some 32 cameras were operating at eight sites along the coasts of New South Wales and Queensland. Coastal imaging techniques are being applied to a range of coastline monitoring programs. Projects include large- and small-scale sand nourishment works, the construction of a nearshore artificial reef structure, and the ongoing management of sand bypassing operations. At the same time, the growing image databases are underpinning more fundamental coastal research. The focus of recent and current research includes rip current behaviour, climate impacts, nearshore bar dynamics, and the development of new image analysis methods to support future research.

ADDITIONAL INDEX WORDS: *Remote sensing, nearshore research, coastal management, coastal engineering, coastal monitoring.*

INTRODUCTION

Remote sensing methods are increasingly being deployed to measure and investigate morphology and hydrodynamics in the littoral zone, across spatial scales ranging from centimetres to kilometres and time-scales ranging from seconds to years. Since the early 1990s, nearshore research originating from Oregon State University in the U.S.A. and now including international user groups in Europe and Australasia, has focused on the development of low-cost video monitoring techniques and methods to observe and measure a broad range of coastal phenomena.

The advent of digital imaging technology now enables near-continuous analysis of coastal geomorphology and nearshore processes at any target site of interest. The key feature of coastal imaging systems that distinguishes them from conventional 'surfcams' is the ability to extract quantitative information from a time-series of digital images. This core capability is achieved through the solution of a set of camera model parameters (HOLLAND *et al.*, 1997) that enable the determination of three-dimensional real-world (x, y, z) position from two-dimensional (U, V) image coordinates (Figure 1). These geo-referenced images are then subjected to a growing range of digital image analysis techniques to identify, enhance, and quantify the particular coastal processes or features of interest.

DOI:10.2112/05A-0004.1 received and accepted 10 May 2005.

The use of a network of video-based and automated monitoring stations was originally conceived of primarily as a research tool. More recently, the application of coastal imaging technology to a growing range of coastal engineering and management applications has been recognised. The ARGUS coastal imaging system (AARNINKHOF and HOLMAN, 1999; HOLMAN *et al.*, 1993) is being used at all the Australian coastal sites described here. The eight Australian sites form part of a network of over 30 ARGUS stations currently operating across four continents.

This review provides a compilation and overview of existing coastal imaging capabilities, illustrated by some of the fundamental and applied research programs underway around the Australian coastline. Following a brief summary of the key concepts that underpin ARGUS-based image analysis methods, the sites in Australia are described where automated coastal imaging systems are currently operating. The practical application of the ARGUS coastal imaging system to coastal geomorphology, engineering, and management is described at four project sites in Australia. At these sites, image-derived data are being used to fulfill and extend a broad range of engineering and management objectives. Several examples of more fundamental research-focused work that has utilised image data collection from across the Australian coastal sites are also described. The reader is introduced to key findings of this current research, with reference to where more detailed published accounts of this work can

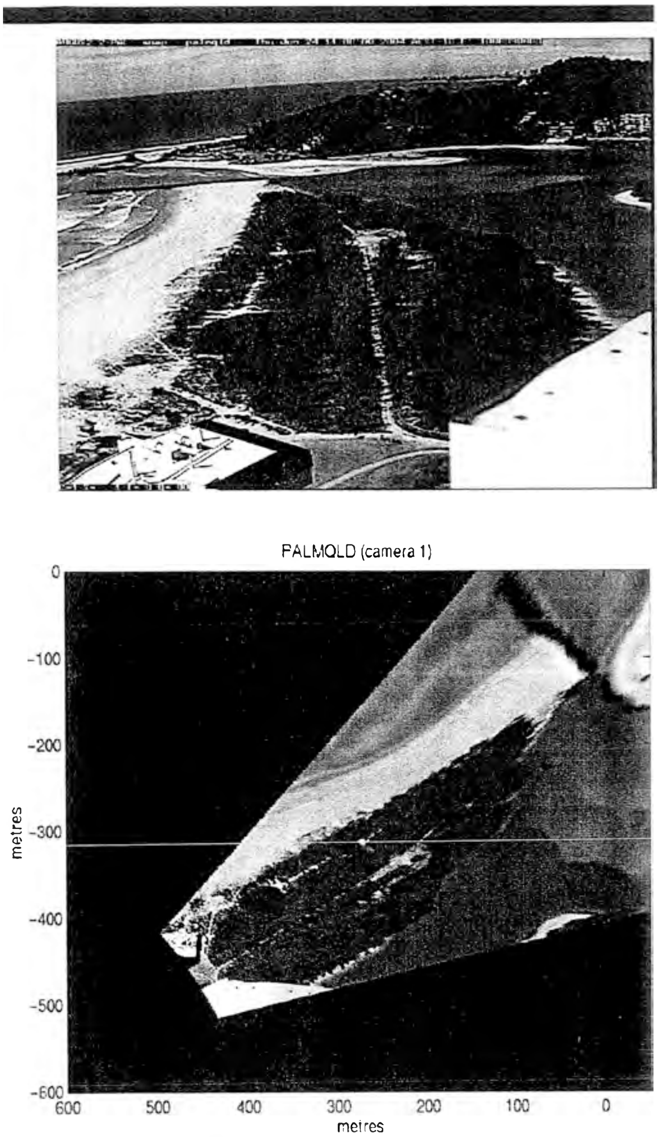


Figure 1. Image rectification that enables the conversion between (U, V) oblique image coordinates (upper panel) and (x, y, z) real-world coordinates (lower panel) is achieved through the solution of a set of camera model parameters. The oblique and rectified image shown is from Palm Beach, QLD (camera 1—looking south), overlooking the adjacent sand spit and entrance to Currumbin Creek.

be found. Finally, some concluding comments are presented to suggest that coastal imaging techniques offer new opportunities for coastal researchers to further contribute to the understanding and better management of the coastal environment.

SYSTEM OVERVIEW

A typical ARGUS coastal imaging station consists of four or five cameras installed at an elevated location that provides a 180° view of the coastline. Fundamentally, data acquisition consists of the automated and routine collection (typically hourly, but for some applications, sampling frequencies of 10 Hz or greater are required) of either full images covering the entire field of view or a time-series of any subset of pixels. In this manner, phenomena that vary both spatially and/or temporally can be identified and measured. Not every image or pixel array that is captured need be subjected to detailed analysis. Rather—and much in the manner of more familiar long-term tide- and wave-monitoring programs that operate around the world—the coastal researcher/engineer/manager can be confident that all 'events' will be recorded and available for future detailed analysis as required. Within the ARGUS system, images are archived within a database structure that facilitates searching and retrieval.

As was noted in the introduction, the ARGUS coastal imaging system has been developed through more than 10 years of ongoing research effort centred at the Coastal Imaging Laboratory at Oregon State University (OSU). The continuing development of the system, with the primary emphasis on new image capture and analysis techniques to support nearshore research, has expanded to include an international user group. A partial selection of past and present image analysis techniques that have been developed within this group includes measurement of incident wave parameters, including breaking height, peak period, direction, celerity dissipation, and spectral characteristics (*e.g.,* LIPPMANN and HOLMAN, 1991); measurement of water depth and nearshore bathymetry (*e.g.,* AARNINKHOF *et al.*, 2003; STOCKDON and HOLMAN, 2000); the use of particle image velocimetry (PIV) applied to the swash zone (*e.g.,* PULEO *et al.*, 2000); nearshore bar position (*e.g.,* VAN ENCKEVORT and RUESSINK, 2001) and morphology (*e.g.,* LIPPMAN and HOLMAN, 1990); dynamics of estuary shoals (*e.g.,* MORRIS *et al.*, 2001); swash dynamics (*e.g.,* HOLLAND *et al.*, 1995); mapping of rip position and spacing (*e.g.,* RANASINGHE *et al.*, 1999a); measurement of rip current position and longshore current velocity (*e.g.,* CHICKADEL, 2001); and the synthesis of many of these phenomena to objectively classify beach morphodynamic variability (*e.g.,* ALEXANDER and HOLMAN, 2001). New image or pixel-based analysis techniques are continuing to be developed and are made available to the wider coastal imaging community through publication in a range of coastal research journals.

