ANALYSIS OF SHORELINE CHANGE:
AUGUST 2001 - JANUARY 2002

REPORT 5
NORTHERN GOLD COAST COASTAL IMAGING SYSTEM

by

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1. INTRODUCTION

This report was prepared by Water Research Laboratory (WRL) for Gold Coast City Council. It is the fifth in a series of six-monthly reports, that describe and quantify the regional-scale coastline changes occurring in response to the implementation of the Northern Gold Coast Beach Protection Strategy (NGCBPS) commencing in 1999.

1.1 General

In July of 1999, an ARGUS coastal imaging system was installed at the northern Gold Coast by WRL, with the assistance of WL|delft hydraulics (The Netherlands) and the Australian Defence Force Academy. This leading-edge technology was selected by Gold Coast City Council to provide quantitative, continuous and long-term monitoring of the predicted growth of the beach. It is this ability to provide quantitative information that distinguishes the ARGUS coastal imaging system from conventional 'webcam' technology.

This is the first time coastal imaging has been used in Australia to monitor the regional-scale response to major coastal engineering works, and it is fitting that this new technology should be used in conjunction with the implementation of the innovative NGCBPS project.

The coastal imaging system installed at the northern Gold Coast became fully operational on 1st August 1999. This timing coincided with the commencement of reef construction. Beach nourishment commenced in February 1999, approximately six months prior to the installation of the coastal imaging system. Beach nourishment was completed in June 2000, and the primary phase of reef construction concluded in December 2000.

The analysis of beach changes during the preceding six-monthly monitoring periods are detailed in a series of reports; August 1999 to February 2000 (Turner and Leyden, 2000a), March 2000 to July 2000 (Turner and Leyden, 2000b), August 2000 to January 2001 (Turner and Adamatidas, 2001) and February 2001 to July 2001 (Turner, 2001). The purpose of this fifth report is to present the results of shoreline change analysis for the monitoring period August 2001 to January 2001, and to assess the net changes that have occurred to northern Gold Coast beaches since the commencement of the monitoring program some 30 months ago in August 1999.
1.2 Operational Issues

In late December 2001 the ARGUS coastal imaging station suffered a lightning strike, which caused a range of hardware damage. Communications between the remote site and WRL were re-established in mid January, following replacement of the lightning-damaged modem. No images were lost during this period, however the loss of communications temporarily stopped the hourly updating of ‘live’ images to the world-wide-web. The image archive was subsequently updated to include the backlog of all images for the first two weeks of January.

In early February 2002 the more serious impacts of the lightning strike were revealed. A failure of the systems disk caused the automated capture of hourly images to cease. To resolve this problem it was necessary to return the main hardware components to WRL for assessment and repair. With a new disk installed, on March 1st the ARGUS system was re-installed and since that time has been fully operational. Thus, no images were lost during January 2002, however no image were collected by the system for much of February 2002.

1.3 What’s New

The major advance that has been achieved for this present monitoring period is that, with the main phase of reef construction completed some 12 months ago, it is now possible to explicitly identify the impacts of the reef at the northern Gold Coast. To achieve this, the new application of an analysis technique called ‘Even-Odd Function Analysis’ has been developed. When applied to shoreline change data for the Narrowneck region, this technique has been found to separately identify and quantify two distinct modes of beach response due to the offshore structure. A description and the first results of this analysis are presented in Section 8. It is intended that this analysis will now be completed on a routine basis, to assess the anticipated continued development of the beach in the vicinity of the submerged reef.

The coastal imaging monitoring program underway at the northern Gold Coast continues to attract national and international attention. Since the presentation and publication of monitoring results in July 2000 at the International Conference on Coastal Engineering and in September 2001 at the 15th Australasian Coastal and Ocean Engineering Conference, a series of papers have been submitted for publication to international professional journals. As noted in the previous monitoring report, over the last 12 months WRL has been collaborating with colleagues in the USA, UK and Netherlands, to assess and validate various analysis techniques for the detection of shorelines captured by ARGUS images. As
this is the primary purpose of the coastal imaging system installed at the northern Gold Coast, this study is of major significance to the monitoring program detailed in this and preceding reports. This extensive study included researchers from four international research institutions, including WRL, applying four different shoreline detection methodologies to a dataset of images that included approximately 40 images of the northern Gold Coast. Also included in the study were images obtained from three other ARGUS sites located in North America and Europe. A pleasing finding of this study was the fact that the shoreline detection technique developed specifically for the northern Gold Coast coastal imaging system (see Section 3.7: for further details refer Turner and Leyden, 2000a) performed best at the Gold Coast. The results of the inter-comparison study have been submitted for publication in the international journal *Coastal Engineering*.

Working with colleagues in the Netherlands, two further papers have been submitted for publication in *Journal of Coastal Research* and *Coastal Engineering* that detail aspects of the northern Gold Coast monitoring program. The former presents an overview of the application of coastal imaging to CZM (Coastal Zone Management) at the Gold Coast, and the latter presents an inter-comparison of a specific image analysis technique at Egmond in the Netherlands and Main Beach at the Gold Coast to map intertidal beach morphology. This work was undertaken by a student visitor to WRL in 2001. A copy of the thesis that was produced during this period was previously forwarded to Council in November 2001.

It is pleasing to note that the ARGUS coastal imaging system at the northern Gold Coast was recognised as one of three finalists in the Science category of the 2001 Queensland Healthy Waterways awards.

### 1.4 Report Outline

Following this introduction, Section 2 of this report provides a brief overview of the Northern Gold Coast Beach Protection Strategy.

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 Northern Gold Coast Coastal Imaging System entitled *System Description and Analysis of Shoreline Change: August 1999 – February 2000* (Turner and Leyden, 2000a).
The web site established to promote and distribute the images collected by the monitoring program is introduced in Section 4. Description includes the web-based image archive that provides unrestricted access to all images, and 'time-lapse' animation files that are updated on a monthly basis.

Section 5 introduces the beach morphodynamic classification model of Wright and Short (1983), which is then used to describe the qualitative beach changes observed using the time-series of daily images for the period covered by the report, August 2001 – January 2002.

The quantitative analysis of shoreline change for the period August 2001 to January 2002 is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total 30 month monitoring period, August 1999 – January 2002.

An assessment of shoreline trends at the reef site at Narrowneck is provided in Section 8. This Section has been significantly expanded from previous reports, to include a description and results of Even-Odd Function Analysis to explicitly analyse and quantify the impacts of the Gold Coast reef at Narrowneck. Section 9 presents an assessment of the occurrence of wave breaking at the reef for the two year period January 2000 to January 2002. Section 10 summarises the major findings of this fifth monitoring period.
2. BACKGROUND

2.1 Northern Gold Coast Beach Protection Strategy

The Northern Gold Coast Beach Protection Strategy (ICM, 1997; Boak et al, 2000) proposed a long-term, sustainable plan to maintain and enhance the beaches at Surfers Paradise, Gold Coast Queensland, Australia (Figure 2.1). Tourism is the Gold Coast's largest industry, however, the tourist economy is at risk of significant downturn due to storm beach erosion.

Gold Coast beaches are dynamic, and coastal erosion has been an ongoing problem since development began last century. Early and more recent coastal protection measures have included the construction of timber walls in the 1920s and 1930s, progressive construction of a continuous boulder wall along the entire northern Gold Coast beachfront, construction of the Gold Coast Seaway and sand by-passing system in the mid-1980s, and periodic beach nourishment since the 1970s.

The Northern Gold Coast Beach Protection Strategy (NGBPS) aims to decrease the risk of economic loss following storm events by increasing the volume of sand within the storm buffer seaward of the existing oceanfront boulder wall. The NGBPS has the dual objectives of increasing the sand volume within the dunal buffer and improving surf quality, through the implementation of sand nourishment and the construction of an artificial reef (McGrath et al., 2000).

The NGBPS is specifically concerned with the 1.75 km of beach between Main Beach and Cavill Avenue at Surfers Paradise (refer Figure 2.1). The reef is located at Narrowneck. This section of coastline is part of the Gold Coast coastal compartment between the Gold Coast Seaway in the north and Burleigh Heads 20 km to the south. The Master Plan for the engineering works now completed at the northern Gold Coast is summarised in Figure 2.2.

2.2 Reef Construction

Construction of the artificial reef at Narrowneck commenced in August 1999, with the major phase of reef building concluded in mid-December 2000. During the present monitoring period, a second phase of construction was completed to raise the crest level of the structure.
The novel shape of the reef was designed following field investigations and extensive numerical model simulations to determine the optimum reef layout (Black, 1998; Black et al., 1998). The final reef design was further tested by a physical model study (Turner et al., 1998a). Reef construction commenced in August 1999, and to date some 406 sand-filled geocontainers (up to 300 tonnes) have been used to construct the reef, including an additional 15 bags placed in November 2001, and a further two bags in December 2001. The reef design consists of two primary layers of stacked geocontainer units. Figure 2.3 shows the progress of reef construction up to and including December 2001.

### 2.3 Sand Nourishment

Nourishment of the northern Gold Coast beaches commenced in February 1999, six months prior to reef construction. Cumulative nourishment volumes for the 17 month nourishment period February 1999 to June 2000 are shown in Figure 2.4, at which time this phase of beach nourishment within the 4500 m study area was completed.

