ANALYSIS OF SHORELINE CHANGE:
FEBRUARY 2002 - JULY 2002

REPORT 6
NORTHERN GOLD COAST COASTAL IMAGING SYSTEM

by

I L Turner

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The work reported herein was carried out by the Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, acting on behalf of the client.

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1. INTRODUCTION

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

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 predicted coastal change. It is this ability to provide quantitative information that distinguishes the ARGUS coastal imaging system from conventional 'webcam' technology.

The northern Gold Coast was the first application in Australia to utilise coastal imaging techniques to monitor regional-scale coastal response to major coastal engineering works, and it is fitting that this should have occurred in conjunction with the implementation of the innovative NGCBPS project.

The coastal imaging system installed at the northern Gold Coast became fully operational on 1\textsuperscript{st} August 1999. This timing coincided with the commencement of construction of the Gold Coast reef. 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. A second phase of reef construction with the addition of several geocontainers to the crest of the reef was completed at the end of 2001.

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), February 2001 to July 2001 (Turner, 2001) and August 2001 to January 2001 (Turner, 2002). The purpose of this sixth report is to present the results of shoreline change analysis for the monitoring period February 2002 to July 2002, and to assess the net changes that have occurred to northern Gold Coast beaches since the commencement of the monitoring program some 36 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 images were collected by the system for much of February 2002.

1.3 What’s New

This report marks three years since the Coastal Imaging station was first installed at Narrowneck, and the sixth in the present series of Environmental Monitoring Program (EMP) reports.

A new 12 month animation has been created and is available for viewing and download at the web site (www.wrl.unsw.edu.au/coastalimaging/goldcst/) and follow the ‘animations’ link). This shows the daily beach changes that have occurred during the entire 12 month monitoring period August 2001 to August 2002. Animations created for each of the two proceeding 12 month monitoring periods can also be found at this same location.

In July 2002 a dual-processor LINUX workstation was installed at WRL in place of the DEC Alpha workstation that was previously used for image archiving and web page server. This upgrade was necessary because of the expanding size of the image archive, and the image processing power required to analyse the images.

Due to the now proven ability of the northern Gold Coast coastal imaging system to monitor the regional-scale impacts of the NGCBPS, it has recently been determined that the system is to be operated for a further four years. To achieve this, maintenance and upgrade
of the system is scheduled for early October 2002. Included will be a major extension of the beach monitoring information that will be obtained by the system, and the mode of delivery of this information will over the next six months move from paper-based reporting, to the on-line presentation of more regularly-updated results of beach monitoring.

Details of these upgrades will be provided in the next six-monthly EMP summary report.

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 in a qualitative manner the beach changes observed using the time-series of daily images for the period covered by this report, February 2002 – July 2002.

The quantitative analysis of shoreline change for the period February 2002 to July 2002 is detailed in Section 6. This is followed in Section 7 by the corresponding analysis for the total 36 month monitoring period, August 1999 – July 2002.

An assessment of shoreline trends at the reef site at Narrowneck is provided in Section 8. This includes the re-analysis of the results of Odd-Even Function analysis to identify differing modes of shoreline response in the lee of the Gold Coast Reef. Section 9 briefly discusses the now ubiquitous occurrence of wave breaking at the reef, following the
placement of additional geocontainers across the crest of the reef at the end of 2001. Section 10 summarises the major findings of this sixth 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 in the event of major 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. In late 2001, 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

Semi permanent buried dredge pipeline along Spit to Narrowneck to facilitate regular dredging.

Sand to be pumped to beaches & nearshore from maintenance & widening of channels (or alternatively from offshore) to provide initial and ongoing nourishment.

Source: McGrath et al. (2000)
Figure 2.3
Figure 2.4

SAND NOURISHMENT

Cumulative volume (m³)

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

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

deposition area

A1a  A1  A2  A3  A4  A5  A6

Completed
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 airplane 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. In July 2002 a dual-processor LINUX workstation was installed at WRL in place of the previous DEC Alpha workstation that was previously 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 snapshot 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 snapshot 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 February 2002 to July 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 $5 \times 5$ 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 overlaid 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 February 2002 to July 2002, this occurred on five occasions during the period February 2002 to July 2002. Shorelines were also not obtained during the entire month of February, due to lightening damage.