ARGUS SITES IN AUSTRALIA

The first installation of an ARGUS coastal imaging station in Australia was undertaken in 1996 by the Coastal Imaging Laboratory at OSU, supported by the Australian Defense Force Academy in Canberra. This was part of an international network of approximately 10 stations that were operating at that time across a range of coastal environments in the U.S.A., The Netherlands, the UK, Australia, and New Zealand. Palm Beach in Sydney, New South Wales (NSW), was selected because of the usual presence of multiple rip currents at this site. Commencing in 1999, a further seven ARGUS stations have been progressively installed in Australia by the Water Research Laboratory, University of New South Wales (WRL), in cooperation with WL Delft Hydraulics in The Netherlands.

The location of all ARGUS sites currently operating in Australia in 2004 are shown in Figure 2. The technology (and data) is shared, but the motivation for site selection between

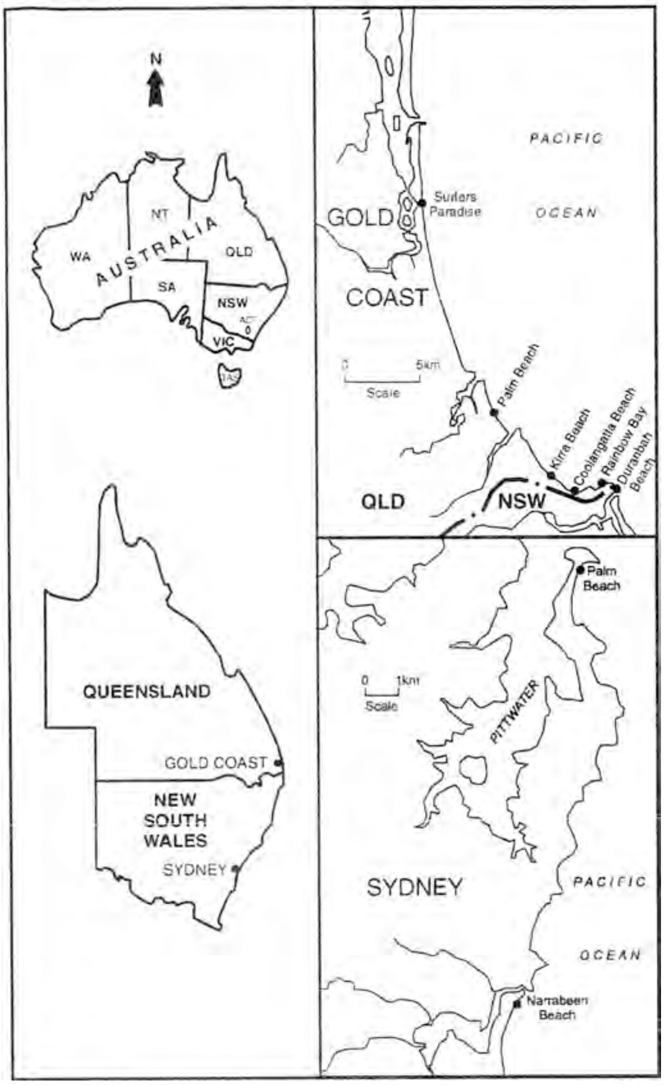


Figure 2. Location of all ARGUS sites currently operating in Australia in 2004.

the world-wide network of ARGUS stations maintained by OSU (including Palm Beach, Sydney) and the WRL sites in NSW and Queensland (QLD) is different. The latter locations were selected specifically to monitor coastal environments dominated by major engineering works and/or significant encroachment of human development within the active beach zone. In contrast, the monitoring stations operated by OSU have been sited to minimize the impact of human activities on beach processes.

The key attributes of all ARGUS sites currently operating in Australia in 2004 are summarised in Table 1, including age of each installation. A brief overview and illustration of each of these locations is provided below.

Palm Beach—NSW

Palm Beach in NSW is located at Sydney's Northern Beaches (Figure 2). The 2-km–long embayment is classic

Table 1. *Australian ARGUS sites in 2004.*

Location*	Site Selection	Embayment Size (km)	Sediment D50 (mm)	Deepwater Wave Climate (m) H_s (H_{max})	Nearshore Refraction-Diffraction	Tide Range (mean spring)	Number of Cameras	Camera Elevation (m)	Year of Installation
Palm Beach NSW	High occurrence of multiple rips	2	0.2	1.5 (12+)	Distinct alongshore gradient	1.3 (semidiurnal)	2	79	1996
Surfers Paradise QLD	Site of world-first hybrid protection-surfing reef and sand nourishment	18+	0.2	0.7 (12+)	Minimal	1.3 (semidiurnal)	4	102	1999
Palm Beach QLD	Site of proposed submerged reef construction and sand nourishment	4.5	0.2	0.7 (12+)	Moderate alongshore gradient	1.3 (semidiurnal)	5	79	2004
Kirra Beach QLD	Sand nourishment	5+	0.2	0.7 (12+)	Moderate	1.3 (semidiurnal)	4	47	2002
Coolangatta Beach QLD	Sand nourishment	0.9	0.2	0.7 (12+)	High	1.3 (semidiurnal)	4	75	2002
Rainbow Bay QLD	Sand nourishment	0.4	0.2	0.7 (12+)	High	1.3 (semidiurnal)	4	58	2002
Duranbah Beach QLD	Sand nourishment	0.5	0.2	0.7 (12+)	Minimal	1.3 (semidiurnal)	4	48	2002
Narrabeen-Collaroy Beaches NSW	Erosion 'hot spot' – site of existing multidecade survey data set	3.5	0.45	1.5 (12+)	Distinct alongshore gradient	1.3 (semidiurnal)	5	45	2004

* NSW = New South Wales, QLD = Queensland.

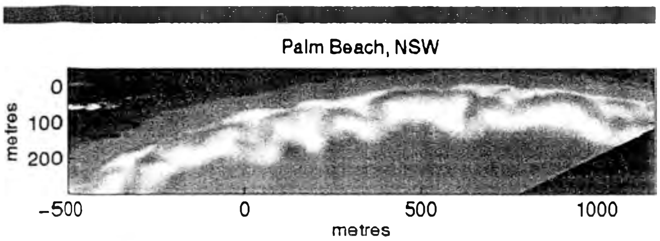


Figure 3. Example of single-camera merged-rectified image at Palm Beach, NSW (north is to the right in figure).

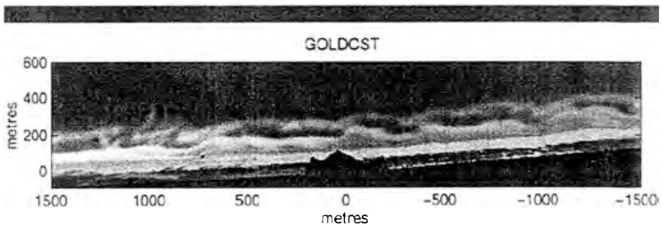


Figure 4. Example of four-camera merged-rectified image at Surfers Paradise, QLD (north is to the left).

zeta-spiral in shape (Figure 3), with a pronounced increasing energy gradient from south to north as a result of increasing exposure to the predominant southeasterly winds and swells of the Tasman Sea. There is little to no net alongshore movement of sand into or out of the embayment, which is contained between rock headlands at the northern and southern end. The beach typically exhibits the full range of intermediate beach states, and multiple rips at quasi-regular spacing alongshore are a characteristic feature of the nearshore (BRANDER, 1999). Despite its location within Australia's largest metropolitan area, coastal engineering structures are absent, and apart from passive dune stabilisation in recent years at the northern end, the beach is largely unaltered from its natural state.