In summary, approximately 1170000 m$^3$ of sand has been placed on the beach and nearshore at the northern Gold Coast. The locations of the six sand nourishment deposition areas are indicated in Figure 2.5. For reference, the location of the reef construction site at Narrowneck is shown in this figure. A small volume of additional sediment (~ 37000 m$^3$) was also deposited approximately 300 m north of deposition area A1 in June 2000, denoted deposition area A1a in Figure 2.4.
source: Turner et al. (1998)
NORTHERN GOLD COAST BEACH PROTECTION STRATEGY

Source: McGrath et al. (2000)
Figure 2.4

SAND NOURISHMENT

cumulative volume (m³)

Jan-99  Apr-99  Jul-99  Oct-99  Jan-00  Apr-00  Jul-00

depositon area

A1a  A1  A2  A3  A4  A5  A6

completed

0  100,000  200,000  300,000  400,000  500,000  600,000  700,000  800,000  900,000  1,000,000  1,100,000  1,200,000
SAND NOURISHMENT DEPOSITION AREAS
3. OVERVIEW OF COASTAL IMAGING, IMAGE TYPES AND IMAGE PROCESSING TECHNIQUES

Comprehensive descriptions of the northern Gold Coast coastal imaging system, image types and imaging processing techniques were detailed in the first NGCBPS coastal imaging report *System Description and Analysis of Shoreline Change: August 1999 – February 2000* (Turner and Leyden, 2000a). 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. The reader is referred to Turner and Leyden (2000a) for further details.

3.1 What is Coastal Imaging?

'Coastal imaging' simply means the automated collection, analysis and storage of pictures, processed to observe and quantify coastline behaviour.

Aerial photography has been the tool most commonly used by coastal managers to monitor regional-scale coastal behaviour. But this is expensive and, therefore, coverage is often 'patchy' and incomplete. Also of course, pictures are only obtained when the aeroplane is in the air and visibility 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 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 documented and available for more detailed analysis as required.

3.2 The Difference between Coastal Imaging and a 'Webcam'

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 Webcams 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. For detailed description and illustration of the methods used to calibrate the lens and cameras installed at the northern Gold Coast, the reader is referred to Turner and Leyden (2000a).

### 3.3 The ARGUS Coastal Imaging System

The ARGUS coastal imaging system has developed out of ten 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 modem from the remote site to the laboratory. The cameras installed at the northern Gold Coast 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 analog I/O card that enables all images to be captured, stored and distributed in standard jpeg digital image file format.

At WRL a host computer stores all images as they are received from the remote site, within a structured archive (at WRL a DEC Alpha workstation is used for this purpose). This workstation is also 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 the northern Gold Coast to WRL. Post-processing of the images is completed using a variety of Unix- and pc-based computer hardware and custom image processing software.

### 3.4 Installation at the Northern Gold Coast

The ARGUS coastal imaging system was installed at the northern Gold Coast in late July 1999. The system is located at an elevation of approximately 100 m above mean sea level, within a roof services area of the Focus Building (Figure 3.2). The Focus Building is
located approximately 60 m seaward of the dune line, approximately 900 m to the south of Narrowneck.

The cameras are mounted externally to the building, and are protected within weatherproof housings (Figure 3.3). The SGI workstation is housed within an air-conditioning services room, where 240 V power and a dedicated phone line 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 dialing in to the remote system from WRL. Occasional cleaning of the camera lenses is also required.

3.5 Image Types

The ARGUS coastal imaging system installed at the northern Gold Coast is presently configured to collect three different types of images. 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 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 the northern Gold Coast 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. Daily daytimex images for the monitoring period described in this report of August 2001 to January 2002 are presented in Appendix A.

### 3.6 Basic Image Processing – Merge, Rectification and Reference to Real-World Coordinate System

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. This is achieved through the solution of the camera model parameters (refer Turner and Leyden, 2000) 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. This merged and rectified image created from four oblique images is analogous to a montage of distortion-corrected photographs taken from an airplane flying directly overhead the northern Gold Coast. 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 the Gold Coast is 5 m; that is, a single pixel represents an area 5 m × 5 m.

Note that the black triangular region in the middle of this plan view image is the region within the otherwise 180° field of view that is not covered by the four-camera system. To include this region in the merged/rectified image would require a fifth camera, which budget constraints could not justify. This missing region is relatively unimportant, however, as it occurs seaward of the surfzone in most conditions.

The final step in the routine processing of images at the northern Gold Coast is the referencing of merged/rectified images to a convenient map reference system. As the coordinates of the cameras are known, this final step is relatively easy to achieve. In Figure 3.6 an example of a merged and rectified image is shown, referenced to Australian Map Grid (AMG) eastings and northings. The referencing of images to real-world coordinates permits the combination of image information with other cadastral information; in Figure 3.6 a merged and rectified timex image is overlayed by an engineering design drawing showing the layout of the geotextile bags comprising the bottom layer of the Gold Coast reef. As illustrated in the upper panel of this figure, specific regions of interest
within an image can be enlarged to examine in greater detail that region of the beach or nearshore.

### 3.7 Technique and Standardised Procedure for Shoreline Mapping

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 ARGUS images. Due to difficulties with the application of existing techniques to the Gold Coast, a new shoreline technique was developed utilising the full-colour information available at the northern Gold Coast site. This technique, developed specifically to analyse the images from the northern Gold Coast coastal imaging system, utilises the different light reflectance properties of 'wet' and 'dry' regions within the images.

A comprehensive description of the shoreline detection technique can be found in Turner and Leyden (2000a). Briefly, the divergence of RGB (Red-Green-Blue) colour components within each image is exploited to define a 'shoreline indicator'. For illustration, in the upper panel of Figure 3.7 a representative cross-shore transect is shown. The individual RBG components along the line of image pixels that define this transect are shown in the middle panel of Figure 3.7. By using an objective method to pick the cross-shore location where the separated colour components diverge, and by repeating this procedure at all positions alongshore, the position of the shoreline indicator along the entire length of beach is defined (lower panel, Figure 3.7). Following this approach, a software tool was written to refine and standardise the full-colour shoreline detection method.

The procedure used to map the shoreline at weekly (nominal seven day) intervals is summarised in Figure 3.8. First, predicted tide information is used each day to determine the hourly timex images that correspond to mid-tide (0 m AHD). The corresponding merged-rectified 4-camera image is then created. The database of wave information is also searched to determine the wave height ($H_s$) and 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 $H_s \leq 1.0$ m. This wave height criteria was used for shoreline mapping as, above this wave height, wave runup at the beach face increases and the width of the swash zone widens, introducing a corresponding uncertainty in the cross-shore position of the shoreline. If the wave height is less than 1.0 m, then the shoreline is mapped. If the wave height exceeds the $H_s = 1.0$ 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 ±3 days from the original target weekly image, to locate a mid-tide image for which the 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. During the period August 2001 to January 2002, this occurred on two occasions only.

Once the mid-tide image to be processed has been identified, the shoreline is mapped. The position of the shoreline is picked at regular 25 m increments alongshore, and then filtered using a five-point running mean. This final step of smoothing the raw shoreline position is used to exclude the potential aliasing by beach face cuspate features which typically exhibit alongshore wavelengths of the order of 20–30 m. Beach width is then calculated relative to a dune reference line. By repeating this procedure every seven days, a growing data base is developed that contains the time-series of weekly shoreline positions obtained at each 25 m distance along the shore. These data are then subjected to a range of analyses as described in the following Sections 6, 7 and 8.
SCHEMATIC OF AN ARGUS COASTAL IMAGING SYSTEM

REMOTE SITE
(Focus Building)

- SGI Workstation
  - image capture
  - image pre-processing

- A/D Video Interface

WATER RESEARCH LABORATORY

- DEC ALPHA Workstation
  - image archive
  - image post-processing
  - web server (image distribution)

WORLD WIDE WEB

- Modem
- Modem

Figure 3.1
LOCATION OF ARGUS COASTAL IMAGING SYSTEM AT THE GOLD COAST

IMAGE COURTESY OF FOCUS APARTMENTS

CAMERAS
CAMERAS MOUNTED AT AN ELEVATION OF APPROXIMATELY 100m
SNAP-SHOT, TIME EXPOSURE AND VARIANCE
IMAGE TYPES

Figure 3.4
Figure WRL 98075-3-6.png

PLAN VIEW IMAGE REFERENCED TO ‘REAL WORLD’ AMG COORDINATE SYSTEM

Figure 3.6
RGB COLOUR TECHNIQUE FOR AUTOMATED DETECTION OF THE SHORELINE
STANDARDISED SHORELINE MAPPING PROCEDURE

1. Northern Gold Coast Coastal Imaging System
2. Gold Coast tide data
3. Create daily merged/rectified image at mid tide
4. Determine corresponding wave conditions
5. Gold Coast wave data
6. Does image satisfy wave height threshold? (Hs ≤ 1m)
7. Select image for proceeding/preceeding day
8. Map Shoreline

Flowchart:
- Start with Northern Gold Coast Coastal Imaging System.
- Use Gold Coast tide data to create a daily merged/rectified image at mid tide.
- Determine corresponding wave conditions.
- Use Gold Coast wave data to verify if the image satisfies the wave height threshold (Hs ≤ 1m).
- If the image does not satisfy the threshold, select the image for the proceeding/preceeding day.
- If the image satisfies the threshold, map the shoreline.
4. COASTAL IMAGING WEB SITE

4.1 Coastal Imaging Home Page

To promote the dissemination of information about the northern Gold Coast coastal monitoring project, and to provide a convenient means to distribute images as they are collected, a coastal imaging site was established on the world-wide web.

The address to locate this web site is: http://www.wrl.unsw.edu.au/coastalimaging/

The 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 at the northern Gold Coast. 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 NGCBPS web site maintained by International Coastal Management and the waverider buoy site run by the Queensland Department of Environment.

For general interest, a record is maintained of the number of visitors to the web site and the countries they are from. At the time of writing, approximately 62,000 hits to the site have been recorded. Visitors from Australia and the USA each account for approximately one third of the total visitor numbers, with the remaining visitors to the site coming from approximately 80 countries world-wide.

4.2 Image Archive

In addition to the snap images which are updated on an hourly basis, all previous images are archived and made available to view and download via the web site. To minimise communication costs, snap images are transferred every hour through the day, but the transfer of hourly var and timex images occurs once per day during the evening.