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 cuspatate 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)

WATER RESEARCH LABORATORY

WORLD WIDE WEB

Camera 1
Camera 2
Camera 3
Camera 4

A/D Video Interface

Modem

SGI Workstation
- image capture
- image pre-processing

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

WATER RESEARCH LABORATORY

REMOTE SITE
(Focus Building)
LOCATION OF ARGUS COASTAL IMAGING SYSTEM AT THE GOLD COAST
CAMERAS MOUNTED AT AN ELEVATION OF APPROXIMATELY 100m
SNAP-SHOT, TIME EXPOSURE AND VARIANCE IMAGE TYPES

Figure 3.4
PLAN VIEW IMAGE REFERENCED TO 'REAL WORLD' AMG COORDINATE SYSTEM
RGB COLOUR TECHNIQUE FOR AUTOMATED DETECTION OF THE SHORELINE
Gold Coast tide data → create daily merged/rectified image at mid tide → determine corresponding wave conditions → does image satisfy wave height threshold? (\(H_S \leq 1\)m) → MAP SHORELINE

- Yes → Gold Coast wave data
- No → select image for proceeding/preceeding day
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.

Due to the establishment of several new coastal imaging stations by WRL, the address to locate the northern Gold Coast coastal imaging web site is slightly changed from previous monitoring periods: http://www.wrl.unsw.edu.au/coastalimaging/goldcst

The northern Gold Coast 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, over 70,000 hits to the northern Gold Coast cameras 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. A new 12 month animation has been included that shows daily beach changes for the 12 month period up to 31 July 2002. Two further extended animations that cover 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 also available for viewing and download via the coastal imaging web site.
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.

[Click on images to view full size.]

[Note: click 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.unimelb.edu.au
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>
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<tbody>
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By examining the daily images – or even more clearly, by viewing 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 February 2002 to July 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 to assist to identify 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 bathymetry is usually characterised by one or more straight and shore-parallel bars. The term 'dissipative' is used to describe beaches that exhibit these characteristics because wave energy is essentially dissipated by extensive wave breaking across the surf zone, before it can reach the shoreline.

At the other end of the beach state spectrum, reflective beaches (Figure 5.1f) are invariably steep, with no nearshore bars. Waves tend to break close to or right at the shoreline, and hence very little wave energy is dissipated; instead it is reflected by the 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 → RBB → TBR). If low wave conditions persist, bars ultimately disappear as the bar becomes welded to the beach to form a terrace (LTT). Beaches of the moderately high energy east Australian open coast are typically observed to transfer between these four intermediate morphodynamic beach states, in response to lower wave conditions interspersed by episodic storm events.

5.2 Morphodynamic Interpretation of Daily Images

All available daily daytimex images for the period February 2002 to July 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 4.500 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 February 2002

Images for the month of February 2002 were not available due to lightning damage to the northern Gold Coast Argus Coastal Imaging system.

5.2.2 March 2002

Significant wave heights during March 2002 were rarely below 1.0 m. During the first week of the month significant wave height progressively rose to 2 m, which was sustained for a period of approximately 4 days, with maximum wave heights during this time reaching up to 4 m. Significant wave heights decreased again to 1 – 1.5 m through to the middle of the month. Between the 17th and 22nd was the only period when significant wave height dropped below 1 m. From the 22nd to the 24th significant wave height again increased to 2 m, decreasing slowing to around 1 m by the 28th, before rising again to 2 m by the 31st.

At the beginning of the month the beach exhibited a complex and highly three-dimensional transitional TBR-RBB beach state. Multiple and regularly-spaced rip channels were located along the beach, with the strongly crescentic single bar system partially welded to the beachface through the first half of the month.

During the relatively calm period of the 17th to 21st of March, only occasional wave breaking was observed across the bar. Commencing the 23rd, increasing wave heights re-initiated wave breaking across the bar, with the result that the bar translated a short distance seawards. Following a brief period during the 24th – 25th when the bar straightened, towards the end of the month characteristic RBB morphology was observed, with a well developed nearshore trough separating the beach face from the rhythmic bar system.
5.2.3 April 2002

At the beginning of April higher wave energy was recorded, with significant waves in excess of 2 m and maximum wave heights up to 4 m. By the end of the first week wave conditions had decreased again, with significant wave heights generally remaining around $H_s = 1$ m, with the exception of periods around the 17th and 19th when waves briefly increased to 1.5 m. From the 28th to the end of the month wave heights began to progressively build, reaching 2 m on the 31st.

RBB morphology prevailed through the first week of April, with this moderate to higher energy beach state in equilibrium with the elevated wave height conditions. As wave height began to decrease towards the end of the week, small and irregular rip and runnel features emerged close to the shoreline.