Surfers Paradise—QLD

Surfers Paradise is located at the northern end of the Gold Coast (Figure 2) in southeast QLD. The coastline is essentially linear and extends uninterrupted some 18+ km alongshore. The nearshore morphology typically exhibits a double-bar system, with the highly three-dimensional and complex inner bar system ever changing in response to varying wave climate, whereas the outer storm bar alternates on a more seasonal basis between linear and crescentic states (Figure 4). The net alongshore movement of sand is estimated to be on the order of 500,000 m^3/y, comprising a gross transport of 650,000 m^3/y to the north and 150,000 m^3/y southward (*e.g.*, DELFT, 1970). A boulder wall revetment backs the entire length of beach, and extensive sand nourishment has been undertaken in recent years to maintain and enhance the subaerial beach width. A hybrid coastal protection-surfing reef structure is located 900 m north of the camera site at Narrowneck.

Palm Beach—QLD

Palm Beach in QLD is located in the central region of the Gold Coast, approximately 10 km north of the Tweed River and 15 km south of Surfers Paradise (Figure 2). The 4.5-km embayment is contained by the trained entrance to Currumbin Creek to the south and the similarly trained Tallubudgera Creek to the north (Figure 5). As is the case for all Gold Coast beaches, the estimated net rate of northward littoral sand transport is on the order of 500,000 m^3/y. The beach and nearshore exhibits the full range of intermediate states in response to the varying incident wave climate, ranging from a shore-welded low tide terrace through to crescentic and more linear offshore bars. In addition to the trained creek entrances, a buried rubble-mound revetment runs near continuously along the dune line, and two rubble mound groynes are located within the central region of the embayment.

Kirra, Coolangatta, Rainbow Bay, Point Danger—QLD/NSW

Four ARGUS coastal imaging stations are located at sites along the southern end of the Gold Coast, straddling the state border between NSW (to the south) and QLD (Figure 2). Together these stations provide near-continuous coverage of approximately 7 km of coastline, comprising five distinct embayments and the entrance to the Tweed River (Figure 6). The beaches are typically of intermediate beach state, with differing degrees of exposure to the incident wave climate. Like the northern Gold Coast, the estimated net rate of littoral sand transport is 500,000 m^3/y toward the north. The entrance to the Tweed River is fully trained by rubble mound breakwaters. Historically, these entrance training structures have resulted in the buildup of sand to the south (Letetia Spit) and a corresponding sand deficit at all beaches to the north (including Duranbah, Rainbow, Coolangatta, and Kirra). A sand bypassing plant now delivers sand around the Tweed River entrance via an under-river pipeline to outlets along the down-drift, northern beaches.

Collaroy-Narrabeen Beach—NSW

Collaroy-Narrabeen Beaches are located on Sydney's northern beaches, approximately 12 km south of the ARGUS site at Palm Beach, NSW (Figure 2). The 3.5-km–long embayment is contained by the rock headlands of Long Reef to the south and Narrabeen Headland to the north (Figure 7). Adjacent to the northern headland, the Narrabeen tidal lake system enters the ocean via a partially engineered entrance. These beaches were made famous in the coastal geomorphol-

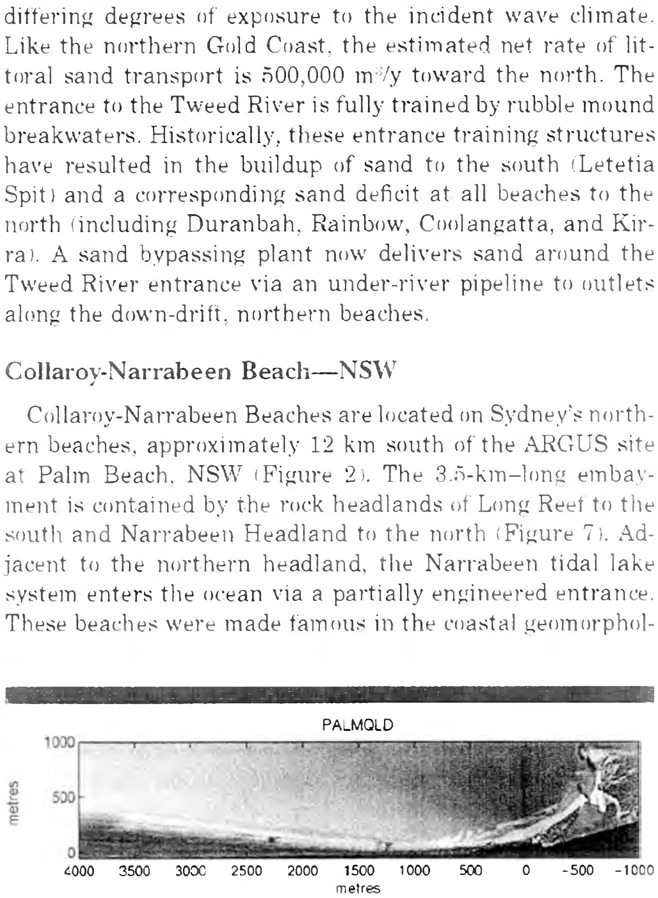


Figure 5. Example of five-camera merged-rectified image at Palm Beach, QLD (north is to the left).

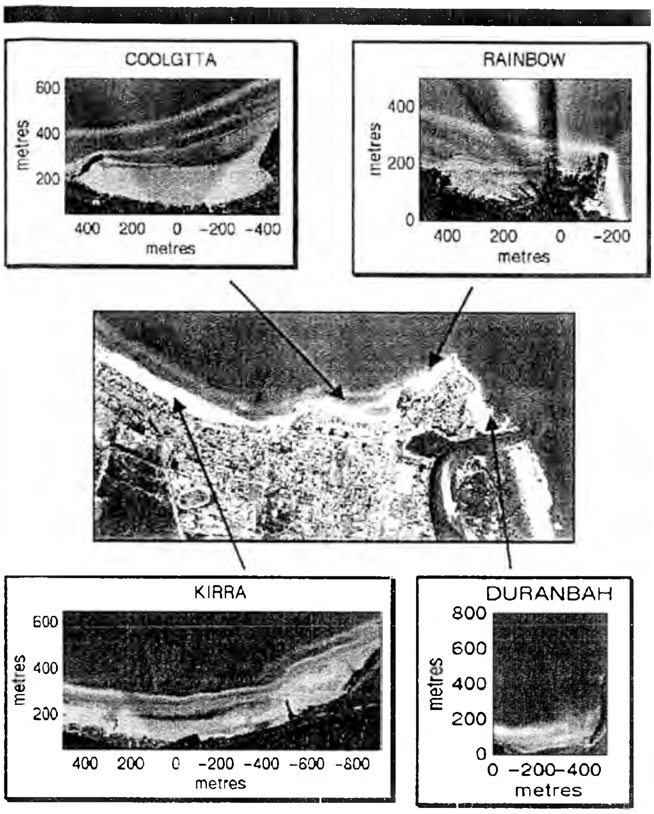


Figure 6. Examples of four-camera merged-rectified images at Kirra, Coolangatta, Rainbow, and Duranbah Beaches.

ogy literature in the late 1970s and 1980s because of the pioneering work undertaken at this site by Don Wright, Andy Short, and colleagues at Sydney University's Coastal Studies Unit, to develop their 'beach state' morphodynamic model of microtidal beaches (*e.g.*, WRIGHT and SHORT, 1984). As is the case at the Palm Beach (NSW) site to the north, a distinct alongshore gradient in wave energy is observed at this site, with the northern end increasingly exposed to the incident wave climate. For 30 years, monthly profiling along the length of the embayment (*e.g.*, SHORT *et al.*, 1996) has revealed the site to be highly dynamic, exhibiting the full range of low- to high-energy, intermediate beach states in response to the varying incident wave climate. Nonengineered revetments structures (ranging from rubble mound walls to broken concrete) are in place in front of a limited number of individual beachfront properties. The beachfront development consists primarily of private residential housing that encroaches onto the frontal dune area well within the active beach zone.