All present and past images can be accessed via the 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 GIF Animations

At the beginning of each month, an animation is created that enables visitors to the web site to view a 'movie' of the preceding month at the northern Gold Coast. These animations are created from one timex picture for each day of the month, taken at the same stage of the tide. The animations provide a particularly informative means of observing beach changes through time. The animations are also made freely available for download by visitors to the web site.

Over time, animations covering longer time periods will be made available via the web site. At the present time, two extended animations that covers the initial 12 month monitoring period (1/8/99 – 31/7/00) and the second year of monitoring (1/8/00 – 31/7/01) are available for viewing and download via the coastal imaging web site.
"WRL Coastal Imaging Home Page - Microsoft Internet Explorer"

"WRL Coastal Imaging Home Page"

"COASTAL IMAGING AT WRL"

"WATER RESEARCH LABORATORY"

"SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING"

"WRL COASTAL IMAGING HOME PAGE"

"These digital images of the northern Gold Coast, Australia (site map) are updated every hour. They are being collected and analyzed to monitor large-scale coastal changes associated with the construction of the Gold Coast Reef and sand movement of the adjacent beaches. All images are saved, and may be viewed (and downloaded) by visiting the image archive."

"FURTHER INFORMATION about WRL contact WRL"

"LET'S CONNECT"

"Click on image to view full size..."

"camera 4 (north) camera 3 (north-east) camera 2 (south-east) camera 1 (south)"

"[Note: Check the "Reload" button on your browser to ensure you are viewing the most recent images."

"CLICK HERE FOR REAL-TIME WAVE INFORMATION"

"WRL contact ian.turner@wrl.uq.edu.au"

Figure 4.1
Argus images at GoldCoast

Camera: c4
Date: 001_Jan.01

<table>
<thead>
<tr>
<th>Time (AEST-10)</th>
<th>Snapshot</th>
<th>Time exposure</th>
<th>Variance image</th>
</tr>
</thead>
<tbody>
<tr>
<td>0500</td>
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<td><img src="image2" alt="Time exposure" /></td>
<td><img src="image3" alt="Variance image" /></td>
</tr>
<tr>
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<td><img src="image4" alt="Snapshot" /></td>
<td><img src="image5" alt="Time exposure" /></td>
<td><img src="image6" alt="Variance image" /></td>
</tr>
<tr>
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<td><img src="image7" alt="Snapshot" /></td>
<td><img src="image8" alt="Time exposure" /></td>
<td><img src="image9" alt="Variance image" /></td>
</tr>
<tr>
<td>0800</td>
<td><img src="image10" alt="Snapshot" /></td>
<td><img src="image11" alt="Time exposure" /></td>
<td><img src="image12" alt="Variance image" /></td>
</tr>
</tbody>
</table>

By examining the daily images – or even more clearly, by watching the monthly animations available at the coastal imaging web site – it is self-evident that the beaches of the northern Gold Coast are continually changing. Bars move onshore and offshore and vary in shape, rips emerge and disappear, and the shoreline changes shape and translates landward and seaward in response to varying wave conditions and beach nourishment. As in previous reports, this section is included to provide a qualitative description of these observed changes during the six-month period August 2001 to January 2002. The objective is not to describe every characteristic of the northern Gold Coast beaches during this period, but rather the aim is to provide an overview of general trends and predominant features.

To summarise beach changes in some structured manner, and in particular to identify any particular beach features that can be attributed to the beach nourishment and reef construction works, it is useful to first outline a systematic beach classification scheme with which to undertake this qualitative analysis. For consistency, this same classification scheme was used in all previous NGCBPS coastal imaging reports, and will continue to be used in future reports to enable inter-comparison as the monitoring program continues.

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 a given point in time. The generalised cross-section and planform 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 topography 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 surfzone, 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 beach face 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 (i.e., 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 $\rightarrow$ RBB $\rightarrow$ 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 daily daytimex images for the period August 2001 to January 2002 are presented in Appendix A. Each of these figures shows a week (seven days) of sequential daytimex images, with the date of each indicated. The region shown in these figures extends 4500 m alongshore, from approximately 1500 m north of the reef construction site at Narrowneck to 3000 m south along the Surfers Paradise Esplanade. The location of the reef is indicated in
these figures for reference, and the colour contrast of the images has been increased to enhance the visibility of nearshore features.

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 August 2001

Characteristic of the entire six month monitoring period August 2001 to January 2002, low wave conditions prevailed for the month of August. During the first week significant wave height declined from 1 m to 0.5 m, with peak wave periods around 10 seconds. The pre-existing RBB morphology persisted due to insufficient wave energy to mobilise sediment movement, and wave breaking was observed on the outer bar for the first three days only, in the immediate vicinity of the reef at Narrowneck. During the following week significant wave heights did not exceed 0.5 m, and as a result limited wave breaking on the inner bar only was observed.

On the 14th of August significant wave height increased to 1 m again and persisted for the next seven days, with peak wave periods progressively increasing from 10 s to 15 seconds during this time. As a result of this moderate increase in wave energy, the inner bar was observed to progressively move shoreward, accompanied by the development of numerous rip channels alongshore. By the end of this week TBR conditions had developed, with the inner bar welding to the beachface. Wave information is not available for the period 23rd – 26th August, however the beach morphology indicates that a short-lived increase in wave height occurred around the 25th, with wave breaking observed across the outer bar in the immediate vicinity of reef, and resulting in the removal of smaller rip channels across the inner bar. Declining wave heights to the end of August saw the reformation of rip channels alongshore and the continued onshore movement of the inner bar. By the 31st of August TBR morphology was again present, with the unusual distinction that rip channels were prevalent to the south of Narrowneck, but were a less distinctive feature to the north.

5.2.2 September 2001

Though the first half of September significant wave heights were of the order of 0.5 m with peak wave periods generally in the range of 10 – 12 seconds. As a result of low wave energy little morphological change was observed and TBR conditions persisted.
Around the 18th of September significant wave heights increased to 1 m, and through to the end of the month generally remained in the range of 1 – 1.5 m. During this time peak wave period persisted in the range of 8 s to 10 seconds. This modest increase in wave energy was observed to re-activate sediment movement, with the inner bar becoming fully welded to the beachface during this period as sediment in the nearshore was transported landward. An intermediate morphology between the TBR and LTT states resulted, with the welded inner bar exhibiting many of the features of a low tide terrace, cut by numerous and regularly spaced smaller rip channels. During the 27th and 28th wave heights increased to exceed 1.5 m, with the results that the inner bar moved a short distance seaward again to form a narrow trough at the beachface. By the end of September a RBB beach state was observed.

5.2.3 October 2001

The month of October was again characterised by relatively low wave energy conditions. In the first week significant wave heights peaked at around 1.5 m, then declined in the general range of 0.5 to 1.5 m. Up to the 14th of October peak wave period remained at 10 sec, then declined to 5 sec, before briefly increasing again up to 12 seconds on the 23rd, before decreasing again to 5 – 6 seconds through the last week of October. Due to generally low wave conditions, lower intermediate beach states persisted for this entire period.

By the end of the first week in October, the inner bar had translated shoreward with the beach evolving again from a RBB to TBR state. Multiple and complex rip channels developed across the inner bar, and persisted for the remainder of the month. The outer bar was inactive during this entire period, with no wave breaking observed seaward of the complex inner bar-channel system. In contrast to the beach state at the beginning of October, within the first 3 – 4 days of the month the distinctive longshore inner trough had been replaced by transverse bar features and rip channels, indicative of generally accretionary conditions at the northern Gold Coast. The persistence of these usually transitional features for a period of several weeks was indicative of the prevailing constant wave energy conditions during this period.

5.2.4 November 2001

The beaches of the northern Gold Coast during the month of November were observed to exhibit three distinct morphodynamic states. Through to the 15th of November TBR conditions persisted, with numerous rip channels exhibiting the regular sinuosity
alongshore that is characteristic of shore-normal incident waves (see Figure 5.1d). During this two week period significant wave heights remained at around 1.0 m, and peak wave periods generally in the range of 10 s – 11 seconds.

From the 15\textsuperscript{th} to the 21\textsuperscript{st} of November the same TBR beach state persisted, but with the notable change that the transverse bar and rip features were observed to become uniformly skewed to the north, which is generally associated with oblique incident waves. The orientation of rip channels to the north-east indicates that the prevailing wave direction during this time was from the south-east. Significant wave heights remained in the similar range of around 1 m, however peak wave period dropped during this period to 5 - 7 seconds.

On the 21\textsuperscript{st} of November significant wave heights increased and peaked in the range of 1.5 - 2 m on the 22\textsuperscript{nd}, coinciding with peak wave periods increasing to 12 – 13 seconds. The beaches of the northern Gold Coast responded rapidly by the removal of rip channels and the translation seaward of the inner bar. By the 23\textsuperscript{rd} the inner bar was completely detached from the beachface, exhibiting a uniform linear form alongshore, and separated from the shoreline by a nearshore trough. This LBT to RBB beach state persisted to the end of November, with minor rhythmic features beginning to develop along the inner bar. The outer bar remained inactive during the entire November period, with insufficient wave heights to cause wave breaking seaward of the shoreline and inner bar system.

5.2.5 December 2001

The month of December saw a gradual return of northern Gold Coast beaches to TBR and LTT beach states. Steady significant waves heights of the order of 1 m prevailed for the entire month, with a constant peak 10 second wave period persisting to the 21\textsuperscript{st}, after which time peak wave period decreased to 6 – 7 seconds.