With the decrease of wave conditions through to the middle and second half of April, the offshore bar increasingly developed a complex three-dimensional form, as the beach state progressed from RBB towards lower energy TBR morphology. Multiple rip systems developed alongshore, with the now sinuous nearshore trough decreased in width as the bar moved onshore, and began to attach to the beach face around the 25th of April. In response to the increase in wave energy in the last few days of April, the bar began to move offshore again, resulting in a transitional TBR-RBB beach state by the end of the month.

5.2.4 May 2002

Significant wave height decreased through the first half of May, decreasing from around 2 m at the beginning of the month to around 1 m by the 15th. Following a minor peak up to 1.5 m on the 20th, significant wave heights decreased to 0.5 m from the 21st to the 25th, then rose again to around 1 m by the 27th, peaking briefly at over 2 m on the 30th.

Through the first half of the month little morphological change was observed, with the beach maintaining a complex TBR state. Wave breaking across the inner bar persisted, with the trough becoming more pronounced through this period.

From the 16th to the 27th of May images were not obtained by the system due to a building power failure. By the 28th much of the rhythmic features of the bar had disappeared, with a more linear LBT beach state prevailing by the end of the month. This was characterised by a linear trough in the nearshore zone separating the straightened bar from the beach face.
5.2.5 June 2002

Wave heights varied through June, with significant wave heights peaking at up to 2.5 m in the first week, then declining to around 0.5 m during the period 9th – 15th. During the higher wave event early in the month, maximum wave heights peaked at around 4 m. A similar peak (Hs = 2.5 m, Hmax = 4 m) was observed 19th – 20th May, then significant wave height declined again to around 1 m up to and including the 29th, before rising again into early July.

Despite the variable wave climate during June, the beach morphology remained relatively unchanged, with an LBT beach state persisting throughout the month. During the periods of larger waves it was apparent that the beach was in equilibrium with these conditions, with the larger waves breaking across the linear offshore bar, and reforming through the deeper trough before breaking again at the beachface. During the intervening (calmer) periods, wave heights were generally insufficient to cause breaking on the outer bar, with limited breaking at the beach face observed at these times.

A particular feature to note during June is the clear evidence of the reef’s influence on sediment deposition trends in the nearshore zone at Narrowneck. A distinctive offset of the bar alignment was observed, with the bar to the south offset in a seaward direction, relative to its position to the immediate north of the reef.

5.2.6 July 2002

The month of July was characterised by relatively low wave heights. Following a peak during 1st – 2nd of Hs = 2.5 m, wave heights rapidly decreased to around 1 m up to the last days of the month.

LBT beach morphology was observed for the entire month of July. The linear and two dimensional bar remained unchanged though the month, with no evidence of more rhythmic features emerging, as was so characteristic during the first months of the present six month monitoring period. Progressively though the first half of the month a subtle detachment of an inner bar from the beach face was observed, with small rip/runnel features emerging, especially along the southern half of the study area. In the second week of May these features skewed to the north, and by the 13th had been largely removed. Through the second half of the month the resulting inshore gutter feature appeared to infill, and virtually disappear again by the end of July.
The offset of the bar coinciding with the location of the reef persisted through July. The bar to the south of the reef was offset seaward, relative to the bar to the immediate north of the reef site.

5.3 Visual Assessment of Beach Width Changes (February 2002 – July 2002)

Beach and nearshore conditions during the present monitoring period February 2002 to July 2002 were characterised by moderate wave energy conditions, with significant wave heights in excess of 2 m and maximum wave heights of 4 m recorded on at least one occasion per month during this time. A qualitative visual assessment of the net 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 01/02/02 and 31/07/02 respectively. The corresponding snap images of the northern beaches obtained from Camera 4 are shown in Figure 5.3. Both north and south, no distinctive changes in beach morphology or alongshore coastal line alignment are apparent, suggesting that the northern Gold Coast beaches remained relatively stable during this period. To the south (Figure 5.2) and north (Figure 5.3) a modest decrease in beach width is discernable, however, from this qualitative comparison of images taken six months apart in February and July, it appears that no pronounced changes occurred to beaches of the northern Gold Coast during this period.

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

The net effects to date of the nourishment program over the entire 36 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 three year monitoring period August 1999 to July 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 erosional trend along the northern Gold Coast beaches, in response to a succession of storms during this period. This contrasted to the following six months (August 2001 to January 2002) during which the beaches recovered, returning to a similar state as was seen 12 months previously in January 2001. As noted in the previous six-monthly report (Turner, 2002), a return to prior conditions following a period of storm erosion suggests that the beaches of the northern Gold Coast at that time were close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000.