ENGINEERING AND MANAGEMENT APPLICATIONS

The growth of coastal imaging research in Australia is to a large part due to the relatively rapid acceptance by state and local governments of new engineering and management applications of the technology (TURNER, 2003a, 2003b). To date, coastal imaging–based monitoring programs are sponsored at three sites by local government authorities in QLD and NSW and at a further four sites through joint cooperation between the QLD and NSW State governments. Links to all these sites can be found at the project web site. Presented below is an overview of four engineering/management programs that utilise coastal imaging capabilities.

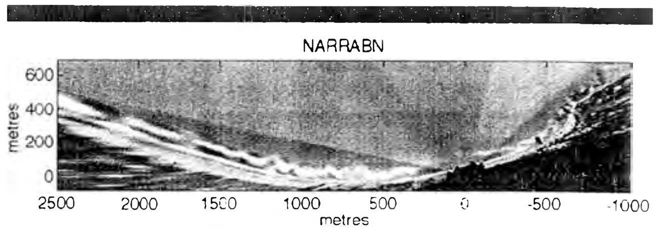


Figure 7. Example of five-camera merged-rectified image at Narrabeen Beach, NSW (north is to the left).

Northern Gold Coast Beach Protection Strategy—Surfers Paradise

Episodic storm erosion is an ever-present threat to the intensely developed Gold Coast region. Early mitigation measures including timber (and later boulder) revetments date back to the 1920s, and extensive sand nourishment campaigns commenced in the 1970s. In 1997, the 'Northern Gold Coast Beach Protection Strategy' was implemented by Gold Coast City Council to maintain and enhance the beaches of Surfers Paradise (BOAK *et al.*, 2000). The aim of the strategy was to decrease the risk of potential economic loss following storm erosion by increasing the volume of sand within the storm buffer seaward of the existing oceanfront boulder wall. The major components of the engineering works included an initial 1.2 Mm^3 of beachface sand nourishment along 2 km of beach front and the construction at Narrowneck of a submerged artificial reef structure to provide a coastal 'control point.' The latter also aims to enhance surfing opportunities at the northern Gold Coast. Sand nourishment was completed in mid-2000, and the major construction phases of the reef were completed at the end of 2001.

Since 1999, the Surfers Paradise ARGUS coastal imaging station has been a core component of the construction and post-construction monitoring effort to document and quantify the success of the Protection Strategy. The primary aim of investigation is to monitor and quantify changing shoreline amenity (*i.e.*, dry beach width) along a 4.5-km length of the coastline (TURNER *et al.*, 2001, 2004). This region incorporates the nourishment area including the reef site, as well as control regions to the north and south. The shoreline is mapped each week, and the resulting database of shorelines is then subjected to a range of analyses. A second focus of this work has been to quantify the more localised response of the coastline in the vicinity of submerged reef structure (JACKSON *et al.*, 2002; TURNER *et al.*, 2000).

The frequency of shoreline mapping (weekly), and the now-several years length of this record, have provided the opportunity to gain new insight into the regional-scale behaviour of the dynamic northern Gold Coast beaches. The response

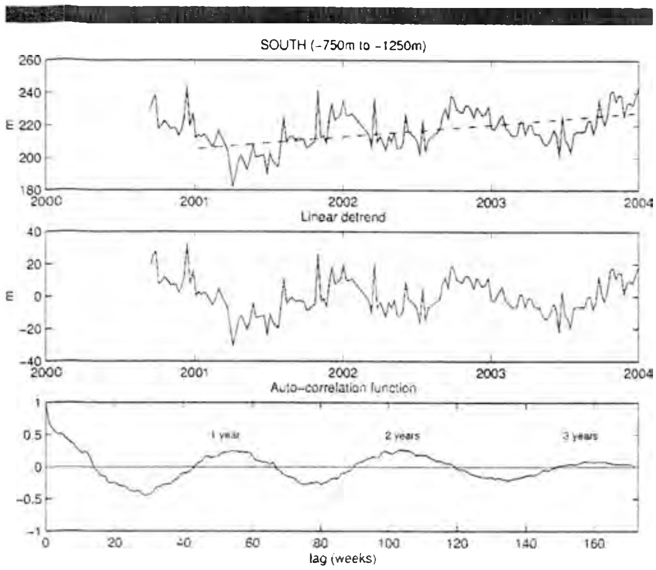


Figure 8. Results of auto-correlation analysis to assess the relative magnitudes of cyclic-seasonal variability *vs.* longer-term erosion/accretion trends at Surfers Paradise, QLD. (Upper panel) Spatially averaged (500 m) beach width for 3.5-year period, 2001–2004, with underlying accretionary trend approximated by linear best fit (~7–8 m/y). (Middle panel) Detrended beach width data, showing ±0.20 m variability with linear trend removed. (Bottom panel) Auto-correlation function calculated from detrended beach width data, revealing the dominance of an annual (52-wk) cyclic erosion/accretion trend.

time of the coastal system to placement of 1.2 Mm^3 of sand nourishment can be measured using this system. Figure 8 summarises the result of an auto-correlation analysis to assess the relative magnitudes of cyclic-seasonal variability *vs.* longer-term erosion/accretion trends. The upper panel shows the raw data of weekly beach width (post–sand nourishment), spatially averaged over a 500-m length of beach within the nourishment area. The middle panel shows the corresponding detrended data, while the lower panel shows the results of auto-correlation performed on this 3.5-year detrended data set. These results reveal the dominance over this period of an annual cycle of erosion (late summer and autumn) and accretion (winter and spring). The magnitude of cyclic beach width changes were on the order of ±20 m (Figure 8, middle panel), compared to an underlying accretionary trend during this same period of the order of 7–8 m/y (upper panel).

Tweed River Sandy Bypassing Project

The ocean entrance to the Tweed River coincides with the border between the states of NSW and QLD. Since the late 1800s, entrance-training works and dredging have been undertaken in an attempt to improve navigability. In the mid-1960s these efforts culminated in the further extension of the entrance breakwalls, which was observed to improve navigation for a period, but in recent years, the entrance bar had reformed and again created navigation difficulties. The northward littoral drift of sediment from NSW to QLD beaches was also interrupted, resulting in the accumulation of sand in NSW against the southern (up-drift) training wall and major erosion along down-drift beaches of the southern Gold Coast in QLD (DYSON *et al.*, 2001). In 2001, a fixed sand bypassing system was commissioned by the joint NSW-QLD state governments. Sand is pumped from the NSW side of the entrance, through a 400-mm–diameter polyurethane-lined steel pipeline that runs beneath the Tweed River to four outlet points along the down-drift beaches (DYSON *et al.*, 2002).

The four ARGUS coastal imaging stations at Duranbah, Rainbow, Coolangatta, and Kirra Beaches are used to assess the beach conditions at each of the outlet points, and this information is in turn fed back into the operational management to determine the rate and location of monthly sand delivery. The use of image-derived information to support ongoing system operations has required the development of new methods for the timely delivery of the required information to the project management team. Every week, a range of analysis techniques are applied to the growing hourly image archive to assist the project management team to observe, quantify, and interpret coastal processes and changing beach conditions at all the sand delivery points. Analyses are updated weekly, and a web-based information delivery system has been developed that provides the necessary information in summary format directly to the project managers' desks (ANDERSON *et al.*, 2003).

The range of 'real-time' information and data that is available to the managers of the sand bypassing project includes the following:

- access to the full archive of current and past hourly images;
- the use of a zoom applet that enables smaller-scale features to be inspected in greater detail;
- plan view (multi-camera and merged-rectified) images of the beaches and river entrance at all high, mid, and low stages of the tide;
- a web-based interface that enables project managers to create and view an animation of daily images and concurrent wave information for any current or past period of interest;
- 'week-to-a-page' weekly summaries to highlight trends in subaerial and nearshore morphology; and
- weekly quantitative analysis of shoreline position and beach width.