Progressively though the month the inner bar translated shoreward, with small rip channels developing in the first week, and increasingly prevalent in the second week of December. By the middle of the month the inner bar had welded to the beachface, resulting in characteristic TBR nearshore morphology. Continuing lower wave conditions resulted in the slow landward migration of sediment in the nearshore, with LTT morphology beginning to be observed during the last week of December. In contrast to the beach state that prevailed in the latter half of November, rip channels were more diffuse and irregularly spaced during this period, with insufficient wave energy to cause significant seaward return flows in the nearshore zone. By the end of December, little ongoing morphological
adjustment was observed, as the beach state approached an equilibrium state with the prevailing lower wave energy conditions.

5.2.6 January 2002

Through to the 23rd of January significant wave heights remained a relatively constant 1 m. Peak wave periods ranged from 6 s to 12 seconds. During this period the beaches of the northern Gold Coast remained in a transitional state that exhibited both TBR and LTT features. The inner bar remained partially welded to the beach face, with numerous and persistent rip channels tending towards the end of this period to become increasing skewed to the north.

Commencing the 24th of January significant wave heights increased up to 2.5 m, with peak wave periods of 10 seconds. The beach rapidly responded by the removal of rip channels and the translation seaward of the inner bar. By the end of January the LBT beach state had fully developed, with the linear inner bar now separated from the beachface by a linear nearshore trough. Extensive wave breaking on the outer bar in the vicinity of the reef was observed during this period.

5.3 Visual Assessment of Beach Width Changes (August 2001 – January 2002)

Beach and nearshore changes during the present monitoring period August 2001 to January 2002 were characterised by mild wave energy conditions and the prevalence of lower intermediate morphodynamic beach states, indicative of generally accretionary conditions. A qualitative visual assessment of the resulting regional trends in beach adjustment during this period can be seen by contrasting images of the beach obtained at the start and end of the present six month monitoring period.

Figure 5.2 shows the snap images obtained at mid-tide from Camera 1 (south) on 01/08/01 and 31/01/02 respectively. The corresponding snap images of the northern beaches obtained from Camera 4 are shown in Figure 5.3. In both cases, the January 2002 images are slightly obscured due to salt spray associated with strong winds at this time. From a visual assessment of these images, the general accretionary trend along beaches of the northern Gold Coast during this time is evident.

To the south (Figure 5.2) the beach appears to have maintained beach width north of Cavill Avenue, and to the south a widening of the subaerial beach is more discernable. At the
northern beaches (Figure 5.3) the widening of the beach is more noticeable, extending from the near foreground to north of Narrowneck.

5.4 Visual Assessment of Total Beach Width Changes (August 1999 – January 2002)

The net effects to date of the nourishment program over the entire 30 month monitoring period are seen in Figures 5.4 and 5.5. In these figures the mid tide beach to the north and south are shown at six-monthly intervals for the entire monitoring period August 1999 to January 2002. During the first six months (August 1999 to January 2000) the on-going nourishment of the northern beach is visible, with no change to the southern beach as this area was yet to be nourished. A dramatic change in the width of the beach occurred between January 2000 and August 2000, when nourishment of the entire stretch of coastline from Narrowneck to Cavill Avenue was completed, with the result that the mid tide beach can be seen to have nearly doubled in width during this time. During the next six months to January 2001 the beach alignment became more uniform alongshore, as the coastline re-adjusted to the new sand volume available within the beach system. The following six-month period of February 2001 – July 2001 saw a general erosionary trend along the northern Gold Coast beaches, due to a succession of storms during this period. By the end of the present six month monitoring period August 2001 to January 2002 from visual assessment it appears that the beach had recovered, returning to a similar state as was seen 12 months previously in January 2001. A return to prior conditions following a period of storm erosion suggests that the beaches of the northern Gold Coast are close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000.

A more quantitative assessment of the response of the northern Gold Coast beaches for the period August 2001 to January 2002 is detailed in Section 6.
MORPHODYNAMIC BEACH STATE MODEL (after WRIGHT and SHORT, 1983)

5.1

a) DISSIPATIVE

outer breaker zone
'trough'
inner breaker zone
beach

b) INTERMEDIATE
LONGSHORE BAR-TROUGH

straight bar ↔ crescentic bar
weak rip

bar
'trough

plunging breaker
deep trough
bar

c) INTERMEDIATE
RYTHMIC BAR AND BEACH (normal or skewed)

normal waves ↔ oblique waves
crescentic bar

ns

plunging breaker
trough

d) INTERMEDIATE
TRANSVERSE BAR AND RIP (normal or skewed)

normal waves ↔ oblique waves

plunging breaker

A
bar
A'

spilling-plunging breaker

B
rip
B'

e) INTERMEDIATE
RIDGE-RUNNEL OR LOW TIDE TERRACE

normal waves ↔ oblique waves

plunging breaker

A

A'

plunging breaker

low berm
ridge

B
runnel
flat
bar
B'

f) REFLECTIVE

steep beach face

berm crest

berm

steep beach face
SNAP IMAGES FROM CAMERA 1 (SOUTH):
01/08/2001 AND 31/01/2002
SIX-MONTHLY BEACH CHANGES (CAMERA 1-SOUTH): AUGUST 1999 - JANUARY 2002

August 1999
January 2000
August 2000
January 2001
August 2001
January 2002
SIX-MONTHLY BEACH CHANGES (CAMERA 4-NORTH):
AUGUST 1999 - JANUARY 2002

August 1999

January 2001

January 2000

August 2001

August 2000

January 2002

The primary function of the coastal imaging system installed at the northern Gold Coast is to quantify shoreline changes during and post beach nourishment and construction of the Gold Coast artificial reef. Analysis of shoreline position and beach width provide an objective measure to assess the achievement of the NGCPBS to meet its aims of enhanced beach amenity and increased storm buffer.

6.1 Weekly Shorelines

All weekly shorelines obtained for the period 1/8/01 to 31/1/02 are shown in Figure 6.1. For reference, these measured shorelines are overlayed onto a representative merged/rectified timex image (image date: 31/1/02). The image represents a 4500 m length of the beach, extending approximately 3000 m to the south of Narrowneck and approximately 1500 m to the north. AMG coordinates are shown, and the location of the reef construction site at Narrowneck is indicated by the overlayed outline of the reef. The landward dune reference line used to calculate beach width is also indicated (red line).

The location of the cameras can be identified by the limited offshore region in front of the Focus Building that is outside the cameras’ fields of view. As noted previously in Section 3.6, this black triangular region occurs in all merged images because it falls between the fields of view of cameras C2 and C3. Note that, for a limited region in front of the cameras, the shorelines are not mapped, as it was found that the shoreline mapping technique in this region proved unreliable. Further investigations are underway to determine the cause of this observation. However, for the purpose of analysing shoreline behaviour along the entire 4500 m study area, this limited region for which shoreline data is not available is not significant.

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 dune reference line. The distance of these shorelines from the dune reference line is plotted in the upper panel, and for convenience the alongshore position in this figure is relative to the location of the ARGUS station (0 m). 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 1/8/01 – 31/1/02 it can be seen from Figure 6.2 that the beach along the 4500 m study region varied in width (relative to the dune reference line) from approximately 60 m to 150 m. The envelope of beach width changes is relatively uniform alongshore, with the beach at any specific location varying by approximately 40 m during this period.

It is important to note here that, although it may appear that the beach alignment changes in the centre of the 4500 m study region, in fact this is not the case, but rather the wider beach in this central region is due to the curvature of the dune reference line used to calculate beach width. In reality, the position of this reference line is somewhat arbitrary, and was selected so as to generally indicate the seaward edge of the vegetation between the beach and The Esplanade.

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

The alongshore variability of the measured shoreline positions during the monitoring period 1/8/01 – 31/1/02 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 all locations alongshore. For reference, in the lower panel the mean shoreline position is overlayed on to a merged/rectified timex image of the northern Gold Coast.

Referring to Figure 6.3, the median beach width at mid tide (relative to the dune reference line) along the 4500 m stretch of coastline during the period 1/8/01 – 31/1/02 was approximately 100-110 m, but can be seen to have varied by over 40 m from 80 m to 120 m. As was discernible from Figure 6.2, relative to the dune reference line the mean beach width was greatest in the central 1000 m region of the 4500 m monitoring area, averaging approximately 120 m.

The analysis of maximum and minimum beach width (upper panel, Figure 6.3) reveals a relatively uniform range of beach variations along the 4500 m study area. Both north and south of the camera, beach widths generally varied by 20–30 m from the mean shoreline position.

The middle panel of Figure 6.3 shows the standard deviation of weekly shorelines from the mean shoreline position during the period 1/8/01 – 31/1/02. The standard deviation of weekly shorelines was generally 10 m–15 m, with a broad region of lower variability (s.d. <
10 m) centered around Narrowneck (1000 m north), and a more limited area approximately 500 m south of the cameras.


To remove the effect of the arbitrary dune reference line appearing to indicate a change in beach alignment in the centre of the 4500 m study region, in Figure 6.4 weekly shorelines for the period 1/8/01 – 31/1/02 have been re-analyzed and plotted relative to the mean shoreline position calculated for the previous monitoring period February 2001 – July 2001 (refer Turner, 2001). In the upper panel the deviation of weekly shorelines from this earlier mean shoreline is plotted. In the lower panel the mean shoreline position for the previous monitoring period February–July 2001 is shown, along with the mean shoreline calculated for the present monitoring period August 2001 – January 2002.