Referring to Figures 5.4 and 5.5, the present monitoring period February 2002 – July 2002 appears to have been the most stable since the commencement of sand nourishment and construction of the reef in August 1999. From the visual assessment of these figures the beaches of northern Gold Coast at the beginning of August 2002 were intermediate to the eroded state that prevailed in August 2001, and the most accreted state that was recorded at the end of January 2002. This observation further supports the conclusion that, post sand nourishment, the beaches of the northern Gold Coast have now achieved a new equilibrium, and beach changes are once again dominated by cyclic erosion-accretion due to seasonal variations of the prevailing wave climate.

A more quantitative assessment of the response of the northern Gold Coast beaches for the period January 2002 to July 2002 is detailed in the following Section 6.
MORPHODYNAMIC BEACH STATE MODEL
(after WRIGHT and SHORT, 1983)
SNAP IMAGES FROM CAMERA 4 (NORTH):
01/02/2002 AND 31/07/2002
SIX-MONTHLY BEACH CHANGES (CAMERA 1-SOUTH):
AUGUST 1999 - AUGUST 2002

August 1999

August 2000

January 2000

January 2001

August 2001

January 2002

August 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 1/2/02 to 31/7/02 are shown in Figure 6.1. For reference, these measured shorelines are overlaid 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 overlaid 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. It has since been determined that the CCD of C3 has been damaged by repeated sun-glint from the surface of the ocean, and this camera is scheduled to be replaced. 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 present monitoring period 1/2/02 – 31/7/02 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 140 m. The envelope of beach width changes is relatively uniform alongshore, with the exception of the beach around 750 m – 1250 m north of the cameras, centred around Narrowneck. While the beach can be seen to have generally varied in width along the 4500 m study region by approximately 30 m - 40 m during this period, at Narrowneck the beach width was less variable with the maximum range of shoreline movement of approximately 20 m. This observation is consistent with the anticipated stabilising influence of the reef.

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 1/02/02 – 31/07/02 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 overlaid 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 1/02/02 – 31/02/02 was approximately 100 m, but can be seen to have varied by approximately 50 m from 70 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 10–20 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 1/02/02 – 31/07/02. The standard deviation of weekly shorelines was generally ~10 m, with a distinct region of lower variability (s.d. ~ 5 m) centered around Narrowneck (1000 m north). As noted in Section 6.1, this confirms the stabilising influence of the reef at Narrowneck.


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 1/02/02 – 31/07/02 have been re-analyzed and plotted relative to the mean shoreline position calculated for the previous monitoring period August 2001 – January 2002 (refer Turner, 2002). 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 August 2001 – January 2002 is shown, along with the mean shoreline calculated for the present monitoring period February 2002 – July 2002.

This analysis shows that, relative to the mean shoreline position for the preceding six month period, the beach had generally eroded. In contrast to the previous six month analysis that revealed a distinct accretionary trend due to low wave conditions (refer Turner, 2002), during the present monitoring period the beach underwent a period of modest shoreline retreat. The results of shoreline mapping summarised in Figure 6.4 show that the beach generally decreased in width by ~ 20 m, which equates to a loss of approximately 50% of the beach accretion that was observed in the prior six months. The shoreline ‘signature’ of the reef at Narrowneck is distinctive in this figure, with the more stable and lower variability shoreline readily discernable in this region.
Figure 6.3

STATISTICAL SUMMARY OF BEACH WIDTH CHANGES:
FEBRUARY 2002 - JULY 2002
WEEKLY BEACH WIDTH CHANGES
FEBRUARY 2002 - JULY 2002
RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION

Figure 6.4
7. QUANTITATIVE ANALYSIS OF TOTAL SHORELINE CHANGES:
AUGUST 1999 – JULY 2002

The completion of a total of three years of monitoring at the northern Gold Coast beaches provides the opportunity to summarise and analyse longer-term shoreline changes observed to date. With sand nourishment completed in mid 2000, and significant erosion-recovery of the beach observed during 2001, as noted earlier it appears that the new equilibrium alignment of the northern Gold Coast coastline has developed, upon which cyclic beach changes can be observed.

7.1 Weekly Shorelines and Shoreline Variability: August 1999 – July 2002

All weekly shorelines for the 156 week period August 1999 to July 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 36 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 – July 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 Adamantidas, 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 evident. 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 recovery 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.

This period of beach erosion was then followed during the 24 – 30 month period (August 2001 – January 2002) by a distinct trend of beach recovery 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. 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 six month period that followed this, sand returned to the subaerial beach, rather than being lost from the beach system.