This last feature is used to highlight current beach conditions relative to 1 week, 1 month, and 1 year prior, as well as long-term temporal trends. Figure 9 shows examples of a 'week-to-a-page' image summary from Coolangatta Beach and the weekly summary of shoreline and beach width analysis for this same site. These data summaries are updated each week, preformatted for easy inclusion in reports, and are available for viewing and download by the NSW and QLD project management teams.

Figure 10 illustrates the value of these data to assess the impacts of the bypassing plant and to inform the monthly decision as to the choice of the location(s) for sandy delivery. The upper panel shows the location of one of the project control survey transects (DMB2) within the central region of Duranbah Beach. The middle panel shows the monthly sand

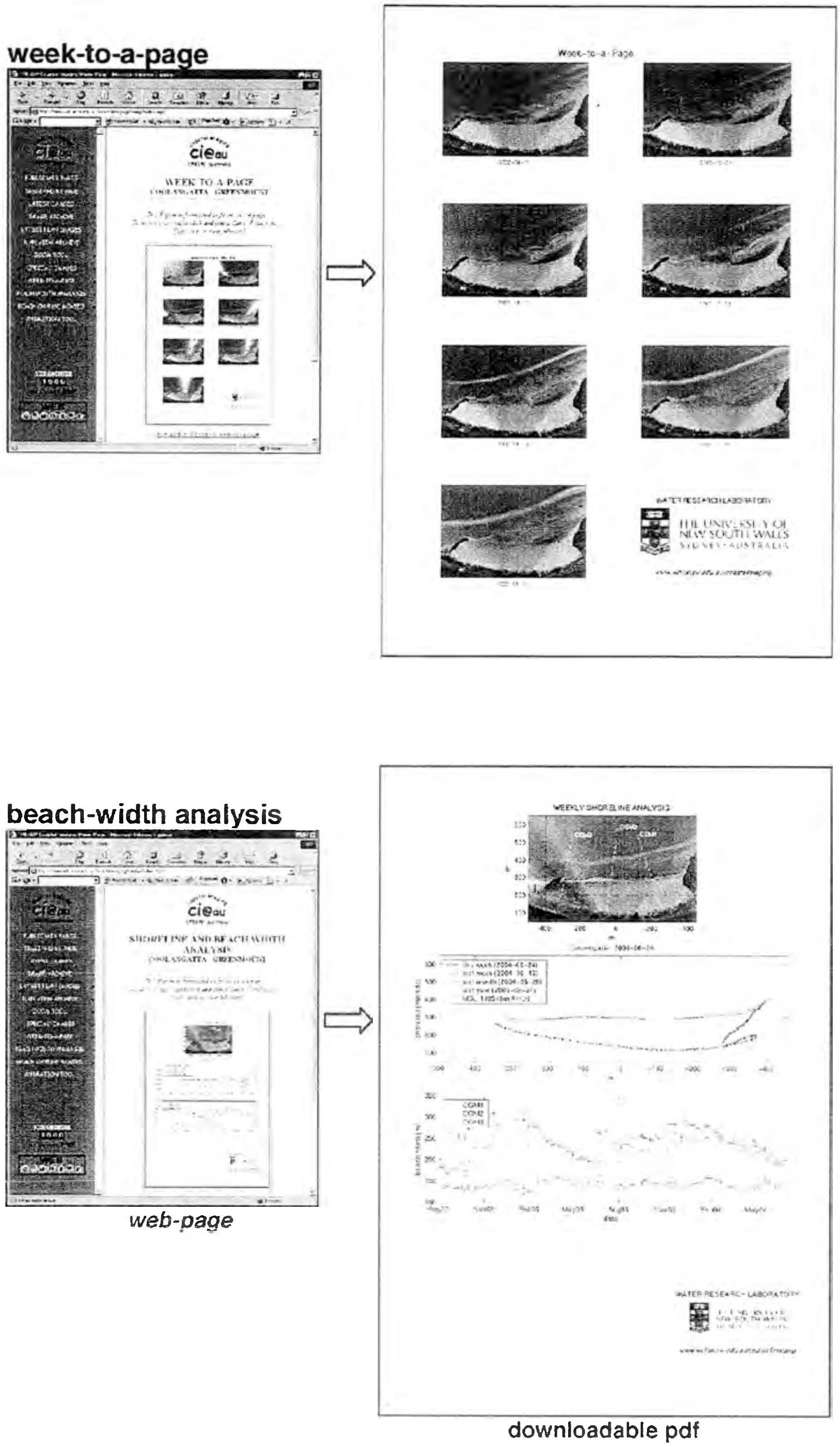


Figure 9. Examples of the range of weekly updated information made available to the Tweed River Entrance Sandy Bypassing Project (TRESBP) management team via the project web site, including 'week-to-a-page' image data summaries and analyses of beach width changes. Examples shown are from Coolangatta Beach, QLD.

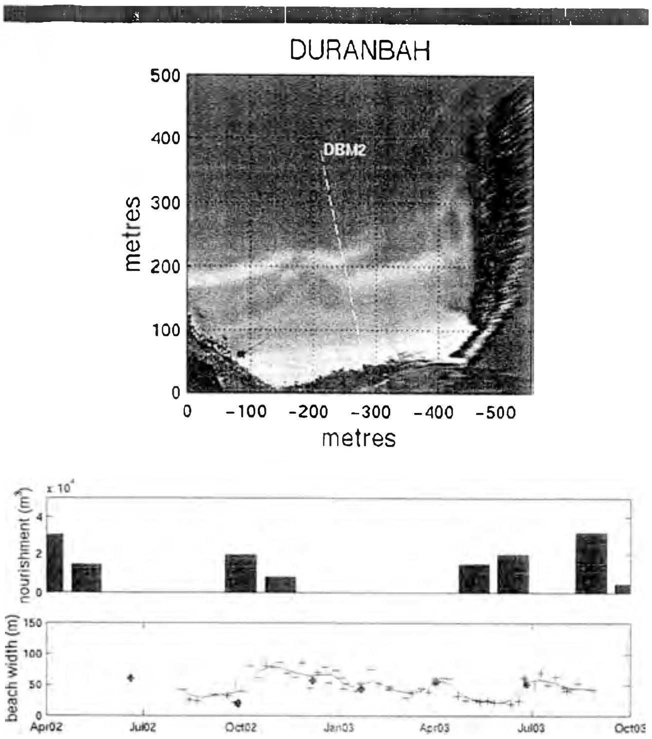


Figure 10. (Upper panel) Location of a control survey line (DMB2) at Duranbah Beach, QLD. (Middle panel) History of monthly sand delivery to the Durnbah embayment for the period April 2002 to October 2003. (Lower panel) Comparison at DMB2 of quarterly conventional surveys of beach width (◆) and weekly image-derived calculations of beach width (–).

delivery to Duranbah Beach by the bypassing plant for a 12-month period in 2002–03, and the lower panel shows the surveyed beach response to this nourishment, based upon conventional (total station) and image-derived techniques. The imaging system first became operational at this site in August 2002. The existence of quarterly survey data is relatively frequent for this type of project; however, the information that is lost when compared to the weekly image-derived surveys is readily apparent in this figure. For example, the rate of beach recovery in response to the nourishment effort undertaken in October–November 2002 was shown from the results of the image-derived data to be much more rapid than what the quarterly surveys indicated. Similarly, from April to July 2003, the erosion–recovery cycle detected and quantified by the imaging system was entirely missed by the quarterly survey effort. For operational applications, the dependence upon imaging methods removes the risk to managers that key behaviour within the coastal system may be missed.