This analysis shows that, relative to the mean shoreline position for the preceding six month period, the beach had generally accreted. In contrast to the previous six month analysis that revealed a net erosional trend due to a succession of storms (refer Turner, 2001), during the present monitoring period the beach underwent a period of recovery. The results of shoreline mapping summarised in Figure 6.4 show that the beach generally increased in width by up to 40 m, which is similar in magnitude to the amount of beach erosion that was observed in the prior six months. The exception to this general trend of beach recovery was in the region immediately south of the cameras, where it appears that a region of over-nourishment may have been present prior to the erosion-recovery cycle, with the beach now exhibiting a more uniform and equilibrium alignment alongshore.
WEEKLY SHORELINES: AUGUST 2001 - JANUARY 2002

distance from dune line (m)

alongshore (m)

WEEKLY BEACH WIDTH: AUGUST 2001 - JANUARY 2002
STATISTICAL SUMMARY OF BEACH WIDTH CHANGES: AUGUST 2001 - JANUARY 2002
WEEKLY BEACH WIDTH CHANGES
AUGUST 2001 - JANUARY 2002
RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION
7. QUANTITATIVE ANALYSIS OF TOTAL SHORELINE CHANGES: AUGUST 1999 – JANUARY 2002

The completion of a total of two and a half years of monitoring at the northern Gold Coast beaches provides the opportunity to summarise and analyse shoreline changes observed to date. With sand nourishment completed in mid 2000, and significant erosion-recovery of the beach observed during 2001, it is anticipated that the new equilibrium alignment of the northern Gold Coast coastline has developed, upon which the more subtle influence of the reef may begin to be identified.


All weekly shorelines for the 131 week period August 1999 to January 2002 are shown in Figure 7.1. As per previous figures, a merged/rectified image is shown in the lower panel for reference, with the outline of the reef indicated. Over the entire 30 month monitoring period mid tide beach width (relative to the dune reference line) along the entire 4500m study region can be seen to have varied by up to 140m. Beach width changes of typically 60m–80m were measured within the central region of the study area, coinciding with the focus of the sand nourishment effort during 1999-2000. Total beach width changes of 40m - 50m were more typical to the north and south.

The variations in shoreline position measured at ten representative survey transects alongshore for the entire period August 1999–January 2002 are shown in Figures 7.2 and 7.3. Figure 7.2 plots the weekly shoreline position at transects spaced at regular 500m intervals north of the camera location, and Figure 7.3 plots the weekly shoreline position at transects spaced at 500m intervals south of the cameras. The alongshore position of each of these representative beach transects is shown in the accompanying merged/rectified image by same colour open circles.

A general trend of increasing beach width is apparent during the initial 18 months of monitoring. The rapid growth of the beach at each of the nourishment areas (refer Figure 2.5) can be seen. As previously noted in the preceding monitoring reports (Turner and Leyden, 2000b; Turner and Adamantidis, 2001; Turner 2001) the lag in beach response at each of these locations matches the progression southward of the beach nourishment program (see Figure 2.4). The effects of nourishment clearly dominate beach changes during the initial 18 month period.
During the period 18 – 24 months, a general erosion trend is clearly evident. As previously noted, the monitoring period February – July 2001 was characterised by a series of storms that resulted in the net recession of northern Gold Coast beaches. Examining this trend in more detail, Figures 7.2 and 7.3 show that the beaches eroded rapidly during the first months of 2001, appear to have partially recovered, then eroded again near the end of this six month period. The degree of partial recover is variable, but at all ten locations spaced at 500 m alongshore, by the end of July 2001 the recovered beach width had again been lost.

In contrast, during the present monitoring period a distinct trend of beach recovery is evident at all locations alongshore (note: shorelines at location y = 0 were not mapped during this time, as noted previously in Section 6.1). Most notably, by January 2002 Figures 7.2 and 7.3 show that the beach had recovered to the extent that beach widths were sufficiently regained to match the conditions that were measured 12 months previously in January 2001. A the central nourished regions of the beach it is concluded that the storms of early to mid 2001 resulted in the offshore movement of sediment, but that during the past six month monitoring period this sand returned to the subaerial beach, rather than being lost from the beach system.

### 7.2 Identification of Regional Shoreline Trends: August 1999 – January 2002

To examine more closely the overall trend of beach width changes during the two and a half year monitoring period August 1999 – January 2002, Figure 7.4 shows the results of analysis to calculate the average shoreline at six-monthly intervals during this period. The average shoreline position was calculated for the months of August 1999, January 2000, July 2000, January 2001, July 2001 and January 2002, and these are plotted in the upper panel of Figure 7.4, relative to the position of the August 1999 shoreline. (Note: there was insufficient beach width at the location of the cameras to enable the shoreline to be mapped during August 1999, and therefore this analysis cannot be undertaken for a small area corresponding to this central region). For reference, in the lower panel the six-monthly average shorelines are overlaid on to an image of the 4500 m study area.

The six-monthly average shorelines presented in Figure 7.4 reveal the underlying regional trends that have occurred along beaches of the northern Gold Coast during the 30 month period August 1999 to January 2002. From August 1999 to July 2000 the central region of the 4500 m study area progressively increased in width by some 30 – 40 m, due to the ongoing sand nourishment in this region during this time. More limited natural accretion of the order of 10 – 20 m was observed during this period at the control regions to the north
and south. From July 2000 to January 2001 the entire region (nourished and unnourished) experienced accretion of some additional 20 m of beach width.

Erosion through the first half of 2001 reduced this wider beach. By July 2001 the additional beach width along the central (nourished) region of the study area was reduced to approximately 30 m wider than the condition of the beach in August 1999. In contrast, at the control areas to the north and south of the nourishment areas, over the six month period January to July 2001 the beaches had returned to the general shoreline alignment that existed prior to the implementation of the NGBPS.

During the final six month period August 2001 to January 2002 this trend reversed, with the beach alignment at the end of the present monitoring period closely matching the conditions that were observed 12 months previously in January 2001. In excess of 60 – 70 m additional beach width was observed in the central nourished area at the end of January 2002, relative to the measured beach width in August 1999. In contrast, at the unnourished control areas to the north and south, natural accretion had resulted in additional beach width of some 40 m.

It is concluded that, 3 years after sand nourishment commenced at the northern Gold Coast in February 1999, and 18 months after the nourishment program was completed in mid 2000, an additional 20 – 30 m of beach has been achieved along approximately 2 km of the coastline, relative to the adjacent unnourished beaches to the north and south.
WEEKLY SHORELINES: AUGUST 1999 - JANUARY 2002 (TOTAL: 130 WEEKS)
TIME-SERIES OF BEACH WIDTH (NORTH):
AUGUST 1999 - JANUARY 2002
TIME-SERIES OF BEACH WIDTH (SOUTH):
AUGUST 1999 - JANUARY 2002
SIX-MONTHLY AVERAGE SHORELINE (RELATIVE TO AUGUST 1999)

Alongshore (m)

Net accretion/erosion (m)

AMG northing

AMG easting

August 1999

January 2000

July 2000

July 2001

January 2002

5.422

5.424

5.426

5.428

6.9055

6.905

6.9045

6.904

6.9035

6.903

6.9025

6.902

6.9015

6.901

x 10^6

x 10^5
8. ASSESSMENT OF SHORELINE TRENDS IN THE LEE OF THE REEF

A primary objective of the Gold Coast Reef is to promote beach widening and stabilisation at Narrowneck by the development of a shoreline salient (ICM, 1997). The natural processes of wave dissipation, wave diffraction and wave refraction were predicted to result in a general widening of the beach, initially in the lee of the reef, then extending progressively southwards as the salient begins to act as a partially bypassing 'headland' (Black, 1998; Turner et al., 1998a). However, super-imposed on these anticipated changes at Narrowneck are the impacts of storms and re-adjustment of the beach following sand nourishment. It is therefore of interest to look more specifically at the shoreline trends within the region of beach in the immediate vicinity of Narrowneck.


Figure 8.1 depicts a detailed view of a 1000 m long region of the beach, centred at the site of the reef. The weekly shorelines for the period 1/8/01 – 31/1/02 are shown. The dune reference line (solid red line) and a schematic of the reef are also shown in this figure for reference. Note that a limited number of the mapped shorelines are discontinuous in this region, due to occasional problems with sun-glint on the ocean surface under unfavourable light conditions resulting from certain combinations of sun angle and sea state.

A relatively uniform alongshore envelope of weekly shorelines is apparent in this figure during the period July 2001 to January 2002. This is clearer in Figure 8.2, where the weekly beach widths (relative to the dune reference line) for the same period are plotted at an exaggerated cross-shore scale. Beach width can be seen to have varied by approximately 40 m during this period, with this variation in beach width relatively uniform alongshore.

The more general trend of beach accretion during this time is evident in Figure 8.3, where the weekly shorelines for the present monitoring period July 2001 – January 2002 are re-analysed and compared to the mean shoreline position for the preceding monitoring period February – July 2001. In the upper panel the change in distance of each successive weekly shoreline from the prior six-month mean shoreline position is plotted. As observed along the entire 4500 m study area (refer Sections 6 & 7), the beach at Narrowneck can be seen to have accreted by up to 30 - 50 m. The relatively uniform accretion of the shoreline at Narrowneck is most clearly shown in the lower panel of 8.3, which contrasts the mean shoreline position during July 2001 – January 2002 to the mean shoreline during the prior
six month period. It can be seen that the shoreline in the vicinity of Narrowneck translated seaward relative to the prior six month period. By this simple comparison of mean shorelines it is not possible to discern any specific influence of the reef at Narrowneck.

Fluctuations of the shoreline position during the present monitoring period July 2001 – January 2002 are shown in Figure 8.4. This figure shows the movement of the shoreline at five representative locations in the vicinity of Narrowneck. At all locations the same general trend is evident: a relatively uniform rate of beach recovery was observed up to November 2001, then an accelerated rate of continuing beach accretion through to the end of January 2002. From visual assessment of this figure, it appears that the most rapid rates of shoreline accretion occurred to the south of the reef, and coincided with the raising of the crest level by the placement of a limited number of additional geocontainers (refer Section 2.2).