Over the last six months (February 2002 to July 2002) a modest net erosional trend is identified in Figures 7.2 and 7.3. Erosion of the shoreline during February to April was then followed by a 1 – 2 month period of partial recovery, followed by stabilisation or minor erosion again up to the end of July. As a generalisation, the beach at the end of the 36 month period to July 2002 was intermediate between the initial (un-nourished) condition in August 1999, and the most accreted states as observed in January 2001 and January 2002. After three years of monitoring, of which the first 12 - 18 months was dominated by sand nourishment works, a cyclic pattern of erosion in the first half of the year followed by accretion in the second half of the year, is beginning to emerge. This cyclic trend over the last two years matches the prevailing wave climate of the south east Queensland coast, and confirms that the beach of the northern Gold Coast are now in equilibrium with the sand nourishment that was placed on the beach during 1999-2000.

7.2 Identification of Regional Shoreline Trends: August 1999 – July 2002

To examine more closely the overall trend of beach width changes during the three year monitoring period August 1999 – July 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, January 2002 and July 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 and further confirm the underlying regional trends that have occurred along beaches of the northern Gold Coast during the 36 month period August 1999 to July 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 un-nourished) 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.

This erosion trend reversed during August 2001 to January 2002, with the beach alignment at the end the six month 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.

During February 2002 to July 2002 the shoreline eroded ~20 m, with this shoreline change occurring uniformly alongshore. Un-nourished regions to the north and south experienced this same degree of modest shoreline retreat as the central nourished beach. This similarity in the behaviour of the unnourished and nourished beaches again confirms that, by the end of 2001, the entire study region had obtained a new equilibrium with the prevailing wave conditions.
It is concluded that, 3.5 years after sand nourishment commenced at the northern Gold Coast in February 1999, and 2 years 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. The unnourished beaches have accreted some 10 – 20 m during this time, with the net result that the nourished beach at Surfers Paradise is some 30 – 50 m wider than in mid 1999.
TIME-SERIES OF BEACH WIDTH (NORTH):
AUGUST 1999 - JULY 2002

Figure 7.2
TIME-SERIES OF BEACH WIDTH (SOUTH):
AUGUST 1999 - JULY 2002
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 1/02/02 – 31/07/02 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.

As per the prior monitoring period (Turner, 2002), a relatively uniform alongshore envelope of weekly shorelines is apparent in this figure during the period February 2002 to July 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 –50 m during this period, with this variation in beach width relatively uniform alongshore.

The more general trend of modest beach erosion during this time is evident in Figure 8.3, where the weekly shorelines for the present monitoring period February 2002 – July 2002 are re-analysed and compared to the mean shoreline position for the preceding monitoring period August 2001 – January 2002. 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 receded on average by ~ 20 m, but that this recession was not uniform alongshore, as described below.
Of particular note in the upper panel of Figure 8.3 is the symmetry of shoreline beach width changes, centred around the central axis of the reef located at $y = 900$ m alongshore. Though subtle, these data indicate that 200 m north and south of this point the shoreline receded to a greater degree than the region ($y = 700$ to $1100$) in the immediate lee of the reef. As noted earlier in the discussion of Figures 6.3 and 6.4, this analysis of weekly beach width and shoreline variability has identified that during the present monitoring period the beach appears to have been more stable within the lee of the reef, as could be anticipated due to the predicted wave sheltering effect of the offshore structure.

Fluctuations of the shoreline position during the present monitoring period February 2002 – July 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 limited shoreline retreat was observed, with a minor reversal of this trend in the first half of July.

### 8.2 Total Monitoring Period: August 1999 – July 2002

For the sake of completeness, Figure 8.5 shows the changing shoreline position for the entire 36 month monitoring period August 1999 to July 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 three 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 six month period August 2001 to January 2002 the beach recovered fully, regaining some 30 – 40 m beach width, of which some 20 – 30 m was removed again during February 2002 – July 2002. 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 the 10 – 20 m net shoreline change observed in this region.

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 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. During the period February 2002 to July 2002 the beach width decreased by 20
– 30 m, matching the shoreline changes observed north of the reef. Over the entire 36
monitoring period, the beach in this region gained an additional 40 – 50 m 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 have been observed since the major phase of reef construction was completed. Figure
8.6 shows the rectified timex image obtained at mid tide on the first day of each month
during the period January 2001 to June 2002, 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.

As first described in the previous monitoring report, a simple and easily applied technique that satisfies both these requirements is Odd-Even Function Analysis. This method has become popular to the 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. For the sake of completeness, and to avoid the reader needing to refer to the previous report, a summary of the implementation and application of the technique is provided below.