Palm Beach (QLD) Beach Protection Strategy

Coastal storms (cyclones) in 1967, 1972, and again in 1974 caused severe structural damage to properties along the beach front at Palm Beach, QLD. Over the ensuing three decades, a number of protection works have been implemented (TOMLINSON *et al.*, 2003). These works include construction of an (almost) continuous seawall, two short rubble-mound groynes, beach nourishment in excess of 1 Mm^3, Tallebugera Creek breakwall, and Currumbin Creek breakwall.

In Figure 6 the creek entrance training works and groynes are evident. Despite these structures and the buried back-beach revetment, storms in May 1996 again highlighted the vulnerability of the central section of Palm Beach. To address these concerns, the 'Palm Beach Beach Protection Strategy' was developed (TOMLINSON *et al.*, 2003). A staged construction approach was adopted in 2003. Immediate works comprise the upgrade of the existing (but substandard) public and private back-beach revetment, construction of a series of (up to three) offshore submerged reef structures, and sand nourishment. However, immediately prior to the commencement of these works in late 2003, protest by the local surfing community and others raised public concerns as to the impact to existing surf conditions of the proposed reef structures. The construction of the proposed reef structures was halted, and the Palm Beach ARGUS station was installed to monitor the existing beach and nearshore conditions at the site.

Figure 11 shows the results of erosion/accretion analysis that is now reported on a routine basis for Palm Beach, using an image analysis technique that enables three-dimensional 'survey' information to be extracted from two-dimensional images (*e.g.*, AARNINKHOF and ROELVINK, 1999). Briefly, the waterline is mapped every hour through a spring tide cycle. The elevation corresponding to the detected waterlines is calculated on the basis of concurrent tide and wave information, which is incorporated in a model that combines the effects of wave setup and swash, at both incident and infragravity frequencies. As illustrated in Figure 11 (upper panel), if this process is repeated at all points alongshore throughout a complete tide cycle, a three-dimensional bathymetry of the beachface—extending from spring high to low tide—is obtained. The derived net change in beachface bathymetry that was measured through the initial 6-month monitoring period at Palm Beach is illustrated in Figure 11 (lower panel). This analysis revealed a distinct trend of beach accretion in the southern third of the beach, in contrast to a more general trend of beach erosion along the northern two-thirds of the embayment. The site of this beachface accretion occurred in the vicinity of sand nourishment of the offshore bar that was completed by contractors during this same period and indicates a landward migration of a portion of this nourishment volume and/or the early development of a shoreline salient in response to the placement of a sand mound in the nearshore zone.

Narrabeen-Collaroy Coastline Monitoring Project

The 3.5-km embayment on Sydney's northern coastline that comprises Narrabeen and Collaroy Beaches exhibits a chronic erosion problem. Historically, between 1944 and 1986 a number of houses were lost, and many others were severely damaged as a result of major storms. More than $100,000,000 of public and private beachfront property, second only to the Gold Coast in terms of the economic value of infrastructure, is currently at risk. The NSW Coastal Council, a peak advisory body to the NSW government, identified Narrabeen–Collaroy as one of beaches of greatest risk amongst the state's

Figure 11. (Upper panel) Intertidal bathymetry along 3.5 km of the Palm Beach embayment, derived from image analysis (13 June 2004). (Lower panel) Estimate of net change in beachface elevation, again derived from image analysis (June–November 2004).

721 beaches and 1590 km of coastline. In 1997, the 'Collaroy–Narrabeen Coastline Management Plan' prepared for Warringah Council–identified upgrading of an existing nonengineered seawall (Figure 12) as one possible option for managing the risk to property at the site. A preliminary design and statement of environmental effects were prepared in 2002. In 2003, following a period of public exhibition, the Council resolved not to proceed with the proposed seawall upgrade at that time, given significant community opposition to the proposal. It was resolved to undertake further investigation into alternate options for management of coastal erosion within the Collaroy–Narrabeen embayment, including the sourcing of offshore sand supplies for beach nourishment.

The ARGUS station installed at Narrabeen–Collaroy in July 2004 is the latest site chosen for this monitoring technology. As per the Palm Beach site in QLD, the initiation of this coastal monitoring program prior to the commencement of possible future engineering works provides the all-too-rare opportunity to first document and quantify the existing conditions. The analysis of these data is affording greater insight to the location, extent, and alongshore variability of the existing erosion hazard. In the future, this same data will enable the impacts and intended improvements of any engineering/management works that may be undertake at the site to be objectively assessed and evaluated.

PRESENT RESEARCH

With the exception of Palm Beach NSW, all the Australian ARGUS sites to date have been installed for primarily engineering and coastal management applications. The wider value of the image databases that continue to grow with the progress of these monitoring programs is well recognised within both the Australian and international research community. A broad range of more fundamental coastal research is now utilising this resource. Space limitations here do no permit a full description of the work underway. Instead, summarised below is a brief description of several examples of this research, with cited references indicating where more detailed published accounts of this work can be found.

Rip Current Behaviour

Investigation of the behaviour of rips currents using image-derived data from Palm Beach NSW was underway prior to the advent of engineering or management ARGUS applications in Australia. This work was undertaken by researchers at the Australian Defense Force Academy in Canberra, in collaboration with OSU. Time-series of daily images comprising several years were analyzed to demonstrate that the location of rip channels within the 2-km Palm Beach embayment do not exhibit any preferred locations along the beach. Rip spacing was not observed to change in response to varying incident wave height, but once formed, rips were observed to migrate alongshore under oblique incident waves. It was concluded from this novel work that gradients in oblique waves causing longshore currents and resulting alongshore sediment transport governed the alongshore migration of rip channels (RANASINGHE *et al.*, 1999b, 2000). Work completed more recently utilising 3 years of image data obtained at the contrasting nonembayed (*i.e.*, long, straight) Surfers Paradise site matched the earlier studies at Palm Beach NSW (WHYTE *et al.*, in press). These new results from a rather different setting further supported the original work of RANASINGHE *et al.* (1999b) that once formed, the position of rips appears to be strongly topographically controlled and does not adjust markedly to varying incident wave height, but instead migrates as a result of oblique wave incidence.

Shoreline Detection and Definition

At the core of many coastal monitoring programs is the identification of the shoreline for the purpose of quantifying the available beach amenity and to assess impacts of new or existing engineering works. The location of the shoreline, and the changing position of this boundary through time, are of

1967 1978

Figure 12. Present condition of the nonengineered revetment that is in place to protect beachfront property at the site of the newly installed ARGUS station at Narrabeen Beach, NSW (Source: Warringah Council).

elemental importance to coastal scientists, engineers, and managers (NRC, 1990).

A range of methods have been developed to identify and map the shoreline from time-series maps, aerial photography, and digital images (BOAK and TURNER, 2005). A recent study was completed at four contrasting ARGUS sites around the world, including the Surfers Paradise site, to test and compare four different image analysis techniques for shoreline detection (PLANT *et al.,* 2006). Absolute errors of the four shoreline mapping methods were estimated by comparison with direct topographic surveys. It was determined that the differences between image-derived *vs.* directly surveyed shorelines depended on differences in the four different mapping methods and the prevailing hydrodynamic conditions. Before accounting for these differences, rms errors ranged from 0.3 to 0.8 m. An empirical correction model that computed local estimates of setup, swash, and surf beat amplitudes reduced errors by about 50%. It was concluded from this study that available remote-sensing methodology can be applied to the shoreline mapping problem in an interchangeable and intercomparable manner across diverse nearshore environments. Current research is underway to gain a better physical understanding of the 'shoreline' feature that is detected by the various ARGUS-based image analysis techniques that are currently available (BOAK and TURNER, 2003).

An extension of this research has been to map the shoreline feature through all stages of the tide, to produce a three-dimensional surface of the intertidal region of the beach (*e.g.,* AARNINKHOF and ROELVINK, 1999). In Australia, this method has been successfully applied at the Surfers Paradise, Palm Beach (QLD), and Tweed sites to help elucidate the fate of sand nourishment (*e.g.,* AANRNIKHOF *et al.*, 2003; Turner *et al.,* 2004) and to examine whether specific elevation contours within the intertidal zone provide a useful proxy for sand volume changes within the wider beach system.