8.2 Total Monitoring Period: August 1999 – January 2002

For completeness, Figure 8.5 shows the changing shoreline position for the entire 30 month monitoring period August 1999 to January 2002 at the same five representative transects in the vicinity of Narrowneck. Again, the locations of the transects are shown in the panel on the left, and the onshore–offshore movement of the shoreline at each transect is shown in the five panels on the right. Four of the transects are located 150 m and 300 m north and south of the reef construction site respectively, while the fifth and central transect is aligned with the centre of the reef. Moving-average curve fitting was applied to these data to help clarify the general erosion/accretion patterns in this figure during the total two year monitoring period.

North of the reef construction site (located in deposition area A2), the beach in the vicinity of Narrowneck can be seen to have widened by 20–25 m through the latter part of 1999, stabilised in the first months of 2000, and then evolved to a generally erosional state from April to August 2000. Accretion then occurred up to December 2000, followed by modest erosion again in January 2001. The net result by this time had been an increase in beach width of the order of 40–50 m. The beach then eroded though the first half of 2001, resulting in a net gain in beach width since the start of monitoring period of approximately 10 – 20 m. During the present monitoring period August 2001 to January 2002 recovered fully, regaining some 30 – 40 m beach width, equating to a net increase of some 40 – 50 m over the entire 30 month monitoring period. It should be noted that sand nourishment had occurred in this area prior to the commencement of monitoring in August 1999 (refer
Section 2.3), so the actual increase in beach width since implementation of the NGBPS is likely to be somewhat greater than this.

At the centre of the reef construction site and the two transects to the south (all located in deposition area A3), beach widening of 50–60 m was observed through to early 2000 in response to ongoing nourishment during this time. At the centre of the reef construction site and 150 m south, this was followed by a period of erosion through to March then accretion to May, after which time a general accretionary trend persisted. At the transect 300 m south the beach continued to increase in width at a generally steady rate through 2000. Again, the net result had been an increase in beach width of the order of 50 – 60 m. Storms in March, April and July 2001 resulted in recession of the shoreline, with the beach in mid 2001 approximately 30 m wider than at the commencement of the monitoring program. Through the present monitoring period August 2001 to January 2002 the beach in the lee of the reef and to the south recovered to at least the January 2001 conditions, and in the case of the two transects 150 m and 300 m south of the reef site, by early 2002 the beach width had exceeded earlier conditions, with up to 70 m gain in additional beach width, relative to the unnourished beach in August 1999.

8.3 Identification of Reef-Induced Shoreline Changes at Narrowneck

Pre- and post-construction weekly shoreline surveys obtained in the vicinity of the Gold Coast Reef represent the integrated result of all natural and engineered processes that contribute to the local alignment of the shoreline at Narrowneck. The variability of the beach in this region is illustrated by the complex and ever-changing nearshore conditions that were observed through 2001. Figure 8.6 shows the rectified timex image obtained at mid tide on the first day of each month, and the variability of the nearshore bar system during this period is rather striking.

Natural factors that determine the alignment of the coastline in this region include episodic storm erosion and recovery, seasonal variations in wave climate, and local gradients in the along-shore sand supply. Engineered factors include the now completed sand nourishment works and altered long-shore/cross-shore sediment transport patterns due to wave diffraction, wave sheltering and nearshore current circulation in the lee of the reef. To assess the degree of coastal protection provided by the structure, it is necessary to discriminate and separately quantify these latter effects using the available dataset of surveyed shorelines.
A sketch to summarise the problem is shown in Figure 8.7. The four fundamental causes of shoreline change that are anticipated in the lee of the Gold Coast Reef are briefly described below:

‘Natural’ shoreline variability
Naturally occurring (i.e., pre-existing) variations at the shoreline are represented by Figure 8.7a. These may be cyclic and result in no net change in the shoreline alignment, or due to existing gradients in sediment transport into and away from the site, may exhibit longer-term erosional or accretionary trends. These effects are independent of the construction of the reef at Narrowneck.

Sand Nourishment
Coinciding with the construction of the reef, the extensive sand nourishment that was undertaken of northern Gold Coast beaches during 1999 and 2000 resulted in significant beach widening (Figure 8.7b). This beach response is again independent of any direct effects of the reef at Narrowneck.

Shoreline Salient
As noted earlier, a primary objective of the Gold Coast Reef is to promote beach widening and stabilisation at Narrowneck by the development of a shoreline salient (Figure 8.7c). A salient is a local widening of the beach caused by the processes of wave dissipation, wave diffraction and wave refraction, resulting in the modification of nearshore current patterns to promote enhanced sand deposition in the lee of the offshore structure. Local beach widening potentially due to the development of a salient in the lee of the reef at Narrowneck would be superimposed upon the effects of natural shoreline variability and sand nourishment.

‘Headland’ Fillet
The numerical and physical model studies completed as a part of the detailed design of the NGCBPS (Black, 1998; Turner et al., 1998a) predicted that salient growth at Narrowneck would tend to cause a secondary depositional effect, by impounding sand at the up-drift southern beach (Figure 8.7d). This second and quite distinct mode of shoreline response is analogous to the build-up of sand against a headland at the down-drift end of a coastal compartment, or against the up-drift flank of a shore-normal groyne. Local examples of this phenomenon include the southern breakwaters at the Tweed River and Gold Coast Seaway. The progressive up-drift extension of the composite salient/fillet depositional feature can potentially extend along-shore many times the length of the structure itself.
8.3.1 Even-Odd Function Analysis

To discriminate the differing modes of shoreline response described above, the method of analysis should meet two requirements. The first is the ability to distinguish and separate ‘natural’ shoreline behaviour from engineered impacts. The second is to both separate and quantify the shoreline salient and sand fillet modes of shoreline response.

A simple and easily applied technique that satisfies both these requirements is Odd-Even Function Analysis. This method has become popular to determine the along-shore extent of the impacts of coastal inlets (Rosati and Kraus, 1997), and as shown below, by careful interpretation can be usefully applied to distinguish and separately quantify modes of shoreline response in the vicinity of offshore-detached structures.

First applied to the coastal engineering analysis of long-shore transport distribution by Berek and Dean (1982), the strength of the technique is its capability to explicitly separate planform shoreline changes that are symmetric (even) about a location, from those which are anti-symmetric (odd). The technique can be equally applied to the analysis of the rate of net changes in foreshore sand volume, if these data are available (e.g., Rosati and Kraus, 1997). Other authors who have described the successful coastal engineering application of even-odd function analysis include Dean and Pope (1987), Dean and Work (1993) and Douglas and Walther (1994).

The most common interpretation of even-odd function analysis is that the (asymmetric) odd function is an indicator of the along-shore extent of the impact of training structures at coastal inlets. However, careful coastal engineering judgement is required in the interpretation of results. For example, at a coastline with a near-zero net littoral drift but significant gross long-shore sediment transport, the odd function approaches a negligible value at all points along the shoreline. However, a groyne or inlet jetty structures along such a coast would tend to impound sediment on both sides, with erosion at some distance outside their shadow zone. For this case, the extent of impact of the groyne or jetties is determined by the distance at which the even (symmetric) function approaches a negligible value. Thus, accurate interpretation of the results of even-odd function analysis requires a site specific knowledge of factors such as the direction and relative magnitudes of net and gross rates of long-shore sediment transport (Rosati and Kraus, 1997).
Referring to the various modes of possible planform changes at Narrowneck as identified in Figure 8.7, it can be seen that shoreline changes represented by Figures 8.7a-c occur symmetrically about a point along the beach located at the centre-line of the offshore structure. Of these three cases, what distinguishes modes a. & b. (i.e., non-structure impacts) from mode c. (shoreline salient) is that the non-structural shoreline changes occur uniformly along-shore. Of course, for this to be the case requires that the size of the region of interest be carefully selected so that it does not exceed the nourishment area. In contrast, the formation of a salient, though symmetric around the centre-line of the structure (Figure 8.7c), is of finite extent along-shore, with no net change equidistant of both ends of the structure. The fourth mode of potential shoreline response (Figure 8.7d) is unique in that it is anticipated to be asymmetric about the structure’s centre-line. These differences between the possible modes of shoreline response are exploited as described below to discriminate and quantify the direct effects of the structure at Narrowneck.

8.3.2 Procedure

Mathematically, an even function \( f_e(x) \) is one which does not change sign when the argument changes sign, i.e.,

\[
f_e(-x) = f_e(x) \quad \text{ (even function)}
\]

Conversely, an odd function \( f_o(i) \) is one which does change sign with the sign of the argument;

\[
f_o(-x) = -f_o(x) \quad \text{ (odd function)}
\]

From the simple summation of Equation (1) and Equation (2) it can be seen that the sum of even and odd functions of any argument reproduces the original data.

To apply even-odd analysis to a set of shoreline data \((x,y)\), it is first necessary to determine the net change in platform alignment \( \Delta y \) at stretch of coastline measured at times \( t_1 = 0 \) and \( t_2 = 1 \), i.e.,

\[
\Delta y(x) = [x,y(0)]_{t_2} - [x,y(0)]_{t_1}
\]
where here the origin of the along-shore coordinate (i.e., \( x = 0 \)) is defined as the centre-line of the offshore structure. Expressing the total shoreline change as the sum of even and odd functions:

\[
\Delta y(x) = \Delta y_e(x) + \Delta y_o(x)
\]

then for negative values of \( x \), by definition

\[
\Delta y(-x) = \Delta y_e(-x) + \Delta y_o(-x) = \Delta y_e(x) - \Delta y_o(x)
\]

Solving Equations (4) & (5) to determine the even and odd functions based on shoreline change data gives

\[
\Delta y_e(x) = 0.5 \times [\Delta y(x) + \Delta y(-x)]
\]

\[
\Delta y_o(x) = 0.5 \times [\Delta y(x) - \Delta y(-x)]
\]

where the function \( y_e(x) \) is symmetric about the centre line of the structure, and the odd function \( y_o(x) \) is asymmetric. Equation 6 and Equation 7 can now be used to discriminate and separately quantify engineered modes of shoreline change that have occurred in response to the construction of the Gold Coast Reef and Narrowneck.