First applied to the coastal engineering analysis of long-shore transport distribution by Berek and Dean (1982), the strength of the technique is the 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.,
\[ \Delta y(x) = [x,y(0)]_{t2} - [x,y(0)]_{t1} \]

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 \(v_o(x)\) 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

**January 2001 to January 2002**

Odd-Even Function analysis of the 12 month period January 2001 to January 2002 was included in the previous monitoring report (Turner, 2002). Since that time re-processing of these data has been undertaken, and for the sake of completeness the results of this original analysis are re-presented here, and then updated to include the current six month monitoring period February 2002 to July 2002.

The period January 2001 to January 2002 was the first 12 months since the major phase of reef construction was completed in December 2000. 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 this initial post-construction 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 15 m of additional beach width during this time 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 by the calculated Even function, 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 is indicative of the anticipated early phase of salient development in the lee of the Gold Coast reef. It was observed during the scale physical model study completed prior to the reef’s construction (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 suggest that this earlier phase of salient development occurred at Narrowneck during 2001. By this mechanism the formation of two proto-salients to the immediate north and south resulted in the additional beach width up to January 2002 of approximately 15 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, accompanied by a similar degree of erosion to the down-drift (northern) beach. Referring to the Odd function shown in Figure 8.8, it is observed that this function is asymmetric about the centre-line of the reef, with approximately 10 m of beach widening to the south matched by a similar magnitude of beach recession to the north. This trend of up-drift accretion and down-drift erosion is characteristic of littoral drift coastlines; a similar shoreline response is commonly observed adjacent to groin structures and river entrance training walls.

The depositional area to the south of the reef identified by the asymmetric Odd function, coincided with the location of further deposition as identified by the symmetrical Even function. This can be interpreted to indicate that deposition in this region during the period January 2001 to January 2002 was enhanced by the asymmetric build-up of sediment on the
up-drift side of the emerging proto-salient feature. By January 2001, this region of up-drift accretion had extended approximately 450 m alongshore to the south of the reef centreline. Conversely, in Figure 8.8 the area of down-drift erosion (Odd function) to the south of the reef coincided with the second region of proto-salient accretion (even function), with the net result that in this region a lesser magnitude of shoreline accretion was observed, extending approximately 400 m to the north of the reef centreline.

The sum of both Odd and Even functions shown in Figure 8.8 (denoted ‘total’ in figure) shows the net shoreline changes at Narrowneck during the 12 month period January 2001 to January 2002, that can be directly attributed to the recent completion of the reef. On the up-drift southern side accretion of the shoreline by up to 25 m extended for a distance of 450 alongshore. On the down-drift northern side of the reef an additional 10 m increase in beach width extended for a distance of 400 m alongshore.

**January 2002 to July 2002**

As was noted earlier in Sections 6 and 7, the present six month monitoring period was characterised by modest net shoreline retreat along the entire 4500 m study area. This trend is also seen in the results of Odd-Even Function analysis completed for this six month period. However these results also suggest that the reef had a positive sheltering effect during this time period, to reduce the degree of shoreline recession that was observed.

Figure 8.9 summarises the results of Odd-Even Function analysis for the period January 2002 to July 2002. As was the case along the entire northern Gold Coast beachfront, these results confirm the general erosional trend. The calculated Odd (asymmetric) function consistent with a slight straightening of the shoreline in the vicinity of the reef, indicated by some 10 m of erosion up-drift of the reef centreline, and a comparable magnitude of accretion immediately down-drift. The Even (symmetric) function confirms the general alongshore retreat of the shoreline at Narrowneck, however a symmetrical trend of a lesser erosion in the lee of the reef is indicated. The net shoreline change (denoted ‘total’ in Figure 8.9) reveals that, whereas the general trend north and south of the reef during this time was retreat of the shoreline by some 30 – 40 m, within the region of +/- 200 m from the reef centreline, a decreased rate of shoreline recession occurred, with a salient-like feature maintained in this localised region.
WEEKLY SHORELINES AT NARROWNECK: FEBRUARY 2002 - JULY 2002
WEEKLY SHORELINES IN LEE OF REEF: FEBRUARY 2002 - JULY 2002

BEACH WIDTH AT NARROWNECK:
FEBRUARY 2002 - JULY 2002

Figure 8.2
WEEKLY BEACH WIDTH CHANGES AT NARROWNECK
FEBRUARY 2002 - JULY 2002
RELATIVE TO PRIOR SIX-MONTH MEAN SHORELINE POSITION

Figure 8.3
Figure 8.4

TIME-SERIES OF BEACH WIDTH AT NARROWNECK:
FEBRUARY 2002 - JULY 2002
TIME-SERIES OF BEACH WIDTH AT NARROWNECK:
AUGUST 1999 - JULY 2002
MODES OF 'NATURAL AND ENGINEERED' SHORELINE RESPONSE

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

8.8
ODD-EVEN FUNCTION ANALYSIS: JANUARY 2002 - JULY 2002
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 have in previous monitoring reports permitted the assessment of the occurrence of wave breaking at the reef. Examples of an oblique (single camera) and corresponding merged-rectified (four camera) images obtained in late 2001 that clearly show wave breaking across the northern and southern halves of the reef are shown in Figure 9.1.