Climate Control of Regional-Scale Coastal Behaviour

The central and southern coastline of NSW is characterised by relatively short (<3 km in length) beaches bounded on either extremity by headlands (SHORT, 1993). Over the last decade, many of these beaches have experienced severe erosion at their southern end, which is normally protected from the dominant southeasterly waves. This erosion does not appear to be associated with severe storm events nor with any long-term recession trend. Rather, it appears to be related to a medium-term (period of 2–8 years) and cyclic process of beach rotation, possibly caused by variations in wave climate associated with phase shifts in the Southern Oscillation Index (SOI) (RANASINGHE *et al.*, 2004; SHORT and TREMBANIS, 2004; SHORT *et al.,* 1996, 2000). Given the Pacific-wide impact of the SOI (El Niño/La Niña) and the documented inverse impact at northwest Pacific beaches (*e.g.,* DINGLER and REISS, 2002; KOMAR *et al.*, 2001; SEYMOUR, 1998), it is likely that similar longer-term cycles of beach erosion/accretion and rotation are a widespread phenomenon on beaches along both Pacific coastal belts.

A new research effort commenced in 2004 based around the Narrabeen–Collaroy ARGUS site, which is working to integrate coastal imaging-derived data with a multidecadal conventional survey data set (believed to be one of the longest beach survey records of any site in the world) to investigate the regional-scale climatic control of coastal erosion and coastline variability over time-scales of months to decades. This collaborative effort brings together researchers from Australian universities, as well as partners in local and state government, and WL Delft Hydraulics in The Netherlands. Following a 3-year period of initial comparison and analysis, it is the intention that the ARGUS techniques may supercede and extend this important survey effort into the foreseeable future.

Other Areas of Active Research

In addition to the research highlighted above, image data obtained across the network of ARGUS sites in Australia are being utilised by researchers both in Australia and internationally to support a range of investigations. These include the analysis of temporal and spatial variability of crescentic sand bars (VAN ENCKEVORT *et al.*, 2004) and the cyclic transition between differing intermediate morphodynamic beach states in response to varying wave climate (RANASINGHE *et al.*, 2004a). Other areas of current investigation that are utilising this resource include the derivation of subaerial beach profiling through the analysis of shadow casting (CURTIS and HOLMAN, 1998; Curtis *et al.*, in press) and the analysis of varying modes of beach response to offshore-detached structures in the nearshore zone (TURNER, in press).

CONCLUSIONS

Applications of coastal imaging technology in Australia and internationally are providing increased opportunities for coastal researchers in the fields of both science and engineering to contribute to the present and future management of the coastline. More fundamentally, existing and emerging imaging capabilities will continue to complement and extend the progress of nearshore research.

From the perspective of practical management applications, in addition to meeting technical monitoring requirements, the use of automated image collection is also providing new opportunities for coastal professionals to meet increased community expectations. By providing public access (via the world-wide web) to regularly updated monitoring program data, and through the opportunity to link this more technical information to educational and other project-specific information, an integrated approach to coastal measurement, monitoring, and dissemination is being implemented. From the research perspective, data collection across a wide range of coastal processes and phenomena can now be obtained, across spatial and temporal scales that are simply unachievable using *in situ* instrumentation.

One of the more wide-reaching challenges for researchers in this field is the better integration of image-derived data with state-of-the-art numerical nearshore models. Within the next few years, better solutions will emerge to enable researchers to fully assimilate the spatial and temporal capabilities of image-derived data with the predictive capability of numerical simulation.

ACKNOWLEDGMENTS

The authors wish to acknowledge our colleagues Graham Symonds and Rosh Ranasinghe for the pioneering ARGUS research completed at the Australian Defense Force Academy, Canberra. The work of these researchers both kick-started and is continuing to contribute to imaging-based research in Australia. Currently operating ARGUS stations referred to in this paper are sponsored by Gold Coast City Council, NSW Department of Infrastructure Planning and Natural Resources, QLD Environment Protection Authority, and the Warringah Council. ILT's research is also funded by the Australian Research Council, UNSW Faculty of Engineering, Warringah Council, and a 2003 Churchill Fellowship. Technological development and systems support for the projects outlined above has been provided by John Stanley (OSU), Irv Elshoff (WL Delft-Hydraulics), and Doug Anderson (UNSW). The ongoing contribution and collaboration within the international ARGUS-user group is invaluable.

LITERATURE CITED

AARNINKHOF, S.G.J. and HOLMAN, R.A., 1999. Monitoring of the nearshore with video. *Backscatter*, 19(2), 8–11.

AARNINKHOF, S.G.J. and ROELVINK, J.A., 1999. Argus-based monitoring of intertidal beach morphodynamics. *Proceedings, Coastal Sediments 99* (New York, ASCE).

AARNINKHOF, S.G.J.; TURNER, I.L.; DRONKERS, T.D.T.; CALJOUW, M., and NIPIUS, L., 2003. A video-based technique for mapping intertidal beach bathymetry. *Coastal Engineering*, 49(4), 275–289.

ALEXANDER, P.S and HOLMAN, R A., 2004. Quantification of nearshore morphology based on video imaging. *Marine Geology*, 208, 101–111.

ANDERSON, D.J.; TURNER, I.L.; DYSON, A.; LAWSON, S., and VICTORY, S., 2003. Tweed River Entrance Sand Bypassing Project: 'real-time' beach monitoring and analysis system via the world-wide-web. *Proceedings of the 16th Australasian Coastal and Ocean Engineering Conference* (Auckland, New Zealand, IEAust), Paper 002 (CD Conference Volume).

BOAK, E.H. and TURNER, I.L., 2003. A process-based analysis of the 'shoreline' as detected in digital images. *Proceedings of the 16th Australasian Coastal and Ocean Engineering Conference* (Auckland, New Zealand, IEAust), Paper 016 (CD Conference Volume).

BOAK, E.H. and TURNER, I.L., 2005. The shoreline detection-definition problem: a review. *Journal of Coastal Research*, 21(4), 688–703.

BOAK, L.; MCGRATH, J., and JACKSON, L.A., 2000. IENCE—a case study—the Northern Gold Coast Beach Protection Strategy. *Proceedings, 27th International Conference on Coastal Engineering* (Sydney, Australia, ASCE), 4, 3710–3717.

BRANDER, R.W., 1999. Field observations on the morphodynamics of rip currents. *Marine Geology*, 157, 199–218.

CHICKADEL, C. and HOLMAN, R.A., 2001. Measuring longshore current with video techniques. Published as a supplement to *EOS, Transactions*, AGU. 82(47).

CURTIS, W.R. and HOLMAN, R.A., 1998. Beach topography lurks in the shadow. *Proceedings of the American Geophysical Union*, Fall meeting (San Francisco, California).

CURTIS, W.R.; HOLMAN, R.A., and TURNER, I.L., In press. Northern Gold Coast beach topography from imaged shadow observations. *Proceedings of the 17th Australasian Coastal and Ocean Engineering Conference* ('Coasts and Ports 2005') (Adelaide, Australia, IEAust).

DINGLER, J.R. and REISS, T.E., 2002. Changes at Monterey Bay beaches from the end of 1982–83 El Nino through the 1997–98 El Nino. *Marine Geology*, 181, 249–263.

DYSON, A.; VICTORY, S., and CONNOR, T., 2001. Sand bypassing the Tweed River Entrance: an overview. *Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference* ('Coasts and Ports 2001') (Gold Coast, The Institution of Engineers Australia), pp. 310–315.

DYSON, A.; LAWSON, S.; VICTORY, S.; BOSWOOD, P.; MAHON, B.; TRUCCHI, L., and CUMMINGS, P., 2002. Tweed River Entrance Sandy Bypassing Project Post-Commissioning Coastal Behaviour. *Proceedings of the 28th International Conference on Coastal Engineering* (Cardiff, ASCE).