8.3.3 Results

The 12 month period January 2001 to January 2002 was selected for analysis, due to the major phase of reef construction having been completed in the previous month December 2000 (refer Section 2.2). The mean position of shorelines for the months of January 2001 and January 2002 were calculated for a 1000 m region of the beach centred at Narrowneck, and then Even-Odd Function analysis applied. The results of this analysis are presented in Figure 8.8.

The lower panel of Figure 8.8 shows the beach at Narrowneck, with the position of the reef indicated. The average shoreline position during January 2002 is also shown for reference. The upper panel of Figure 8.8 summaries the results of Even-Odd Function analysis, based upon the net change in beach width during the period January 2001 – January 2002.
Focussing first on the Even function, this reveals that over the twelve month period to January 2002 a distinctive symmetrical trend of beach widening developed, characterised by approximately 20 m of additional beach width to the immediate north and south of the reef. These two depositional features each extended approximately 300 m alongshore. In the lee of the reef no net change in beach width was identified, indicating that for the central 200 m of Narrowneck a symmetrical trend of net shoreline change did not occur.

The Even function depicted in Figure 8.8 clearly identifies the early phase of salient development in the lee of the Gold Coast reef. It was observed in the scale physical model study completed for the reef (Turner et al, 1998a) that salient formation was anticipated to exhibit several distinct stages. The first of these was observed to commence with the formation of smaller ‘proto-salients’ either side of the reef centreline. At a later stage these transitional depositional features were observed to progressively grow laterally and merge into a single salient feature. The results of the Even function shown in Figure 8.8 show that this earlier phase of salient development has occurred at Narrowneck. The formation of two proto-salients to the immediate north and south resulted in the additional beach width to date of approximately 20 m.

The secondary ‘headland’ effect of this emerging salient feature at Narrowneck can be also seen to have resulted in additional deposition of sediment on the up-drift (southern) beach. Referring to the Odd function shown in Figure 8.8, it can be seen that this function is close to zero along the entire region to the north (down-drift) of the reef, but to the south an asymmetric trend of net beach widening of some 25 m is identified. This coincides with the location of the symmetrical Even function, confirming that (symmetric) salient deposition in this region during the period January 2001 to January 2002 was enhanced by the (asymmetric) build-up of sediment at the up-drift side of the reef. To date, this region of up-drift accretion has extended approximately 450 m alongshore to the south of the reef centreline. From the results of the scale physical model study, it was observed that this anticipated southward progression of the enhanced beach could be anticipated to occur over a significantly longer time scale than the initial phase of salient formation.

Finally, the sum of both Odd and Even functions shown in Figure 8.8 identifies that the net impact of the reef to January 2002 has been to promote an additional 20 m increase in beach width over 400 m to the immediate down-drift northern side of Narrowneck, and of the order of 40 – 50 m accretion over ~450 m on the up-drift southern side. It will be of great interest to repeat this analysis in future monitoring periods, to separately identify and quantify the potential continued growth and eventual merging of the salient features, and the anticipated progressive southward build-up of sediment along the up-drift beach.
WEEKLY SHORELINES AT NARROWNECK: AUGUST 2001 - JANUARY 2002
WEEKLY SHORELINES IN LEE OF REEF: JULY 2001 – JANUARY 2002

BEACH WIDTH AT NARROWNECK:
AUGUST 2001 - JANUARY 2002

Figure 8.2
WEEKLY BEACH WIDTH CHANGES AT NARROWNECK
AUGUST 2001 - JANUARY 2002
RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION
Figure 8.4

TIME-SERIES OF BEACH WIDTH AT NARROWNECK:
AUGUST 2001 - JANUARY 2002
TIME-SERIES OF BEACH WIDTH AT NARROWNECK: AUGUST 1999 - JANUARY 2002
VARIABLE NEARSHORE BAR MORPHOLOGY IN THE LEE OF GOLD COAST REEF
MODES OF 'NATURAL AND ENGINEERED' SHORELINE RESPONSE

a. erosion/accretion (pre-existing)
b. sand nourishment
c. shoreline salient
d. 'headland' fillet

Figure 8.7
ODD-EVEN FUNCTION ANALYSIS: JANUARY 2001 - JANUARY 2002

- F-odd
- F-even
- F-(odd+even)
9. **ASSESSMENT OF WAVE BREAKING AT THE REEF**

It was noted in Section 2.1 that the Gold Coast Reef was designed to serve two functions. The dual purpose of the structure is to: (1) act as a ‘control point’ at Narrowneck to promote beach widening and extend the design life of the sand nourishment, and (2) to improve the surfing conditions at Narrowneck (McGrath et al., 2000).

The regional-scale focus of this monitoring program does not permit the use of the video system to assess the surf ‘quality’ (i.e., wave shape, peel angle, etc) at the reef. However, the images that are obtained from the system on an hourly and daily basis do permit the assessment of the occurrence of wave breaking at the reef, and the measurement of the occurrence of wave breaking across this structure, relative to breaking waves on the adjacent natural storm bar. The following provides an assessment of wave breaking at the reef during the 24 month period January 2000 – January 2002, i.e., since commencement of reef construction.

9.1 **Number of Reef Wave Breaking Days per Month**

Wave breaking on the reef at Narrowneck is now usually visible in images obtained by the coastal imaging system. Reef construction took place in 2000 through the two periods January–May and September–December (refer Figure 2.3), with the crest level raised as additional geocontainers were placed at the site. ‘Topping up’ of the reef during the present monitoring period by the placement of an additional 17 geocontainers in November – December 2001 raised the crest towards its final design level (refer Section 2.1). Figure 9.1 shows an example timex image from camera 4 and the corresponding merged/rectified images created from all four camera images at this time. Wave breaking seaward of the inner bar in the distinctive shape of the reef is discernable. Breaking waves across the two halves of the reef are clearly visible, with these two linear regions of wave breaking separated by the deeper paddling channel that bisects the reef structure. This pattern of wave breaking is particularly evident in the merged and rectified timex images, as can been seen in the lower panel of Figure 9.1 and the monthly images in Figure 8.6.

Figure 9.2 shows the number of days per month for the period commencing January 2000, up to and including January 2002, for which wave breaking at the reef was observed in at least one of the hourly images obtained per day. During the first reef construction period (January - May 2000) a trend is evident of increasing wave breaking activity at the site. In January 2000 wave breaking was visible at the reef for at least one hour per day for a total
of 20 days, which had increased to around 30 days per month by April 2000. This trend is consistent with the work underway at that time to raise the crest level of the structure.

From the middle of 2000 to May 2001, wave breaking at the reef occurred in a minimum of one hourly image (per day) for at least 90% of the time, indicating that the reef crest was sufficiently shallow to cause wave breaking in all but the smallest wave conditions. The exception to this was in May 2001, when an approximately ten day period of very low wave activity \((Hs \approx 0.5 \text{ m})\) resulted in a total of 8 days when no wave breaking at the reef was visible. During the most recent monitoring period August 2001 to January 2002 the occurrence of wave breaking declined to between 10 and 25 days per month, due to the low wave conditions that generally prevailed throughout this time.

9.2 The Occurrence of Wave Breaking Relative to the Adjacent Storm Bar

The above assessment of the number of days per month that wave breaking occurred at the reef indicates that the structure is sufficiently shallow to cause waves to break on the majority of days. However, waves are also observed to break on the adjacent storm bar and, therefore, it is of interest to determine the additional wave breaking achieved at Narrowneck following the construction of the reef.

A summary of the analysis of all daylight hourly images for the period 1 January 2000 to 31 January 2002 is shown in Figure 9.3. In total, the results of approximately 9000 images are included in this analysis. The lower panel of this figure shows the count of hourly daylight images in which waves were observed to break on the reef, and the corresponding number of images in which wave breaking on the adjacent storm bar was also visible. To assist the interpretation of this information, in the upper panel of this figure the percentage occurrence of wave breaking at the reef only (i.e., no visible breaking on the adjacent bar) is plotted. It can be seen from this analysis that early in 2000 wave breaking only on the reef was occurring around 20% of the time, indicating that 80% of the time waves were breaking on reef, they were also breaking on the adjacent bar. However, the increasing influence of the reef through the year can be clearly seen, up to the final three months of 2000 when 80%–100% of the time wave breaking at the reef was occurring in the absence of breaking on the adjacent bar. The occurrence of wave breaking at the reef only was variable during the present monitoring period February – July 2001, due to the periods of high wave activity associated with storm events, during which time the beaches of the northern Gold Coast effectively closed-out, with extensive breaking across the outer (storm) bar. Through the present monitoring period August 2001 to January 2002, despite
the decline in the total number of hourly reef wave breaking images due to consistently small wave conditions, from the analysis summarised in the upper panel of Figure 9.3 it is apparent that around 80% of the time wave breaking at the reef was observed in the absence of breaking on the adjacent bar. During the months of August, November and December 2001, waves were never observed in the hourly images to be breaking at the adjacent bar at Narrowneck.

The above analysis does not consider the quality of the breaking waves for surfing (peel angle and breaker type), nor the coincidence of breaking waves with favorable winds for surfing, but simply the occurrence of additional breaking waves due to the reef. Wave breaking at the reef only is of course partially a function of the prevailing wave climate in any particular month, however, it may be concluded from these results that the reef continues to achieved the objective of increasing potential surfing opportunities at Narrowneck.
VISIBLE WAVE BREAKING ON REEF

Figure 9.1
ASSESSMENT OF WAVE BREAKING ON REEF

NUMBER OF DAYS PER MONTH (JANUARY 2000 - JANUARY 2002)

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Figure 9.2
ASSESSMENT OF WAVE BREAKING ON REEF AND ADJACENT BAR
HOURLY IMAGES (JANUARY 2000 - JANUARY 2002)

Figure 9.3

- Gold Coast Reef
- Adjacent storm bar
10. CONCLUSIONS

The six month monitoring period August 2001 to January 2002 is the third following the completion of beach nourishment in June 2000 at the northern Gold Coast, and second since completion of the major phase of reef construction in December 2000. During November – December 2001 an additional 17 geocontainers were placed, to further raise the crest level of the reef.