In previous monitoring reports completed during the construction of the reef, the progressive increase in the occurrence of wave breaking was documented and quantified as additional geocontainers were placed. With the placement on the reef crest of additional geocontainers immediately prior to the present monitoring period in November-December 2001 (refer Section 2.2), it is now observed that waves break near continually across the reef structure. The previous identification of wave breaking on the reef versus the adjacent bar is now less distinctive, as the bar(s) in the immediate vicinity of the reef now generally intersect and integrate with the reef structure. It is concluded that the depth of the reef crest now results in near continual wave breaking at Narrowneck.
VISIBLE WAVE BREAKING ON REEF

Figure 9.1
10. CONCLUSIONS

The six month monitoring period February 2002 to July 2002 marks two years since the completion of beach nourishment in June 2000 at the northern Gold Coast, and six months since geocontainers were placed across the crest of the Gold Coast Reef.

10.1 Beach Width

Beach and nearshore conditions during the present monitoring period February 2002 to July 2002 were characterised by moderate wave energy conditions, with significant wave heights in excess of 2 m and maximum wave heights of 4 m (or greater) recorded on at least one occasion per month during this time. A visual assessment of beach changes during February 2002 to July 2002 (Figure 5.2 & Figure 5.3) reveals no distinctive changes in beach morphology or alongshore coastal line alignment during this period, with the beaches of the northern Gold Coast remaining relatively stable. A modest decrease in beach width is discernable.

Extending this qualitative visual assessment of images to include the entire three 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 erosion trend along the northern Gold Coast beaches, due to a succession of storms during this period. This contrasted to the following six months (August 2001 to January 2002) during which the beach recovered, returning to a similar state as was seen 12 months previously in January 2001. This return to prior conditions following a period of storm erosion suggests that the beaches of the northern Gold Coast at that time were close to regaining a new equilibrium, post the extensive sand nourishment works completed in mid 2000. The present monitoring period February 2002 – July 2002 appears to have been the most stable to date. From the visual assessment of these figures, the beaches of northern Gold Coast at the beginning of August 2002 were intermediate to the eroded state that prevailed in August 2001, and the most accreted state to date that was
recorded at the end of January 2002. This observation further supports the conclusion that, post sand nourishment, the beaches of the northern Gold Coast have now achieved a new equilibrium, and beach changes are once again dominated by cyclic erosion-accretion in response to seasonal variations of the prevailing wave climate.

Based upon the quantitative analysis of weekly shoreline positions during the present monitoring period 1/2/02 – 31/7/02, the mid tide beach along the 4500 m study region varied in width (relative to the dune reference line) from approximately 60 m to 140 m (Figure 6.2). The envelope of beach width changes was relatively uniform alongshore, with the exception of the beach around 750 m – 1250 m north of the cameras, centred around Narrowneck. While the beach can be seen to have generally varied in width along the 4500 m study region by approximately 30 m - 40 m during this period, at Narrowneck the beach width was less variable with the maximum range of shoreline movement of approximately 20 m. The median beach width at mid tide (relative to the dune reference line) along the 4500 m stretch of coastline during the period 1/02/02 – 31/02/02 was approximately 100 m, but can be seen to have varied by approximately 50 m from 70 m to 120 m (Figure 6.3). The standard deviation (s.d.) of weekly shorelines from the mean shoreline position during the period 1/02/02 – 31/07/02 was generally ~10 m, with a distinct region of lower variability (s.d. ~ 5 m) centered around Narrowneck (1000 m north), suggestive of a stabilising influence of the reef at Narrowneck.

When the weekly shoreline data for the period February 2002 to July 2002 was re-analysed to assess beach width changes relative to the mean shoreline position for the preceding six month period (Figure 6.4), the beach had generally eroded. In contrast to the previous six month analysis that revealed a distinct accretionary trend due to low wave conditions, during the present monitoring period the beach underwent a period of modest shoreline retreat. The beach generally decreased in width by ~ 20 m, which equates to a loss of approximately 50% of the beach accretion that was observed in the prior six months. The shoreline ‘signature’ of the reef at Narrowneck is distinctive in Figure 6.4, with the more stable and lower variability shoreline readily discernable in this region.