HOLLAND, K.T.; RAUBENHEIMER, B.; GUZA, R.T., and HOLMAN, R.A., 1995. Runup kinematics on a natural beach. *Journal of Geophysical Research*, 100(C3), 4985–4993.

HOLLAND, K.T.; HOLMAN, R.A.; LIPPMAN, T.C.; STANLEY, J., and PLANT, N., 1997. Practical use of video imagery in nearshore oceanographic field studies. *IEEE Journal of Oceanic Engineering*, 22(1), 81–92.

Holman, R.A.; Sallenger, A.H.; Lippmann, T.C.D., and Haines, J.W., 1993. The application of video image processing to the study of nearshore processes. *Oceanography*, 6(3), 78–85.

Jackson, A.; Tomlinson, R.; McGrath, J., and Turner, I.L., 2002. Monitoring of a multifunctional submerged geotextile reef breakwater, Gold Coast, Australia. *Proceedings of the 28th International Coastal Engineering Conference* (Cardiff, ASCE).

Komar, P.D.; Allan, J.; Dias-Mendez, G.M.; Marra, J.J., and Ruggiero., P., 2001. El Nino and La Nina: erosion processes and impacts. *Proceedings of the 27th International Conference on Coastal Engineering* (Sydney, ASCE), pp. 2414–2427.

Lippmann, T.C. and Holman, R.A., 1990. The spatial and temporal variability of sand bar morphology. *Journal of Geophysical Research*, 95(C7), 11575–11590.

Lippmann, T.C. and Holman, R.A., 1991. Phase speed and angle of breaking waves measured with video techniques. *Proceedings of the Coastal Sediment '91* (New York, ASCE), pp. 542–556.

Morris, B.D.; Davidson, M.A., and Huntley, D.A., 2001. Measurements of the response of a coastal inlet using video monitoring techniques. *Marine Geology*, 175, 251–272.

National Research Council, 1990. *Managing Coastal Erosion*. Washington, DC: National Academy Press, 182p.

Plant, N.G.; Aarninkhof, S.G.J.; Turner, I.L., and Kingston, K. In press. The performance of shoreline detection models applied to video imagery. *Journal of Coastal Research*, in press.

Puleo, J.; Holland, K.T.; Kooney, T.N., and Sallenger, A.H., 2000. Field observations of swash zone flow patterns and 3D morphodynamics. *Proceedings of the 27th International Conference on Coastal Engineering* (Sydney, ASCE), pp. 637–650.

Ranasinghe, R.; Symonds, G., and Holman, R., 1999a. Video imaging: a new technique for coastal zone management. *Proceedings of the 14th Australasian Coastal and Ocean Engineering Conference* (Coasts and Ports '99) (Perth, IEAust), pp. 555–560.

Ranasinghe, R.; Symonds, G., and Holman, R., 1999b. Quantitative characterisation of rip currents via video imaging. *Proceedings of Coastal Sediments '99* (New York, ASCE), pp. 987–1002.

Ranasinghe, R.; Symonds, G.; Black, K., and Holman, R., 2000. Processes governing rip spacing, persistence, and strength in a swell dominated, microtidal environment. *Proceedings of the 27th International Conference on Coastal Engineering* (Sydney, USACE), pp. 454–467.

Ranasinghe, R.; Symonds, G.; Black, K., and Holman, R., 2004a. Morphodynamics of intermediate beaches: a video imaging and numerical modelling study. *Coastal Engineering*, 51(7), 629–655.

Ranasinghe, R.; McLoughlin, R.; Short, A., and Symonds, G., 2004b. The Southern Oscillation Index, wave climate, and beach rotation. *Marine Geology*, 204, 273–287.

Seymour, R., 1998. Effects of El Ninos on the west coast wave climate. *Shore and Beach*, 66, 3–6.

Short, A.D., 1993. *Beaches of the New South Wales Coast*. Sydney, Australia: Australian Beach Safety and Management Program, 356p.

Short, A.D.; Cowell, P.J.; Cadee, M.; Hall, W., and van Dijck, B., 1996. Beach rotation and possible relation to the Southern Oscillation. *Ocean and Atmosphere Pacific*. Adelaide, 329–334.

Short, A.D.; Trambanis, A., and Turner, I.L., 2000. Beach oscillations, rotation and the southern oscillation, Narrabeen Beach, Australia. *Proceedings of the 27th International Coastal Engineering Conference* (Sydney, ASCE), pp. 2439–2452.

Short, A.D. and Trembanis, A., 2004. Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia—time series, PCA and wavelet analysis. *Journal of Coastal Research*, 20, 523–532.

Stockdon, H.F. and Holman, R.A., 2000. Estimation of wave phase speed and nearshore bathymetry from video imagery. *Journal of Geophysical Research*, 105(C9), 22015–22033.

Tomlinson, R.; McGrath, J.; Jackson, L.A.; Stuart, G.; Robertson, A.; DaGata, M., and Corbett, B., 2003. Processes to develop an integrated and multi-functional coastal management strategy for Palm Beach Gold Coast. *Proceedings of the 16th Australasian Coastal and Ocean Engineering Conference* (Coastal and Ports '03) (IEAust), Paper 67 (CD Volume).

Turner, I.L. In press. Discriminating modes of response to offshore-detached structures. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, in press.

Turner, I.L.; Leyden, V.; Symonds, G.; McGrath, J.; Jackson, A.; Jancar, T.; Aarninkhof, S., and Elshoff, I., 2000. Predicted and observed and coastline changes at the Gold Coast artificial reef. *Proceedings of the 27th International Coastal Engineering Conference* (Sydney, ASCE), pp. 1836–1847.

Turner, I.L.; Dronkers, T.; Aarninkhof, S., and McGrath, J., 2001. The application of video imaging to quantify beach response to sand nourishment and construction of an artificial reef. *Proceedings of the 15th Australasian Coastal and Ocean Engineering Conference* (Gold Coast, IEAust), pp. 55–60.

Turner, I.L., 2003a. Applications of coastal imaging technology to coastal engineering and coastal management in Australia. *Proceedings of the 16th Australasian Coastal and Ocean Engineering Conference* (Auckland, IEAust), Paper 159 (CD Conference Volume).

Turner, I.L., 2003b. Coastal imaging analysis at engineered sandy coasts—practical applications in SE Australia. *Proceedings of the Coastal Sediments 2003* (Clearwater, Florida, ASCE).

Turner, I.L.; Aarnihkhof, S.J.D.; Dronkers, T.D.T., and McGrath, J., 2004. CZM applications of ARGUS coastal imaging at the Gold Coast, Australia. *Journal of Coastal Research*, 20(3), 739–752.

Whyte, D.; Turner, I.L., and Ranasighe, R. In press. Rip characterisation at the Gold Coast, QLD: an analysis using video imaging techniques and comparison with Palm Beach, NSW, Australia. Coast and Ports 2005 (Adelaide, IEAust).

Wright, L.D. and Short, A.D., 1984. Morphodynamic variability of beaches and surf zones, a synthesis. *Marine Geology*, 56, p. 92–118.

WRL (Water Research Laboratory, University of New South Wales), 2005. Project web site. http://www.wrl.unsw.edu.au/coastal/imaging/

van Enckevort, I.M.J. and Ruessink, B.G., 2001. Effect of hydrodynamics and bathymetry on video estimates of nearshore sandbar position. *Journal of Geophysical Research*, 106(C8), 16969–16979.

van Enckevort, I.M.J.; Coco, G.; Ruessink, B.G.; Suzuki, K.; Turner, I.L.; Plant, N.G., and Holman, R.A. 2004. Field observations of nearshore crescentic sandbars. *Journal of Geophysical Research*, 109, C06028, 17p.