10.1 Beach Width

A visual assessment of beach changes during August 2001 to January 2002 (Figure 5.2 & Figure 5.3) reveals that this period was characterised by mild wave energy and the prevalence of lower intermediate morphodynamic beach states, indicative of generally accretionary conditions. From visual assessment of images, to the south of Cavill Avenue a widening of the subaerial beach is discernable, while to the north of the cameras a widening of the beach is more noticeable, extending from the near foreground to north of Narrowneck.

Extending this qualitative visual assessment of images to include the entire 2.5 year monitoring period (Figures 5.4 and 5.5) it is observed that, during the first six months (August 1999 to January 2000) the on-going nourishment of the northern beach is visible, with no change to the southern beach as this area was yet to be nourished. A dramatic change in the width of the beach occurred between January 2000 and August 2000, when nourishment of the entire stretch of coastline from Narrowneck to Cavill Avenue was completed, with the result that the mid tide beach can be seen to have nearly doubled in width during this time. During the next six months to January 2001 the beach alignment became more uniform alongshore, as the coastline re-adjusted to the new sand volume available within the beach system. The following six-month period of February 2001 – July 2001 saw a general erosional trend along the northern Gold Coast beaches, due to a succession of storms during this period. By the end of the present six month monitoring period August 2001 to January 2002 from visual assessment it appears that the beach had fully recovered, returning to a similar state as was observed 12 months previously in January 2001. A return to prior conditions following a period of storm erosion suggests that the beaches of the northern Gold Coast are close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000.
Based upon the quantitative analysis of weekly shoreline positions during the present monitoring period 1/8/01 – 31/1/02, the mid tide beach along the 4500 m study region varied in width (relative to the dune reference line) from approximately 60 m to 150 m (Figure 6.2). The envelope of beach width changes was relatively uniform alongshore, with the beach at any specific location varying by approximately 40 m during this time. The median beach width at mid tide (relative to the dune reference line) along the 4500 m stretch of coastline during the period 1/8/01 – 31/1/02 was approximately 100-110 m, but ranged from 80 m to 120 m (Figure 6.3). The alignment of the beach generally varied by 20 – 30 m from the mean shoreline position. The standard deviation (s.d.) of weekly shorelines was generally 10 m – 15 m, with a broad region of lower variability (s.d. < 10 m) centered around Narrowneck (1000 m north), and a more limited area approximately 500 m south of the cameras (Figure 6.3).

When the weekly shoreline data for the period August 2001 to January 2002 was re-analysed to assess beach width changes relative to the mean shoreline for the preceding 6 month monitoring period (i.e., January – July 2001), it was apparent that the beach of the northern Gold Coast had generally increased in width by up to 40 m (Figure 6.4), which is similar in magnitude to the amount of beach recession that was observed in the prior six months. The exception to this general trend of beach recovery was in the region immediately south of the cameras, where it appears that a region of over-nourishment may have been present prior to the erosion-recovery cycle, with the beach now exhibiting a more uniform and equilibrium alignment alongshore. In contrast to the first three monitoring periods covering the period August 1999 to January 2001 when the major influence on beach and shoreline changes was observed to be the impact of sand nourishment, for both this and the preceding monitoring period it was observed that storm erosion and recovery dominated measured beach response.

Over the entire 30 month monitoring period mid tide beach width (relative to the dune reference line) along the 4500 m study region can be seen to have varied by up to 140 m (Figure 7.2 & 7.3). Beach width changes of typically 60 m – 80 m were measured within the central region of the study area, coinciding with the focus of the sand nourishment effort during 1999-2000. Total beach width changes of 40 m - 50 m were more typical to the north and south. A general trend of increasing beach width was apparent during the initial 18 months of monitoring, clearly indicating the dominant effect of nourishment clearly dominate beach changes during the initial 18 month period. In contrast, during the period 18 – 24 months, a general erosion trend occurred. The monitoring period February – July 2001 was characterised by a series of storms that resulted in the net recession of northern Gold Coast beaches. In contrast, during the present monitoring period a distinct trend of
beach recovery was evident at all locations alongshore. Most notably, by January 2002 the beach had recovered to the extent that beach widths were sufficiently regained to match the conditions that were measured 12 months previously in January 2001. At the central nourished regions of the beach it is concluded that the storms of early to mid 2001 resulted in the offshore movement of sediment, but that during the following six months this sand returned to the subaerial beach, rather than being lost from the beach system.

It is concluded that, 3 years after sand nourishment commenced at the northern Gold Coast, and 18 months after the nourishment program was completed, an additional 20 – 30 m of beach width has been achieved along approximately 2 km of the coastline, relative to the adjacent unnourished beaches to the north and south.

### 10.2 Impacts of Reef Structure

To assess the degree of coastal protection provided by the artificial reef at Narrowneck, it is necessary to discriminate and separately quantify the ‘natural’ and ‘engineered’ factors that determine the observed alignment of the coastline at Narrowneck (Figure 8.7). Natural factors include episodic storm erosion and recovery, seasonal variations in wave climate, and local gradients in the along-shore sand supply. Engineered factors include the now completed sand nourishment works and altered long-shore/cross-shore sediment transport patterns due to wave diffraction, wave sheltering and nearshore current circulation in the lee of the reef. The new application of ‘Even-Odd’ Function Analysis was applied to the data set of weekly shorelines in this region for the 12 month period January 2001 to January 2002, to separately identify and quantify the beach response (post sand nourishment) to reef construction.

Following completion of the major phase of reef construction, two distinct modes of beach response have been identified (Figure 8.8) The first is a (symmetrical) accretionary trend that corresponds to the early phase of salient development in the lee of the reef. The formation of two proto-salients to the immediate north and south has to date resulted in the additional beach width in these two regions of the order of 20 m. Sediment deposition by this mechanism has to date extended for a distance of approximately 300 m alongshore 400 to 450 m from the centreline of the reef. Based upon the results of the scale physical model study completed for the reef (Turner, 1998a), it could be anticipated that in the future these two depositional features may progressively merge, to form a single salient in the lee of the reef.
The secondary effect of this emerging salient feature at Narrowneck is that it has resulted in the additional deposition of sediment on the up-drift (southern) beach. This mode of sediment deposition at Narrowneck exhibits a distinct asymmetry, with 20 – 30 m increase in beach width to the south of the reef site, but no corresponding deposition to the north. Based upon the results of the scale physical model study (Turner, 1998a), it may be anticipated that this southward progression of enhanced sediment deposition may continue to extend southward along the up-drift beach, but over a significantly longer time scale than the initial phase of salient formation.

In summary, the net impact of the reef to January 2002 has been to promote an additional ~20 m increase in beach width to the immediate down-drift northern side of Narrowneck, and of the order of 40 – 50 m accretion on the up-drift southern side. It will be of great interest to repeat this analysis in future monitoring periods, to separately identify and quantify the anticipated continued growth of the salient feature, and progressive southward build-up of sediment along the up-drift southern beach.

10.3 Wave Breaking at Reef

Wave breaking on the reef at Narrowneck is commonly visible in images obtained by the coastal imaging system (Figure 9.1). During the first reef construction period (January - May 2000) a trend is evident of increasing wave breaking activity at the site. In January 2000 wave breaking was visible at the reef for at least one hour per day for a total of 20 days, which had increased to around 30 days per month by April 2000 (Figure 9.2). This trend is consistent with the work underway at that time to raise the crest level of the structure. From the middle of 2000 to May 2001, wave breaking at the reef occurred in a minimum of one hourly image (per day) for at least 90% of the time, indicating that the reef crest was sufficiently shallow to cause wave breaking in all but the smallest wave conditions. The exception to this was in May 2001, when an approximately ten day period of very low wave activity (Hs ≈ 0.5 m) resulted in a total of 8 days when no wave breaking at the reef was visible. During the most recent monitoring period August 2001 to January 2002 the occurrence of wave breaking declined to between 10 and 25 days per month, due to the calm wave conditions that prevailed throughout this time.

Based upon the analysis of all daylight hourly images for the period 1 January 2000 to 31 January 2002 (approximately 9000 images in total), it was determined that early in 2000 wave breaking on the reef was occurring around 20% of the time, indicating that 80% of the time waves were breaking on the adjacent bar at the same time they were observed to break.
on the reef (Figure 9.3). However, the increasing influence of the reef through the year can be clearly seen, up to the final three months of 2000 when 80%–100% of the time wave breaking at the reef was occurring in the absence of breaking on the adjacent bar. The occurrence of wave breaking at the reef only was variable during the monitoring period February – July 2001, due to the periods of high wave activity associated with storm events, during which time the beaches of the northern Gold Coast effectively closed-out, with extensive breaking across the outer (storm) bar. Through the present monitoring period August 2001 to January 2002, despite the decline in the total number of hourly reef wave breaking images due to consistently small wave conditions, around 80% of the time wave breaking at the reef was observed in the absence of breaking on the adjacent bar. During the months of August, November and December 2001, waves were never observed in the hourly images to be breaking at the adjacent bar at Narrowneck. This analysis did not consider the quality of the breaking waves for surfing (peel angle and breaker type), nor the coincidence of breaking waves with favorable winds for surfing, but simply the occurrence of additional breaking waves due to the reef.

It is concluded that the reef has achieved the objective of significantly increasing potential surfing opportunities at Narrowneck.
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12. REFERENCES