Over the entire 3 year 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 during this
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. From August 2001 to January 2002 a distinct trend of beach recovery at all locations alongshore was observed. 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. During the present monitoring period a modest net erosional trend was recorded. As a generalisation, the beach at the end of the 36 month period to July 2002 was intermediate between the initial (unnourished) condition in August 1999, and the most accreted states as observed in January 2001 and January 2002.

Following the completion of three years of shoreline monitoring, of which the first 12 - 18 months of measured beach changes were clearly dominated by the sand nourishment works, it is concluded that a cyclic pattern of erosion in the first half of the year followed by accretion in the second half of the year, is beginning to emerge. This cyclic trend over the last two years matches the prevailing wave climate of the south east Queensland coast, and confirms that the beaches of the northern Gold Coast are now in equilibrium with the sand nourishment that was placed on the beach during 1999-2000.

It is concluded that, 3.5 years after sand nourishment commenced at the northern Gold Coast in February 1999, and 2 years 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. The unnourished beaches have accreted some 10 – 20 m during this time, with the net result that the nourished beach at Surfers Paradise is some 30 – 50 m wider since mid 1999.

### 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 updated application of ‘Even-Odd’ Function Analysis was applied to
the data set of weekly shorelines in this region to separately identify and quantify the beach response (post sand nourishment) to reef construction.

For the period January 2001 to January 2002, corresponding to the first complete seasonal (12 month) cycle following completion of the major phase of reef construction, two distinct modes of beach response were 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 resulted in the additional beach width in these two regions of the order of 15 m. Sediment deposition by this mechanism 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 ‘headland’ effect of this emerging salient feature during the period January 2001 to January 2002 also resulted in additional deposition of sediment on the up-drift (southern) beach, accompanied by a similar degree of erosion to the down-drift (northern) beach. By this mechanism approximately 10 m of beach widening to the south of the reef was matched during this period by a similar magnitude of beach recession to the north. This trend of up-drift accretion and down-drift erosion is characteristic of barriers on littoral drift coastlines; a similar shoreline response is commonly observed adjacent to groyne structures and river entrance training walls. From the results of Odd-Even Analysis, the net impact of the reef at Narrowneck during the 12 month period January 2001 to January 2002, was to promote accretion of the updrift southern beach by up to 25 m for a distance of 450 alongshore, and 10 m of beach accretion for a distance of 400 m on the down-drift northern side of the reef.

Odd-Even Function analysis for the present six month monitoring period January 2002 to July 2002 (Figure 8.9) shows that, as was the case along the entire northern Gold Coast beachfront, a general erosional trend prevailed. The calculated Odd (asymmetric) function was consistent with a slight straightening of the shoreline in the vicinity of the reef, indicated by some 10 m of erosion up-drift of the reef centreline, and a comparable magnitude of accretion immediately down-drift. The Even (symmetric) function confirms the general alongshore retreat of the shoreline at Narrowneck, however a symmetrical trend of erosion in the lee of the reef is indicated. Whereas the general trend north and south of the reef during this time was retreat of the shoreline by some 30 – 40 m, within the region of +/- 200 m from the reef centreline, a decreased rate of shoreline recession occurred, with a salient-like feature maintained in this localised region.
In summary, the net impact of the reef during the first complete 12 month seasonal cycle to January 2002 was to promote additional accretion of the updrift southern beach by up to 25 m for a distance of 450 alongshore, and 10 m of net beach accretion for a distance of 400 m on the down-drift northern side of the reef. During the present monitoring period to July 2002 a net erosional trend along the entire 4.5 km study area was observed. However, a decreased rate of net shoreline recession was measured at Narrowneck, with a salient-like feature maintained in this localised region.

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). In previous monitoring reports completed during the construction of the reef, the progressive increase in the occurrence of wave breaking was documented and quantified as additional geocontainers were placed. With the placement on the reef crest of additional geocontainers immediately prior to the present monitoring period in November-December 2001 it is now observed that waves break near continually across the reef structure. The previous identification of wave breaking on the reef versus the adjacent bar is now less distinctive, as the bar(s) in the immediate vicinity of the reef now generally intersect and integrate with the reef structure. It is concluded that the depth of the reef crest now results in near continual wave breaking at Narrowneck.

It is concluded that the reef continues to achieve the objective of significantly increasing potential surfing opportunities at Narrowneck.
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12. REFERENCES


